MUSCLE ENDURANCE PERFORMANCE OF QUADRICEPS AND HAMSTRINGS, AND FUNCTIONAL ABILITY BEFORE AND AFTER ARTHROSCOPIC MENISCAL SURGERY: A CASE CONTROLLED INTER-LIMB COMPARISON

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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 and no material which, to a substantial extent, has been accepted for the qualification of any other degree or diploma of a university or other institution of higher learning, except where due acknowledgement has been made in the acknowledgements.

Signed ....

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ABSTRACT

OBJECTIVE

The objective of this study was to investigate muscle performance of the quadriceps and hamstrings muscles, as well as lower limb function in participants with meniscal lesions that required partial meniscectomy. It was of particular interest to assess whether there were significant deficits in an inter-limb assessment of muscle strength and endurance, as well as performance in a repetitive hop test, one week prior to surgery and six weeks after partial meniscectomy. Additionally, the relationship between performance measures (isokinetic and hopping) and perceived function (questionnaires) was examined.

STUDY DESIGN

An inter-limb comparison of isokinetic knee flexion and extension muscle strength and endurance, and a functional hop endurance was implemented on 21 participants with meniscal injury before and after partial meniscectomy. Testing was performed one week prior to surgery, and again six weeks after surgery. For the control group, 22 healthy matched participants performed the same testing protocols on two occasions, six weeks apart.

BACKGROUND

Surgery is often required for tears to the meniscus of the knee. The minimal nature of modern surgical intervention for meniscal injuries has led to a belief that exercise rehabilitation after surgery is often not needed. Rehabilitation, when undertaken, has been focused upon strengthening. Yet many activities require muscular endurance capability. Without sufficient endurance, fatigue can lead to added stress upon joint structures, leading to further inflammation and potentially long-term damage in the form of osteoarthritis.

METHOD

Forty-six participants aged between 24 and 57 years were recruited. Three participants were excluded as they had post-operative complications. Therefore, the total sample size for the current study was 21 participants in the partial meniscectomy group and 22 participants in the control group.

A Biodex isokinetic dynamometer was used to assess quadriceps and hamstrings strength (peak torque) and endurance performance (peak torque over 30 consecutive maximum effort repetitions). A functional performance endurance test was performed on a force plate, and assessed changes in flight time over 30 consecutive hops, four seconds apart. Self-reported function was measured using the Lower Limb Task Questionnaire (LLTQ) and Knee Injury and Osteoarthritis Outcome Score (KOOS). All assessment protocols where performed at two testing session; one week prior to surgery and six weeks after partial meniscectomy. Analysis of Variance (ANOVA) and Pearson correlation coefficients were utilised for the statistical analysis with an alpha level set to 0.05.

RESULTS

The partial meniscectomy group had significant ($p<0.05$) quadriceps and hamstrings deficits and functional hop deficits on the injured limb when compared to the non-injured limb and control participants. These differences across limbs ranged between six and eighteen percent. Specifically, in measures of endurance, there were significant differences ($p<0.05$) across limbs pre-operatively in the quadriceps, hamstrings, and functional hop test (six to 10 percent deficits), and these were also observed post-operatively in the quadriceps and functional hop test (seven to 15 percent deficits). The decrement of peak torque in the quadriceps and flight time in the maximal effort repeated hop test were at a lesser rate compared to the non-injured limb and the control group limbs ($p<0.05$).

There were clinically significant (greater than 10 points) improvements in self-reported function between pre- and post-operative scores. This was observed in all subscales of the KOOS, and the recreational section of the LLTQ. Despite these improvements, participants had significantly lower functional scores ($p<0.05$) compared to control subjects in all measures of self-reported function post-operatively. There was a significant relationship between LLTQ RA and the repeated hop task where lower scores moderately correlated ($r= -0.51$) with deficits across limbs in flight time during the highest three hops of this task. The remaining correlations between self-reported function and performance tasks were not significant ($p>0.05$).

CONCLUSION

In respect of endurance of quadriceps and hamstring muscles, the findings suggest that endurance across the 30 repetitions is satisfactory for return to recreational low intensity activities. However, deficits of greater than 10 percent were observed across limbs in quadriceps muscle performance pre- and post- surgery, and these should be addressed by further rehabilitation.

The across limbs percent deficits in the quadriceps and hamstrings muscles strength and endurance measures were not significantly related to perceived function. This was thought to be related to the differences in complexity of the tasks involved. There was a significant correlation between function as measured by the recreational section of the LLTQ and hop performance task, and this could be advantageous in clinics where performance testing cannot take place.

Overall the results suggest that increased formal rehabilitation is needed for individuals who have had a partial meniscectomy. The current belief in the orthopaedic community that return to full sport at six weeks post-operation is appropriate therefore needs to be reassessed.

1. Chapter 1: INTRODUCTION

1.1. STATEMENT OF THE PROBLEM

This study investigated quadriceps and hamstrings muscle endurance and repeated hop performance before and after partial meniscectomy surgery. It also compared lower limb functional questionnaires with strength, endurance performance, and hop endurance testing to examine if there was a relationship between such measures.

Although the knee is one of the largest joints in the human body, unlike other joints, its strength and stability is derived from the ligaments, meniscal tissue and muscles surrounding it, rather than just bony configuration (Brukner, 2012). Injury to these stabilising structures in the knee are commonly observed in a sporting population. In New Zealand, Accident Compensation Corporation (ACC) statistics reported that the knee was the most commonly injured site in the body. During the period of July 2016 and June 2017 there were 160,386 new claims received with an estimated cost of $257,830,846 (Accident Compensation Corporation, 2017). To understand the epidemiology of knee injuries, Majewski, Susanne, and Klaus (2006) analysed a sample of 6434 participants with acute knee injuries over a 10 year timeframe. They found that of the 44.8 percent that had an internal knee injury, 24 percent were injuries to the medial meniscus and 8.2 percent to the lateral meniscus.

Arthroscopic surgery is commonly used after meniscal injury. New Zealand records reported 8541 procedures in 2010, 6783 procedures in 2011, and 6336 procedures in 2012 (Accident Compensation Corporation, 2010). Although surgical intervention is a well-used treatment modality for both traumatic and degenerative meniscal tears, individuals who have had such treatment are often predisposed to further meniscal injury, degeneration and knee osteoarthritis (Accident Compensation Corporation, 2010; Lohmander, Englund, Dahl, & Roos, 2007). It has been argued that strength deficits following arthroscopic meniscectomy may partly contribute to loss in function and increased risk of injury (McLeod, Gribble, Pfile, & Pietrosimone, 2012). Most studies investigating meniscus injury have focused on quadriceps peak torque following meniscal surgery (Ericsson, Roos, & Dahlberg, 2006; Gapeyeva, Pääsuke, Ereline, Pintsaar, & Eller, 2000; Matthews & Dianne, 1996; Osteras, Osteras, & Torstensen, 2014; Stein, Mehling, Jost, Auhuber, & Jager, 2009; Stensrud, Risbergm, & Roos, 2014). Some studies have reported quadriceps strength deficits of up to 40 percent in the 12 weeks after surgery (McLeod et al., 2012). Previous work examining hamstrings deficits has shown there are minimal deficits (McLeod et al., 2012).

While identifying strength deficits is important in the rehabilitation process (Hart, Pietrosimone, Hertel, & Ingersoll, 2010), many activities, at work and sport, may also require endurance capability. Without sufficient muscle endurance, fatigue can lead to added stress upon joint structures leading to further damage within the knee joint (White et al., 2018), and in the long-term, osteoarthritis (Øiestad, Juhl, Eitzen, Thorlund, & Øiestad, 2015). Only two previous studies by Ericsson, Dahlberg, and Roos (2009) and St-Pierre et al. (1992) have utilised an endurance test for individuals with meniscal surgery. These authors however, did not report deficits across limbs or made comparisons with a control group. Instead, their focus was upon changes in endurance as a result of a training programme.

Endurance as a concept can be interpreted in many ways. One may think of it involving low intensity muscle work that is sustained for as long as possible. Alternatively, it might also be thought of as the ability to repeatedly perform high intensity exercise. As previous research has focused on strength, which involves maximal effort muscle activity, and shown deficits across injured and non-injured limbs following knee injuries, a natural or logical extension of such research was to focus the current study upon the ability to sustain repeated maximal effort muscle work. Thus, when the word "endurance" is encountered within this thesis it refers to this interpretation.

Functional performance measures commonly used to indicate readiness for return to sport, lack consistency across the literature and fail to incorporate components such as endurance and fatigue. Of the located studies, most included at least one of the following tests; single hop for distance, triple hop for distance, crossover hop, vertical hop for height, square hop test, and timed six-meter hop test (Ericsson et al., 2009; Ericsson et al., 2006; Koutras, Letsi, Papadopoulos, Gigis, & Pappas, 2012; Stensrud et al., 2014; Thorlund, Aagaard, & Roos, 2012). Each individual test has been separately validated in healthy individuals, to accurately represent functional components such as power, strength, and dynamic postural balance (Hamilton, Shultz, Schmitz, & Perrin, 2008; Ostenberg, Roos, Ekdahl, & Roos, 1998; Teyhen et al., 2014). However, poor correlations have been reported between tests and it has been suggested that each test may assess different constructs (Roos, Mrnell, Gardsell, Lohmander, & Lindstrand, 1995).

No functional performance measures have been found that assess endurance across limbs. Some tests assess endurance during bilateral jumping tasks (Cormac, Netwon, McGuigan, & Doyle, 2008; Marina & Rodriguez, 2012; McNeal, Sands, & Stone, 2010), but unilateral limb assessments are essential to allow accurate appraisal of a deficit in an injured limb. Additionally, it is suggested that a limb symmetry index of at least 85 to 90 percent is desirable for safe return to sport after lower limb injury (Schmitt, Quatman, Paterno, Best, & Flanigan, 2014). Hence, it is important to establish that endurance based tests of function to identify notable deficits across injured and non-injured limbs.

1.2. PURPOSE OF THE STUDY

Given the lack of information available concerning muscle endurance performance following meniscal injuries, as well as other lower limb injuries, the purpose of the current study was to establish if there are deficits in quadriceps and hamstrings muscle endurance performance in individuals with meniscal injury and subsequent surgery. It also aimed to establish whether these deficits might also be observed in function as measured by an endurance hop test. Measures were taken prior to and after surgery, the latter being at six weeks, a point when the patient has been cleared for return to sport. Therefore, a cross-sectional inter-limb comparison design was utilised. The research questions were:

1. Are there inter-limb differences in Isokinetic peak torque of the knee extensor and flexor muscles at angular velocities of 60 and 180 degrees per second?
2. Are there inter-limb differences in isokinetic peak torque of the hamstrings and quadriceps during 30-repetitions of flexion and extension at an angular velocity of 180 degrees per second?
3. Are there inter-limb differences in the slope of the relationship between peak torque and repetitions during the maximum effort isokinetic endurance test?
4. Are there inter-limb differences in flight time measured on a force plate, during 30 consecutive maximum height single leg hops, four seconds apart?
5. Are there inter-limb differences in the slope of the relationship between flight time and repetitions during the maximum effort repeated single leg hops?
6. Is there a relationship between perceived measures of function (questionnaires) and measured performance (hop tests)?

1.3. SIGNIFICANCE OF THE PROBLEM

Injury to the meniscus is commonly seen in an athletic population and due to the favourable success rate and minimal risk involved, partial meniscectomy is a widely accepted procedure for medical management. However, the magnitude of muscle endurance and functional deficits before and after partial meniscectomy is not well understood. The results of this study will benefit the health professionals involved in the treatment of meniscal lesions, patients affected by this condition, and funding agencies involved in the support of such individuals. If this study confirms deficits in muscle endurance performance and function, therapeutic intervention after partial meniscectomy can be encouraged and individuals better targeted in rehabilitation and exercise prescription. Ultimately, this will strengthen the understanding around neuromuscular mechanisms associated with arthroscopic surgery, optimise management and reduce the long-term dysfunction associated with meniscal injury.

2. Chapter 2: LITERATURE REVIEW

2.1. INTRODUCTION

This chapter is divided into five main sections. The first section outlines the search strategy used for the literature review. The second section describes the anatomy of the meniscus, its structural characteristics, mechanical properties, types of injury, and current surgical management options. The third and fourth sections discuss strength and endurance performance after partial meniscectomy. The final section covers the functional impact of partial meniscectomy, reviewing the current hop performance tests used in clinical practice and in research. The chapter concludes with a summary.

2.2. LITERATURE SEARCH

2.2.1. Introduction

There were two components of interest when undertaking the literature search. The first was to identify muscle dysfunction that had been assessed before and after partial meniscectomy surgery. It was of particular interest to determine if there had been any assessment of muscle endurance. The second objective was to identify functional performance assessments for the lower limb currently used to indicate the readiness to return to sport and determine if they included elements of endurance.

2.2.2. Search strategy

2.2.2.1. Inclusion and exclusion criteria

Articles were analysed in this literature review if they met the following criteria:

- participants had either acute and degenerative tears of the meniscus that required partial meniscectomy and had the isokinetic peak torque data of the hamstrings and quadriceps muscles assessed before and after surgery
- articles that assessed muscle endurance in partial meniscectomy
- articles that assessed functional hop testing in partial meniscectomy

- articles that included assessment of endurance using functional hop testing in healthy populations.

Studies were excluded if they:

- did not measure strength using an isokinetic dynamometer
- did not assess strength (peak torque) before or after surgery
- were not published in the English language.

2.2.2.2. Search strategy and resources used

The following electronic databases were searched over a time period of April 2015 to March 2018:

- CINAHL Plus
- Medline
- SPORTDiscus
- Google Scholar
- Google
- EBSCO Health Databases
- PEDro (Physiotherapy Evidence Database)
- Cochrane Library
- Auckland University of Technology Library Catalogue including E-Journals

Additionally, the reference lists of the included articles were reviewed to locate key authors and further studies not identified in the original search.

2.2.2.3. Search terms

Each database was searched to identify studies within the following themes:

- peak torque before and after partial meniscectomy
- endurance before and after partial meniscectomy
- functional performance measures before and after partial meniscectomy.

Search terms and truncations were modified to suit individual requirements for each database. These terms were used individually and as a phrase, using a Boolean data type. Terms were searched using both generic subject fields, or for specific authors using the author field. The main search terms used are outlined in Table 2.1.

Table 2.1: Terms used in literature search

Search Terms		
meniscus	hop	endurance
strength	quadriceps	hamstring
vertical hop	knee	function
cartilage	menisc*	jump
single leg jump	peak torque	muscle
torque	flexor	extensor
jump	fatigue	thigh

∗ = Truncation

2.3. MENISCUS

The menisci are an integral part of the knee joint and are vital for the effective loading and long-term preservation of articular cartilage. They have a role in enhancing the articulation of the femur on the tibia to increase stability (Shoemaker & Markolf, 1986), act as a shock absorber (Seedhom & Hargreaves, 1979; Voloshin & Wosk, 1983), provide lubrication (MacConaill, 1932) and sensory feedback for proprioception (Gardner, 1948; Schutte, Dabezies, Zimny, & Happel, 1987). Both the medial and lateral menisci play a critical role in distributing axial force and reducing stresses on the tibia during ambulation. They therefore play a role in the protection of articular cartilage and can reduce deterioration and degeneration in the knee. A more detailed commentary of their anatomy, functional biomechanics, cellular and matrix characteristics and mechanical properties of the meniscus is presented below.

2.3.1. Anatomy

The position and shape of the menisci are fundamental for joint attenuation and stability. In adults, the lateral meniscus covers a larger portion of the tibial plateau (80 percent laterally), compared to the medial meniscus (60 percent medially) (Greis, Bardana, Holmstrom, & Burks, 2002). The attachment of the menisci to the tibial plateau is achieved through transverse ligaments located primarily at the anterior and posterior horns (Johnson et al., 1995; Kohn & Moreno, 1995). This is also where the greatest concentration of blood vessels, nerve supply and proprioceptive receptors are found (Brindle, Nyland, & Johnson, 2001; Freeman & Wyke, 1967; Schutte et al., 1987). Although there is a similarity in appearance, the lateral meniscus displays a greater variety in size, shape, and thickness compared to the medial meniscus (Clark & Ogden, 1983; Greis et al., 2002). This design helps to promote mobility of the meniscus during normal joint movement and therefore provides dynamic support to the knee.

2.3.2. Cellular and matrix characteristics

The menisci's cellular makeup and characteristics enable the tissue to withstand high forces. The tissue of the meniscus consists mainly of water and an elaborate collagen network that has a predominantly circumferential alignment (Fox, Bedi, & Rodeo, 2012). Human meniscal tissue is found to be comprised of 70 percent water and 30 percent organic matter (Brindle et al., 2001). The organic matter is mostly collagenous (75 percent), which consists primarily of type I collagen fibres that provide the structural scaffolding (Brindle et al., 2001). The concentration and presence of type I collagen is what differentiates the meniscus from articular cartilage, which is predominantly type II collagen (Messner & Gao, 1998). The arrangement and alignment of this type I collagen provides resistance to stresses from different directions (e.g. shearing and compression), often simultaneously (Beaupré et al., 1986; Ghosh & Taylor, 1987; Merkel, 1980).

2.3.3. Mechanical properties

The menisci can accept 50 to 70 percent of weight bearing load during gait activities (M. I. Chen, Branch, & Hutton, 1996; Fukubayashi & Kurosawa, 1980; Kurosawa, Fukubayashi, & Nakajima, 1980). Due to the minimal presence of elastin (0.06 percent), the menisci can also exhibit the viscoelastic property of 'creep', where deformation can occur over time-dependant loading (Fox et al., 2012). It has been well established that with the removal of the menisci, the contact area for the femur decreases and the contact forces on the articular surfaces of the tibial plateau increase (Fukubayashi & Kurosawa, 1980; Kettelkamp & Jacobs, 1972; Kurosawa et al., 1980; Paletta, Manning, Snell, Parker, & Bergfeld, 1997). In a normal knee, compression can cause the menisci to displace between five to ten millimetres during knee flexion and extension movements (Thompson, Thaete, Fu, & Dye, 1991). The shape of the menisci will also change during motion, as the anterior horns displace further than the posterior horns (Thompson et al., 1991). This prevents the femur from contacting the posterior margin of the tibia and concurrently serves to convert vertical compressive forces into horizontal hoop stresses (Messner & Gao, 1998). The mechanical properties of the menisci are essential to normal function of the knee, and they are most challenged during weight bearing activities that include rapid change of direction or pivoting.

2.3.4. Traumatic meniscal injury

Injury to the meniscus usually involves a coupled compressive force to the knee with transverse plane tibiofemoral rotation. This is thought to cause a 'pinch' resulting in subsequent tearing of the meniscal tissue (Wheatley, Krome, & Martin, 1996). Isolated injury can occur and is classified based on the location and type of tear. Depending on the depth of the tear, they are classified as partial or full thickness, of which full thickness can be stable or unstable (Brindle et al., 2001). Although there is a clear categorisation of meniscal tears, the functional consequences on the knee joint can vary and often will not be associated with the nature of the tear. Meniscal tears can be asymptomatic, as shown by Englund et al. (2008), who identified the presence of meniscal tears through the use of Magnetic Resonance Imaging (MRI) in 61 percent of asymptomatic volunteers over 50 years of age. Although the presence of acute meniscal tears is commonly reported, degenerative meniscal tears are also prevalent. These types of meniscal tears often do not have an associated acute trauma and the prevalence increases with age.

It can be difficult to ascertain which individuals would benefit from arthroscopic surgery. There are however some factors which are associated with better outcomes following surgery, such as smaller deficit size (less than two centimetres), pre-operative duration of symptoms less than 18 months, no prior surgical treatment, younger patient age group, and higher levels of activity (pre-injury and post-injury) (Heir et al., 2010).

