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## Hamstring muscle function following anterior cruciate ligament reconstruction using semitendinosus and gracilis autografts

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O L L S C O I L L U I M N I G H

Hamstring muscle function following  
anterior cruciate ligament  
reconstruction using semitendinosus  
and gracilis autografts

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Research MSc

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## Abstract

**Title: Hamstring muscle function following anterior cruciate ligament reconstruction using semitendinosus and gracilis autografts.**

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***Background:*** The effect of anterior cruciate ligament reconstruction (ACLR) using hamstring tendon grafts on residual hamstring muscle strength and function remains unclear, while the relationship between pre-operative and post-operative hamstring strength has not been established.

***Objective:*** To assess hamstring strength before and after ACLR using semitendinosus and gracilis tendon grafts (STG), and to evaluate the relationships between pre-operative and post-operative hamstring strength, and between hamstring strength and knee function.

***Methods:*** This study consisted of three parts: Firstly, a systematic review of current literature that investigated hamstring strength. Secondly, a retrospective analysis of isokinetic hamstring strength pre-operatively and six months following ACLR over five years. Thirdly, subjective assessment of current hamstring and knee function using the Tegner scale, Knee Self-Efficacy Scale (K-SES) and a hamstring questionnaire developed for this study based on the K-SES (K-SES Ham).

***Results:*** (1) Eleven studies met the inclusion criteria for the systematic review. Between limb hamstring peak torque (PT) deficits ranged from 10-19% and 6.4-12.6% at six and 12 months, respectively. Only three of the studies reported both pre and post-operative results. Absolute PT values were found to be low at 96Nm at 60°/s (Range 77-121.8Nm) with just one study normalising PT to body weight (PTBW). (2) Fifty-four patients agreed to participate in the retrospective data analysis. Low between limb PT deficits were identified pre-operatively (5.87%) and post-operatively (7.25%). Statistically significant improvements were found post-operatively for both the injured and uninjured limbs compared to pre-operative values. Strong correlations were identified between pre and post-operative scores for PT, PTBW, Total work and average PT. The mean absolute PT at 60°/s of 103.02Nm was higher than previously reported but lower than expected, when normalised to body weight (PTBW). (3) The median score for the Tegner was 7.0, K-SES 8.27 and K-SES Ham 8.66 at a mean of 3.66 years post-operatively. PTBW consistently correlated with the Tegner scale and K-SES across both speeds of 60 and 180°/s.

***Conclusion:*** ACLR with STG grafts resulted in good patient outcomes in terms of comparative objective hamstring strength and subjective knee and hamstring muscle performance. Hamstring strength actually improved post-operatively, with small deficits of less than 10% detected between limbs. The strong relationship between pre-operative and post-operative scores supports the need for more intensive pre-habilitation to gain optimal post-operative results. PTBW may be a more beneficial parameter than relative PT deficits in terms of predicting patient subjective performance, and future studies need to fully examine the importance of PTBW to assess its links to injury prevention and performance.

## **Declarations**

This study forms part of original research and I have not previously submitted material to this effect either in published or unpublished form to either University of Limerick or any other institution.

Signature

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## List of Abbreviations

ACL= anterior cruciate ligament

ACLR= anterior cruciate ligament reconstruction

BPTB= bone-patellar tendon-bone

ST= semitendinosus

STG= semitendinosus and gracilis

PT= peak torque

PTBW= peak torque per body weight

Ave PT= average peak torque

TPT= time to peak torque

K-SES =Knee Self-Efficacy Scale

K-SES Ham= Knee Self-Efficacy Scale hamstring section

Ft/lb= foot/ pounds

@= at

°/s= degrees per second

m= males

f= females

mths= months

IKDC=international knee documentation committee scores

ms= milliseconds

Pre-op= pre-operative

Post-op= post-operative

SD=standard deviation

CASP= critical appraisal skills programme

N= newtons

J= joules



# **Chapter 1: Introduction**

The purpose of this study is to provide more comprehensive information on the effect of hamstring muscle grafting during anterior cruciate ligament reconstruction (ACLR) on residual hamstring strength and self-reported function post-operatively. It also aims to establish the importance of pre-operative strength on post-operative outcomes.

The following seven chapters present the core work of this Masters by research (MSc). Chapter one outlines the background and rationale for this research study, while chapter two provides a more detailed critical appraisal and interpretation of the existing literature that has investigated hamstring strength after ACLR, which will be presented as a comprehensive systematic review. The gap in the existing literature will then be evident, leading to the key questions of the MSc. In order to inform research, the main study of this MSc was performed consisting of two parts- part one: an analysis of existing data and part two: a questionnaire based study. Chapter three describes the methods used for this main study, while chapters four and five report the results of both part one (the data analysis) and part two (questionnaire results). Chapter six provides an interpretation and discussion of the results identified with conclusions presented in Chapter seven.

## **1.1 Overview of chapter one:**

Chapter one provides the background to the study by outlining the role and functions of the anterior cruciate ligament (ACL) together with the incidence and mechanism of ACL injury. It will outline the anatomy and function of the hamstring muscle group and discuss the different type of grafts used during ACLR and the rationale for hamstring grafting. It will also highlight the importance of hamstring strength and the possible consequences of hamstring weakness after hamstring tissue grafting. It will outline the current gaps in the literature in relation to hamstring strength after ACLR providing the rationale for this current study, namely the lack of clarity on the effect of hamstring muscle grafting on residual hamstring muscle strength and function.

## **1.2 Anterior cruciate ligament**

The ACL originates on the posterior-medial aspect of the lateral femoral condyle and runs anteriomedially to insert on to the intercondylar notch on the tibial plateau (Moore and Agur 1995). The ACL acts as one of the primary stabilisers of the knee joint whose primary role in the knee is to control anterior translation of the tibia on the femur and also to act as a secondary restraint to excessive external rotation of the tibia (Schultz, 2000). Greatest stress is placed on the ACL when valgus or rotatory forces are applied to the knee joint in full extension (Renstrom et al., 2008).

## **1.3 Hamstring muscle group anatomy and function**

The hamstring muscle group consists of three distinct muscles which are bi-articular in nature, whose primary functions are to extend the hip and flex the knee while also controlling tibial rotation at the knee joint in a flexed position. The three muscles that make up the hamstring muscle group are the biceps femoris, semimembranosus and semitendinosus which all have an origin on the ischial tuberosity. The biceps femoris has a second short head origin on the linea aspera of the femur and inserts on to the head of the fibula and is the primary lateral rotator of the knee. The semimembranosus and semitendinosus muscles insert on to medial tibial condyle and medially rotate the knee (Moore and Agur., 1995). As the hamstring muscles flex the knee, they work synergistically with the ACL to prevent hyperextension of the knee joint and excessive anterior displacement of the tibia on the femur (Ardern et al., 2010).

The semitendinosus is so named due to its cord-like distal tendon which along with the gracilis (which arises from the inferior pubic ramus) and sartorius muscles have a common insertion on the anterior-medial aspect of the tibia called the pes anserinus (Charalambous and Kwaees. 2012). The gracilis muscle's primary function is as a hip adductor. During ACL reconstruction harvesting of tendons from the semitendinosus alone or from both semitendinosus and gracilis tendons can be performed to be used to reconstruct the ruptured ACL. If the latter technique is chosen, then these two tendons are combined and looped forming the combined double looped semitendinosus and gracilis tendon grafts or STG grafts. In clinical practice and in the published literature, these grafts are referred to as hamstring grafts despite the use of an adductor muscle. Thus it is evident that the hamstring muscle

group play a vital role in recovery of lower limb function following ACL reconstruction surgery both during surgery itself and in restoring knee function.

#### **1.4 Mechanism of ACL injury**

ACL injuries may result from a traumatic blow or collision to the knee, but are often associated with non-contact injuries and occur when an athlete is landing from a jump, pivoting or decelerating suddenly (Bruckner and Kahn 2001). Possible risk factors for ACL injury include playing surface, footwear, type of competition, anatomical factors, and hormonal factors (Renstrom et al., 2008). Neuromuscular factors have also been investigated as a possible risk factor with analysis of jump and hop techniques identifying that athletes who land with low knee flexion angles and hence low hamstring activation are at higher risk of ACL injuries than those athletes with higher hamstring muscle activation (Myer et al., 2009, Paterno et al., 2012, Hewett et al., 2001). This hamstring recruitment has been identified as been greater in men than women, and this has been identified as a possible reason for increased risk of primary ACL injury in women participating in sport (Myer et al., 2009, Paterno et al., 2012, Hewett et al., 2001).

#### **1.5 Incidence of ACL injury**

ACL injuries occur most frequently in sporting populations due to the mechanism of injury but can occur in the general population. The Scandinavian ACL registry 2004-2007 (Granan et al., 2009) identified that the annual incidence of primary ACL reconstructions in Norway was 34 per 100,000 inhabitants, while in Denmark the incidence was 38 per 100,000 and in Sweden 32 per 100,000. Interestingly, for the age group most at risk i.e. the sporting age groups of 16–39 years of age, the annual incidence rose to 85 primary ACL reconstructions per 100,000 inhabitants in Norway and 91 per 100,000 (Denmark) for the 15–39-year age group. No such registry exists for Ireland or the United Kingdom.

#### **1.6 Treatment**

Complete rupture of the ACL can be treated conservatively or by surgical means through reconstruction of the ligament (ACLR). While a decision on the need for surgical reconstruction is based on various factors including patient's activity levels and age, it has been stated (Mohtadi et al., 2011) that ACL reconstruction is the

“most commonly recommended intervention for patients with anterior cruciate ligament rupture”. ACLR involves reconstruction of the ligament using tissue taken most commonly from the patient’s own body tissue (autograft using muscle tendon grafts) or foreign tissue such as synthetic tissue (allografts) (Kim et al., 2010).

### **1.7 Graft choice**

Debate still exists as to the best choice of tendon graft for an ACLR between hamstring grafts and bone-patellar tendon-bone grafts (BPTB). While BPTB grafts have often been regarded as the gold standard, hamstring autografts such as STG grafts have become more popular and are currently the most commonly used grafts as reported by the Scandinavian ACL registry (Granan et al., 2009). This is due to the fact that hamstring grafting is associated with similar functional knee performance as compared to BPTB grafts but with reduced anterior knee pain (Li et al., 2012, Mohtadi et al., 2011, Keays et al., 2010, Vairo et al., 2010, Goldblatt et al., 2005).