2.3.5. Meniscectomy

Currently, arthroscopic surgeries for meniscal injury are performed with the clinical justification relating to mechanical obstruction of the joint movement. Between July 2008 and June 2009, a total number of 8999 arthroscopic procedures were performed in New Zealand at a cost of $29,275,965 (Accident Compensation Corporation, 2010). Early literature has established a relationship between the size of resected tissue and articular joint loading that is linked to long-term radiographic degeneration (Fairbank, 1948). For this reason, partial meniscectomy is the preferred option with the removal of a section of tissue, ideally toward the central segments of the meniscal body. The amount of force able to be resisted by the menisci post resection is linearly related to the amount of meniscal tissue that is removed (Baratz, Fu, & Mengato, 1986). People after arthroscopic partial meniscectomy experience higher knee adduction moments during gait than healthy controls (Hall et al., 2014). Additionally, there may also be changes in knee stability after meniscectomy. L. Chen et al. (2015) found that removal of the horn of the meniscus can compromise rotational stability but not anterior tibial translation of the knee. This study reviewed knee stability after different portions of meniscal tissue were resected in vitro. A decrease in contact area with the meniscus and subsequent increase in peak stress on the tibial articular cartilage after a meniscectomy are regarded as the main reason for long-term articular changes frequently observed (Fairbank, 1948; Fukubayashi & Kurosawa, 1980; Jones, Smith, & Reisch, 1978).

2.3.6. Relationship with osteoarthritis

Even after partial meniscectomy there is an associated increase in the prevalence of osteoarthritis. Overall, in patients presenting with symptomatic osteoarthritis, a previous history of meniscal injury or surgery is reported in 70 to 90 percent of individuals (Englund, Guermazi, & Lohmander, 2009). Once the meniscus is compromised, increased loading of other structures within the knee joint can cause cartilage loss, bony alterations; to subchondral bone and trabecular bone, increased bone mineral density and ultimately malalignment of the knee, which sets in motion the cycle of knee osteoarthritis (Eichinger et al., 2016; Roemer et al., 2017). Additional to the mechanical changes mentioned above, the incidence of osteoarthritis can be linked to adaptations in the neuromuscular system after surgery. One of the biggest modifiable risk factors in the incidence progression of osteoarthritis is muscle performance (Øiestad et al., 2015). Further investigation and review of muscle performance after meniscal injury and partial meniscectomy follows.

2.4. QUADRICEPS MUSCLE PERFORMANCE

2.4.1. Quadriceps role in function of the knee

Quadriceps function, strength and endurance are considered important following meniscal injury. The quadriceps muscle group plays an important role in stability, shock absorption and control of motion during walking and running (Pandy & Andriacchi, 2010). During walking, the quadriceps contribute significantly to compressive forces at the knee (Pandy & Andriacchi, 2010). As the quadriceps have a large role in the support and function of the knee, weakness of this muscle group has been linked to dysfunctional movement patterns and injury (Kumar, Manal, & Rudolph, 2013). An increase in knee adduction moments is known to be associated with quadriceps weakness (Kumar et al., 2013; Mündermann, Dyrby, & Andriacchi, 2005) and has been observed after meniscectomy (Sturnieks, Besier, & Lloyd, 2011). This type of movement pattern places further load on the medial compartment of the knee, increasing the risk of meniscal damage and osteoarthritis (Miyazaki et al., 2002). Additionally, persistent quadriceps weakness from altered pathomechanics is associated with increased joint space narrowing (Segal et al., 2010). Joint space narrowing is observed in 42 percent of individuals after arthroscopic meniscectomy (Rockborn & Gillquist, 1996) and may be a catalyst in the development and progression of knee osteoarthritis (Andriacchi et al., 2004; Slemenda et al., 1997). The quadriceps muscles are important in normal function and protection of the knee joint. Therefore, understanding the implications of knee surgery on muscle performance is essential to assist in the rehabilitation process.

2.4.2. Quadriceps muscle deficiency after meniscal injury and surgery

Persistent quadriceps weakness after knee meniscal injury and surgery is commonly observed. Studies have reported quadriceps strength deficits of up to 40 percent in the 12 weeks after surgical intervention (McLeod et al., 2012). Isolated injuries to the meniscus of the knee lead to alterations in quadriceps muscle fibre architecture and neuromuscular control (Gapeyeva et al., 2000; Hioki, Furukawa, & Akima, 2014). After surgery, pain, joint effusion, fear of movement, and surgical damage to the joint and surrounding musculature can cause deficits in activation and structure of the quadriceps muscles (Haggmark, Jansson, & Eriksson, 1981).

Early investigation into atrophy of the thigh muscles following knee pathology identified a greater effect on quadriceps musculature in comparison to the adductors and hamstrings muscle groups (Young, Stokes, & Iles, 1987). Young et al. (1987) identified that a five percent loss in mid-thigh circumference corresponded to a 22 to 33 percent difference in quadriceps cross-sectional area. After partial meniscectomy, Hioki et al. (2014) has shown that there is selective atrophy to different areas of the quadriceps. This selective atrophy may be due to the positioning of knees commonly being in an extended position after knee injury, however, it may also be due to the morphology of the quadriceps muscles (Hioki et al., 2014). Skeletal muscle fibre type distribution is a significant determinant of a muscle's performance in humans, and can be altered following injury and surgery (Larsson & Moss, 1993). In the quadriceps, a mixture of slow twitch (type I) and fast twitch (type IIa and IIx) fibre types are present, contributing to both aerobic and anaerobic performance (Bagley et al., 2017; Larsson & Moss, 1993). Additionally, the architecture of the quadriceps is oblique in nature with variable muscle thickness, fascial and fibre angles, and fascial and fibre length between the four different subdivisions of the muscle groups. (Blazevich, Gill, & Zhou, 2006). This morphological design enables the quadriceps to play a variable role in functional tasks through performance over different muscle lengths and at difference joint angular velocities. After short periods of disuse, atrophy can affect both fibre type and muscle architecture of the quadriceps altering the muscles performance (Suetta, 2017). For example, four months following meniscectomy, atrophy has been detected in the quadriceps when measured at the anterior proximal thigh, lateral mid-thigh and anterior mid-thigh (Hioki et al., 2014).

A muscles force producing capacity is not only dependant on cross-sectional area and muscle mass, but also on the excitability of the neural pathways. Arthrogenic Muscle Inhibition (AMI) has been identified as a major contributing factor to quadriceps muscle weakness after partial meniscectomy (Glatthorn, Berendts, Bizzini, Munzinger, & Maffiuletti, 2010), sometimes in the absence of pain (Shakespeare, Stokes, Sherman, & Young, 1985). It is thought to be linked to articular swelling, pain and joint laxity (Hopkins & Ingersoll, 2000; Rice & McNair, 2010), which can alter afferent information from mechanoreceptors in the knee joint, activation of inhibitory interneurons and reduction of motor neuron recruitment (Hopkins & Ingersoll, 2000). Although it has been suggested that this is a mechanism to protect the joint, long-term AMI can reduce the effect of rehabilitation and strength training (McLeod et al., 2012). In the initial stages after injury, AMI is at its most severe and quadriceps strength is predominantly affected, compared to other muscles acting on the knee joint (Hart et al., 2010). A 50 to 90 percent reduction in quadriceps activation has been measured after meniscectomy within the first four days post-surgery (Shakespeare et al., 1985). The impact of AMI reduces over time, but can remain present for 18 to 33 months after significant knee injury (Rice & McNair, 2010). After arthroscopic meniscectomy, residual levels of AMI can remain apparent four years post-surgery when data is compared with healthy age match controls, despite no evidence of further joint degeneration within the patient group (Becker, Berth, Nehring, & Awiszus, 2004).

2.4.3. Measurement of muscle strength

The assessment of muscle performance can be achieved through a number of different methods. After meniscectomy, isokinetic assessment is commonly used to assess peak torque by comparing results to the unaffected limb. Isokinetic muscle testing is safe and has good validity and reliability (Maffiuletti, Bizzini, Desbrosses, Babault, & Munzinger, 2007). This type of testing however, does not mimic natural movement of the knee and is standardised to a set range of motion over which repeated trials are undertaken (Gapeyeva et al., 2000). There are a variety of parameters that have been used when testing knee strength after partial meniscectomy, and these include different modes of isokinetic muscle action, joint angular velocities and testing protocols. An overview of the located studies is presented in Table 2.2. Most commonly, the range of motion is set from full knee extension to between 90 and 120 degrees of knee flexion. The joint angular velocities of isokinetic dynamometers are often set at 60 and 180 degrees per second while the type of muscle action is usually concentric. These angular velocities allow the are used for their relationship to functional tasks such as walking and running (Gapeyeva et al., 2000; Pincivero, Lephart, & Karunakara, 1997). Peak torque is calculated as the best value achieved over three to five repetitions. All studies compared peak torque to the non-injured limb, and only one (Thorlund, Aagaard, & Roos, 2010) compared the results to healthy non-injured controls. They reported no significant difference across the injured and non-injured limbs and when compared to controls limbs, two years post-operatively. Contralateral limb weakness has been observed after knee injury (Hart et al., 2010), and therefore, a peak torque comparison to healthy control participants would enhance our understanding of the magnitude of weakness present after partial meniscectomy.

2.4.4. Quadriceps peak torque

Most studies investigating meniscus injury have focused on quadriceps peak torque following meniscal surgery and did not include a pre-operative assessment (Ericsson et al., 2006; Gapeyeva et al., 2000; Glatthorn et al., 2010; Thorlund et al., 2012). Overall, there was consensus that quadriceps weakness was evident after surgery, however, the significance of pre-existing weakness prior to the surgical intervention is unclear. One study did investigate quadriceps strength in those eligible for partial meniscectomy without post-operative assessment and found the quadriceps to be significantly impaired (13 percent deficit) when compared to the non-injured side (Stensrud et al., 2014). Of the studies that did include both pre- and post-operative testing, most focus on the effect of an exercise programme on strength, compared to one with no exercise (Moffet, Richards, Malouin, Bravo, & Paradis, 1994; St-Pierre et al., 1992). Across the studies, inter-limb deficits ranged from 12 to 40 percent. One study (Matthews & Dianne, 1996) performed an inter-limb comparison using an isokinetic dynamometer that confirmed the presence of quadriceps strength deficits before surgery (15 percent) that increased after surgery. As this is the only study to perform isokinetic testing before and after surgery, the extent of quadriceps weakness observed has yet to be supported. Gapeyeva et al. (2001) performed an inter-limb comparison, both pre- and post-operatively, using a custom made dynamometric chair to assess isometric strength. Notably, they reported significant quadriceps strength deficits (14.2 to 17.5 percent) in the injured leg that remained six months after partial meniscectomy, suggesting changes in muscle performance after surgery may be long-term.

2.4.5. Quadriceps muscle endurance and fatigue

In respect of quadriceps muscle performance, the focus in research and in clinical practice has been on minimising strength deficits. Another parameter affecting quadriceps muscles performance is fatigue. The ability to maintain levels of submaximal activity over time is a requirement of many work and sporting activities, yet it has received little attention in the literature. There are two main constructs suggested to contribute to fatigue; the first is peripheral and involves an inability to supply metabolic substrates to the contracting muscles to meet the energy demand, and the second is centrally driven, where a reduction in neural drive or motor command to working muscles results in a decline in force output (Ansley, 2003). To date, few studies have assessed the effect of fatigue on muscle force production and lower limb functional performance after meniscal injury and surgery. Ericsson et al. (2009) examined quadriceps muscle endurance four years post-meniscal surgery. Endurance was measured as the total work achieved over 25 maximal effort repetitions at 180 degrees per second, measured using an isokinetic dynamometer. These authors did not report deficits across limbs or use control participants. Instead, their focus was on changes in endurance as a result of a training programme. Interestingly, they found a significant improvement ($p<0.05$) in quadriceps endurance (seven percent) was achieved with a four month supervised strengthening programme, where the control group did not change (Ericsson et al., 2009). St-Pierre et al. (1992) also considered a fatigue test calculating the total work, average power and the ratio of the last three contractions to the first three contractions, of 15 consecutive maximal effort repetitions, before and after partial meniscectomy. The focus of this study was to assess the training effect of delayed versus early training after partial meniscectomy. Although they reported deficiencies in quadriceps endurance performance (12 to 17 percent across limbs) before surgery, they found all fatigue measures (in both early and delayed exercise) returned to the level of the unaffected side at six weeks post operation. In the injured limbs, peak torque decreased by 21 percent (early exercise group) and 19 percent (delayed exercise group) over the 15 repetitions preoperatively, and 21 percent and 17 percent respectively six weeks after partial meniscectomy. In the non-injured limbs, the torque decreased by 25 percent (early exercise) and 22 percent (delayed exercise).

Endurance performance testing has been used after other types of surgical intervention. Cavalcante, Teixeira, Sousa, Lima, and Oliveira (2016) conducted a study on 17 elite soccer players five to seven months after anterior cruciate ligament reconstruction. Each individual was required to undergo 15 maximum effort contractions at 300 degrees per second on a Biodex isokinetic dynamometer. They analysed fatigue as the ratio between the work done in the final third by the work done in the first third in the injured and the non-injured limbs. They reported a decrease in peak torque of 20 percent in the injured limb and 29 percent in the non-injured limb over 15 consecutive repetitions. Although the rate of fatigue was higher in the non-injured compared to the injured limb, there was no significant difference between groups. They suggested this difference in fatigue was a consequence of quadriceps weakness of the injured leg after surgery, but also indicated this may be due to the development of type II muscle fibre hypertrophy after chronic anterior cruciate ligament deficiency (Cavalcante et al., 2016; McNair & Wood, 1993).

2.4.6. Measurement of quadriceps muscle endurance performance

From the literature search, there were no studies that provided data to assess endurance capacity before and after partial meniscectomy. Isokinetic endurance testing has been undertaken in healthy individuals. For instance early work described by Thorstensson and Karlsson (1976) examined the decline in maximum knee extension torque across 50 repetitions at 180 degrees per second. They used a ratio of the last three repetitions to the initial three contractions to describe fatigability in peak torque over the isokinetic endurance test, reporting an average decline of 45 percent. They also found a strong correlation between this and the concentration of type II muscle fibres. Later investigation of the relationship however indicated this is not always the case, with poor correlations shown in resistance trained individuals (Bagley et al., 2017). Nevertheless, the difference in the mean values toward the start of the endurance test and the end of the endurance test are a commonly used measures in the investigation of endurance performance (Maffiuletti et al., 2007; McCarthy, Callaghan, & Oldham, 2008). Pincivero et al. (1997) investigated the reliability of measures of fatigability (total work, average power, and the difference in work performed during the first 10 repetitions to the last 10 repetitions) over 30 repetitions utilising an isokinetic dynamometer at 180 degrees per second. They reported intraclass correlation coefficients ranging between 0.61 to 0.89 measures. Maffiuletti et al. (2007) additionally included a measure of slope (highest peak torque to the peak torque of the last repetition) with the ratio of the last four repetitions and the first four repetitions over 20 repetitions. They reported higher intraclass correlation coefficients (0.85 and 0.89) across the measures. The combination of a measure of difference in peak torque between the beginning and the end of the endurance test, and fatigue slope measurements has been subsequently supported across the literature (Bosquet et al., 2010; Pincivero, Gandaio, & Ito, 2003; Pincivero, Gear, & Sterner, 2001). McLeland et al. (2016) also determined a strong correlation between 30 repetitions during endurance testing with the original Thorstensson test of fatigability. They reported a Pearson correlation coefficient of r= 0.81.

Table 2.2: Isokinetic quadriceps peak torque deficits before and after partial meniscectomy

Study	Status	Sample	Mean age	Interventions	Assessment	Test Intervals	Side to side deficit
St-Pierre et al. (1992)	Early training Delayed training	7 M 0 F 6 M 3 F	35.8 years 35.8 years	APM (early training) APM (delayed training)	IKD (Cybex) 3 reps 60 °/sec 120 °/sec 180 °/sec 240 °/sec	Pre-op Post-op (2 weeks) (6 weeks) (10 weeks)	Pre-op (all velocities) Range 12% - 21%*
Matthews and Dianne (1996)	Inter-limb comparison	17 M 5 F	35.1 years	APM	IKD (Cybex) 3 reps 60 °/sec 120 °/sec 180 °/sec 240 °/sec	Pre-op Post-op (2 weeks) (4 weeks) (6 weeks) (8 weeks) (10 weeks) (12 weeks)	Pre-op 15% - 60 °/sec* Post op (2 weeks) 40% - 60 °/sec* 30% - 120 °/sec* 29% - 180 °/sec* 21% - 240 °/sec* Post op (4 weeks) 25% - 60 °/sec* 22% - 120 °/sec* 17% - 180 °/sec* 19% - 240 °/sec* Post op (6 weeks) 20% - 60 °/sec* 17% - 120 °/sec* 17% - 180 °/sec* Post op (8 weeks) 18% - 60 °/sec* 15% - 120 °/sec* Post op (10 weeks) 15% - 60 °/sec* 13% - 120 °/sec* Post op (12 weeks) 14% - 60 °/sec* 12% - 120 °/sec*

Table 2.2: Continued: Isokinetic quadriceps peak torque deficits before and after partial meniscectomy.

Study	Status	Sample	Mean age	Interventions	Assessment	Test Intervals	Side to side deficit
Moffet et al. (1994)	Exercise group Control	15 M 16 M	42 years 38 years	APM (exercise) APM (no exercise)	IKD (Kin-Com) 3 reps 30 °/sec 180 °/sec	Pre-op Post test (3 weeks)	Pre-op (control) 18% - 30 °/sec* 12% - 180 °/sec* Pre-op (exercise) 40% - 30 °/sec* 30% - 180 °/sec* Post op (control) 40% - 30 °/sec* 40% - 180 °/sec* Post-op (exercise) 30% - 30 °/sec* 30% - 180 °/sec*
Gapeyeva et al. (2000)	Inter-limb comparison	21 M	26.4 years	APM (exercise)	IKD (Cybex) 3 reps 60 °/sec 180 °/sec	Post-op (4 weeks) (12 weeks) (24 weeks)	Post-op (4 weeks) 28.6% - 60 °/sec* 31% - 180 °/sec* Post-op (12 weeks) 19.8% - 60 °/sec* 15% - 180 °/sec* Post-op (24 weeks) 18.2% - 60 °/sec*
Ericsson et al. (2006)	Inter-limb comparison	26 M 16 F	45.7 Years	APM	IKD (Biodex) 5 reps 60 °/sec 180 °/sec	Post-op (208 weeks)	9% - 60 °/sec* 6% - 180 °/sec*
Glatthorn et al. (2010)	Inter-limb comparison	10 M 4 F	44 Years	APM	IKD (Biodex) 3 reps 60 °/sec 180 °/sec	Post op (24 weeks)	14.5%*

Table 2.2: Continued: Isokinetic quadriceps peak torque deficits before and after partial meniscectomy.

Study	Status	Sample	Mean age	Interventions	Assessment	Test Intervals	Side to side deficit
Thorlund et al. (2010)	Inter-limb comparison	21 M 10 F	46 years	APM group	IKD (KinCom) 4 reps 30 °/sec	Post-op (104 weeks)	APM group 2.6% concentric 3.1% eccentric
	Control	19 M 12 F	45.9 years	Healthy individuals			Control group No difference
Stensrud et al. (2014)	Inter-limb comparison	53 M 29 F	48.9 years	APM	IKD (Biodex) 5 reps 60°/sec	Pre-op only	13%*

* = statistically significant (p<0.05), APM = arthroscopic partial meniscectomy, IKD = Isokinetic dynamometer, M = Male, F = Female, °/sec = degrees per second, reps = repetitions, % = percent, op = operation,

2.5. HAMSTRINGS MUSCLE PERFORMANCE

2.5.1. Hamstrings role in function of the knee

The hamstring muscles also have an important role in the normal functional performance of the knee. Although there is no direct muscular attachment to the meniscus, indirect capsular insertions of the hamstrings to the medial meniscus suggest some influence on the stability and protection of the knee (Pandy & Andriacchi, 2010). Contraction of the hamstrings is known to reduce anterior tibial shear force, rotation and translation and loading at the knee during weight bearing flexion (Mesfar & Shirazi-Adl, 2006; Shelburne, Torry, & Pandy, 2006). Additionally, co-activation of the hamstrings with the quadriceps can reduce the net joint movement, providing protection and stability to the knee during the stance phase of gait (Pandy & Andriacchi, 2010). An increase in anterior-tibial shear force on the knee during landing activities has been observed (Malfait et al., 2016) when the appropriate co-contraction of the hamstrings and quadriceps is not achieved. After meniscectomy, a decrease in knee flexion and increase in tibial external rotation can occur during load bearing activities (Bulgheroni, Bulgheroni, Ronga, & Manelli, 2007; Netravali, Giori, & Andriacchi, 2010), which may be influenced by the hamstring muscles performance. Similar biomechanical factors have been seen (Nicolas, Nicolas, François, Michel, & Nathaly, 2015) after a meniscal tear with a reduction in knee flexion angle, knee flexion/extension range of motion, and knee abduction/adduction compared to healthy controls.

2.5.2. Hamstrings muscle deficiency after meniscal injury and surgery

Previous work examining hamstrings deficits has shown there to be minimal effect after knee injury (McLeod et al., 2012). Compared to the quadriceps, the hamstrings have more type II fibres and are longer muscle fibres, with lower overall pennation angles and cross-sectional area (Wickiewicz, Roy, Powell, & Edgerton, 1983). Differences in muscle anatomy and architecture may alter the extent of atrophy seen in the hamstrings compared to the quadriceps after periods of disuse. After partial meniscectomy, the cross-sectional area of the hamstrings and adductors remains unchanged compared to control participants, with the majority of atrophy observed in the quadriceps muscle groups (Akima & Furukawa, 2005). Further to this, the hamstrings cross-sectional area shows little difference before and after surgery, suggesting that the hamstrings may not be affected in the same way as the quadriceps after meniscal injury and surgery (Hiroshi & Takemitsu, 2005). There are however neuromuscular mechanisms which may influence strength and endurance performance of the hamstrings after knee injury. AMI from the knee has an excitatory effect of flexion reflex pathways through the flexor withdrawal reflex and a reduction in normal descending control mechanisms (Rice & McNair, 2010). After partial meniscectomy, an increase in muscle activity of the hamstrings occurs during walking activities, compared to control participants (Sturnieks et al., 2011), which can remain at least eight weeks after surgery (Durand, Richards, Malouin, & Bravo, 1993). Additionally, the proximal attachments of the hamstrings allow the muscles to activate more in conjunction with other hip extensors. This would be advantageous where the knee is immobilised following injury.

2.5.3. Measurement of hamstrings muscle strength

Similar to quadriceps strength performance testing, after partial meniscectomy the hamstring muscles are often assessed in research studies through the use of an isokinetic dynamometer. An overview of the articles which included hamstrings isokinetic assessment after partial meniscectomy is provided in Table 2.3. Again, there was a variety of testing parameters used, including muscle contraction (concentric, isometric), angular velocities (60 and 180 degrees per second) and equipment used.

2.5.4. Hamstrings peak torque

Although most studies identify that there is no change in hamstrings peak torque after partial meniscectomy (Ericsson et al., 2006; Glatthorn et al., 2010; Thorlund et al., 2010), this effect may be underrepresented without pre-operative assessments. Stensrud et al. (2014) performed testing on individuals eligible for partial meniscectomy and found a small but significant reduction (3.4 percent) in hamstrings strength before surgery compared to the non-injured limb. Similar to quadriceps performance testing, most studies performing pre-operative testing used isokinetic strength measures to investigate the effect of an exercise intervention on muscle performance (Moffet et al., 1994; St-Pierre et al., 1992). They reported deficits across limbs between four and 22 percent. The only study (Matthews & Dianne, 1996) to perform an inter-limb comparison to investigate hamstrings strength before and after partial meniscectomy, only recorded significant deficits two weeks after surgery (17 to 23 percent). Again, these findings have yet to be supported across the literature. One recent study (Ganderup, Jensen, Holsgaard-Larsen, Thorlund, & Thorlund, 2017) to perform pre- and post-operative testing found similar deficits pre-operatively (nine percent) using an isometric hamstrings testing protocol, which was also not significant. Moffet et al. (1994) used a control group with no exercise after surgery and found an increase in flexion work deficits (nine percent) from pre-test to post-test, whereas the exercise groups deficits reduced (seven to eight percent). Only one study (Thorlund et al., 2010) used a control group of healthy individuals two years after surgery, where no significant differences were observed across limbs and between limbs in the control group.

2.5.5. Hamstrings muscle endurance and fatigue

The assessment of hamstrings muscle performance has been dismissed by many due to the minimal effect after injury and surgery (McLeod et al., 2012). Further testing of other components of muscle performance may be more sensitive in detecting changes in the hamstrings after partial meniscectomy. There were two studies (Ericsson et al., 2009; St-Pierre et al., 1992) which considered endurance testing after partial meniscectomy. Both reported a mean improvement in hamstrings endurance performance with exercise after partial meniscectomy, however again, these findings were not statistically significant. Interestingly, St-Pierre et al. (1992) reported a significant difference in hamstrings endurance of the injured limb before surgery compared to the non-injured limb, which returned to the level of the non-injured limb six weeks after surgery. The deficit pre-surgery was 25 percent in the delayed exercise group and 19 percent in the early exercise group. In the injured limbs, peak torque decreased between 20.2 to 25.5 percent over the 15 repetitions pre-operatively, and 31.6 to 36.9 percent six weeks after surgery. In the non-injured limbs, peak torque decreased by 25.2 to 28.7 percent.

2.5.6. Measurement of hamstrings muscle endurance performance

Compared to the quadriceps endurance performance in healthy individuals, the reliability of hamstrings endurance assessment using an isokinetic dynamometer is limited. This has been consistently reported in studies measuring isokinetic peak torque over 20 to 30 repetitions (Bosquet et al., 2010; Maffiuletti et al., 2007; Pincivero et al., 1997). Pincivero et al. (1997) reported intraclass coefficient correlation values of 0.52 to 0.78 in knee flexor endurance performance using a ratio of work during the last 10 repetitions and work during first 10 repetitions only. For this measure, participants were required to perform 30 maximum contractions at 180 degrees per second. Better reliability for hamstrings fatigability has been determined (Maffiuletti et al., 2007), through a combination of the ratio of the last four contractions to the first four contractions and fatigue slope (regression of the second repetition to the last repetition), measured over 20 repetitions at 180 degrees per second (intraclass correlation coefficient 0.78 to 0.81). For the hamstrings, Bosquet et al. (2010) recommends the most reliable measure of hamstrings endurance is achieved over 30 repetitions including a measure of the mean difference between the beginning and end of the endurance test, and a fatigue slope calculation. Due to the neuromuscular changes observed after partial meniscectomy, further testing of muscle endurance would assist to better understand the impact on hamstrings muscle performance.

Table 2.3: Isokinetic hamstrings peak torque deficits before and after partial meniscectomy

Study	Status	Sample	Mean age	Interventions	Assessment	Test Intervals	Side to side deficit
St-Pierre et al. (1992)	Early training	7 M 0 F	35.8 years	APM (early training)	IKD (Cybex) 3 reps 60 °/sec 120 °/sec 180 °/sec 240 °/sec	Pre-op Post-op (2 weeks) (6 weeks) (10 weeks)	Pre-op 15.8% - 60 °/sec* 21.8% - 240 °/sec*
	Delayed training	6 M 3 F	35.8 years	APM (delayed training)			
Matthews and Dianne (1996)	Inter-limb comparison	17 M 5 F	35.1 years	APM	IKD (Cybex) 3 reps 60 °/sec 120 °/sec 180 °/sec 240 °/sec	Pre-op Post-op (2 weeks) (4 weeks) (6 weeks) (8 weeks) (10 weeks) (12 weeks)	Pre-op 9.4 – 60 °/sec 6.3 – 120 °/sec Post op (2 weeks) 23% - 60 °/sec* 17.4% - 120 °/sec* 8% - 180 °/sec Post op (4 weeks) 12.4% - 60 °/sec 10.5% - 120 °/sec 5.7% - 180 °/sec Post op (6 weeks) 11% - 60 °/sec 7.9% - 120 °/sec 3% - 180 °/sec Post op (8 weeks) 8.3% - 60 °/sec 5.9% - 120 °/sec 0% - 180 °/sec Post op (10 weeks) 7% - 60 °/sec 6.5% - 120 °/sec 2% - 180 °/sec Post op (12 weeks) 7.9% - 60 °/sec 5.9% - 120 °/sec 1.8% - 180 °/sec

Table 2.3: Continued: Isokinetic hamstrings peak torque deficits before and after partial meniscectomy

Study	Status	Sample	Mean age	Interventions	Assessment	Test Intervals	Side to side deficit
Moffet et al. (1994)	Exercise group Control	15 M 16 M	42 years 38 years	APM (exercise) APM (no exercise)	IKD (Kin-Com) 3 reps 30 °/sec 180 °/sec	Pre-op Post test (3 weeks)	Pre-op (control) 11% - 30 °/sec 10% - 180 °/sec Pre-op (exercise) 12% - 30 °/sec 12% - 180 °/sec Post op (control) 20% - 30 °/sec 19% - 180 °/sec Post-op (exercise) 5% - 30 °/sec 4% - 180 °/sec
Ericsson et al. (2006)	Inter-limb comparison	26 M 16 F	45.7 Years	APM	IKD (Biodex) 5 reps 60 °/sec 180 °/sec	Post-op (364 weeks)	1% - 60 °/sec 1% - 180 °/sec
Glatthorn et al. (2010)	Inter-limb comparison	10 M 4 F	44 Years	APM	IKD (Biodex) 3 reps 60 °/sec 180 °/sec	Post-op (24 weeks)	6.9% - 60 °/sec 4% - 180 °/sec
Thorlund et al. (2010)	Inter-limb comparison Control	21 M 10 F 19 M 12 F	46 years 45.9 years	APM group Healthy individuals	IKD (KinCom) 4 reps 30 °/sec	Post-op (147 weeks)	APM group 1.4% concentric 1.6% eccentric Control group No difference
Stensrud et al. (2014)	Inter-limb comparison	53 M 29 F	48.9 years	APM	IKD (Biodex) 5 reps 60°/sec	Pre-op only	3.4%*

* = statistically significant (p<0.05), APM = arthroscopic partial meniscectomy, IKD = Isokinetic dynamometer, M = Male, F = Female, °/sec = degrees per second, reps = repetitions, % = percent, op = operation.

2.6. FUNCTIONAL PERFORMANCE IN MENISCAL INJRUY AND AFTER PARTIAL MENISCECTOMY

Functional performance tests are often used to indicate readiness to return to sport after injury. Assessments most often involves hopping and jumping tasks, as these allow a comparison across limbs. The consensus for clinical decisions is to achieve side-to-side differences in performance that are equal to or less than 10 percent of the contralateral non-injured limb (Adams, Logerstedt, Hunter-Giordano, Axe, & Snyder-Mackler, 2012; Di Stasi, Logerstedt, Gardinier, & Snyder-Mackler, 2013; Keays, Bullock-Saxton, Newcombe, & Kaeys, 2003; Schmitt, Paterno, & Hewett, 2012). As discussed above, injury to the meniscus and subsequent surgery has a clear effect on strength, and perhaps endurance of the quadriceps and hamstrings muscles. The functional implications of such impairments are thought to be important. Performance testing enables an appreciation of how impairments in strength and endurance, and self-reported function may be related.

2.6.1. Implications of meniscal injury and partial meniscectomy upon function

Movement strategies adopted after knee injury are often assumed to protect the joint and to avoid further pain and dysfunction, while simultaneously allowing appropriate performance of skills. Some changes in neuromuscular control may lead to larger forces being placed upon the joints. For instance, greater than normal knee adduction moments have been observed after partial meniscectomy (Schipplein & Andriacchi, 1991). The external knee adduction moment calculated in gait analysis is considered a valid estimate of medial tibiofemoral compartment loading (Trepczynski, Kutzner, Bergmann, Taylor, & Heller, 2014; Zhao et al., 2007), and has been associated with quadriceps weakness (Lewek, Rudolph, Axe, & Snyder-Mackler, 2002). In addition, generalised co-contraction, as a compensation strategy, may lead to increased compression forces within the knee joint. After meniscectomy, these changes in kinematics have been observed during side stepping and leg cross over activities (Besier, Lloyd, & Ackland, 2003; Lloyd & Buchanan, 2001; Zhang, Xu, Wang, & Hendrix, 2001). Similar knee joint kinematics have been observed in tibiofemoral joint osteoarthritis (Andriacchi et al., 2004), and may be a factor in the increased prevalence seen after meniscal injury and surgery (Fabricant, Rosenberger, Joki, & Ickovics, 2008). Ericsson et al. (2006) observed that functional performance and self-perceived function remained impaired in middle aged individuals four years after meniscectomy. This suggests that functional deficits can exist long after the acute phase, in some cases years after injury (Becker et al., 2004).

2.6.2. Functional testing associated with strength and power

Functional testing is usually easy to administer, however the validity of performance testing is difficult to ascertain. Hegedus, McDonough, Bleakley, Cook, and Baxter (2015) performed a systematic review of functional performance testing of knee injuries and found that although testing is useful in detecting differences between limbs, there is a poor correlation between constructs of each test. There is also a low correlation with hop testing and the ability to predict functional outcomes, such as re-injury (Bremander, Dahl, & Roos, 2007; Hegedus et al., 2015). There are six physical performance tests pertinent to the knee that have been substantially studied in an athletic population; the one-leg hop for distance, six meter timed hop, the crossover hop for distance, the triple jump, and the single leg vertical leap (Hegedus et al., 2015). Each of these tests have been shown to independently correlate to measures of strength and/or power (Hamilton et al., 2008; Hsu, George, & Chmielewski, 2016; Teyhen et al., 2014). Of these, Bremander et al. (2007) investigated the reliability and validity of individual tests after meniscectomy. They found that two tests; maximum number of knee bends in 30 seconds and one-leg hop for distance, had good test-retest reliability and an ability to discriminate with regard to age, gender and symptoms with an acceptable floor to ceiling effect.

2.6.3. Functional performance after meniscal injury and partial meniscectomy

There are few papers concerned with functional performance after meniscectomy that incorporate components such as endurance and fatigue. Table 2.4 identifies the studies that include a comparison of hop performance before and after partial meniscectomy. Of the located studies, most are focused upon activities that involve strength and power. For instance, single hop for distance, triple hop for distance, vertical hop for height, square hop test and timed six-meter hop test (Ericsson et al., 2006; Ganderup et al., 2017; Goodwin et al., 2003; Hsu et al., 2016; Stensrud et al., 2014; Thorlund et al., 2010; Thorlund et al., 2012). These tests have generally been validated in healthy individuals (Hamilton et al., 2008; Ostenberg et al., 1998; Teyhen et al., 2014). The key findings from these studies are that deficits ranging between seven to 16 percent are often observed before surgery. Post-surgery limb deficits range from two to 19 percent. These deficits did appear to change over time, with near resolution in defects across limbs two years after surgery (Thorlund et al., 2010; Thorlund et al., 2012), that returned (10 to 19 percent) four years after surgery (Ericsson et al., 2006).

2.6.4. Functional testing for endurance

Although most of the previously mentioned tests have a hopping focus, there is currently no functional hop test to assess endurance after knee injury. Endurance performance testing has been performed in healthy and athletic populations where usually fatigue is usually achieved using localised or general protocols just before hop performance tests (Gustavsson et al., 2006; Santamaria & Webster, 2010). Several investigators have used this type of model to understand the effect on knee joint landing biomechanics during fatigued circumstances in healthy individuals (Chappell et al., 2005; Fagenbaum & Darling, 2003; McLean et al., 2007; Ortiz et al., 2010; Rodacki, Fowler, & Bennett, 2002; Wojtys, Wylie, & Huston, 1996). Generally, these fatiguing interventions have led to an observed deterioration in landing kinematics (Fagenbaum & Darling, 2003).

Other modes of endurance testing in healthy individuals have involved physiological and biomechanical assessment of a decline in force production, muscle activation and kinematics through activities like double leg jumping (Bosco, 1999; McNeal et al., 2010). In such assessments, participants are required to jump as many times as they are able over a 60 second timeframe. This test has a strong relationship with performance on the Wingate test (McNeal et al., 2010). Although it demonstrates good validity in assessing power-endurance (Bosco, Luhtanen, & Komi, 1983; McNeal et al., 2010), it cannot differentiate between limbs, reducing its usefulness in clinical situations. A single leg repeated hop test over a 60 second period has been assessed in an athletic population. However, the results from this test were linked to acrobatic performance and not as a test for limb endurance constructs (Marina & Rodriguez, 2012).

Current single leg hop tests used to investigate endurance performance in the lower limb do not appear to demonstrate appropriate validity (Ostenberg et al., 1998; Roos, Östenberg, Roos, Ekdahl, & Lohmander, 2001). For instance, the square hop test requires participants to hop in and out of a box in a clockwise direction as many times as possible in 30 seconds. Although this test has been used in two studies (Ericsson et al., 2009; Ericsson et al., 2006) after partial meniscectomy, the association to endurance had been assumed from the fatiguing nature of the test. Nevertheless, these findings showed a 10 percent deficit across limbs post-surgery. Ros, Holm, Friden, and Heijne (2013) further investigated the responsiveness of the square hop test after 30 minutes of aerobic work and found that performance did not change despite the presence of objective and subjective fatigue. Roos et al. (2001) used two functional performance tests (30 second knee bending and 30 second one leg raising) for endurance after full meniscectomy. These authors found an approximate difference of 13 percent in the number of knee bends, between the injured limb and the corresponding limb in the control group (matched in age and gender). There was no significant difference in the number of single leg raises over 30 seconds between groups. The 30 second lateral hop test has also been used in healthy individuals to assess endurance performance. In this test participants were required to hop on one leg between two parallel lines, recording the number of successful hops achieved in 30 seconds. The number of successful hops achieved, however was not found to be significantly associated with any measure of isometric strength endurance (Kollock, Van Lunen, Ringleb, & Oñate, 2015).

Thus, at this time there has been limited research examining endurance in functional performance tests. Yet such tests could provide important information relating to the ability to sustain performance. Endurance ability is relevant to many sporting endeavours which require repeated high intensity activation of muscles to achieve the goals of the overall performance.

Table 2.4: Functional performance tests before and after partial meniscectomy

Study	Status	Sample	Mean age	Interventions	Assessment	Test Intervals	Side to side deficit
Goodwin et al. (2003)	Exercise Group	39 M 6 F	45 years	APM (supervised exercise)	1-leg hop (height)	Post-op (6 weeks)	Control group 18% - 1-leg hop* Exercise group 12% -1-leg hop*
	Control Group	35 M 6 F	41 years	APM (home exercise)			
Ericsson et al. (2006)	Inter-limb comparison	26 M 16 F	45.7 years	APM	1-leg hop (distance) 1-leg rising (number) Square hop	Post-op (208 weeks)	19% - 1-leg hop* 2% - 1-leg rise* 10% - square hop*
Thorlund et al. (2010)	Inter-limb comparison	21 M 10 F	46 years	APM group	1-leg hop (distance) 1-leg knee bend (30 sec)	Post-op (104 weeks)	APM group 2.5% - 1-leg hop 5% - knee bend
	Control	19 M 12 F	45.9 years	Healthy Individuals			Control group No difference
Thorlund et al. (2012)	Inter-limb comparison	17 M 5 F	46.6 years	APM	1-leg hop (distance) 1-leg knee bend (30 sec)	Post-op (104 weeks) (208 weeks)	Post op (104 weeks) 1% - 1-leg hop 1.2% - knee bend
	Control	14 M 11 F	46.6 years	Healthy Individuals			Post op (208 weeks) 1% 1-leg hop 4% - knee bend
Stensrud et al. (2014)	Inter-limb comparison	53 M 29 F	48.9 years	APM	1-leg hop (distance) 1-leg knee bend (30 sec) 6MTH (number)	Pre-op only	11% - 1-leg hop* 7% - knee bend* 9% - 6MTH*

Table 2.4: Continued: Functional performance tests before and after partial meniscectomy

Study	Status	Sample	Mean age	Interventions	Assessment	Test Intervals	Side to side deficit
Hsu et al. (2016)	Inter-limb comparison	20 M 2 F	19.4 years	APM (Standard exercise) APM (Quadriceps specific exercise)	1-leg hop (distance)	Post-op (6 weeks) Post rehab (52 weeks)	Post (6 weeks) 11.4% - both groups* Post op (52 weeks) 1.1% - both groups*
Ganderup et al. (2017)	Inter-limb comparison	17 M 6 F	46 years	APM	1-leg hop (distance) 1-leg knee bend (30 sec)	Pre-op Post-op (12 weeks) (52 weeks)	Pre-op 11% - knee bends* 16% - 1-leg hop* Post op (12 weeks) 13% - knee bend* 16% - 1-leg hop* Post op (52 weeks) 0% - knee bends 3.6% - 1-leg hop

* = statistically significant (p<0.05), APM = arthroscopic partial meniscectomy, M = Male, F = Female, sec = seconds; 6MTH = six-minute timed hop, % = percent, op = operation.