### **1.8 Importance of hamstring strength and the implications of surgery**

Irrespective of which tendon graft is used, lower limb muscle strengthening has been identified as an essential part of the ACLR rehabilitation process (Kruse et al., 2012) and a key objective marker for guiding return to sport after ACLR (Barber-Westin and Noyes, 2011, Renstrom et al., 2008). Together with this, the hamstring muscle group work as a natural synergist with the ACL in helping to prevent excessive anterior translation of the tibia (Makihara et al., 2006). Hamstring muscle weakness has been associated with poor knee function in ACL deficient knees (Tsepis et al., 2004) and with increased risk of ACL injury in previously uninjured females (Myer et al., 2009) and thus, it is important that hamstring strength is optimised during rehabilitation to prevent future ACL injury.

However, a possible consequence of harvesting the semitendinosus and gracilis tendons during ACLR is associated deficits in the strength of hamstring muscle group due to muscle atrophy and abnormal attachment of the residual tendons (Anderson et al., 2002). Several studies have identified strength deficits in the hamstring muscle group following ACLR (Xergia et al., 2011, Dauty et al., 2005, Mohtadi et al., 2011, Forster and Forster, 2005). However, the extent of the strength

deficit and the types of hamstring grafts used is inconsistent and both the predictors and clinical relevance of such strength deficits have not been fully explored (chapter two). Thus, while hamstring grafting becomes more popular, the effect of this grafting surgery on residual hamstring muscle strength has not been clearly established. Also, the clinical significance of any such weakness on either hamstring function or knee function is not known at long term follow-up.

## **1.9 Current deficits in the literature**

This research was performed to examine and strengthen certain areas of deficit in the literature:

### **1.9.1 Lack of clarity in defining strength deficits**

While hamstring grafting has become more popular, the full effects of hamstring grafting on residual strength are unclear (Xergia et al., 2011). The lack of consistency in reporting hamstring muscle deficits is often affected by methodological differences that exist between studies. Importantly, the reference point for strength comparisons also varies between studies, with some studies comparing results of hamstring graft groups to BPTB groups (Anderson et al., 2002, Bizzini et al., 2006), others comparing between sexes (Gobbi et al., 2004) or comparing between hamstring grafts (Tashiro et al., 2003, Ardern and Webster, 2009).

The use of isokinetic dynamometry to objectively assess muscle strength after ACL is well documented (Pua et al., 2008, Xergia et al., 2011), but the parameters recorded and reported can affect interpretation of results. Critically, studies (Choi et al., 2012, Keays et al., 2001) have often reported relative deficits between limbs without reporting the actual recorded absolute scores for each limb to allow for further analysis. While comparing strength between legs is a valuable comparison, several studies have highlighted concerns to using the contralateral limb as a sole reference point (Hiemstra et al., 2007, Beynon et al., 2002). Others (Paterno et al., 2012) have identified that athletes with a primary ACL injury are more likely to injure the contralateral ACL than the ipsilateral ACL, which questions the use of the contralateral limb as a primary benchmark. Relative scores are only as accurate as the reference point used for comparison and it has been recommended that studies in

this area report both absolute and relative figures (Anderson et al., 2002). Critically no published systematic review has previously focused on absolute strength deficits either before or after surgery, which would allow for greater depth of analysis between studies. Further research is needed to obtain and present absolute hamstring strength values to enable clinicians and researchers compare studies with normative and reference data banks. This will enable a more accurate assessment of hamstring strength scores after surgery in order to establish the absolute true effect of STG grafting on hamstring grafting.

### **1.9.2 Lack of testing of important parameters**

Previous studies have tended to focus on a narrow range of parameters with small sample sizes and long term follow up periods (Chapter two). In order to fully investigate hamstring muscle function, the hamstring muscle group needs to be tested using a range of parameters. Studies have focused on a limited range of parameters such as peak torque (PT) and speeds of 60 degrees per second ( $^{\circ}/s$ ), however it is widely accepted that gender and body weight can affect PT (Dvir, 1995). Despite this, many studies do not separate by gender during their analysis even though it has been reported that females have significantly greater flexion PT deficits after ACLR with STG grafting (Gobbi et al., 2004, de Jong et al., 2007) and are more at risk of primary ACL rupture (Paterno et al., 2012). By analysing PT relative to a person's body weight (PTBW) and gender, it allows for a better analysis and interpretation of results. While  $60^{\circ}/s$  remains the most commonly used testing speed, studies which report a spectrum of higher speeds may correlate better with specific functional demands (Anderson et al., 2002).

Other testing parameters such as hamstring:quadriceps ratios (Copland et al., 2009, Petersen and Holmich, 2005) and hamstring time to peak torque (TPT) (Bien, 2011) have been identified as useful in preventing injury and their importance in hamstring muscle assessment needs to be examined. An increase in quadriceps concentric peak torque relative to hamstring peak torque has been identified as a possible risk factor for hamstring muscle injury (Freckleton et al., 2013) as the force generated during concentric agonist knee extension may overload the eccentric antagonist force of the hamstring muscle. Forceful quadriceps contraction at or near terminal extension without adequate hamstring co-activation can also place high forces on the ACL

(Renstrom et al., 2008). This is due to the ability of the hamstring muscle group to produce posterior tibial translation, thus counteracting the anterior tibial pull of the quadriceps. Thus, it is important that the hamstring muscle group can generate adequate forces relative to the quadriceps as measured by the hamstring: quadriceps ratios. Likewise, it is important that these hamstring forces can be generated as quickly as possible as measured by the time to peak torque (TPT). TPT have been suggested as part of ACL prevention programmes to improve neuromuscular hamstring performance to aid the ACL in restricting anterior tibial excursion (Bien et al 2011). Thus, more comprehensive analysis of these parameters would allow for a complete assessment of objective hamstring muscle performance to fully understand the effect of hamstring grafting during ACLR. The primary aim of this study is to fully examine the absolute hamstring strength values six months following ACLR with STG grafts across a range of isokinetic parameters to determine the full effect of hamstring muscle grafting on residual strength.

### **1.9.3 Pre-operative strength and its relationship to post-operative strength**

For the treating physician/therapist the first six to 12 months is often the critical time during the rehabilitation process as it is often the time that a decision on return to sport is made (Keays et al., 2001). Thus, crucially it is this period of the first six to twelve months that optimisation of hamstring strength needs to occur to allow for safer return to sporting activity, and it is important to understand predictive factors that may result in better outcomes in this early time frame.

Pre-operative quadriceps strength has been linked with post-operative strength (Eitzen et al., 2009) but the relationship between pre-operative hamstring strength and post-operative hamstring strength has not been established (Yasuda et al., 1995, Janssen et al., 2013, Adachi et al., 2003). While studies have reported pre-operative scores (Anderson et al., 2002, Keays et al., 2007, Keays et al., 2003), no study has reported the relationship between pre-operative hamstring strength and hamstring strength six months post-operatively. The need for pre-operative testing for full assessment of muscle strength rehabilitation has previously been identified (Goradia et al., 2006). Insufficient high quality evidence exists as to factors that may predispose some patients to greater hamstring deficits post ACLR with hamstring

grafting than others, or that examines the relationship between pre-operative hamstring muscle strength and post-operative strength deficits.

Further research is needed to fully investigate the effect of pre-operative strength on post-surgical outcomes to assess the importance of pre-habilitation in aiding the return to full strength following ACLR. It is hypothesised that some patients awaiting ACLR surgery may undergo muscle strength deconditioning secondary to factors including pain, swelling and fear of use (Keays et al., 2001). The effect of this deconditioning on long term outcomes post-operatively needs to be established to determine if patients need to be better managed pre-operatively in terms of strength training. Thus, this study will identify pre-operative strength across a range of isokinetic parameters and aims to establish the relationship between pre-operative strength and post-operative strength, to help identify which strength parameter can most predict post-operative scores.

#### **1.9.4 Identification of subjective function and its relationship to hamstring strength.**

In order to determine the clinical significance of the effect of hamstring on function, it is necessary to identify subjective patient outcomes after ACLR with hamstring grafts. Despite many studies identifying good outcomes after ACL surgery in terms of objective functional tests including hop tests and agility tests, many patients still do not return to their primary sport (Ardern et al., 2012., Gobbi et al., 2006.) with fear of injury and fear of movement (kinesiophobia) reported as a barrier to return to sports (Hartigan et al., 2013, Kvist et al., 2005). Thus, objective markers alone cannot fully determine the effectiveness of a rehabilitation programme and it is necessary that subjective patient outcomes in terms of self-reported function needs to be assessed.

Likewise, it has been suggested that other psychological factors including self-confidence, optimism and self-motivation can predict ACL surgery outcomes (Everhart et al., 2013.) All these emotions are linked to the theory of self-efficacy (Everhart et al., 2013) developed by Bandura (1977), which states that self-efficacy affects how a person feels, thinks and acts (Thomee 2007). In this way, self-efficacy covers a spectrum of human behaviour and emotions rather than just focusing on

single psychological factors in isolation e.g. fear or anger. High levels of self-efficacy have been shown to positively influence post-operative outcomes in ACLR (Te Weirike et al., 2013) and other knee surgeries (Wylde et al., 2012). Measuring self-efficacy can ultimately help to determine how patients feel about their knee function and how likely they are to challenge their knee and return to full activities like before surgery. For this, reason it was decided that a secondary aim of this study would be to assess long-term subjective outcome in individuals following ACLR to determine the long term effects of ACLR with STG grafts on how patient's perceptions, attitudes and functional performance are affected.