2.7. LITERATURE REVIEW SUMMARY

Meniscal injury is common in the sporting population and arthroscopic partial meniscectomy is widely used for medical management. Persistent weakness of the quadriceps muscles is frequently identified across the literature after partial meniscectomy, with changes in hamstrings muscle strength being less apparent. There has been minimal investigation into endurance performance in the quadriceps and hamstrings after meniscal injury and arthroscopic partial meniscectomy. While the single repetition hop test is often used in return to sport criteria, few papers have examined the effect of repeated maximal effort hop tests in performance across limbs. Ongoing deficits in muscle performance after partial meniscectomy may be a modifiable risk factor for re-injury and for the development and progression of osteoarthritis. An examination of the effects of repeated maximal effort repetitions might highlight additional deficits that are modifiable by training, and hence be beneficial to rehabilitation following meniscal surgery.

3. Chapter 3: MATERIALS AND METHODS

3.1. INTRODUCTION

This chapter is divided into five main sections. The first section describes the study design and the second outlines the selection of participants. The third section presents the equipment and questionnaires used and the fourth section describes the procedures for testing protocols. The final section defines the statistical techniques used to analyse the data.

3.2. DESIGN

This study used a case-controlled, inter-limb comparison design between participants with a meniscus tear pre-operatively and six weeks after undergoing partial meniscectomy. This also included healthy non-injured control participants assessed six weeks apart. Participants underwent an isokinetic strength and endurance test of the knee extensors and flexors and a hop endurance test on a force plate.

3.3. PARTICIPANTS

3.3.1. Partial meniscectomy and control group

Participants were invited to participate through advertising at Auckland University of Technology, or referral from physiotherapy and knee surgery clinics on the North Shore, Auckland. To determine sample size, an initial power calculation was performed on data from Ericsson et al. (2009) who examined work done by quadriceps over 25 repetitions in an isokinetic dynamometer. Thereafter, pilot testing provided further confirmation of the sample size. To detect a 10 percent difference across limbs in quadriceps work done with the alpha level at 0.05 and the power set to 0.8, a sample size of 21 was required. An additional three participants were included to allow for the 10 to 15 percent drop-out rate reported in previous prospective studies (Ericsson et al., 2009).

Participants in the surgery group were those with a unilateral meniscal tear scheduled to undergo arthroscopic partial meniscectomy. Diagnosis of meniscal injury was confirmed through MRI and arthroscopy at the time of surgery. All participants were over the age of 20 years and fluent in English. Participants who underwent a partial meniscectomy for both an acute meniscal tear and degenerative tear were included in the study. Individuals who had an arthroscopic meniscal repair procedure or had associated ligament or chondral ailment were excluded from the study. In addition, participants who underwent surgery were excluded if they were not given clearance by their surgeon to return to unrestricted functional levels.

A control group of 22 healthy participants with no previous traumatic injury of the lower limb or neurological illness served as the control group and were matched in both age and gender with the surgical group. Exclusion criteria for these participants included: 1) previous traumatic knee injury; 2) current neurological or musculoskeletal ailments other than the meniscal injury that may independently influence strength; 3) cardiovascular conditions considered as risk factors to exercise.

Written and verbal explanations of the procedures were provided to all participants and an opportunity for participants to ask further questions was provided following the explanations (Appendix 1). Personal and medical information of each participant was documented and coded to prevent identification of individual results. Ethical approval was received from the Auckland University of Technology Ethics Committee on 16 December 2015, reference number 15/381 (Appendix 2) and all participants signed a document of informed consent on inclusion (Appendix 3).

3.4. EQUIPMENT

3.4.1. Isokinetic dynamometer

A Biodex isokinetic dynamometer (Biodex Medical Systems Incorporation, Shirley, New York, United States of America) was used to assess muscle strength and endurance. Validity and reliability of isokinetic assessment of knee extensor and flexor muscle strength (Gapeyeva et al., 2000; Maffiuletti et al., 2007) and endurance (Manou, Arseniou, Gerodimos, & Kellis, 2002; Pincivero et al., 1997) has been established. Seat height, seat depth, chair distance, lever arm length, and level arm distance were documented and recorded to ensure consistency between assessments. The seat angle was always set to 85 degrees and fixation straps were placed over the thigh, hips, and chest to reduce compensatory movements.

3.4.2. Force plate

A force plate (model: True Impulse; Northern Digital, Hong Kong Science Park, Shatin, Hong Kong) was used to collect vertical force profiles during single leg vertical hops. A force plate is one of the most widely used sports laboratory measurement tools and is considered the gold standard for measuring forces associated with sporting movements such as jumping (Jiménez-Reyes et al., 2017). Single leg hop tests are a typical measure used for functional assessment and have been shown to have high test-retest reliability, sensitivity, specificity and accuracy (Fitzgerald, Axe, & Snyder-Makler, 2000; Gustavsson et al., 2006). The reliability of a repeated vertical hop test was established prior to testing on healthy participants. The reliability testing protocol and findings are detailed in section: 3.6.4.

3.5. QUESTIONNAIRES

A specifically designed questionnaire was used to collect information concerning age, gender, affected knee, duration of knee symptoms (days), working status (unemployed/employed) and current medications. In this questionnaire participants also documented current levels of rehabilitation (minutes/week) and physical activity levels, using a nominal scale of six categories (refer Appendix 4). This scale of physical activity has been adapted from Grimby (1986). The Occupational Sitting and Physical Activity Questionnaire (OSPAQ) was used to collect hours of work and level of activity within the daily environment. This was recorded as an allocated percentage to each daily task; sitting (including driving), standing, walking, heavy labour or physically demanding tasks. The total of all tasks equated to 100 percent (refer Appendix 5). The OSPAQ questionnaire is considered a valid and reliable tool to measure physical activity levels in an office environment (Jancey, Tye, McGann, Blackford, & Lee, 2014; Reis, DuBose, Ainsworth, Macera, & Yore, 2005).

The Knee injury and Osteoarthritis Outcome Score (KOOS) and the Lower Limb Task Questionnaire (LLTQ) were used to assess perceived functional levels. The KOOS is a self-administered questionnaire with five sub-scales; pain, symptoms, activities of daily living (ADL), sports and recreation (Sport/Rec), and knee related quality of life (QOL). This questionnaire requires the participant to recall information from the week prior to the provision of the questionnaire. The KOOS uses five Likert boxes. Each of these boxes is allocated a score from zero to four. A normalised score for each sub-scale was calculated for analysis and interpretation (refer Appendix 6). This tool is a valid and reliable means of providing information related to functional performance in knee injury and osteoarthritis (Roos, Roos, Lohmander, Ekdahl, & Beynnon, 1998).

The LLTQ comprises two components to rate levels of difficulty in ADL and recreational activities (RA). Participants were required to identify the difficulty of 10 tasks within a 24-hour time period or estimate their level of difficulty if they had not performed the task in that period. These were rated using a Likert scale using the following categories; no difficulty (4), mild difficulty (3), moderate difficulty (2), severe difficulty (1), and unable (0). These categories were scored from 4 to 0 respectively and were subsequently summed to provide a score out of 40 (refer Appendix 7). This questionnaire was chosen as it is a concise measure of function, with high levels of reliability, validity and responsiveness (McNair et al., 2007).

3.6. PROCEDURES

Meniscal surgery participants attended two assessment sessions; approximately one week before surgery and six weeks after surgery. Control participants also undertook two sessions of testing six weeks apart. Each session's duration was approximately 60 minutes, and the assessment was administered by the same physiotherapist who had ten years of clinical experience. During each visit, testing procedures were divided into five sections: 1) a familiarization; 2) standardised warm up; 3) Biodex isokinetic dynamometry peak torque assessment; 4) Biodex isokinetic dynamometry endurance assessment, and 5) a functional hop test for endurance on the force plate. Appropriate rest intervals (five minutes) were provided between these procedures to ensure adequate recovery (Maffiuletti et al., 2007).

3.6.1. Familiarization and general warm-up

During the familiarization session, the demographic variables concerning the participants were collected. All participants completed the questionnaires including the client information sheet, KOOS, LLTQ and OSPAQ. Participants then undertook a standardized warm up of five minutes of stationary cycling with a low-load level at 70 revolutions per minute. During this time, a description of the isokinetic dynamometer was provided and verbal instructions about the assessment process were given. An opportunity to answer any questions was also provided to the participant.

3.6.2. Biodex isokinetic dynamometry peak torque assessment

Participants were seated in the isokinetic dynamometer. Randomisation by the toss of a coin established the first limb to be tested. The seat was adjusted and positions recorded to enable replication at the second testing session. Straps were used to stabilise the chest, hip and thigh. The axis of rotation of the knee joint was aligned with the axis of the dynamometer lever arm. The tibial limb attachment was placed just superior (three to four centimetres) to the medial malleolus with the foot in the plantigrade position. The knee of the measured leg was positioned at a flexion angle of 90 degrees. Range of motion during testing was set from 90 degrees to full extension. An assessment was undertaken to ensure that patients achieved full range of motion across all isokinetic tests in all sessions. Participants were instructed to hold their arms across their chest to further isolate knee joint movements. Participants then performed five submaximal effort knee extension and flexion movements across the previously mentioned range of motion. Testing was performed at two joint angular velocities: 60 and 180 degrees per second.

Participants then completed five maximal effort extension and flexion repetitions at each angular velocity (60 and 180 degrees per second). Verbal encouragement was given through this test to achieve greater peak torque results and ensure maximum effort was achieved (Gapeyeva et al., 2000). The highest peak torque value from these five repetitions at each angular velocity was recorded and used for subsequent analyses. A similar methodology has been used previously and the reliability of this measure has been established after knee injury and in meniscectomy (Gapeyeva et al., 2000; Maffiuletti et al., 2007).

3.6.3. Biodex isokinetic dynamometry endurance assessment

For measurement of muscle endurance, participants were seated in the same testing position on the isokinetic dynamometer as the strength testing protocol. The endurance test was performed approximately five minutes after the muscle strength testing. Participants were required to extend and flex through a range of 90 degrees to full extension at an angular velocity of 180 degrees per second only. Instructions were given to perform each of the 30 repetitions at maximum effort, and verbal encouragement was given. Previous research has established the reliability of this test (Bosquet et al., 2010; Maffiuletti et al., 2007). Torque data throughout the 30 repetitions was collected continuously at a sample rate of 100 hertz using the Biodex System Pro software (Biodex Medical Systems 2018) and saved for subsequent analyses. The dependant variables of interest were the mean peak torque of the highest three repetitions at the start of the task and the last three repetitions. Rate of fatigue was measured by calculating the slope of the peak torque of consecutive repetitions (newton meter/repetition) from the repetition with the highest peak torque to the last repetition (Maffiuletti et al., 2007). Data were analysed from both limbs in surgery and control groups.

3.6.4. Functional hop test for endurance on the force plate

The single leg hop test is a typical measure used for functional assessment for the return to sport and has a good ability to discriminate performance in the injured knee (Bremander et al., 2007). This test has also been shown to have high test-retest reliability, sensitivity, specificity and accuracy (Fitzgerald et al., 2000; Gustavsson et al., 2006). However, reliability testing for repeated maximum effort hops has not been established. Therefore, the following protocol was performed.

Fifteen healthy individuals (11 female and four male) with a mean age of 30 years ($\pm$10 years) were recruited for hop endurance test reliability analysis. All participants were physically active with no previous traumatic knee injury, or current cardiovascular, neurological or musculoskeletal ailments. These individuals performed the test at two time points, seven days apart. The dependent variables were the mean flight time of three trials at the beginning of the test and the last three trials of the test. Data was analysed from both limbs in these healthy participants.

Before each test, the force plate was calibrated. Participants were instructed to hop to the beat of a metronome timed at four second intervals. Each hop was performed with hands on hips and instructions given to hop as high as they were able for 30 consecutive hops. Participants received verbal encouragement during the task. Participants were able to place their opposite foot down briefly for balance if needed following the completion of a hop, but were required to quickly return to one foot before the next hop. Each participant had two practice test hops before the main test commenced.

Throughout the hop test vertical ground reaction force data were recorded at a sample frequency of 1000Hz and digital data were collected and processed with a customised software program (LabVIEW 2016: National Instruments Corporation, Austin, Texas United States of America). The dependant variable was flight time which was calculated between take-off and landing for each of the 30 hops utilising a "peak and valley" module within the LabVIEW software. Thereafter, the value was visually checked using a manual cursor routine (McIntyre, Mawston, & Cairns, 2012).

Intersession reliability analysis of hop test endurance measures for the right and left limbs was excellent and produced intraclass coefficient correlations between 0.88 and 0.95 with confidence intervals ranging from 0.68 to 0.98. Subsequently, this protocol was utilised in the testing of meniscal surgery and control group participants with a six-week interval between tests.

3.7. STATISTICAL ANALYSIS

Statistics Package for Social Science (SPSS) version 25 (International Business Machine Corporation, Armonk, New York, United States of America) and Microsoft Office Excel 2017 (Microsoft Corporation, Redmond, Washington, United States of America) were used for the data analyses. Descriptive statistics were calculated for the dependant variables and data were checked for normality utilising the Shapiro-Wilk test. An alpha level of 0.05 was utilised for all analyses. To answer the key questions presented in Chapter 1, the following analyses were performed:

Questions:

1. Are there inter-limb differences in isokinetic peak torque of the knee extensor and flexor muscles at joint angular velocities of 60 and 180 degrees per second before and after surgery?

A repeated measures design was used where the within subject-factors were limb (injured versus non-injured) and session (pre-operative versus six weeks post-operative). To determine differences between the non-injured limb of meniscal surgery participants and control group limb, an additional Analysis of Variance (ANOVA) was undertaken. Where interactions were apparent, t-tests with Bonferroni corrections were utilised.

2. Are there inter-limb differences in isokinetic peak torque of the knee extensor and flexor muscles during 30-repetitions of flexion and extension at a joint angular velocity of 180 degrees per second before and after surgery?

A repeated measures design was used where the within subject-factors were limb (injured versus non-injured), session (pre-operative versus six weeks post-operative), and time (start versus end of endurance test). To determine differences between the non-injured limb of meniscal surgery participants and the control group limb, an additional ANOVA was undertaken. Where interactions were apparent, t-tests with Bonferroni corrections were utilised.

3. Are there inter-limb differences in the slope of the relationship between peak torque and repetitions during the maximum effort isokinetic endurance test?

A repeated measures design was used where the within subject-factors were limb (injured versus non-injured), and session (pre-operative versus six weeks post-operative). To determine differences between the non-injured limb of meniscal surgery participants and the control group limb, an additional ANOVA was undertaken. Where interactions were apparent, t-tests with Bonferroni corrections were utilised. Slopes from each individual were assessed (R^2) to determine the appropriateness of each linear model ($p<0.05$).

4. Are there inter-limb differences in flight time during 30 consecutive maximum effort single leg hops before and after surgery?

A repeated measures design was used where the within subject-factors were limb (injured versus non-injured), session (pre-operative versus six weeks post-operative), and time (start versus end of endurance test). To determine differences between the non-injured limb of meniscal surgery participants and the control group limb, an additional ANOVA was undertaken. Where interactions were apparent, t-tests with Bonferroni corrections were utilised.

5. Are there inter-limb differences in the slope of the relationship between flight time and repetitions during the maximum effort repeated single leg hops?

A repeated measures design was used where the within subject-factors were limb (injured versus non-injured), and session (pre-operative versus six weeks post-operative). To determine differences between the non-injured limb of meniscal surgery participants and the control group limb, an additional ANOVA was undertaken. Slopes from each individual were assessed (R^2) to determine the appropriateness of each linear model ($p<0.05$).

6. Is there a relationship between perceived measures of function (questionnaires) and measured performance (hop tests)?

Pearson correlation coefficients were calculated. The variables were LLTQ (RA), KOOS (Pain) and KOOS (Sport/Rec). These were chosen as they reflected higher loading activities that were similar to the physical performance tests undertaken in the current study. These variables were correlated with selected post-surgery variables (peak torque, endurance and hopping) that showed significant changes across limbs. Such changes would reflect impairments/deficits that could potentially influence perceived function.

4. Chapter 4: RESULTS

4.1. INTRODUCTION

This chapter is divided into three main sections. The first section describes the demographic data and characteristics of all participants. The second section is divided into four subsections that include self-reported function, quadriceps performance, hamstrings performance and hop performance. Comparisons have been made between the injured and injured limb, pre- and post-operatively. Comparisons have also been made between the non-injured limb and the right limb of participants in the control group. The third section identifies the relationship between self-reported function and muscle and functional performance tests.

4.2. DEMOGRAPHICS

Forty-six participants volunteered to participate in the study. Twenty-four had a meniscal tear and underwent an arthroscopic partial meniscectomy. Three participants had post-operative complications and decided not to return for the second testing session. One discovered they had an unrelated medical illness, and the other two had increased pain and inflammation post-operatively and did not want to return due to the risk of further damage. The remaining group of 21 participants included sixteen males and five females. Each participant fully completed pre-operative testing one week before surgery and post-operative testing six to seven weeks after surgery. One subject developed an infection after surgery and was hospitalised for one week to address this issue. Post-operative testing for this subject was completed eight weeks post-surgery. Twenty-two participants of a similar age and gender participated as controls. All participants in this group were able to fully complete both testing sessions six weeks apart. Table 4.1 presents the demographic data for these groups, while Table 4.2 displays the characteristics of each group.

Pre-operatively, participants in the partial meniscectomy group worked an average of 35 hours, four days of the week. The OSPAQ identified that over two thirds of activity involved sitting (49 percent) and standing (18 percent), with the remaining third involving walking (21 percent), and heavy labour (10 percent). Participants returned to normal levels of activity at six weeks after surgery, where reported occupational levels slightly increased with an average of 37 hours of work, four and a half days of the week. There was a slight change in the type of work, with an increase in static activities (53 percent sitting and 22 percent standing), and a decrease in walking (18 percent) and heavy labour (seven percent).

Table 4.1: Demographic data

	Mean	SD	Range
Partial Meniscectomy Group			
Age (years)	42.3	11.4	26 - 64
Gender (M:F)	16:5		
Height (meters)	1.73	0.1	1.54 - 1.96
Mass (kg)	82.3	15.6	55.9 - 119.9
BMI (kg/m^2)	27.4	3.8	22.1 - 37.8
Control Group			
Age (years)	41.8	11.5	25 - 62
Gender (M:F)	16:6		
Height (meters)	1.75	0.9	1.61 - 1.96
Mass (kg)	81	17.1	55.9 - 121.9
BMI (kg/m^2)	26.1	4.2	20.8 - 40

SD = standard deviation; BMI = body mass index; M = male; F = female; kg = Kilogram; kg/m^2 = Kilograms per meter square

The median time period from injury to surgery was 196 days (range 35 days to 670 days). Most participants (67 percent) attempted conservative rehabilitation beforehand, ultimately resulting in surgical intervention. In the partial meniscectomy group, 15 participants underwent an average of 78 minutes per week of rehabilitation pre-surgery. This included a variety of activities such as stationary cycling, walking, strengthening exercise (home and gym based), Pilates and proprioceptive exercise. The remaining six participants in the partial meniscectomy group undertook informal rehabilitation using similar exercise programmes in the gym. The dominant leg was the injured limb in 12 participants in the partial meniscectomy group. The control group did not differ in terms of occupational or physical activity levels compared to the meniscal surgery group. Post-surgery, all participants were involved in exercise therapy including walking, stationary cycle, or gym based exercise including strength and proprioception.