Previous studies have measured patient's subjective ratings of their knee function in terms of global knee functioning using measures such as the Tegner, Lysholm, International Knee Documentation Committee (IKDC), and Noyes Questionnaire (Kim et al., 2011, Ardern et al., 2010, Lautamies et al., 2008) with varying outcomes. The Tegner scale was chosen as a measure of subjective global function in this study as it is a commonly reported measure of subjective performance after ACL surgery (Ko et al., 2012, Kim et al., 2011, Lautamies et al., 2008) which rates activity levels from 0-10, from inactivity to international performance. Scales such as the Tegner have an inherent ceiling effect (Ko et al., 2012) and measure knee function using defined activities without assessing how a person feels about his/her performance. However, it is a quick and easy scale and allows a crude measurement of knee performance for comparison across studies.

Critically, no previous study has examined self-efficacy at long term follow-up after ACLR with STG grafts. Also it has not been established what effect if any, that that harvesting of hamstring muscle tissue has on patients own perception of their hamstring muscle performance or self-efficacy. No published study has examined if patients after ACLR with STG grafts reported residual problems with hamstring function during daily/sporting activities or felt that their hamstring function had been adversely affected.

No previous studies have examined the relationship between isokinetic strength and subjective function to establish if hamstring strength is associated with subjective performance. In this way, the clinical significance of potential hamstring muscle weakness has not been established. This study aims to identify if hamstring muscle

strength is affected by harvesting during ACLR and ultimately determine if any such weakness affects hamstring or knee performance as rated by the patients themselves.

Self-efficacy has been identified as a judgement of one's potential ability to perform a task, rather than a measure of whether or not one actually can or does perform the task (Thomee et al., 2006). The Knee self-efficacy scale (K-SES) allows participants to answer questions about current function and also in relation to future performance, while increased self-efficacy has also been associated with improved functional outcomes after ACLR (Thomee et al., 2006). This thus allows for a greater evaluation of self-reported performance than previous measures by recording how a patient feels about doing a certain task rather than if he/she can do it.

### **1.10 Present research**

To inform the evidence base to optimise rehabilitation following ACLR and to better understand the effect of hamstring strength on hamstring function after ACLR, this research was developed. The research aims are to:

- (1) Appraise and synthesise the current literature to establish the existing evidence base into hamstring strength after ACLR through a systematic review to establish if hamstring strength deficits exist before or after ACLR using STG grafts (chapter two).
- (2) Identify the effect of hamstring muscle grafting on post-operative hamstring strength in absolute terms across a wider range of isokinetic parameters than previously reported, through retrospective data mining over five years
- (3) To establish the long term effect of ACLR on subjective global knee and hamstring function through long term follow up questionnaires such as the Tegner scale and Knee Self-Efficacy scale (K-SES)
- (4) Identify the relationship between pre and post-operative isokinetic strength results
- (5) Examine the relationship between hamstring strength and long term subjective function.

## Hamstring muscle function following ACLR with STG grafts

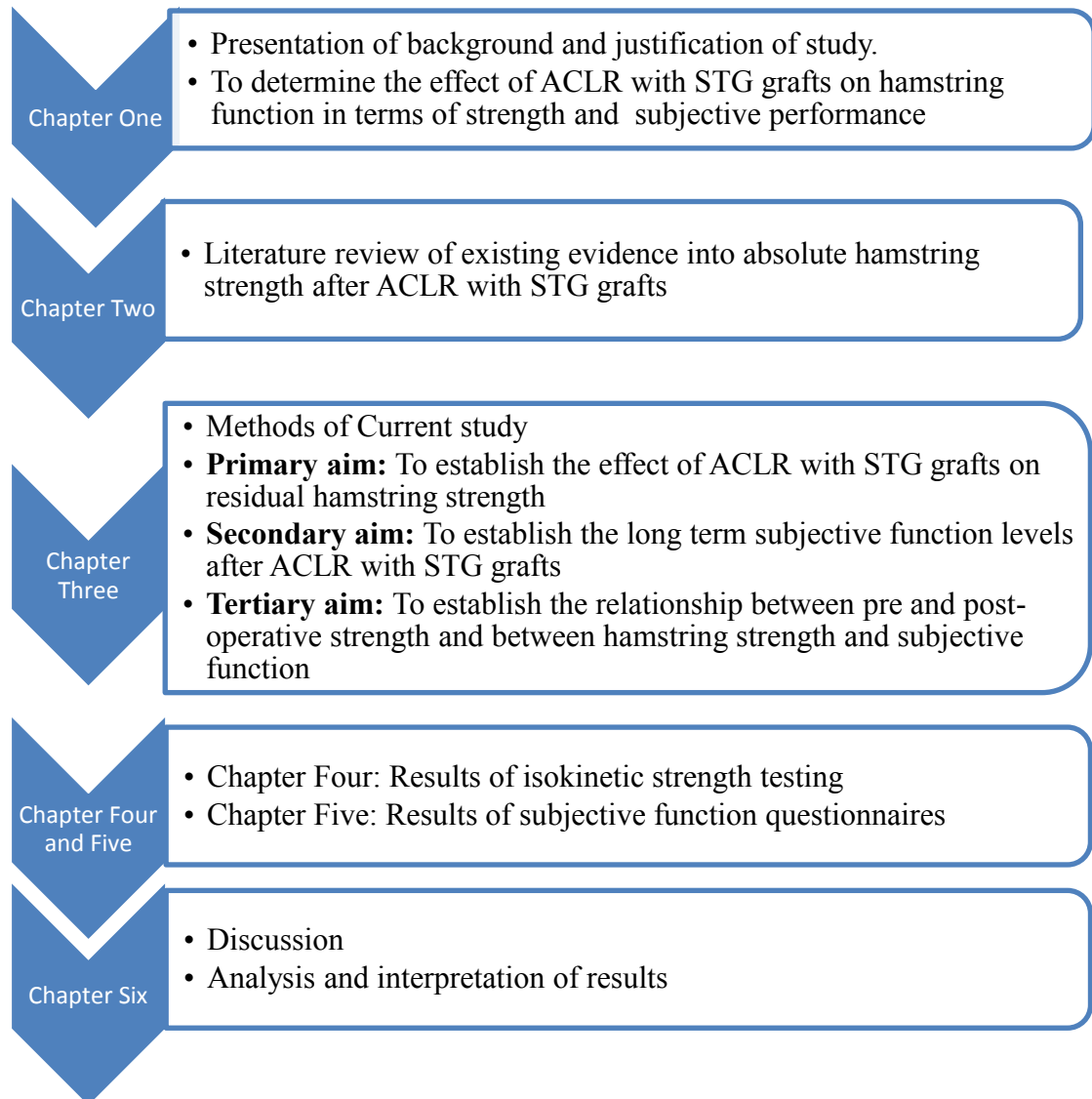


Figure 1.1: Outline of Study

## **Chapter 2: Systematic Literature Review**

Chapter one identified the need to clarify the post-operative effects of hamstring grafting during ACLR. The purpose of this chapter is to identify the current evidence in relation to hamstring muscle strength deficits after ACLR using the most commonly used hamstring tendon graft i.e. combined double looped semitendinosus and gracilis tendons (STG) and to establish the effect of pre-operative strength on post-operative strength. A systematic review of the databases MEDLINE, SPORTSdiscus, Cinahl, AMED and Cochrane library were searched using specific search terms for original articles which reported both absolute and relative hamstring muscle strength on isokinetic testing after ACLR with STG grafts. Study quality of the included studies was assessed using the Critical Appraisal Skills Programme (CASP) tool for case and cohort studies with findings reported and discussed. The following paper has been accepted for publication by the Journal of Isokinetics and Exercise Science.

**Title: Hamstring muscle strength before and after anterior cruciate ligament reconstruction. A Systematic Review.**

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**Abstract:**

***Background:*** The effect of hamstring tendon grafting during anterior cruciate ligament reconstruction (ACLR) on residual hamstring muscle strength remains unclear.

***Objectives:*** To identify if hamstring muscle strength deficits exist after ACLR using the ipsilateral semitendinosus and gracilis tendons (STG) in absolute and relative terms, and ascertain if pre-operative strength influences post-operative strength outcomes.

***Methods:*** A search was performed using five databases; MEDLINE, SPORTSDiscus, Cinahl, AMED and Cochrane. Original articles that reported both absolute and relative hamstring muscle strength on isokinetic testing after ACLR with STG grafts were evaluated, selected and critically appraised.

***Results:*** Eleven studies that met the inclusion criteria were included in the review. Hamstring peak torque (PT) deficits in the reconstructed leg compared to the

contralateral side ranged from 10-19% and 6.4-12.6% at six and 12 months, respectively. Minimal deficits were reported at five to six year follow up. In absolute terms the mean PT identified was low at 96Nm at 60°/s (Range 77-121.8Nm) with just one study normalising PT to body weight (PTBW). Only three of the included studies reported both pre and post-operative results with two studies identifying similar reductions in PT of 8.6-9% in the operated limb from pre-operatively to six months.

**Conclusion:** Deficits in hamstring strength were found to exist up to one year post-operatively but appear to resolve by five to six years. It is recommended that future studies report PTBW for better interpretation of results to allow for comparisons against normative data. More research is needed to examine the influence of pre-operative hamstring muscle strength on post-operative results.

**Keywords:** anterior cruciate ligament, hamstring, semitendinosus, gracilis, isokinetic, muscle strength, knee flexor, torque

## **2.1 Introduction**

Anterior Cruciate Ligament (ACL) injuries are a common orthopaedic occurrence particularly among younger sporting populations (Granan et al., 2009). Surgical reconstruction of the ligament allows for greater knee joint stability, which aids functional performance and potentially reduces the risk of early osteoarthritis (Mohtadi et al., 2011, Keays et al., 2010). Hamstring tendon grafting has become increasingly popular as an alternative to bone-patellar tendon-bone (BPTB) grafting (Ardern and Webster, 2009, Granan et al., 2009), with combined double looped semitendinosus and gracilis grafts (STG) the most commonly used hamstring tendon grafts (Granan et al., 2009).