Table 4.2: Participant characteristics at baseline

Participant characteristics	APM	Control
Average physical activity rating scale	4.1/6	4.9/6
Working status (Employed: Unemployed)	22:0	20:2
Average Days worked in last 7 days	4 days	4.5 days
Average hours worked in last 7 days	35.5 hours	37.3 hours
OSPAQ (sitting)	50 percent	50 percent
OSPAQ (standing)	18 percent	26 percent
OSPAQ (walking)	22 percent	18 percent
OSPAQ (heavy labour)	10 percent	6 percent
Duration of knee symptoms (days) (mean $\pm$ SD)	217.2 ($\pm$ 174.5)	
Number undergoing rehabilitation	15/22 participants	
Average minutes per week	78.6 minutes	
Rehabilitation type:		
Stationary cycle	11/15 participants	
Gym exercise (machine or classes)	12/15 participants	
Home exercise	4/15 participants	

OSPAQ = Occupational Sitting and Physical Activity Questionnaire, APM = Arthroscopic Partial Meniscectomy; SD = Standard Deviation

4.3. SELF-REPORTED FUNCTION

Perceived functional scores measured through the KOOS and LLTQ before and after surgery are displayed in Table 4.3. There was a main effect between groups at pre- and post-operative testing, with an interaction across meniscal and control groups (p>0.05). Subsequent analysis of the interaction showed the control group scored significantly higher in all questionnaire subcategories when compared to the meniscal group (p<0.05), and only the meniscal group significantly improved questionnaire scores (LLTQ and KOOS) after surgery (p<0.05). Six weeks after partial meniscectomy, an improvement of two points was observed in ADL and 16 points in RA for the LLTQ. Similar improvements where seen using the KOOS questionnaire; 18 points (pain), 15 points (symptoms), 12 points (ADL), 15 points (Sport/Rec), and 25 points (QOL). There was no significant change in LLTQ and KOOS scores of the control group across time points (p<0.05).

Table 4.3: Perceived functional scores of the control and partial meniscectomy group at baseline (pre) and after six weeks (post).

	Control Group			APM Group			
	Pre	Post	*p*-value	Pre	Post	Diff.	*p*-value
KOOS							
Pain	97/100	98/100	NS	70/100	88/100	20.4%	0.000
Symptoms	95/100	97/100	NS	67/100	81/100	17.3%	0.002
ADL	99/100	99/100	NS	82/100	94/100	12.8%	0.002
Sport/Rec	96/100	95/100	NS	57/100	72/100	20.8%	0.030
QOL	96/100	97/100	NS	41/100	65/100	36.9%	0.003
LLTQ							
ADL	39/40	39/40	NS	33/40	38/40	13.2%	0.003
RA	37/40	38/40	NS	17/40	25/40	32%	0.003

KOOS = Knee injury and Osteoarthritis Outcome Score; LLTQ = Lower limb Task Questionnaire APM = Arthroscopic Partial Meniscectomy; NS = Not Significant; Diff. =Difference, RA = Recreational Activities, ADL = Activities of Daily Living, Sport/Rec = Sport and Recreation, QOL = Quality Of Life; % = percent.

4.4. QUADRICEPS PERFORMANCE

During the maximal isokinetic torque task at the velocity of 60 degrees per second, quadriceps peak torque of meniscus participants was significantly less on the injured limb compared to the non-injured limb both pre-and post-operation (p<0.05). Figure 4.1 shows that pre-operatively, there was a difference in peak torque of 13 percent between the injured and non-injured limbs and post-operatively there was a difference in peak torque of 18 percent. Peak torque at 180 degrees per second showed a main effect for limb (injured and non-injured) (p<0.05). Figure 4.2 shows there was a limb by pre-versus post interaction where a strength deficit (15 percent) in the injured limb was only evident six weeks following surgery (p<0.05). There was no significant difference (p>0.05) across limbs in the control group, and between the control and the non-injured limbs of meniscus participants.

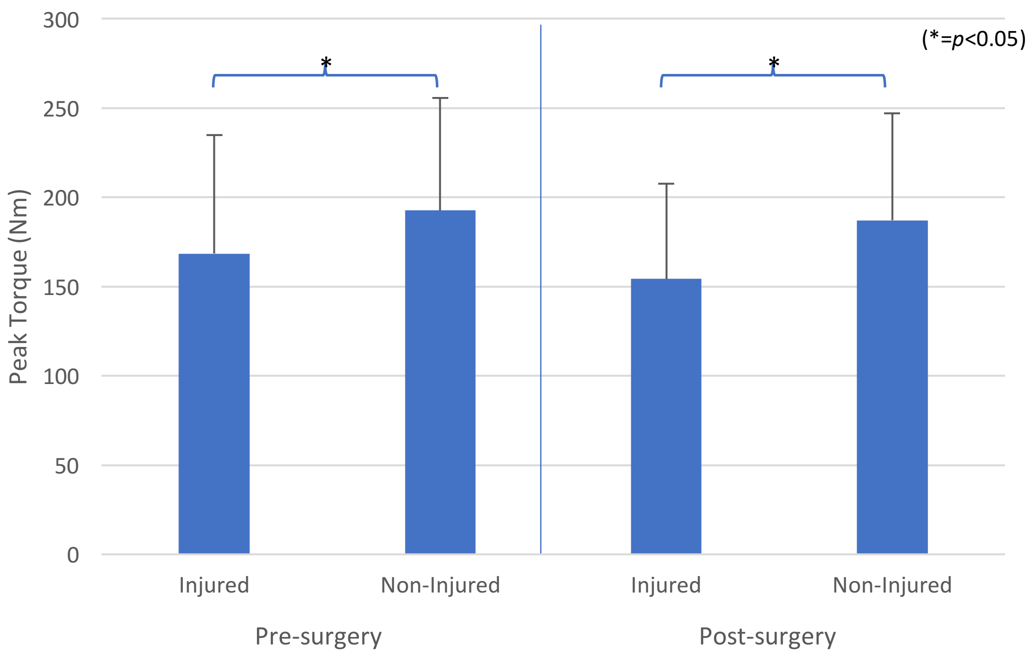

Figure 4.1: Peak torque of quadriceps at 60 degrees per second pre-and post-surgery.

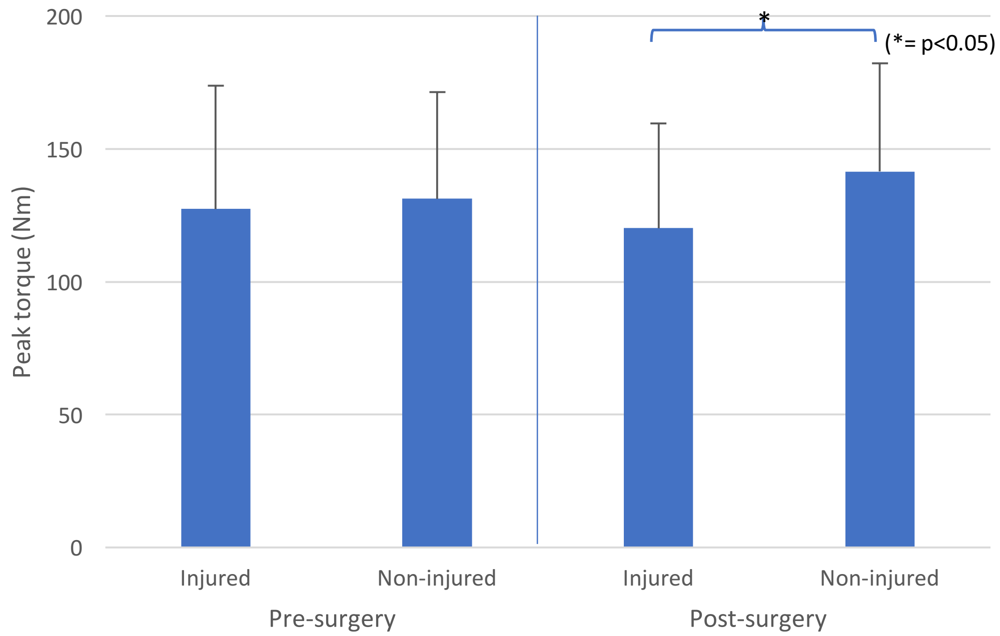

Figure 4.2: Peak torque of quadriceps at 180 degrees per second pre-and post-surgery.

For comparison of knee extensor torque in the isokinetic endurance task, the mean of the highest three repetitions and the last three repetitions in the injured and the non-injured limbs both pre-operatively and post-operatively are presented in Figure 4.3. For the meniscus participants, a main effect was found for limb (injured versus non-injured limbs) ($p<0.05$) and time (highest three versus last three repetitions) ($p<0.05$). There was also a significant limb by time interaction ($p<0.05$), where torque deficits in the injured limb were evident in all conditions ($p<0.05$) except the last three trials prior to surgery. For the highest three trials, peak torque deficits of 10 percent (prior to surgery) and 15 percent (post-surgery) were evident in the injured limb ($p<0.05$). This deficit on the injured limb was also present in the last three repetitions post-operatively (nine percent, $p<0.05$). Pre-operatively, there was no significant difference in the last three repetitions across limbs ($p>0.05$).

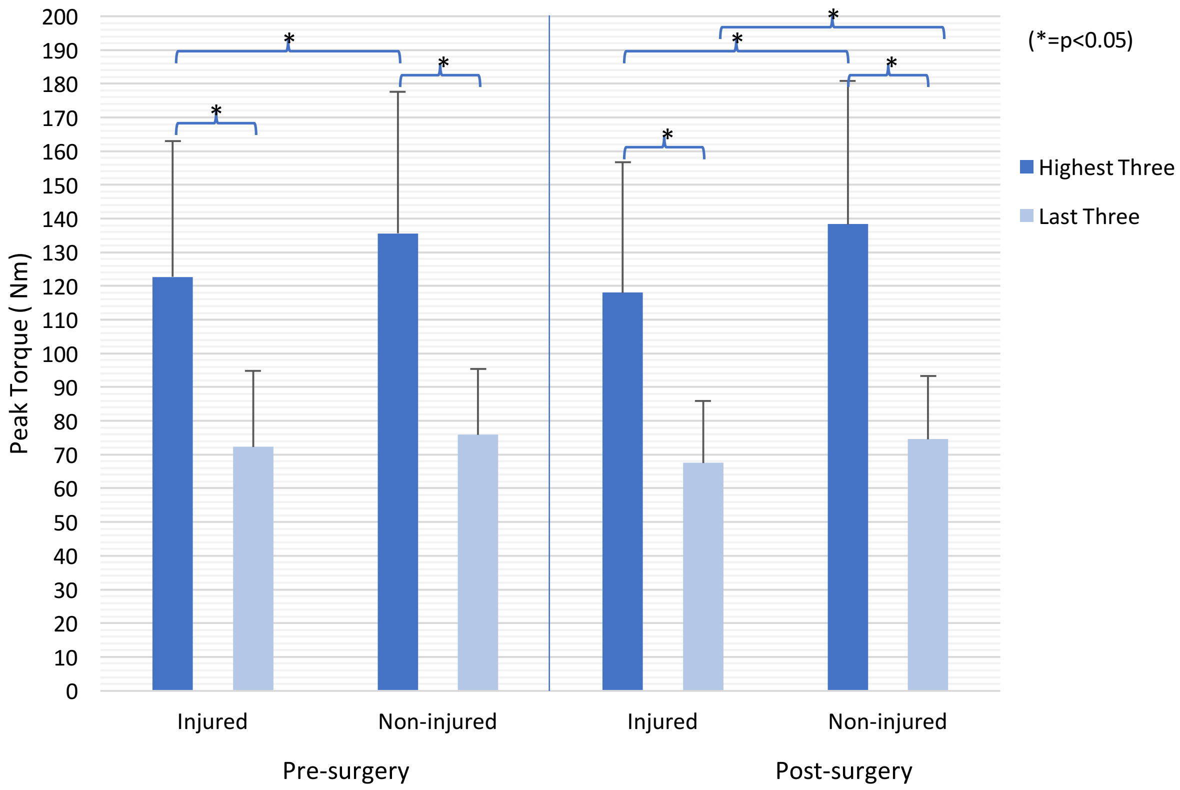

Figure 4.3: Partial meniscectomy group data. Mean peak torque and standard deviation of the highest three quadriceps repetitions and the last three quadriceps repetitions from 30 consecutive repetitions on the injured and non-injured limbs pre- and post- surgery.

For control participants, there was a significant difference between the highest three repetitions and the last three repetitions at session one and six weeks later ($p<0.05$). However, there was no significant difference ($p>0.05$) in knee extensor torque measures between the right and left limbs, and torque measures taken at baseline (pre) and six weeks (post) thereafter ($p>0.05$). This is shown in Figure 4.4. Furthermore, no significant differences ($p>0.05$) were found between the right limb of the control group and the non-injured limb of the meniscal group six weeks apart.

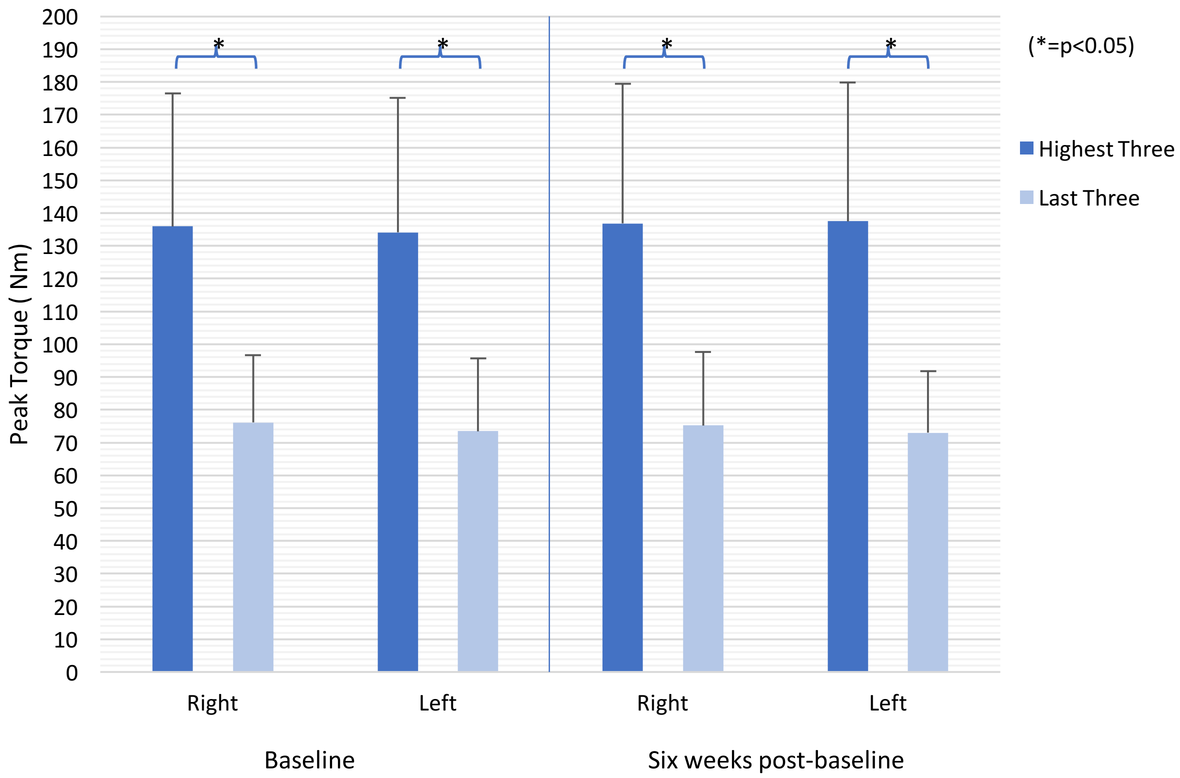

Figure 4.4: Control group data. Mean peak torque and standard deviation of the highest three quadriceps repetitions and the last three quadriceps repetitions from 30 consecutive repetitions on the right and left limbs at baseline and six weeks later.

Statistical analysis of the quadriceps fatigue slope data showed a main effect for limb (injured versus non-injured) ($p<0.05$), but no effect for time (pre- versus post-surgery). Pooled data from pre- and post-surgery showed that peak torque on the injured limb decreased at a slower rate (mean = -2.32 newton meter/repetition^{-1}, confidence interval = -2.79, -1.79) than the non-injured limb (mean= -1.909 newton meter/repetition^{-1}, confidence interval = -2.31, -1.50) ($p<0.05$). Control participants displayed similar fatigue slopes in right and left limbs, and these did not differ ($p>0.05$) to the non-injured limb of meniscus participants.

4.5. HAMSTRINGS PERFORMANCE

Hamstrings peak torque at a velocity of 60 degrees per second during the maximal isokinetic torque task was significantly lower on the injured limb compared to the non-injured limb before and after surgery (p<0.05) (Figure 4.5). These deficits were not significantly different from one another, with a seven percent deficit across limbs pre- and post-operation. No significant difference between injured and non-injured limbs were found for hamstrings peak torque at a joint angular velocity of 180 degrees per second (Figure 4.6). In control participants, there was no significant difference across limbs and between the control group limb and the non-injured limb of the meniscal participants, pre-and six weeks post baseline at both joint angular velocities.

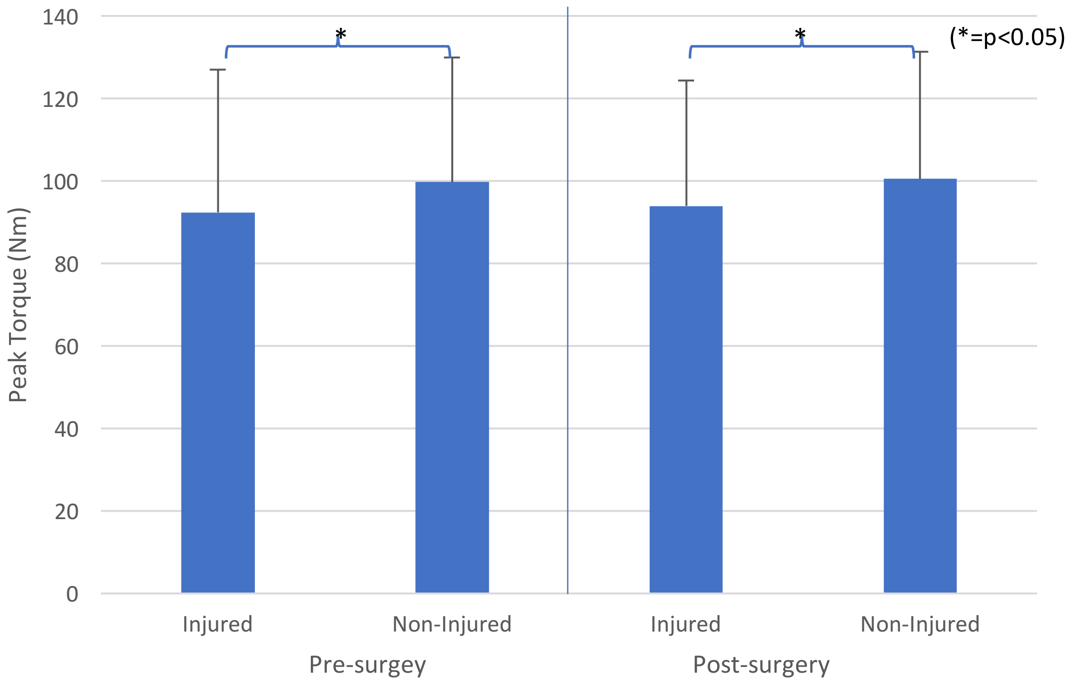

Figure 4.5: Peak torque of hamstrings at 60 degrees per second pre-and post-surgery.