The hamstring muscle group functions to flex the knee and extend the hip joint, and works synergistically with the ACL to prevent anterior tibial excursion (Ardern et al., 2010, Vairo et al., 2008, Anderson et al., 2002). ACL reconstruction (ACLR) surgery and hamstring muscle weakness have independently been linked with an increased risk of hamstring muscle strain (de Visser et al., 2012, Croisier et al., 2008), while hamstring muscle weakness has been associated with an increased risk of primary ACL rupture injury in females (Myer et al., 2009). A deficit in hamstring muscle strength has a detrimental effect on lower limb function (Goradia et al., 2006). Thus, it is important that the effect of an ACLR with hamstring grafting on residual hamstring muscle strength is fully understood, to ensure that strength is optimised to prevent future hamstring muscle and ACL injury.

Currently, the effect of harvesting hamstring muscle tissue on residual hamstring strength is unclear (Xergia et al., 2011). Hamstring strength deficits following harvesting have been associated with muscle atrophy, abnormal attachment of the residual semitendinosus tendons and lack of compensation by the semimembranosus and biceps femoris muscles (Makihara et al., 2006). Muscle strengthening is an essential part of the rehabilitation process (Kruse et al., 2012) to optimise strength outcome and guide return to sport after ACLR (Barber-Westin and Noyes, 2011, Renstrom et al., 2008). Despite rehabilitation, several studies have identified strength deficits in the hamstring muscle group following ACLR (Xergia et al., 2011, Dauty et al., 2005, Forster and Forster, 2005, Mohtadi et al., 2011), however the extent of the deficit following the different types of hamstring grafts is variable.

Two comprehensive reviews (Xergia et al., 2011, Dauty et al., 2005) examined the relative deficits between limbs following ACLR and while comparing strength between legs is a valuable tool, discrepancies may exist when using the contralateral

limb as a sole reference point (Beynon et al., 2002, Hiemstra et al., 2007). Reporting relative deficits can be misleading as minimal differences compared to a weak uninjured limb may suggest a better outcome to what exists in real terms. Critically, no published review has examined absolute strength values either before or after surgery to allow for future comparisons against normative values for the general population as they compare for gender or weight. Absolute scores allow the reader to independently interpret findings as they relate to other studies, sporting groups, age profiles etc. For example, if two studies (A and B) report the same group mean side to side strength deficits with similar participants but different rehabilitation protocols, then each protocol appears equally useful. However, if absolute values are reported, one may see that although the relative deficits are similar, the participants in study B may have achieved higher absolute strength in the individual limbs which would support the protocol in study B. In order to avoid this misinterpretation it has been recommended that studies in this area report both absolute and relative figures (Anderson et al., 2002).

Additionally, the significance of pre-operative hamstring muscle strength has not been reported. Pre-operative quadriceps strength has been linked with post-operative strength (Eitzen et al., 2009) but the relationship between pre-operative and post-operative hamstring strength has not yet been established (Yasuda et al., 1995, Janssen et al., 2013, Adachi et al., 2003) and the clinical significance of any such weakness has not been fully identified.

This systematic review was performed to examine the literature in relation to people who underwent ACLR using the ipsilateral STG graft and who had objective isokinetic hamstring muscle strength results reported in absolute terms.

Specifically this review aims to identify:

- (1) the relative deficits that exist in hamstring muscle strength at different timelines following ACLR,
- (2) the absolute hamstring strength values recorded at different timelines and the isokinetic parameters reported,
- (3) the effect of pre-operative hamstring muscle strength on post-operative strength.

## **2.2 Methodology**

A systematic review of the databases MEDLINE, SPORTDiscus, AMED, CINAHL and the Cochrane library was conducted. Studies published between January 2002 and December 2013 were eligible for inclusion. Keywords used to identify relevant articles were a combination of “anterior cruciate ligament”, “hamstring”, “semitendinosus”, “gracilis”, “muscle strength”, “isokinetic”, “knee flexor strength”, “hamstring torque” using a combination of AND and OR. Titles and abstracts were initially reviewed and full texts were collated for all articles that provisionally met the inclusion criteria.

### **2.2.1 Inclusion criteria**

Only original, peer-reviewed studies published in the English language were eligible. Selected studies had to use isokinetic dynamometry to objectively assess hamstring muscle strength following ACLR using STG grafts without additional knee ligament surgery. Studies that reported both absolute and relative values or only absolute values for the operated leg and reported deficits compared to the opposite or control limb were eligible for inclusion. All participants were over 18 years of age. Studies

were not limited by design due to the variations in this area including retrospective/prospective studies, cohort studies and cross sectional studies.

### **2.2.2 Exclusion criteria**

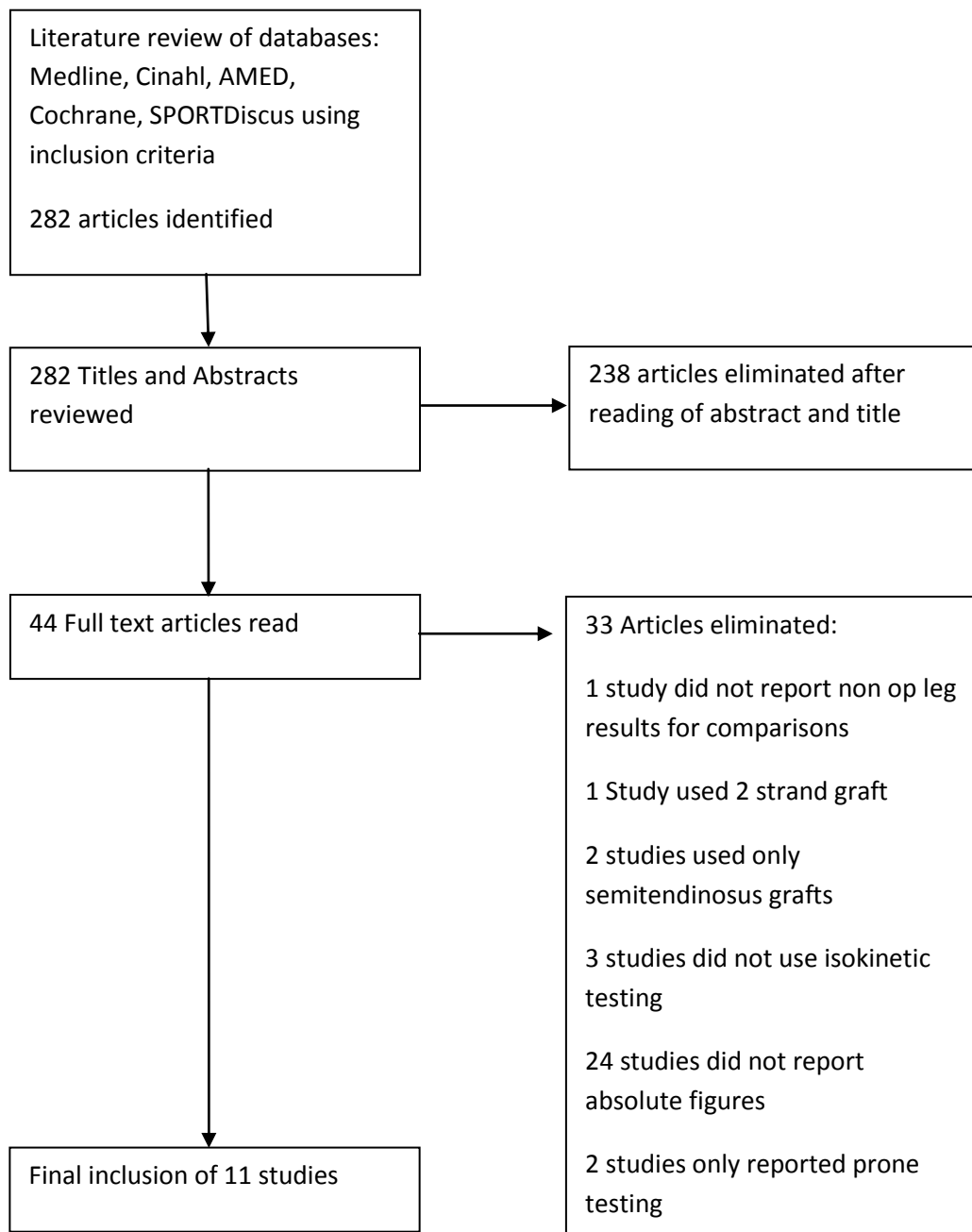
Studies that did not isolate STG group results from other grafts (e.g. BPTB grafts) or did not use isokinetic testing were excluded from this review. Studies that reported strength values for specific joint angles and not throughout full range of motion, or studies which reported test results for the prone testing position only were excluded. This was performed in an attempt to limit variability in the results and to focus on the standard seated position test throughout full range of motion.

Full text articles were then further reviewed and included as appropriate based on the above criteria. The initial search and validation process was performed by the primary author (CM) with validation cross checked by another author (AC) once the initial results had been shortlisted using random sampling.

### **2.2.3 Study appraisal**

For critical appraisal of studies the critical appraisal skills programmes (CASP-UK) for case control and cohort studies was used which assess case studies over 11 criteria and cohort studies over 12 criteria. These include appropriate methodology, acceptable recruitment of cases and controls, control of bias, reporting of confounding factors, accuracy and applicability of results. All articles were initially appraised by the primary author (CM) with another author (AC) repeating the process using random selection to check for accuracy.

**Figure 2.1: Selection of Included Studies**



#### **2.2.4 Data Extraction**

Data extraction was performed using a customised tabular checklist to include results such as sample size, age, weight, height, activity levels and rehabilitation protocols. Isokinetic parameters extracted included the testing equipment name, timelines used

for testing, testing speeds and testing parameters along with the absolute and relative values reported for each test result.

All values reported are for concentric testing unless otherwise stated, as this was the most widely reported mode of contraction with only one study reporting eccentric testing (Anderson et al., 2002). Original relative PT deficits between limbs were extracted from articles where detailed (Keays et al., 2003, Ko et al., 2012, Lautamies et al., 2008, Ardern et al., 2010, Kim et al., 2011), or were calculated based on the absolute values given and expressed as a strength index of the operated leg/non operated leg multiplied by 100 to obtain a percentage. The extraction of data was checked and validated by the primary author and cross-referenced by two separate authors (AC, KOS) using random selection.

### **2.2.5 Data analysis**

Due to the wide variation in study design, study parameters and rehabilitation protocols it was not feasible to perform a meta-analysis of results. Instead results were collated and presented in a descriptive form with the use of tables, with the most commonly reported speeds and testing parameter isolated for clarification.