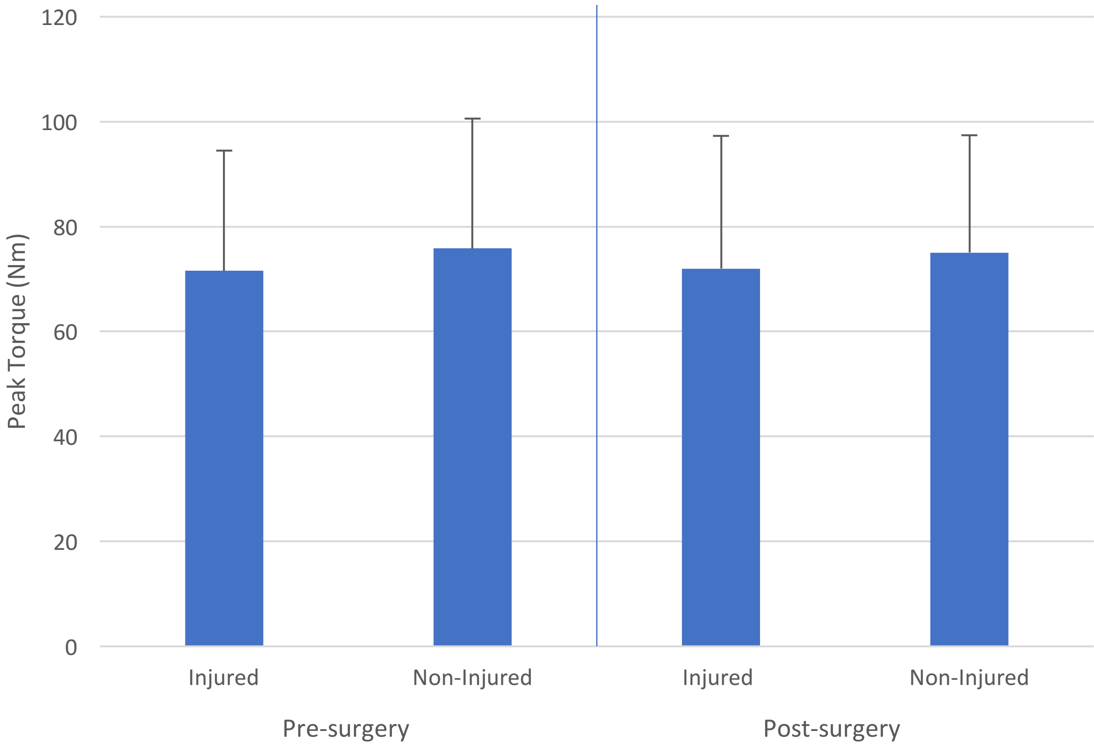

Figure 4.6: Peak torque of hamstrings at 180 degrees per second pre-and post-surgery.

With regard to hamstrings fatigue, the mean of the highest three repetitions and the last three repetitions, pre- and post-operatively, on the injured and non-injured limb are shown in Figure 4.7. There was a main effect of time where the highest three repetitions were significantly greater than the last three repetitions both before and after surgery ($p<0.05$) and a time by limb interaction ($p<0.05$). Subsequent paired t-tests showed that the only condition to show a significant difference between the injured and non-injured limbs was the highest three repetitions prior to surgery ($p<0.05$). This showed that there was a six percent deficit in the surgery limb at the start of the endurance test. In control participants, there was also a significant effect of time ($p<0.05$). No significant differences in peak torque were found across limbs in the control group, and between the control group limb and the non-injured limb of meniscus participants.

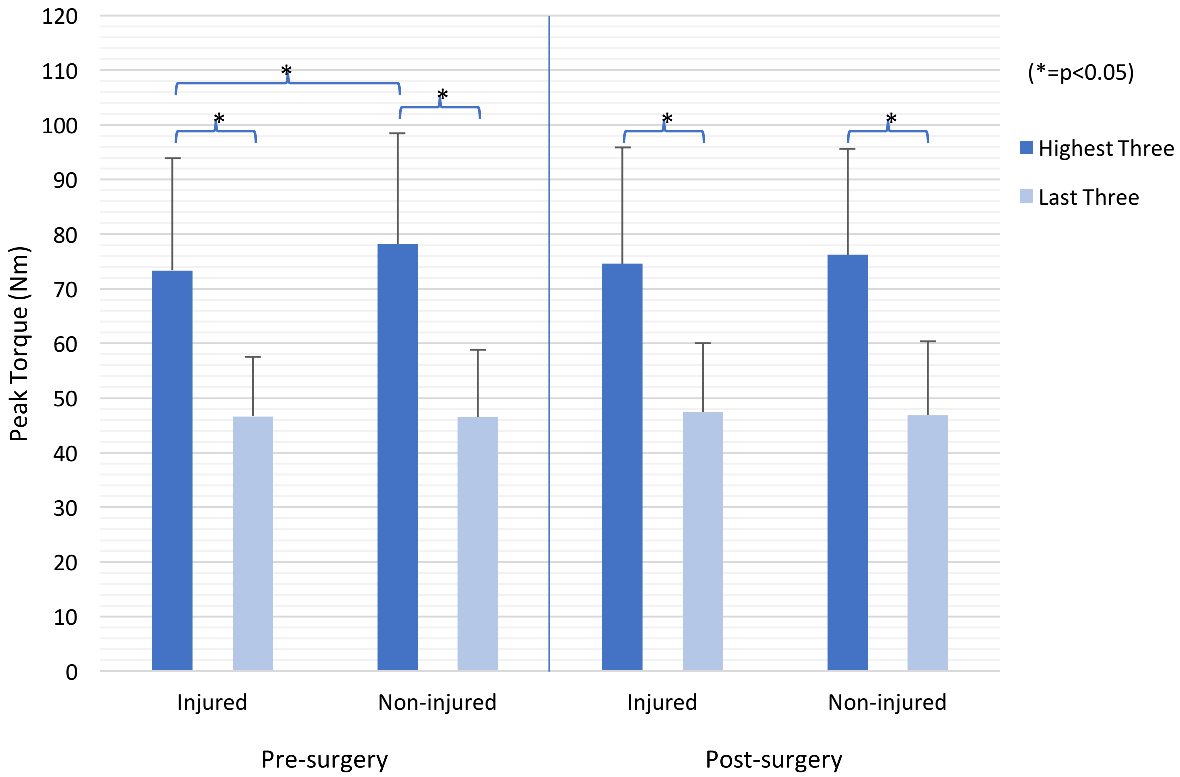

Figure 4.7: Partial meniscectomy group data. Mean peak torque and standard deviation of the highest three hamstrings repetitions and the last three hamstrings repetitions from 30 consecutive contractions on the injured and non-injured limbs pre- and post-surgery.

Fatigue slopes of the injured and non-injured limbs of the meniscal group were similar, and not different between the control group limb and the non-injured limb of the meniscal group. This indicated that the hamstring muscles of the injured limb of the meniscus participants fatigued at a similar rate to the non-injured limb and to those of control participants.

4.6. REPEATED HOP TEST PERFORMANCE

The mean flight time of the highest three hops and the last three hops on the injured and non-injured limbs, pre- and post-operatively are shown in Figure 4.8. For meniscus participants, a main effect was found for limb (injured versus non-injured) ($p<0.05$) and time (highest three versus last three repetitions) ($p<0.05$). There was also a significant interaction between limb and time ($p<0.05$). Subsequent t-tests showed that in all conditions, except for the last three hops pre-surgery, there were significant differences ($p<0.05$) between the injured and non-injured limbs ($p<0.05$). There was a difference of seven percent pre-operation and nine percent post-operation in the mean of the highest three hops. Post-operation, a seven percent difference was evident in the mean of the last three hops. In control participants, there was a significant difference between the highest three repetitions and the last three repetitions ($p<0.05$), but there was no difference between limbs at baseline or six weeks later. There was no significant difference between the control group limbs and the non-injured limbs in the meniscal group at baseline and six weeks.

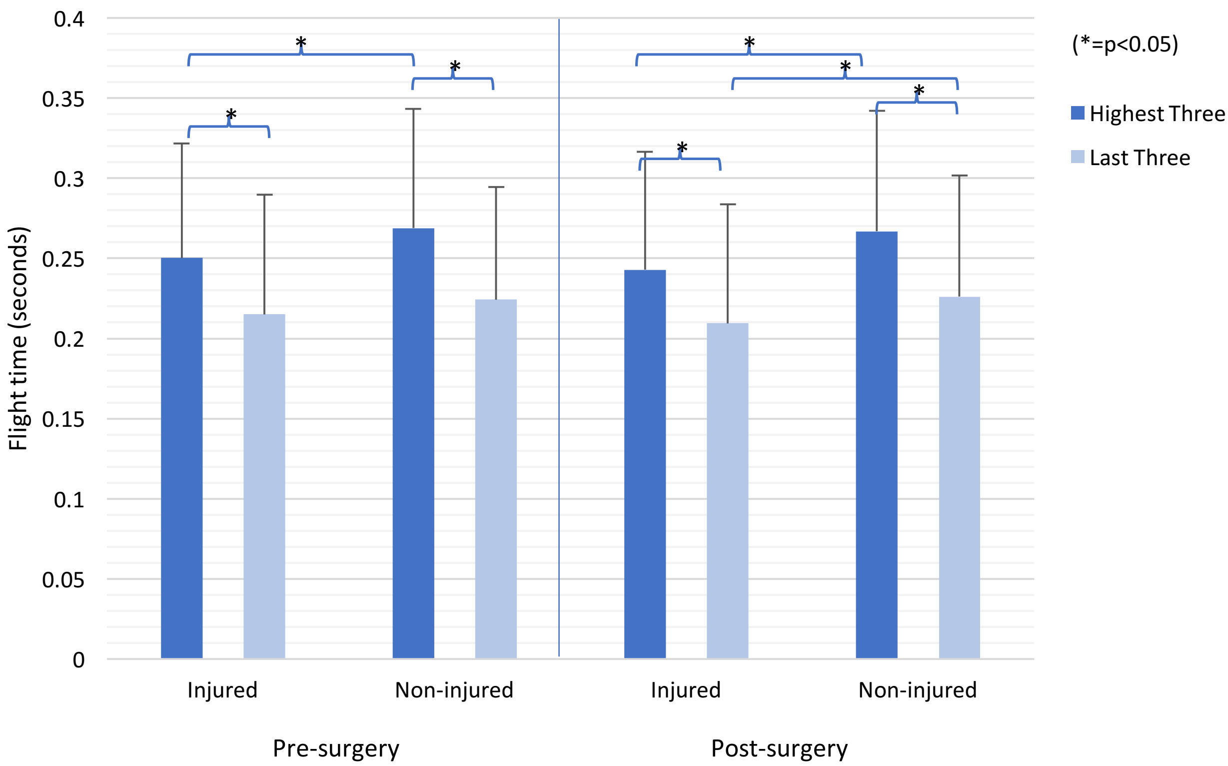

Figure 4.8: Partial meniscectomy group data. Mean and standard deviation for flight time of the highest three hops and the last three hops on the injured and non-injured limbs pre- and post-surgery.

For fatigue slope data, there was a main effect for limb (injured versus non-injured) ($p<0.05$) but no effect for time (pre- versus post-surgery). Pooled data from pre- and post-surgery showed fatigue slopes for meniscus participants differed, with significantly lower fatigue slopes in flight time in the injured limb (mean= -0.00901 second/repetition^{-1}, confidence interval= -0.001158, -0.000643) than the non-injured limb (mean= -0.001496 second/repetition^{-1}, confidence interval = -0.001886, -0.001106) ($p<0.05$). This indicated that hop flight time decreased at a higher rate in the non-injured limb. Fatigue slopes were similar for the right and left limbs in control participants, and did not differ between the non-injured limb of meniscus participants and the control participants limbs.

4.7. ASSOCIATION BETWEEN SELF-REPORTED FUNCTION AND PERFORMANCE TESTS

The Pearson correlation coefficients between self-reported functional questionnaire scores (KOOS pain, KOOS Sport/Rec and LLTQ RA) and impairments, measured as the percentage difference across limbs in strength and endurance tests six weeks after partial meniscectomy has been presented in Table 4.4. Correlations were performed post-operatively, as this is when participants are cleared to return to sporting and recreational activities. For this reason, functional questionnaires relating to sport, pain and recreation were chosen for comparisons. The difference across limbs in quadriceps and hamstrings peak torque at a joint angular velocity of 180 degrees per second was selected, as this speed closely resembles the speed in which the questionnaire tasks would be undertaken. For endurance data, the deficit across limbs in the mean of the highest three repetitions was used for comparison, as this is where significant deficits were observed in both hop and quadriceps endurance performance. There was a moderate correlation ($r= -0.51$) identified post-operatively between LLTQ RA scores and the percentage deficit in flight time of the highest three hops during the hop endurance task. This has been shown in Figure 4.9 where participants with smaller deficits in flight time across limbs tended to score better in the LLTQ RA score. The remaining correlations between physical tests and functional questionnaires were poor and did not exceed $r= -0.4$.

Table 4.4: Pearson correlation coefficient between self-reported function in KOOS pain, KOOS Sport/Rec and LLTQ RA with the percentage difference across limbs in quadriceps and hamstrings muscles peak torque at 180 degrees per second, and the highest three repetitions in quadriceps endurance and hop endurance assessments six weeks post-surgery.

	KOOS Pain	KOOS Sport/Rec	LLTQ RA
Quads Endurance	-0.26	-0.22	0.16
Quads PT - 180 °/sec	-0.30	-0.24	0.24
Hams PT - 180 °/sec	-0.14	-0.14	-0.37
Hops Endurance	-0.39	-0.14	-0.51*

°/sec = degrees per second, RA = Recreational Activities; Sport/Rec = Sport and Recreation; PT = Peak Torque; KOOS = Knee injury and Osteoarthritis Outcome Score; LLTQ = Lower Limb task questionnaire; * = p<0.05

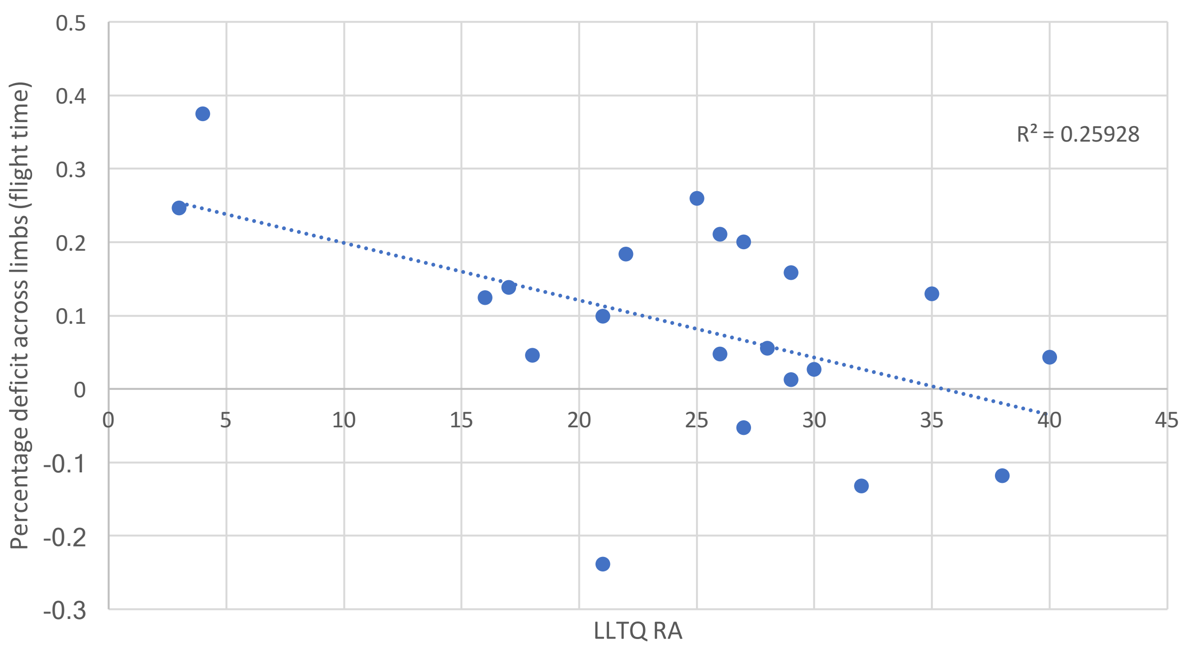

Figure 4.9: The relationship between LLTQ RA and the percentage deficit across limbs of the flight time of the highest three repetitions post-operatively (r= -0.51).

5. Chapter 5: DISCUSSION AND CONCLUSIONS

5.1. INTRODUCTION

This chapter is divided into five main sections. The first section concerns the demographics of the partial meniscectomy group and control participants before and after surgery. The second, third and fourth sections discuss quadriceps, hamstrings, and hop endurance performance before and after partial meniscectomy. The fifth section is focused upon the relationships found between the muscle performance testing, hop endurance performance, and perceived functional performance. Thereafter, the limitations, conclusions and clinical implications, and recommendations are presented.

5.2. PARTICIPANTS

The two groups (meniscal and control) were similar in demographics, with no significant differences in age, gender, height, weight, and body mass index between the control group and those with meniscal injury. The mean age (43.2 years) and body mass index (27.4 kilogram per square meter) of the participants were similar to that previously reported in the literature (Ericsson et al., 2006; Ganderup et al., 2017; Gapeyeva et al., 2000; Glatthorn et al., 2010; Matthews & Dianne, 1996; Moffet et al., 1994; St-Pierre et al., 1992; Stensrud et al., 2014; Thorlund et al., 2010; Thorlund et al., 2012). The time from injury to surgery varied from 35 to 670 days (median 196 days), and falls within the range documented in the literature (Hsu et al., 2016; Osteras et al., 2014; St-Pierre et al., 1992; Stensrud et al., 2014). Longer waits for surgery are surprising in light of the need to limit any progression in tears, yet in the current study, most participants (67 percent) attempted conservative rehabilitation before opting for surgical intervention. This is an emerging theme, where approximately one third of individuals with meniscal tears will not respond adequately to conservative treatment and require surgical intervention (Mezhov, Teichtahl, Strasser, Wluka, & Cicuttini, 2014). A contributing factor to choosing surgery may be related to occupational and sporting demands of these individuals. In the current study, 71 percent of participants in the partial meniscectomy group describe a moderate to heavy physical activity status (scored above four on the physical activity scale), and were keen to return to sporting activities involving pivoting or change of direction as soon as possible.

Participants returned to normal levels of work six weeks after surgery, with occupational levels increasing to an average of 37 hours of work. Although time spent at work following surgery increased, more time was designated to sedentary activities (sitting and standing) and less time undertaking heavy intensity activities. Similar findings are found in the literature, with most subjects returning to normal daily activities by four weeks after surgery (Lubowitz, Ayala, & Appleby, 2008). Ilich et al. (2013) further investigated this area using an Actigraphy physical activity monitor three months after partial meniscectomy. They found that although participants reported similar exercise and daily activity routines to non-surgery controls, they did not perform activities to the same intensity.

In the current study, while all meniscal participants had been involved in an exercise programme, approximately 70 percent participated in formal pre-operative rehabilitation with a therapist. Post-operatively, formal rehabilitation levels increased with 86 percent of participants involved in exercise therapy and rehabilitation ranging from 30 minutes to five hours per week (median two hours per week), while the remaining subjects undertook their own gym or weights programme. The above participation numbers in lower limb exercise therapy was consistent with a number of studies that have reported that exercise rehabilitation can contribute to short term improvements in strength and function (self-reported and performance) (Ericsson et al., 2009; Kise et al., 2016; Moffet et al., 1994; Osteras et al., 2014).

5.3. SELF-REPORTED FUNCTION

Scores in the KOOS subscales for the meniscectomy group prior to surgery fell within the normal ratings compared to other literature (Ganderup et al., 2017; Stensrud et al., 2014; Thorlund et al., 2016). Reported functional scores using the LLTQ and KOOS questionnaires improved after partial meniscectomy. This resulted in clinically meaningful changes of 10 points or greater (Roos & Lohmander, 2003; Stensrud, Roos, & Risberg, 2012) in all questionnaires, with the exception of LLTQ ADL. Improvement in KOOS pain scores were similar to those reported by Skou, Pihl, Nissen, Jørgensen, and Thorlund (2018) who reported that after surgery QOL and Sport/Rec subscales increased up to one year after partial meniscectomy. Roos, Roos, Ryd, and Lohmander (2000) also found a significant improvement across all subscales of the KOOS 12 weeks after meniscus surgery. However, improvements in Sport/Rec scores were considerably more (42 percent) compared to the those seen in the current study (21 percent). It is thought that most recreational athletes will take approximately seven to 12 weeks to return to sport after partial meniscectomy (Kim, Nagao, Kamata, Maeda, & Nozawa, 2013).