## **2.3 Results**

The initial search identified 282 articles that included the key terms which resulted in 11 studies (Keays et al., 2007, Keays et al., 2003, Anderson et al., 2002, Segawa et al., 2002, Lautamies et al., 2008, Kim et al., 2011, Ko et al., 2012, Ardern et al., 2010, Vairo et al., 2008, Elmlinger et al., 2006, Burks et al., 2005) after applying the inclusion/exclusion criteria. Figure 1 outlines the process by which the final inclusion number was reached.

### **2.3.1 Study appraisal**

All studies used the non-operated limb as the primary control for strength comparisons. Six studies (Kim et al., 2011, Ardern et al., 2010, Lautamies et al., 2008, Keays et al., 2007, Segawa et al., 2002, Anderson et al., 2002), also compared scores to different grafts including BPTB (Lautamies et al., 2008, Keays et al., 2007, Anderson et al., 2002), hamstrings allografts (Kim et al., 2011), and semitendinosus only grafts (Ardern et al., 2010, Segawa et al., 2002) with two of these studies also including a control group (Keays et al., 2007, Vairo et al., 2008). Five studies examined their cohort over two or more timeframes (Ko et al., 2012, Keays et al., 2007, Burks et al., 2005, Keays et al., 2003, Anderson et al., 2002).

All studies had a well-defined aim, had appropriate study design and testing procedures with results appropriately statistically analysed. For the majority of studies, a lack of detail in the recruitment process and lack of interpretation of confounding factors, especially gender, was evident.

### **2.3.2 Population demographics**

A total sample size of 363 participants were included consisting of 239 males and 124 females with two studies (Ko et al., 2012, Kim et al., 2011) excluding female participants. The ages of participants ranged from 20.8 to 34 years of age. The sporting activities (Table 2.1) of the included participants generally reflected a young, active population with no specific sport or sporting levels identified, and no high level national or international level athletes reported.

### **2.3.3 Rehabilitation protocols**

It was deemed inappropriate to compare between rehabilitation protocols due to wide variation between studies (Table 2.1). This included the use of post-operative knee immobilisation (Burks et al., 2005) compared to no immobilisation (Keays et al., 2003) and different numbers of treatment sessions across the studies reported, with one study not reporting the rehabilitation protocol used (Vairo et al., 2008).

### **2.3.4 Isokinetic parameters**

The reported isokinetic parameters and hamstring muscle PT deficits are shown in Tables 2.3 and 2.4. All scores are for the mean group results as only one study (Keays et al., 2003) separated male and female scores in result analysis. A wide variation of timelines were used which ranged from pre-operatively (Anderson et al., 2002, Keays et al., 2007, Keays et al., 2003), to six years post-operatively (Keays et al., 2007) with a range of testing parameters and testing equipment (Table 2.2). The most commonly used testing speed was 60 degrees per second ( $^{\circ}/s$ ) across all studies with speeds of up to 240 $^{\circ}/s$  reported in one study (Vairo et al., 2008). PT was the most widely used testing parameter with only one study (Vairo et al., 2008) not reporting this value. All studies used the standard seated position (as per inclusion/exclusion criteria) while three studies (Ko et al., 2012, Kim et al., 2011, Elmlinger et al., 2006) also reported test results using the prone position. For accuracy of comparison, only results in the seated position are reported. For clarity, the results for just PT at 60 $^{\circ}/s$  only in the sitting position are shown in Table 2.3 while Table 2.4 reports all the other testing parameters and results.

### **2.3.5 Relative deficits**

Two studies, which reported PT at six month follow up (Anderson et al., 2002, Keays et al., 2003) identified hamstring PT deficits in the operated leg compared to opposite limb at 60°/s of 19% and 10% respectively. No study reported an improvement in hamstring PT at six months from pre-operative testing in any testing parameter. At 12 months post-surgery at 60°/s two studies (Anderson et al., 2002, Ko et al., 2012) reported PT deficits of 11.7% and 12.6% respectively, while one (Segawa et al., 2002) reported PT deficits of just 6.4%. In the five studies that reported a follow up greater than 24 months, PT deficits of less than 5% were reported throughout except for one study (Kim et al., 2011) which identified a deficit of 13.5%.

### **2.3.6 Absolute scores**

Three studies reported absolute PT before surgery with scores of 84Nm (Anderson et al., 2002), 99Nm (Keays et al., 2003) and 105Nm (Keays et al., 2007) for the reconstructed leg. Nine of the studies reported absolute PT values post-operatively at 60°/s in the standard sitting testing position over a range of time frames up to six years. Only one study (Vairo et al., 2008) reported PT relative to body weight (PTBW), while another (Burks et al., 2005) reported peak force and not PT. The scores for PT in the operated limb ranged from a minimum of 77Nm at six months (Anderson et al., 2002) to a maximum of 121.8Nm at 12 months post-operatively (Segawa et al., 2002).

## **2.4 Discussion**

Eleven studies met the inclusion criteria for this review using a range of isokinetic parameters along with objective and subjective assessments. No other systematic review was identified which examined the literature that specifically reported absolute scores. The plethora of parameters and variety of rehabilitation protocols rendered comparisons and synthesis of the data complex, and thus precluded a meta-analysis. The methodological quality of the included studies was low. There was a lack of blinding of participants and assessors throughout, while the use of a control group is difficult in this field of research due to difficulty obtaining an age-matched control group with similar activity levels.

It is clear from the included studies that heterogeneity exists between studies in terms of the timelines used, isokinetic parameters recorded and sample sizes recruited. In general terms, it would appear that hamstring strength deficits are present in the first six to 12 months and are largely resolved at longer term follow up of greater than two years.

### **2.4.1 Relative hamstring strength deficits post-operatively**

The most consistent testing parameter across all the studies was PT at 60°/s, which is thus the best parameter to compare strength deficits. PT is consistently the most commonly reported parameter in the literature (Brown, 2000), as it represents the point of maximum strength during muscle performance. Using these parameters hamstring PT deficits generally appear to exist in the first six to 12 months (6.4-19%), with four studies reporting values for this period (Anderson et al., 2002, Keays et al., 2003, Ko et al., 2012, Segawa et al., 2002). PT deficits at six months ranged from 10% (Keays et al., 2003) to 19% (Anderson et al., 2002). It is difficult to

determine factors responsible for the differences in results between these two studies due to heterogeneity in the rehabilitation protocols, but it is worth noting that the participants in the study with 19% deficits (Anderson et al., 2002) had significantly poorer pre-operative absolute and relative strength scores compared to the study with 10% (Keays et al., 2003). No study examined correlations between pre-operative and post-operative results.

At 12 month follow up, Segawa et al. (2002) identified minimal PT deficits of 6.4 % compared with two others (Anderson et al., 2002, Ko et al., 2012) which identified deficits greater than 10 %. The differences in reported deficits between studies may again be explained by variations in rehabilitation protocols which were not consistent across the included studies. It is interesting, however, that the absolute figures reported by Segawa et al. (2002) (121.8Nm) were considerably higher than all other ten studies. Segawa et al. (2002) reported the highest pre-operative scores of any study in a combined group of STG and BPTB grafts, but did not isolate between different grafts during pre-operative assessment making it difficult to draw definite conclusions. In this review two studies (Ko et al., 2012, Elmlinger et al., 2006) reported values approximately two years post-operatively identifying deficits of 4-11%. These findings are similar to other systematic reviews which examined deficits at two years post-operatively (Xergia et al., 2011, Dauty et al., 2005).

Strength deficits appear to have resolved at longer than two years post-operatively with only one study (Kim et al., 2011) out of the five studies which reported follow up at greater than 24 months reporting PT deficits greater than 5%. Deficits of less than 10% are generally considered normal or negligible in terms of isokinetic testing (Xergia et al., 2011, Sapega, 1990) and deficits of less than 10% have also been used

as one of the guiding factors for returning athletes to sport along with full range of motion, swelling and healing times (Hartigan et al., 2010).

A possible explanation for poorer results in the first six to 12 months may be that the residual hamstring muscle tissue has not fully regenerated into functioning muscle with adequate strength which can take up to 18 months (Carofino and Fulkerson, 2005). Thus, while deficits appear to be resolved at long term follow up, they exist in the first six to 12 months. This has implications for the rehabilitation process as patients may be returning to sport during this time period without full recovery of hamstring strength. For the treating physician/therapist the first six to 12 months is often the critical time during the rehabilitation process as it is often the time that a decision on return to sport is made (Keays et al., 2001). Thus, it is this period of the first six to 12 months that optimisation of hamstring strength needs to occur to allow for safer return to sporting activity.

#### **2.4.2 Absolute Peak Torque**

Considering absolute strength values, the average post-operative PT at 60°/s for all studies was 96Nm. The score of 96Nm is lower than one would expect for the average 70 kilogram male but good for a 60 kilogram female based on Biodex normative data for their System 3 dynamometer (Biodex Medical Systems, Shirley, NY), which is supported by work by Dvir (1995). These scores reflect the general population based on gender and body mass. Although they do not take into account occupation, sporting level etc., they do provide a reference point for analysis as gender and body mass play an important role in isokinetic evaluation (Dvir, 1995).

Without qualifying scores for gender and body mass a full interpretation of these scores is impossible. When normalised for body weight, male PT is expected to be

1.55- 2.04 times body weight and female PT's 1.49-1.76 times body weight similar to the findings of a recent review of isokinetic scores in team sports (Hadzic et al., 2013). One study allowed for separate analysis of male and female results (Keays et al., 2003) separately while only one reported absolute figures related to body weight (Vairo et al., 2008).

At first glance, the participants in the study by Lautamies et al. (2008) and Segawa et al. (2002) had similar outcomes with relative post-operative deficits of 3.5% and 6.4% respectively. However, in absolute terms, the scores of 96Nm (Lautamies et al., 2008) vary considerably from 121.8Nm (Segawa et al., 2002) with neither study reporting body weight. This highlights the issue of focusing on relative deficits, which may be small but do not fully show if hamstring strength has reached optimal levels for that persons weight, gender and functional demands when compared against the general population or specific sport.

Together with this, the recording of absolute figures can allow clinicians a reference point for expected outcomes. As stated 96Nm is a relatively low figure based on Biodex normative data, which may suggest that patients' hamstring strength is not being fully optimised or maybe that new a reference level of hamstring strength needs to be obtained for post-operative ACLR patients. Future studies need to isolate female and male results and report absolute values as they relate to body weight to establish the real outcome of muscle strength after ACLR.

### **2.4.3 Relationship between pre-operative and post-operative strength**

Only three of the included studies (Anderson et al., 2002, Keays et al., 2003, Keays et al., 2007) reported post-operative hamstring scores compared to pre-operatively, with two studies (Keays et al., 2003, Anderson et al., 2002) identifying similar

reductions in PT of 8.6-9% in the operated limb from pre-operatively to six months. Thus, post-operative hamstring strength appears to return to a level marginally below pre-operative levels. However, when comparing between points during the rehabilitation process, it is critical that the baseline score is of satisfactory level. An improvement in strength from a poor pre-operative score may suggest better outcomes than are actually present, and it is important that the impact of pre-operative strength is fully understood. Interestingly, the group post-operative strength deficits in this review at six months were greater (19% (Anderson et al., 2002) versus 10% (Keays et al., 2003)) when bigger strength deficits existed pre-operatively (8.6% (Anderson et al., 2002) versus 1.1% (Keays et al., 2003)). These results may suggest that those with poorer strength pre-operatively may maintain this deficit post-operatively but the lack of studies makes it difficult to draw firm conclusions as none of these studies used a control group for comparisons.

## **2.5 Limitations**

The primary limitation of this review was an inability to perform a meta-analysis of result data. The inconsistency in reporting isokinetic variables between studies makes such analysis complicated and difficult to perform, while inconsistencies in study design and rehabilitation protocols affected the ability to accurately compare between studies. Due to the lack of reporting of eccentric strength values, only concentric values were extracted which may limit a full evaluation of hamstring muscle strength.

## **2.6 Conclusions**

Hamstring muscle deficits appear to exist post ACLR with STG grafts in the first six to 12 months at which point a decision on return to sport is often made. These

deficits are largely resolved at follow up greater than two years although absolute values reported suggest low muscle strength in real terms and future studies need to isolate absolute values as they relate to body weight for full interpretation. The influence of pre-operative strength on post-operative strength has not been fully examined.

Further research is needed which identifies absolute and relative values to fully identify hamstring muscle deficits post ACLR. Also, further examination of the relationship between pre and post-operative hamstring strength deficits needs to be performed, specifically to identify if patients with poorer scores before surgery have poorer scores during rehabilitation, especially within the first six months during which time rehabilitation is most active. Finally, research is needed to identify the clinical significance of the effects of hamstring strength deficits pre and post-operatively.

**Table 2.1: Included study demographics, primary aims and rehabilitation protocols**

<b>Author</b>	<b>Sample size</b>	<b>Participant mean age</b>	<b>Mean Group Body Weight (kg)</b>	<b>Mean Group Height (m)</b>	<b>Reported sporting activity</b>	<b>Study aims</b>	<b>Rehabilitation Protocol</b>
<b>Ko et al., 2012</b>	N=23 STG=23 M=23 F=0	30.9	77.3	1.71	“young active males”  No specific sport or sporting level reported	Strength and functional tests of 23 patients following ACLR with STG.  No control group	None documented
<b>Kim et al., 2011</b>	N=73 STG=39 M=39 F=0	29.5	76.81	1.73	No details	Comparing strength and functional test results of patients following ACLR with hamstring autografts v allografts  No control group	HEP with follow up. WBAT with brace locked in extension by 2 weeks. FWB with unlocked brace after 2 weeks. CKC exercises, Running at 3 mths

<b>Ardern et al., 2010</b>	N=50 STG=30 M=15 F=15	20.8	78	1.71	“Patients participated in sport”  No specific sport or sporting level reported	Comparing strength results between ST graft group and STG graft group  No control	WBAT. No brace. CKC exercises. Running at 3 mths
<b>Lautamies et al., 2008</b>	N=288 STG=113 M=65 F=48	29	Not reported	Not reported	“Majority non-athletes”  No specific sport reported  Mean Tegner= 7	Comparing strength results between BPTB grafts and STG grafts  No control	CKC rehab. Crutches for 2 weeks FWB. No brace. Jogging at 6 weeks
<b>Vairo et al., 2008</b>	N=14 STG=14 M=5 F=9	22.5	68.4	1.66	“Recreationally active 3 days a week”  No specific sport reported	Comparing strength and biomechanical results between STG graft group and 14 control subjects	Same rehab in both groups. Not documented
<b>Keays et al., 2007</b>	N=62 STG=31 M=22 F=9	27	Not reported	Not reported	“active participants”  Tegner range 5-10	Comparing strength and functional results between BPTB and STG graft groups and	Pre-op for 6 weeks. Post op focusing on strength,

					No specific sport reported	control group	balance and stability. No brace. No running guidelines
<b>Elmlinger et al., 2006</b>	N=20 M=13 F=7	27	75.5	1.74	No details reported	Strength and functional tests results of patients following ACLR with STG.  No control group	Retrospective study. No rehab protocol described
<b>Burks et al., 2005</b>	N=9 M=5 F=4	28	Not reported	Not reported	No details reported	MRI and strength results of patients following ACLR with STG grafts	Early ROM with brace for 2-4 weeks. Crutches for 2 weeks. Running at 3 and half months. Hamstring exercises after 6 weeks

<b>Keays et al., 2003</b>	N=31 STG=31 M=22 F=9	27	Not reported	Not reported	No details reported	Comparing strength and functional test results pre and post-operatively for patients following ACLR with STG grafts	Pre-op for 6 weeks. Post-op brace for 2 weeks. 10 sessions over 6 months. 2:1 emphasis on quads:hams. Jogging at 3 months
<b>Segawa et al., 2002</b>	N=62 STG=30 M=15 F=15	20.8	Not reported	Not reported	No details reported	Comparing strength results between ACLR with ST grafts and STG grafts	Brace for 1 week, then AROM and PWB. Jog at 3 months
<b>Anderson 2002</b>	N=45 STG =23 M=15 F=8	34	74	1.74	No details reported	Comparing strength results between BPTB and STG graft groups	Shelbourne and Nitz 1990. CPM post op. WBAT. No brace. Early ROM. Run at 4 months. Sports at 6 months

N=total number of participants in study, STG=Number of participants who underwent ACLR with semitendinosus and gracilis grafts  
M=males F=Females, FWB= Full weight bearing, WBAT= weight bearing as tolerated, CPM= continuous passive motion, HEP= home  
exercise programme, CKC= closed kinetic chain, AROM= active range of motion, PWB=partial weight bearing, mths= months, pre-  
op=pre-operatively, quads=quadriceps, hams=hamstrings

Ages, body weight and height are the reported means for the full groups

**Table 2.2: Summary of isokinetic testing equipment, timelines used and testing parameters**

<b>Author</b>	<b>Mean Timelines used</b>	<b>Isokinetic Dynamometer</b>	<b>Isokinetic parameters and speeds</b>
<b>Ko et al., 2012</b>	12 mths post-op 24 mths post-op	Biodex	PT @ 60°/s
<b>Kim et al., 2011</b>	32 mths post-op	Biodex	PT @ 60°/s
<b>Ardern et al., 2010</b>	31.4 mths post-op	Biodex	PT @60°/s and 180°/s
<b>Lautamies et al., 2008</b>	5 years post-op	Lido Multijoint	PT, ave torque@ 60 and 180°/s
<b>Vairo et al., 2008</b>	21.4 mths post-op	Biodex	PT/BW@60°/s TPT @60°/s Total work @240°/s
<b>Keays et al., 2007</b>	Pre-op, 6 years post-op,	Cybex	PT @ 60°/s PT @120°/s

<b>Elmlinger et al., 2006</b>	25.8 mths post-op	Biodex	PT and total work @ 60 and 180°/s
<b>Burks et al., 2005</b>	6 and 12mths post-op	Kin Com	Peak force @ 60°/s and 180°/s
<b>Keays et al., 2003</b>	Pre-op, 6 mths post-op	Cybex	PT @60°/s  PT @120°/s
<b>Segawa et al., 2002</b>	12 mths post-op	Cybex	PT @60°/s
<b>Anderson 2002</b>	Pre-op, 6 mths post-op, 12 mths post-op,	KinCom	PT @60°/s

PT=Peak Torque, PT/BW=Peak torque as a percentage of body weight, TPT=time to peak torque, pre-op=pre-operatively, post-op=post-operatively, °/s = degrees per second, mths=months, @=at

**Table 2.3: Reported absolute mean and relative deficits (in brackets) for PT at 60°/s**

Author	Pre-operative	6 months	12 months	1-2years	2-3 years	3-5 years	5-6 years	% change from pre-operative hamstring strength to post-operative
<b>Ko et al., 2012</b>	-	-	97.9Nm (12.6%)	100Nm (11.2%)	-	-	-	N/A
<b>Kim et al., 2011</b>	-	-	-	-	98.3Nm (13.5%)	-	-	N/A
<b>Ardern et al., 2010</b>	-	-	-	-	91.5Nm (5%)	-	-	N/A
<b>Lautamies et al., 2008</b>	-	-	-	-	-	-	96Nm (3.5%)	N/a
<b>Keays et al., 2007</b>	99Nm (1%)	-	-	-	-	-	103Nm (3%)	4%
<b>Elmlinger et al., 2006</b>	-	-	-	-	91Nm (4%)	-	-	N/A

<b>Keays et al., 2003</b>	105.5Nm (1.1%)	96.3Nm (10%)	-	-	-	-	-	-8.6%
<b>Segawa et al., 2002</b>	-	-	121.8Nm (6.4%)	-	-	-	-	-
<b>Anderson 2002</b>	84Nm (8.6%)	77Nm (19%)	91Nm (11.7%)	-	-	-	-	Pre-op to six months (-9.0%)  Pre-op to 12 months (8.3%)