Although improvements were observed at six weeks after partial meniscectomy, subcategories that indicated significant dysfunction remained, compared to healthy age and gender matched individuals. After partial meniscectomy, average KOOS and LLTQ ADL scores were similar to control subjects, indicative of light loading and intensity tasks being performed successfully. Additionally, KOOS subscales for pain and symptoms were greater than 80 points, indicative of reductions in inflammation. However, in the current study, when compared to control subjects, participants after partial meniscectomy still scored considerably lower in subscales for QOL (65/100), Sport/Rec (72/100) and LLTQ RA (24/40). Of particular note, the RA component of the LLTQ shows activity level was considerably less than the 36 to 40 points, that might be expected when they have little difficulty undertaking more higher intensity or loading tasks (McNair et al., 2007). Using the KOOS questionnaire, Herrlin, Hållander, Wange, Weidenhielm, and Werner (2007) reported similar QOL (63/100) and Sport/ Rec (70/100) scores to the current study eight weeks after partial meniscectomy. In summary, although post-surgery participants improved notably in their daily activities and had decreased pain, participants still experienced moderate difficulty with higher intensity activities like squatting, running, twisting, and kneeling. This is comparable with other studies (Roos et al., 2000; Skou et al., 2018) reviewing perceived function before and after partial meniscectomy. These high intensity activities are essential in the return to sport process, and partial meniscectomy and six weeks of rehabilitation does not appear to restore perceived levels of function. Longer term studies have identified a trend after partial meniscectomy where 59 percent of participants will not achieve pre-injury activity levels after six months after surgery (Herrlin et al., 2007).

5.4. QUADRICEPS MUSCLE PERFORMANCE

Pre-operatively, peak quadriceps torque performance was reduced in individuals with meniscal injury compared to the non-injured limb and to control participants (13 percent) at angular velocity 60 degrees per second. This finding was comparable to other studies where pre-operative strength deficits of 13 percent (Stensrud et al., 2014) and 15 percent (Matthews & Dianne, 1996) at a joint angular velocity of 60 degrees per second have been reported. Matthews and Dianne (1996) also assessed peak torque at 180 degrees per second and found no significant difference before surgery. These findings were remarkably similar to the current study, where pre-operatively a significant ($p<0.05$) strength deficit of 13 percent was observed at an angular velocity of 60 degrees per second, and no significant difference at 180 degrees per second.

Post-operatively across limbs, peak torque deficits were evident (18 percent at 60 degrees per second and 15 percent at 180 degrees per second). These most likely reflect changes in quadriceps muscle activation due to reduced activity and symptoms associated with surgery (Rice & McNair, 2010). In respect to previous studies, Matthews and Dianne (1996) found a difference of 17 percent in isokinetic strength six weeks after partial meniscectomy. These authors noted that strength deficits steadily decreased over time, with a 14 percent deficit remaining after 12 weeks. In agreement with this finding, four weeks after partial meniscectomy, Gapeyeva et al. (2000) reported 28 to 31 percent differences in isokinetic quadriceps strength, that reduced to 18.2 percent after 24 weeks. However, Glatthorn et al. (2010) also observed a similar quadriceps strength deficit (14.5 percent) that remained present 24 weeks after partial meniscectomy. There is apparent near resolution of strength deficits two years after surgery (Thorlund et al., 2010), however one longitudinal study showed that deficits (nine percent at 60 degrees per second, and six percent at 180 degrees per second) were observed four years after partial meniscectomy (Ericsson et al., 2006). Although these deficits exist four years after partial meniscectomy, they do not represent a clinically significant difference across limbs (greater than 10 percent) (Augustsson, Thomeé, & Karlsson, 2004).

In the current study, the deficits across limbs in quadriceps peak torque were of clinical significance, and need to be addressed for the safe return to sport and recreational activities. Return to sport guidelines (Thomeé et al., 2011) suggest that a player returning to low levels of activities that are not demanding on the knee can have a deficit of up to 10 percent across limbs. However, for those returning to competitive activities involving contact, pivoting, and jumping, strength deficits should be at zero.

In the peak torque endurance tests undertaken pre-operatively, deficits were observed between limbs (10 percent) during the highest three repetitions but not during the final three repetitions of the task. Post-operatively, differences of 15 and nine percent were observed in the mean peak torque of the highest three repetitions and the last three repetitions of the endurance test respectively. Of all the studies to investigate endurance performance in meniscal injury, which were few in number, St-Pierre et al. (1992) reported fatigue measures pre-operatively, and at weeks two, six, and 10. This study examined two groups allocated either to early or delayed exercise after partial meniscectomy. The difference across limbs pre-operatively was less in the current study (10 percent) compared to St-Pierre's et al, (1992) early exercise (17 percent) and delayed exercise (12 percent) groups. Six weeks after surgery, the early exercise group had the same quadriceps deficit across limbs as the current study (15 percent), whereas the delayed exercise group had a larger deficit across limbs (27 percent). However, it should be noted that St-Pierre et al. (1992) made no direct comparisons between the injured and non-injured limb. They instead recorded an average quadriceps total work value for the non-injured limb, which was used to compare with the injured limb across each time point after surgery. Therefore, the reported deficits may not accurately represent the deficits across limbs at each time point assessed after surgery.

Irrespective of limb (injured versus non-injured) or group (control versus meniscus) there was a significant reduction in peak quadriceps torque throughout the endurance task. The reduction in peak torque between the highest three trials and the last three trials was between 39 and 44 percent. This decrease in force production was higher than that reported by Pinto, Blazevich, Andersen, Mil-Homens, and Pinto (2018) who found a 30 to 35 percent reduction in peak isokinetic extension torque between maximal repetitions and the average of repetitions 28 to 30. These differences are likely to be as a result of the testing velocity.

Pinto et al. (2018) used a joint angular velocity of 300 degrees per second whereas the current study tested subjects at 180 degrees per second. Lower isokinetic velocities will result in the muscle having longer time under tension per repetition. Longer time under tension has been associated with a greater reduction in muscle force (fatigue) (Spendiff, Longford, & Winter, 2002) and may explain why the current study had a greater reduction in torque over the same number of repetitions.

Control participants had no differences across limbs in the endurance test, and this was consistent across testing sessions six weeks apart. These findings are similar to other studies that have involved participants without pathology (Pincivero et al., 2001; Pincivero et al., 1997). There are a number of possible physiological mechanisms associated with the current endurance task. Cairns et al. (2017) included biopsies and measures of neuromuscular activation in a study examining the effect of repeated maximal voluntary contractions over time on quadriceps torque. They concluded that in healthy individuals, multiple factors (disturbances in sarcoplasmic reticulum, calcium released, raised inorganic phosphate and hydrogen, and lowered adenosine triphosphate associated with calcium release) were responsible for the observed fatigue. In the current study, visual inspection shows that differences across the injured and non-injured limbs before and after surgery were consistently observed in the early to mid-stages of the endurance task. Cairns et al. (2017) found that in some participants (41 percent), early loss in peak torque of maximum voluntary contractions during repeated testing were attributed to impaired central activation. Becker et al. (2004) used twitch interpolation to detect central activation deficits following partial meniscectomy and demonstrated deficits in maximum voluntary activation of the injured limb (20 percent) and non-injured limb (17 percent) four years after surgery, compared to control participants (11 percent). Similar changes in activation have been observed after anterior cruciate ligament injury and reconstruction, and after total knee joint arthroplasty (Chmielewski, Stackhouse, Axe, & Snyder-Mackler, 2004; Drechsler, Cramp, & Scott, 2006; Mizner, Petterson, Stevens, Vandenborne, & Snyder-Mackler, 2005; Urbach, Nebelung, Röpke, Becker, & Awiszus, 2000; Urbach, Nebelung, Weiler, & Awiszus, 1999).

Furthermore, in respect to mechanisms associated with the above-mentioned deficits, particularly in participants post-surgery, residual swelling and inflammation are known risk factors for reducing activation of muscle fibres in the quadriceps (Hopkins & Ingersoll, 2000; Rice & McNair, 2010), leading to decreased peak torque. Some researchers (Cobian, Koch, Amendola, & Williams, 2017) have also observed that after knee injury (and partial meniscectomy) an increased latency in the activation of muscles is apparent, and this has been thought to reflect a reduction in the rate of force development observed up to six weeks after partial meniscectomy.

Although both isokinetic tests for strength and endurance require participants to perform maximum effort extension and flexion contractions, there are cognitive factors that may contribute to performance (Mayer, Gatchel, Betancur, & Bovasso, 1995). The design of the two testing protocols (strength and endurance) was such that participants were aware of the larger number of repetitions involved in endurance testing compared to strength testing and hence may have 'paced themselves' at the start of the endurance test. However, a qualitative post hoc assessment of differences in quadriceps peak torque calculated from an average of the highest three repetitions in the endurance test and the maximal torque generated during the five-maximum voluntary efforts in the strength test were small (approximately three to four newton meter). This would indicate that the knowledge of having to perform an endurance task did not significantly influence the ability of the participants to generate peak quadriceps torque.

Typically, most individuals (control and partial meniscectomy) did not achieve peak torque values until three to five repetitions of the endurance task had been completed. However, once peak torque was reached, there was a relatively linear decrease in peak torque through the remaining repetitions. This pattern was similar to that reported by Pinto et al. (2018) in healthy subjects. Slope analysis of data from the highest torque value to the last repetition showed that on the injured limb there was a slower rate of torque decrement when compared to the non-injured limb and control subjects. This indicated that the injured limb fatigued at a slower rate than the non-injured limb and those of control subjects. These findings may be explained by the metabolic changes that occur in muscle following knee injury. Stockmar, Lill, Trapp, Josten, and Punkt (2006) investigated metabolic profiles and fibre characteristics of the vastus medialis muscle in chronic anterior cruciate ligament injury. There was reduced glycolytic activity and a shift to more oxidative metabolism in each fibre type. They suggested these changes may lead to reduced ability to generate rapid force with a shift to more oxidative metabolism in muscle. The slower rate of fatigue observed in the injured knee may reflect a shift in the quadriceps muscle to a more oxidative metabolism and improved the endurance capacity. This shift to type I muscle fibre characteristics is important because there is a direct relationship in the percentage of type I fibres and fatigue resistance of the quadriceps muscle group (Cairns et al., 2017).

5.5. HAMSTRINGS MUSCLE PERFORMANCE

Pre- and post-operation, significant differences ($p<0.05$) were observed in measures of peak torque at a joint angular velocity of 60 degrees per second. However, they were not large (seven percent). No differences were observed at the 180 degrees per second joint angular velocity. For endurance testing, the difference in peak torque between the mean of the highest three repetitions was significantly greater ($p<0.05$) in the non-injured limbs compared to the injured limbs, but only at the start of pre-operative testing. Furthermore, the deficit was low (six percent) and the slope of the fatigue profile was not different across limbs. A possible explanation for the difference in hamstrings performance could be due to the lack in specificity of the isokinetic testing parameters compared to the quadriceps. The functional role of the hamstrings in many daily and sporting activities is to act eccentrically to decelerate the lower leg (Pandy & Andriacchi, 2010), and rarely to perform repeated maximal concentric contractions. In the quadriceps, repeated concentric contractions are commonly required for many functional and sporting tasks. As such, the testing parameters for hamstrings endurance may not be as sensitive in identifying deficits across limbs compared to the quadriceps (Bosquet et al., 2010). Further research might consider eccentric muscle performance. It has also been reported that AMI is primarily associated with quadriceps inhibition (Rice & McNair, 2010). Rice and McNair (2010) indicated the neural pathways that are activated by damage, swelling and inflammation in the knee joint do not appear to connect with an inhibitory path to the alpha motor neurons of the hamstrings muscle group.

The presence of hamstring performance deficits before partial meniscectomy has been reported in the literature (St-Pierre et al., 1992; Stensrud et al., 2014), however there is variability in the size of deficits observed. Previous authors have described deficits between 3.4 to 21.8 percent for a range of three weeks to seven years before surgery (St-Pierre et al., 1992; Stensrud et al., 2014). Post-operatively, across limbs deficits in hamstrings muscle strength (Ericsson et al., 2006; Glatthorn et al., 2010; Moffet et al., 1994; Thorlund et al., 2010) have most often not been statistically significant ($p>0.05$). Matthews and Dianne (1996) were the only authors to detect a significant difference in hamstrings strength, and their deficits of between 17.4 and 23 percent were reported for two weeks after surgery. However, these authors found these deficits across limbs were resolved at six weeks post-operatively.

In respect to previous hamstrings endurance studies, there were no studies located to directly compare endurance performance across limbs before and after surgery. Utilising data from descriptive tables in St-Pierre et al. (1992), hamstrings endurance performance between limbs was calculated. These identified a deficit of 19 (exercise group) and 25 percent (delayed exercise group) before partial meniscectomy, which decreased to eight and six percent respectively six weeks after surgery. Further comparisons have been made in anterior cruciate ligament reconstruction with an ipsilateral hamstrings graft. Tow, Chang, Mitra, Tay, and Wong (2005) tested individuals two years after anterior cruciate ligament reconstruction on a Biodex isokinetic dynamometer. In a seated positon, they tested endurance asking participants to complete as many repetitions as they were able to in 45 seconds at a joint angular velocity of 240 degrees per second. They found no significant difference in hamstrings endurance performance between the injured and non-injured limb. As a consequence of this finding, Vairo (2014) hypothesised that the seated position may influence results and thus assessed individuals with the same testing methodology in a prone position. Again, there was no significant difference in hamstrings endurance performance between the injured and non-injured limb approximately two years after surgery. Due to the nature of the graft used in anterior cruciate ligament reconstruction, the findings for hamstrings performance were surprising to these authors, however, they suggested that hamstrings performance is likely a reflection of the type of rehabilitation programmes completed after surgery.

5.6. HOP ENDURANCE PERFORMANCE

Hop performance across limbs was impaired both before and after partial meniscectomy. Pre-operatively this was observed as a difference in flight time across limbs during the highest three hops but not the last three hops. A small deficit of seven percent across limbs ($p<0.05$) was observed. This was comparable to Stensrud et al. (2014), who reported similar significant differences across limbs (nine to 13 percent) in functional performance before meniscal surgery. Slightly larger deficits have also been reported (Ganderup et al., 2017), with deficits ranging from 11 to 16 percent pre-operatively in individuals with meniscal injury.

Post-surgery, a significant difference in flight time of the highest three hops (nine percent) and the last three hops (seven percent) across the injured and non-injured limbs was observed. This indicates that partial meniscectomy and rehabilitation may not result in improvements in functional performance at the six week point post-surgery. Two studies (Goodwin et al., 2003; Hsu et al., 2016) were located that compared functional performance across limbs at this time after surgery. Both of these studies investigated the effect of exercise compared to no exercise post-operatively. Interestingly, both groups remained with significant deficits in functional performance across limbs even with exercise intervention. They reported slightly higher deficits (11.4 to 18 percent) compared to the current study. Hsu et al. (2016) also included a one year follow up investigation where smaller deficits (1.1 percent) were reported. Deficits can still be apparent four years post-operation as shown by Ericsson et al. (2006) who reported a mean of 10 percent across limbs in single leg hop for height, single leg rise and square hop tasks. In respect to the current study, based on previously mentioned recommendations for returning to sport (Schmitt et al., 2014; Thomeé et al., 2011), the mean seven percent deficit observed would allow participants to return to lower intensity sports that were more recreational than competitive.

In functional performance tests incorporating fatigue, clinically significant differences across limbs have been identified in individuals with other knee injuries. After anterior cruciate ligament injury and reconstruction deficits ranging between 11 and 28 percent have been reported across the injured and non-injured limbs (Augustsson et al., 2004; Gustavsson et al., 2006). A battery of tests, including a side hop test for endurance, were included in these studies. The side hop test required participants to hop as many times as they were able between two parallel lines over a 30 second timeframe (Gustavsson et al., 2006). This is a different protocol to the current study where participants had some time to stabilise themselves prior to starting the subsequent hop (i.e. a four second interval). Augustsson et al. (2004) also used a fatiguing protocol (unilateral weight machine knee extensions until failure) which was followed by a single hop performance on the injured limb compared to the non-injured limb. When fatigued, a significantly greater (11 percent) difference across limbs was observed compared to pre-fatigue hops in which the performance deficits were three percent across limbs.

In control participants, there was no difference across limbs in hop endurance performance across the six-week interval between tests. Other studies (Leister et al., 2017; White et al., 2018) that incorporated fatigue into hop performance testing with healthy individuals have also observed this finding. Between the highest three hops and the last three hops though, there was a notable fatigue effect with mean changes of 15 percent across the 30 hops. Interestingly, the percent change in hop tests across the 30 repetitions was notably less (13 to 17 percent) than the change observed in the quadriceps (44 to 47 percent) and hamstring (31 to 43 percent) endurance tests. This would suggest that perhaps some compensatory kinematic techniques are being utilised by participants to lessen the effect that the repeated task might have upon a single muscle group. For instance, it may be that hip muscles are activated more to counter advancing fatigue in the quadriceps muscle as the test proceeds. Further research is needed to test this conjecture.

5.7. THE RELATIONSHIP BETWEEN SELF-REPORTED FUNCTIONAL AND IMPAIRMENTS IN MUSCLE AND FUNCTIONAL PERFORMANCE TESTS

In the current study, there was a moderate correlation (r= -0.51) between the percent difference in flight time across injured and non-injured limbs in hop endurance tasks and LLTQ RA scores post-operatively. This was statistically significant ($p<0.05$). The remaining correlations were low (r= -0.14 to -0.39) and not statistically significant ($p>0.05$). Few studies have previously investigated an association between self-reported function and physical performance scores before and after partial meniscectomy. Only two studies have specifically investigated this relationship in individuals with partial meniscectomy. Four years after partial meniscectomy, Ericsson et al. (2006) examined the relationship between self-reported function (KOOS questionnaire) and performance of the quadriceps and hamstrings peak torque at two different angular velocities; 60 and 180 degrees per second. They reported moderate correlations (r= 0.38 to 0.60, $p<0.05$) in the quadriceps to all five subscales of the KOOS questionnaire using the ratio between the injured and non-injured limbs, whereas the hamstrings findings only correlated significantly with KOOS symptoms (r= 0.39, $p<0.05$). These findings correspond with the current study, however more correlations may be due to the longer time frame after surgery. In contrast, Thorlund et al. (2010) reported weak and nonsignificant correlations (r= 0.07 to 0.21) between KOOS Sport/Rec and various muscle strength variables, two years after partial meniscectomy. In participants after anterior cruciate ligament reconstruction, Wilk, Romaniello, Soscia, Arrigo, and Andrews (1994) found low to moderate correlations (r= 0.31-0.67) between quadriceps strength and a functional hop test and self-reported functional scores when using specific questions related to knee function approximately six months after surgery. Overall, this finding provides some support for the inclusion of increased muscle work in the rehabilitation programme following partial meniscectomy.

5.8. LIMITATIONS

The cohort in the meniscectomy group did not all do the same exercise programs pre- or post-surgery. This was not possible to arrange given the different surgeons and their preferences for exercise therapy.

This study did not include any subjective or objective measure of fatigue, such as rating of perceived exertion or changes in electromyography profile to quantify fatigue. Therefore, it is possible that participants did not provide full effort during the fatigue tests. Measuring activation deficits could have provided information related to this point; however, the equipment required was not available over the full-time period of the study.

This study did not analyse limb movements during the hop performance testing. This might have provided important information related to changes in limb alignment during the repeated hopping task. Previous research has highlighted that some limb alignments are potentially injurious and manifest themselves under fatigue conditions.

The joint angular velocities tested on the Biodex dynamometer were much less than those often observed at the knee joint during sporting activities. However, those chosen were typical of that utilised by previous researchers, and this enabled good comparison with the literature.