Nm= Newton metres, pre-op=pre-operatively, (-) value indicates deterioration from previous score, (+) value indicates an improvement from previous score

**Table 2.4: Remaining isokinetic absolute and relative scores across remaining parameters and speeds**

Author	PT @120°/s	PT@ 180°/s	Total work @ 60°/s	Total work @180°/s	Total work @ 240°/s	PTBW @ 60°/s	TPT @60°/s	Peak force @ 60°/s	Peak force @ 180°/s
<b>Ko et al., 2012</b>	-	-	-	-	-	-	-	-	-
<b>Kim et al., 2011</b>	-	-	-	-	-	-	-	-	-
<b>Ardern et al., 2010</b>	-	67.4Nm (2.6%)	-	-	-	-	-	-	-
<b>Lautamies et al., 2008</b>	-	80Nm (5%)	-	-	-	-	-	-	-
<b>Vairo et al., 2008</b>	-	-	-	-	1030.6J (0%)	51.7% (no deficit)	460.7ms (97.2ms faster than uninjured side)	-	-
<b>Keays et al., 2007</b>	Pre-op 83Nm (0%) 6 years	-	-	-	-	-	-	-	-

	post-op 88Nm (3%)								
<b>Elmlinger et al., 2006</b>	-	76.2Nm (4%)	513.5J (13%)	777.3 (4%)	-	-	-	-	-
<b>Burks et al., 2005</b>	-	-	-	-	-	-	-	6mths post-op 191N (26%) 12 mths post-op 203N (21%)	6 mths post-op 197N (16%) 12 mths post-op 209N (13%)
<b>Keays et al., 2003</b>	Pre-op 86.3Nm (1%) 6 mths post-op 81.6Nm	-	-	-	-	-	-	-	-

	(9.9%)								
<b>Segawa et al., 2002</b>	-	-	-	-	-	-	-	-	-
<b>Anderson 2002</b>	-	-	-	-	-	-	-	-	-

Nm= Newton metres, post-op= post-operatively, mths=months, mths=months, PT= Peak Torque, PT/BW= Peak torque as a percentage of body weight, TPT= time to peak torque, °/s=degrees per second, ms=milliseconds, @=at, N= Newtons, J=joules, pre-op=pre-operatively, post-op=post-operatively

## **Chapter 2: Additional Information**

One of the objectives of this thesis was to examine the relationship between hamstring strength and function. In order to investigate this, the eleven studies that met the inclusion criteria for the published systematic review were further examined to establish those studies which reported objective and/or subjective functional measures, and to examine reported relationships between the hamstring strength and knee function.

### **2.7 Relationship between hamstring strength and function following ACLR**

The results of the functional tests reported in the 11 studies are shown in table 2.5. Five studies included in this review examined the relationship between isokinetic testing and functional performance as measured across a range of objective tests. One study (Keays et al., 2003) found no positive relationship between hamstring strength and function. Three authors (Ko et al., 2012, Kim et al., 2011, Lautamies et al., 2008) did find a positive relationship using the standard seated test position while one study (Elmlinger et al., 2006) found a positive relationship between functional performance and prone test results. Hop tests were used by all authors to examine function but one study (Keays et al 2003) did not find a positive relationship between hamstring strength tests and functional tests. This study (Keays et al 2003) examined their patients at the earliest stage of six months following surgery at which time functional performance may have been limited by other factors including fear (Ardern et al., 2013) which may possibly account for decreased functional performance. Overall these results would suggest some evidence that hamstring strength appears to correlate with objective functional performance at follow up longer than six months.

Studies included in this review measured patient's subjective ratings of their knee function in terms of global knee functioning using measures such as the Tegner, Lysholm, International Knee Documentation Committee (IKDC), and Noyes Questionnaire. None of the included studies reported the results of any correlations between isokinetic strength and subjective function. Included measures such as the IKDC have an inherent ceiling effect (Ko et al., 2012) and measure knee function using defined activities but do not allow for analysis of self-efficacy as outlined in

chapter one. Self-efficacy has been identified as a judgement of one's potential ability to perform a task (Thomee et al., 2006) and as such helps to identify how a patient feels about performing an activity rather than whether or not they can do it. Future studies should attempt to incorporate such factors using scales such as the Knee Self-Efficacy Scale (K-SES) designed specifically for ACLR (Thomee et al., 2006) to determine the influence that muscle strength has on self-efficacy and ultimately performance.

Together with examining global knee performance, it is necessary to attempt to isolate hamstring muscle function and hamstring self-efficacy to determine the full effect of hamstring strength or weakness. This author is currently unaware of any such measure that subjectively assesses hamstring muscle performance following ACLR which limits full examination of hamstring strength post-surgery. While PT deficits were detected in the first six to 12 months post-surgery in this review, at which time many patients return to sport, the impact of these deficits on hamstring muscle performance has not been identified. Future studies need to isolate hamstring muscle function during patient subjective assessment to discover both the incidence of injury and patient self-efficacy, and establish how it relates to hamstring muscle strength.

## **2.8 Additional information conclusions**

There appears to be limited evidence to support a relationship between hamstring muscle strength and global functional performance post ACLR at longer term follow up. No relationship has been identified between hamstring strength and subjective hamstring muscle performance. Isokinetic muscle strength testing allows for objective identification of muscle function across a range of parameters but studies have often focused on a narrow range such as PT and PT deficits limiting the understanding of the relationship between strength and function. Further research is needed which identifies absolute and relative values including PT, average PT (ave PT), PTBW, TPT and hamstring to quadriceps ratios for both males and females in larger sample sizes than commonly reported, to fully identify hamstring muscle deficits following ACLR.

Finally, more research is needed to identify the effect of hamstring strength on subjective levels of global performance and hamstring performance and establish if a link exists between pre-operative strength and post-operative function.

**Table 2.5: Relationship between hamstring strength and knee function**

Author	Objective Functional tests	Subjective assessment global knee function Test	Subjective assessment of hamstring function	Relationship between hamstring strength and function
<b>Ko et al., 2012</b>	Co-contraction, shuttle run, carioca- One leg hop, specific.	Tegner, Lysholm, IKDC,	None	Correlation identified between strength deficits and functional performance
<b>Kim et al., 2011</b>	One leg hop Co-contraction, carioca, shuttle Run	Lysholm Tegner IKDC	None	Deficits in standard test position correlated with functional performance more than hyperflexion scores
<b>Ardern et al., 2010</b>	None	IKDC	None	None reported
<b>Lautamies et al., 2008</b>	One leg hop	Tegner, Lysholm, IKDC,	None	Correlations between increased hamstring strength at 180°/s and single leg hop distance
<b>Vairo et al., 2008</b>	Biomechanical analysis of jump performance	None	None	None reported
<b>Keays et al., 2007</b>	Shuttle run, side step, carioca, single leg hop	Noyes Questionnaire	None	Not isolated for reporting
<b>Elmlinger et al., 2006</b>	Forward, medial, lateral hops	IKDC Short Form 36	None	Prone isokinetic scores correlated to functional performance
<b>Burks et al., 2005</b>	None	None	None	None reported

<b>Keays et al., 2003</b>	Shuttle run, side step, carioca, single leg hop	Noyes Questionnaire	None	No correlation identified between hamstring and hop or agility scores
<b>Segawa et al., 2002</b>	None	Lysholm	None	None reported
<b>Anderson 2002</b>	None	None	None	None reported

IKDC=International knee Documentation Committee score

## **Chapter 3: Methodology**

### **3.1 Introduction**

In order to further increase the current evidence and knowledge of the effect of hamstring grafting during ACLR as described in chapter two, and achieve the aims as set out in chapter one, a research study consisting of two parts was developed. This chapter details the study design, participant selection, testing methods and statistical analysis of the main part of this research study.

### **3.2 Study Design**

This study consisted of two parts:

- (1) A retrospective longitudinal study collecting and analysing isokinetic strength results over five years
- (2) A cross-sectional study examining the current knee and hamstring function using self-reported questionnaires

Ethical approval for the study was obtained through the Mid-Western Regional Hospital Research Ethics committee (see Appendix A), now known as University Hospital Limerick.

### **3.3 Part One: Retrospective study of objective isokinetic hamstring strength**

#### **3.3.1 Participant selection:**

A retrospective longitudinal study was conducted on all patients who underwent arthroscopic ACLR between January 2007 and December 2011, in the University Hospital Limerick, Ireland. A total of 344 patients were initially identified as having undergone an ACLR in the selected time period. This list was generated through the hospital inpatient enquiry system (HIPE) and was cross-referenced against physiotherapy department records.

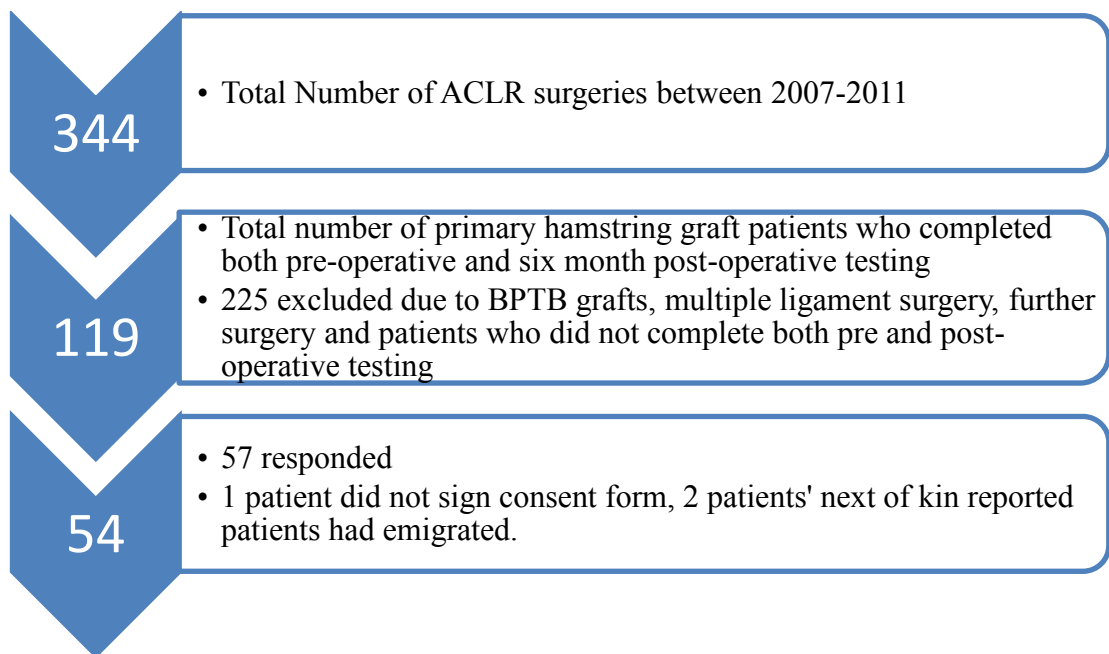
#### **3.3.2 Exclusion criteria**

Patients who underwent ACLR using BPTB grafts or who had multiple ligament surgery were excluded from the study. Isokinetic scores on patients who underwent repeat surgeries on the contralateral or ipsilateral side were excluded for clarity.