The endurance test was focused upon only one element of fatigue. That is, the ability to undertake repeated maximum effort exercise. As such, the findings are not generalizable to more aerobic fatiguing tasks that are encountered in sports nor are they related to low level submaximal tasks such as those involved in daily living.

In respect of blinding, analysis procedures were only conducted by one person (the candidate), However the procedures were undertaken using automated routines and checked be an independent person.

5.9. CONCLUSIONS AND CLINICAL IMPLICATIONS

Although surgical intervention is a well-used treatment modality for both traumatic and degenerative meniscal tears, individuals who have had such treatment are often predisposed to further meniscal injury, degeneration and knee osteoarthritis (Accident Compensation Corporation, 2010; Lohmander et al., 2007). Previous studies have identified that there are deficits between limbs in quadriceps and hamstrings strength and functional performance after partial meniscectomy, however no previous studies have investigated whether endurance performance (as defined in the current study as repeated maximal efforts) might be impaired before and after surgery.

In respect of endurance of quadriceps and hamstring muscles, the findings suggest that endurance across the 30 repetitions is satisfactory (for return to recreational low intensity activities) given that the deficits observed across legs at the end of the endurance tests were less than 10 percent. Interestingly, deficits across legs were higher at the start of the endurance test (highest three repetitions), and hence are likely more related to strength than sustained performance. The findings related to the strength testing provide further evidence of notable deficits in quadriceps muscles. In fact, these deficits in quadriceps strength are more apparent post-surgery where 15 and 18 percent deficits were observed, and certainly need to be addressed by further exercise training.

The percent deficits in the quadriceps and hamstrings muscles were not significantly related to perceived function. This is not surprising as the muscle performance testing involves a simple task of flexing and extending the knee as hard as one can. In contrast, undertaking recreational activities involves a combination of strength and neuromuscular coordination and balance. Additionally, in most physical activities, strength and coordination has to occur across multiple joints to perform the task without difficulty.

The above notion concerning complexity in these tasks were supported by the finding that there was a significant correlation between function as measured by the recreational section of the LLTQ and hop performance (highest three). That is, a greater deficit across limbs at this point of the endurance test was related to lower scores on the LLTQ RA. In the LLTQ the patient is asked to surmise difficulty levels across 10 recreational tasks all of which involve multi-joint activity, and furthermore, four of the tasks involve a hop like activity where the body leaves the ground (jumping for distance, running fast, jumping upwards and land, stop and start moving quickly). Thus, it is perhaps not a surprising finding that a moderate correlation was observed. It is encouraging though that perceived function and physical performance are correlated, particularly as many rehabilitation clinics do not have the space to undertake performance tests.

Perceived function in recreational or sports activities, while improved from pre-operation levels remained well below what would be considered normal function in these tasks. Given the lack of significant correlations between function, strength and endurance measures, it would seem important that clinicians focus more on skills training in specific tasks that the patients are wanting to return to in their work and sport. That is not to say that strength should be neglected. Indeed, minimising quadriceps strength deficits should be regarded as important not only for increasing task performance (e.g. attaining maximum height in a hop), but also for the important role muscles play in protecting the joint from injury. For example, their ability to absorb energy at landing can lead to less stress being placed on other joint structures, ultimately protecting those structures from injury. The need for increasing strength where deficits are present is therefore multi-factorial.

Finally, overall the results suggest that increased formal rehabilitation is needed for individuals who have had a partial meniscectomy. The current belief in the orthopaedic community that return to full sport at six weeks post-operation is appropriate needs to be reassessed. The findings suggest that additional exercise rehabilitation is needed and this should be focused upon remedying muscle deficits in quadriceps as well as improving neuromuscular skills in tasks related to recreational activities. This is particularly so if individuals are returning to sports that demand contact with other players and involve jumping and landing activities. Neglecting either of these exercise program elements could lead to increased chance of further injury, and in the knee with only a partial meniscus, the increased chance of osteoarthritis developing.

5.10. RECOMMENDATIONS FOR FUTURE RESEARCH

- As the endurance test used in the current study (concentric repeated knee flexion and extension repetitions) is not specific to the functional use of the hamstrings muscles through daily and sporting activities, it would be of interest to see if eccentric hamstrings endurance performance produces more reliable outcomes.
- There is currently no consistent functional performance measure for endurance across the literature. Further investigation into the repeated hop test to establish validity and the relationship to other variables such as quadriceps and hamstrings endurance would be of interest.
- The repeated hop test did not display a magnitude of fatigue across the 30 repetitions similar to the quadriceps and hamstrings endurance tests. It would be of interest to examine kinematic strategies adopted during the hop task, to determine if there is a relationship with the isokinetic performance measures.
- The hop test probably involves the storage-release of elastic energy within the muscle-tendon unit. This is an area of interest for further research.
- The current study was not designed to identify specific mechanisms associated with fatigue during isokinetic and hop tests. More comprehensive tests involving other measurements (e.g. electromyography) may provide better insight into fatigue mechanisms.

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APPENDICES

APPENDIX 1

Participant Information Sheet

AUT UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Date Information Sheet Produced:

20 October 2015

Project Title

Leg muscle performance and functional ability before and after arthroscopic meniscal surgery.

An Invitation

My name is Natalie Parlane, and I am a physiotherapist and Masters student in the Health and Rehabilitation Research Institute at AUT University. I would like to invite you to take part in our research project called '*Muscle endurance performance of quadriceps and hamstrings, and functional ability before and after arthroscopic meniscal surgery'.* Your participation in this project is voluntary and you may withdrawal at any time prior to the completion of data collection.

What is the purpose of this research?

The purpose of this research is to identify changes in muscle endurance (fatigue) performance before and after surgery for meniscal (cartilage) injury. It is also of interest to see if there is a relationship between this and a repeated hop test which is easy to use in a clinical environment. Recent research has identified weakness in the thigh muscles early after surgery which can be present for up to four years. However, we do not know if these deficits also exist in the endurance of muscles. This research will be written up for publication in an international journal and will be part of a Masters thesis.

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

You will have responded to an advertisement about the study and you have been diagnosed through magnetic resonance imaging (MRI) as having a meniscal (cartilage) injury required to undergo arthroscopic surgery or you are matched in age and gender to these cases. You may be excluded from participating if you have had previous knee injury, surgery, or current cardiovascular, neurological or musculoskeletal conditions other than meniscal injury or are unable to communicate or understand English.

What will happen in this research?

If you participate in this project, you will be asked to attend a two data collection sessions at the AUT University, 90 Akoranga Drive on the North Shore. The first session will be conducted before surgery and the second after you have been cleared from your surgeon to return to activity (typically after 6 weeks). During these sessions, we will assess the thigh muscles of the knee using an isokinetic dynamometer. You will also be required to perform a repeated hop test and complete questionnaires which will provide information about your strength, endurance and daily activity.

For questionnaires, you will be seated in a comfortable chair in front of a desk. During the strength assessment, you will be seated and supported in the isokinetic dynamometer (strength testing machine) and hop testing will be performed on top of a plate that measures loads (force plate) close to a wall for support. We will give you careful instructions for each of these tasks and you will be able to practice them in most cases. Overall, the tests should not take longer than two hours.

What are the discomforts and risks?

There are no major risks associated with these tests, they are all non-invasive and safe. However, if you have knee pain either before or after surgery, you might experience some discomfort during the strength and hop testing. These tests are designed to mimic normal activities of daily living (e.g. walking, jogging, stairs, squatting and sit to stand) so are unlikely to cause any greater discomfort than what you currently experience.

How will these discomforts and risks be alleviated?

If you consider any of the movements excessively painful, you can stop at any time or ask for our help. Similar tests have previously been done without report of adverse effects, however a physiotherapist who has the appropriate knowledge and skills in dealing with injury will be conducting the experiment, and therefore can provide advice as required.

What are the benefits?

You will not receive direct benefit from participating in this research. The project outcomes will provide us with more information about the relationships between strength, endurance and function after meniscal surgery. This will help provide further information for the safe return to sport and activity, preventing the risk of re-injury or longer term chronic conditions such as arthritis. These findings might also lead to new and improved treatments after knee meniscal surgery.

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 (ACC), providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

You will be given a code upon entry to the study and your name will not be used. The consent form, which will contain both your name and code, will be stored in a locked filing cabinet and kept separate from the study. No individual results will be identifiable in the study.

What are the costs of participating in this research?

The cost of participating in this project will be your time. The data collection time is expected to last approximately two hours.

What opportunity do I have to consider this invitation?

You will have as long as you like to consider this invitation after receiving the information sheet. We will call you after 7 days to see if you would like to participate. If you need more time than this to decide, just let us know.

How do I agree to participate in this research?

You will need to complete a consent form at the beginning of the data collection session. This session will be scheduled after you have told us that you would like to participate.

Will I receive feedback on the results of this research?

A one-page summary of the study results will be sent upon completion of the project. There will be a section in the Consent Form to indicate if you would like to receive this information.

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 9 921 9999 ext 7143 or Grant Mawston, *grant.mawston@aut.ac.nz*, +64 9 921 9999 ext 7180

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

Whom do I contact for further information about this research?

Researcher Contact Details:

Natalie Parlane, AUT University North Shore Campus
Ph: 0275725126
Email: natalie.parlane@gmail.com

Project Supervisor Contact Details:

Dr Peter McNair, AUT University North Shore Campus
Ph: +64 9 921 9999 ext 7143
Email: peter.mcnair@aut.ac.nz

Dr Grant Mawston, AUT University North Shore Campus
Ph: +64 9 921 999 ext 7143
Email: grant.mawston@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on the 16th December 2015 AUTEC Reference number 15/381

APPENDIX 2

AUTEC Secretariat
Auckland University of Technology
D-88, WU406 Level 4 WU Building City Campus
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethic

16 December 2015
Peter McNair
Faculty of Health and Environmental Sciences

Dear Peter,

Re Ethics Application: **15/381 Muscle endurance performance of quadriceps and hamstrings, and functional ability before and after arthroscopic meniscal surgery: a case controlled inter-limb comparison.**

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 16 December 2018.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 16 December 2018;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 16 December 2018 or on completion of the project.

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this. If your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply there.

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

All the very best with your research,

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

Cc: Natalie Parlane natalie.parlane@gmail.com, Grant Mawston

APPENDIX 3

Consent Form

Project title: **Muscle endurance performance of quadriceps and hamstrings, and functional ability before and after arthroscopic meniscal surgery: a case controlled inter-limb comparison**

Project Supervisors: **Professor Peter McNair, Dr Grant Mawston**

Researcher: **Natalie Parlane**

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 20th October 2015.
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- ○ I do not have diabetes, a neurological condition or a musculoskeletal condition affecting my knee and lower limb. I have never had surgery on my knees. If I am in the pain free control group, I am currently pain free and have not experienced constant pain for 3 months or more at any time in my life.
- ○ I agree to take part in this research.
- ○ I wish to receive a copy of the report from the research (please tick one): Yes○ No○
- ○ I would like to be contacted in regard to other studies conducted at the Health and Rehabilitation Research Institute (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 the 2nd of October
AUTEC Reference number 15/381

APPENDIX 4

CLIENT INFORMATION SHEET

Age: ______________________________

Gender: M ☐ F ☐

Affected Knee: R ☐ L ☐

Duration of knee symptoms (days): ______________________________

Current working status: ☐ Unemployed ☐ Employed

Current Medications (Please List):

____

____

____

____

Current levels of rehabilitation (minutes/ week): ______________________________
- describe type of exercise i.e. general strength training or lower leg specific training

____

____

Physical Activity Scale
Rate your physical activity level according to the below scale: ____________________

1. Hardly any physical activity
2. Mostly sitting, sometimes a walk, easy gardening, or similar tasks
3. Light physical exercise -2-4 hours per week, eg, walks (including to and from shops), fishing, dancing, ordinary gardening
4. Moderate exercise 1-2 hours per week, eg, jogging, swimming, gymnastics, heavier gardening, home repair, or easier physical activities >4 hours per week
5. Moderate exercise at least 3 hours per week, eg, tennis, swimming, jogging
6. Hard or very hard exercise regularly (several times a week), in which the physical exertion is great, eg, jogging, skiing

APPENDIX 5

Supplementary Digital Content 1

Appendix. Occupational Sitting and Physical Activity Questionnaire (OSPAQ)

1. How many hours did you work in the last 7 days? _______________ hours

2. During the last 7 days, how many days were you at work? ______________ days

Example:

Jane is an administrative officer. Her work day involves working on the computer at her desk, answering the phone, filing documents, photocopying, and some walking around the office. Jane would describe a typical work day in the last 7 days like this:

Sitting (including driving)	90 %
Standing	5 %
Walking	5 %
Heavy labour or physically demanding tasks	0 %
Total	100 %

3. How would you describe your typical work day in the last 7 days? (This involves only your work day, and does not include travel to and from work, or what you did in your leisure time)

a. Sitting (including driving)	________%
b. Standing	________%
c. Walking	________%
d. Heavy labour or physically demanding tasks	________%
Total	________%

Make sure this adds up to 100%

Scoring:

Minutes sitting at work per week = Item 1 * Item 3a
Minutes sitting per workday = (Item 1/Item 2) * Item 3a
Similar calculations can be done for standing, walking, and heavy labour.

APPENDIX 6

KOOS KNEE SURVEY

Today's date: _____/______/______ Date of birth: _____/______/______

Name: ____

INSTRUCTIONS: This survey asks for your view about your knee. This information will help us keep track of how you feel about your knee and how well you are able to perform your usual activities.
Answer every question by ticking the appropriate box, only one box for each question. If you are unsure about how to answer a question, please give the best answer you can.

Symptoms
These questions should be answered thinking of your knee symptoms during the **last week**.

S1. Do you have swelling in your knee?

Never	Rarely	Sometimes	Often	Always
☐	☐	☐	☐	☐

S2. Do you feel grinding, hear clicking or any other type of noise when your knee moves?

Never	Rarely	Sometimes	Often	Always
☐	☐	☐	☐	☐

S3. Does your knee catch or hang up when moving?

Never	Rarely	Sometimes	Often	Always
☐	☐	☐	☐	☐

S4. Can you straighten your knee fully?

Always	Often	Sometimes	Rarely	Never
☐	☐	☐	☐	☐

S5. Can you bend your knee fully?

Always	Often	Sometimes	Rarely	Never
☐	☐	☐	☐	☐

Stiffness
The following questions concern the amount of joint stiffness you have experienced during the **last week** in your knee. Stiffness is a sensation of restriction or slowness in the ease with which you move your knee joint.

S6. How severe is your knee joint stiffness after first wakening in the morning?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

S7. How severe is your knee stiffness after sitting, lying or resting **later in the day**?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Pain

P1. How often do you experience knee pain?

Never	Monthly	Weekly	Daily	Always
☐	☐	☐	☐	☐

What amount of knee pain have you experienced the **last week** during the following activities?

P2. Twisting/pivoting on your knee

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P3. Straightening knee fully

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P4. Bending knee fully

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P5. Walking on flat surface

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P6. Going up or down stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P7. At night while in bed

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P8. Sitting or lying

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P9. Standing upright

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Function, daily living

The following questions concern your physical function. By this we mean your ability to move around and to look after yourself. For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A1. Descending stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A2. Ascending stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A3. Rising from sitting

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A4. Standing

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A5. Bending to floor/pick up an object

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A6. Walking on flat surface

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A7. Getting in/out of car

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A8. Going shopping

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A9. Putting on socks/stockings

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A10. Rising from bed

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A11. Taking off socks/stockings

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A12. Lying in bed (turning over, maintaining knee position)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A13. Getting in/out of bath

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A14. Sitting

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A15. Getting on/off toilet

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A16. Heavy domestic duties (moving heavy boxes, scrubbing floors, etc)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A17. Light domestic duties (cooking, dusting, etc)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Function, sports and recreational activities

The following questions concern your physical function when being active on a higher level. The questions should be answered thinking of what degree of difficulty you have experienced during the **last week** due to your knee.

SP1. Squatting

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP2. Running

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP3. Jumping

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP4. Twisting/pivoting on your injured knee

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP5. Kneeling

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Quality of Life

Q1. How often are you aware of your knee problem?

Never	Monthly	Weekly	Daily	Constantly
☐	☐	☐	☐	☐

Q2. Have you modified your life style to avoid potentially damaging activities to your knee?

Not at all	Mildly	Moderately	Severely	Totally
☐	☐	☐	☐	☐

Q3. How much are you troubled with lack of confidence in your knee?

Not at all	Mildly	Moderately	Severely	Extremely
☐	☐	☐	☐	☐

Q4. In general, how much difficulty do you have with your knee?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

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

APPENDIX 7

Health and Rehabilitation Research Centre
Auckland University of Technology

LOWER LIMB TASKS QUESTIONNAIRE

ACTIVITIES OF DAILY LIVING SECTION

Patient: _______________ **Date:**_____________

INSTRUCTIONS
Please rate your ability to do the following activities in the **past 24 hours** by circling the number below the appropriate response.

If you did not have the opportunity to perform an activity in the **past 24 hours**, please make your *best estimate* on which response would be the most accurate.

Please also rate how important each task is to you in your daily life according to the following scale:

1. = Not important
2. = Mildly important
3. = Moderately important
4. = Very important

Please answer all questions.

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE	IMPORTANCE OF TASK
1. Walk for 10 minutes	4	3	2	1	0	1 2 3 4
2. Walk up or down 10 steps (1 flight)	4	3	2	1	0	1 2 3 4
3. Stand for 10 minutes	4	3	2	1	0	1 2 3 4
4. Stand for a typical work day	4	3	2	1	0	1 2 3 4
5. Get on and off a bus	4	3	2	1	0	1 2 3 4
6. Get up from a lounge chair	4	3	2	1	0	1 2 3 4
7. Push or pull a heavy trolley	4	3	2	1	0	1 2 3 4
8. Get in and out of a car	4	3	2	1	0	1 2 3 4
9. Get out of bed in the morning	4	3	2	1	0	1 2 3 4
10. Walk across a slope	4	3	2	1	0	1 2 3 4

TOTAL (/40):_____

Enquiries concerning this questionnaire: Peter J. McNair PhD, Health and Rehabilitation Research Centre, Auckland University of Technology, Private Bag 92006, Auckland; New Zealand. email: peter.mcnair@aut.ac.nz Phone: 921-9999 Ext 7143

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APPENDIX 8

Health and Rehabilitation Research Institute
Auckland University of Technology

LOWER LIMB TASKS QUESTIONNAIRE
RECREATIONAL ACTIVITIES SECTION

Patient: _______________ **Date:**_____________

INSTRUCTIONS
Please rate your ability to do the following activities in the **past 24 hours** by circling the number below the appropriate response.

If you did not have the opportunity to perform an activity in the **past 24 hours**, please make your *best estimate* on which response would be the most accurate.

Please also rate how important each task is to you in your daily life according to the following scale:

1. = Not important
2. = Mildly important
3. = Moderately important
4. = Very important

Please answer all questions.

	UNABLE	SEVERE DIFFICULTY	MODERATE DIFFICULTY	MILD DIFFICULTY	NO DIFFICULTY	IMPORTANCE OF TASK
1. Jog of 10 minutes	0	1	2	3	4	1 2 3 4
2. Pivot or twist quickly while walking	0	1	2	3	4	1 2 3 4
3. Jump for distance	0	1	2	3	4	1 2 3 4
4. Run fast/sprint	0	1	2	3	4	1 2 3 4
5. Stop and start moving quickly	0	1	2	3	4	1 2 3 4
6. Jump upwards and land	0	1	2	3	4	1 2 3 4
7. Kick a ball hard	0	1	2	3	4	1 2 3 4
8. Pivot or twist quickly while running	0	1	2	3	4	1 2 3 4
9. Kneel on both knees for 5 minutes	0	1	2	3	4	1 2 3 4
10. Squat to the ground/floor	0	1	2	3	4	1 2 3 4

TOTAL (/40):_____

Enquiries concerning this questionnaire: Prof. Peter McNair PhD, Health and Rehabilitation Research Institute, Auckland University of Technology, Private Bag 92006, Auckland; New Zealand. email: peter.mcnair@aut.ac.nz Phone: 921-9999 Ext 7143

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