### 3.3.3 Inclusion criteria

Only patients who underwent ACLR with STG grafts who completed an objective isokinetic strength test pre-operatively and again six months post-operatively were included for final assessment. This resulted in a final eligible total of 119 eligible patients (Figure 3.1). All eligible participants were sent a stamped addressed envelope with an information leaflet on the study (Appendix B) and a consent form (Appendix C). Participants were given four weeks to respond to consent for inclusion, and the isokinetic results of those who consented for participation were then retrospectively obtained and analysed.

**Figure 3.1: Participant selection for study inclusion**



BPTB= bone patellar tendon bone grafts

### 3.3.4 Surgical Technique

All patients underwent the same surgery which was performed by one of the co-investigators, Mr. Dermot O’Farrell, using STG grafts. The surgery was performed arthroscopically with standard anterior-medial and lateral incisions ports. The hamstring tendons (semitendinosus and gracilis tendons) were harvested through an incision in the superior-medial tibia and subsequently prepared for insertion by

combined looping of both tendons. The hamstring grafts were finally passed through tibial and femoral tunnels and secured with intrafix screws.

### **3.3.5 Isokinetic strength data collection**

The results of isokinetic scores obtained between pre-operatively and post-operatively were retrieved by manual searching of participants test results. All tests were performed using the Biodex System 3 dynamometer (Biodex Medical Systems, Shirley, NY) between 2007 and 2011. The pre-operative scores were taken on initial assessment and the post-operative scores after patients had completed six months of rehabilitation as per the rehabilitation protocol (see Appendix G). Thus, all tests were performed and results collected prior to the start of the study, and thus data analysis involved retrospectively collecting and extracting the isokinetic data.

Once the list of consenting participants had been identified, the test results for each participant were obtained. This was done by manually examining the electronic test database on the Biodex System 3, identifying the relevant participant and cross checking for date of birth to ensure correct identity. By analysing the date of surgery for each patient, the relevant pre-operative test and six month post-operative test was identified and printed off in hard copies to allow input for data analysis. The results were then inputted manually into the statistical package for social sciences (SPSS) version 20 (SPSS Inc, Chicago, IL, USA).

### **3.3.6 Testing Procedure**

The testing procedure was the same for each patient and test. Each patient underwent a 10 minute warm up before each test using a cycle ergometer followed by bilateral hamstring and quadriceps stretching bilaterally for 30 seconds each stretch. Patients were tested in the standard upright sitting position with hips and knees flexed to 90 degrees (Figure 3.2). Patients were strapped in at the waist and the thigh of the evaluated leg to help isolate hamstring and quadriceps muscle function. The tibial pad was attached just proximal to the lateral malleolus so that the patient was actively able to freely move the ankle. The lateral femoral condyle of the evaluated knee was aligned with the rotational axis of the dynamometer. During the test, the patients were allowed to hold the handles at either side of the chair similar to the

procedure described by Lautamies et al. (2008) to ensure stability and consistency of effort.



**Figure 3.2: Standard isokinetic knee muscle strength testing position (Biodex Medical Systems, Shirley, NY)**

Each patient performed concentric knee extension and flexion over three sets of five repetitions for each limb, starting with the uninjured limb. The first set of five was performed at  $60^{\circ}/s$ , the second set at  $180^{\circ}/s$  and the final set at  $240^{\circ}/s$ , with a rest period of ten seconds between each set. These speeds were selected as they included the velocity spectrum of muscle performance with slower speeds of  $60^{\circ}/s$  most reflecting strength while faster speeds of  $240^{\circ}/s$  reflecting endurance (Brown, 2000).

Patients were instructed “*to kick as hard and as fast as you can for every kick*” to ensure standardisation. A range of values were recorded for each patient for analysis including PT, ave PT, PTBW, total work, TPT, PT deficits and hamstrings to quadriceps ratios across the three speeds to allow for a comprehensive analysis of isokinetic variables. This was performed for both the reconstructed (operated) and non-reconstructed (unoperated) limb. Testing was performed by three different people over the five years. The testing personnel were all chartered physiotherapists and received the same department training on isokinetic testing to ensure standardisation of testing.

### **3.4 Part Two: Assessment of current subjective function**

Part two of this research consisted of a cross sectional study of current function of consented participants. Participant selection was the same as described in part one of this study. The participants who gave consent for inclusion were requested to complete two self-reported functional assessment questionnaires. These questionnaires were sent in the post along with the consent form and participants were requested to complete and return within four weeks in the stamped addressed envelope provided.

Firstly, global knee function was assessed using the Tegner activity scale questionnaire (Appendix D) that classifies participant sporting and work function across 11 levels ranging from competitive sport (level 10) to disability (level 0). This has been proven to be a valid (correlating with the Short Form-12 with statistical significance,  $r=0.2$ ), reliable (intraclass correlation coefficient= $0.8$ ), and responsive scale (Briggs et al., 2009) and is frequently used as an assessment tool in this field (Ko et al., 2012, Kim et al., 2011, Lautamies et al., 2008).

In order to obtain information regarding how patients rated their own ability to perform tasks after the ACL surgery, the K-SES was used (Appendix E). The K-SES measures 22 items across four categories (A-D) including daily activities, sport and leisure activities, physical activities and future knee function with proven reliability (intraclass correlation coefficient= $0.75$ ), validity (correlating with the SF-36  $r=0.8$ ) for patients with ACL injury (Thomee et al., 2006). For scoring purposes, a mean score is obtained for each section and a total mean score obtained across the four sections together. This mean score for each of the four sections was defined as K-SES A, K-SES B, K-SES C, K-SES D. The combined total mean score of all four sections was defined as K-SES total for analysis purposes.

An additional section relating to hamstring muscle function in isolation was also added to this questionnaire specifically for this study to assess perceived hamstring ability with six items. This section was scored in exactly the same way with the answers for each question added and divided by the number of questions to obtain a mean score. This was defined as K-SES Ham (Appendix F). This was created by adapting existing questions in the standard K-SES to focus specifically on hamstring self-efficacy during common functional activities. The aim was to isolate hamstring

muscle performance from global knee function to identify the relationship between hamstring self-efficacy and hamstring muscle strength. Results in the K-SES ham were correlated against other K-SES scores to assess for validity (see results chapter four).

### **3.5 Data Analysis**

All analysis was performed using the SPSS statistical software package (version 20.0). All data was initially checked for normality of distribution using the Kolmogorov-Smirnov statistic and demographic data of mean age, height, gender and body weight were obtained. Isokinetic strength data was initially analysed to obtain descriptive statistics to establish means and standard deviations across a range of speeds and parameters as stated above, for both pre-operative and post-operative tests independently. The results of the post-operative and pre-operative tests were compared using paired sample T-tests to establish the statistical significance of changes that occurred between these two time lines. The relationship between pre-operative and post-operative strength was analysed using Pearson's product-moment coefficient ( $r$ ), while hierarchical multiple regression analysis was also performed to control for additional factors such as age, time from initial injury to surgery, time from pre-operative assessment to surgery and time from surgery to follow-up.

Participant responses to the questionnaires were again analysed for mean and standard deviations using the SPSS package. The relationship between responses and isokinetic strength both pre and post-operatively was analysed using Spearman's rank order coefficient.

## **Chapter 4: Results Part One**

### **Results of Objective Isokinetic Testing**

#### **4.1 Introduction:**

Chapter four presents the results of the statistical analysis performed on all objective isokinetic scores. Firstly, the demographic characteristics of the patient population will be presented followed by analysis of isokinetic scores obtained pre and post-operatively. Comparisons between pre and post-operative tests will be presented followed by a sub-analysis of the results by gender. Finally, the results of correlation tests between pre and post-operative testing will be reported.

#### **4.2 Population**

A total study sample of 54 patients, were included in the final analysis. Table 4.1 outlines the population demographics of the patients who met the inclusion criteria.

**Table 4.1: Population demographics**

	Total Group N=54	Males N=38	Females N=16
Age at time of surgery (Mean $\pm$ SD in yrs)	26.90 $\pm$ 10.42	26.33 $\pm$ 8.8	28.25 $\pm$ 13.67
Body Weight (Mean $\pm$ SD in kg)	78.11 $\pm$ 14.79	82.45 $\pm$ 14.01	67.81 $\pm$ 11.33
Height (Mean $\pm$ SD in M)	1.75 $\pm$ 0.09	1.78m $\pm$ 0.08	1.67m $\pm$ 0.05

N=number, yrs=years, kg=kilograms, m= metres, SD= standard deviation

### **4.3 Timeline:**

The median length of time between the ACL injury and surgery date was 9.06 months (range 1.35 to 211.35 weeks). Pre-operative testing was performed at a median of 10.14 weeks (range 0.57-57.00 weeks) prior to surgery. Patients were subsequently tested at six months (24 weeks) post-operatively (median 26.71, range 21.43-37.57 weeks).

### **4.4 Isokinetic scores**

For purposes of clarity, the analysis of the isokinetic scores is separated into four parts. All scores presented are for concentric strength testing. Firstly, the isokinetic data obtained for both the operated and unoperated limbs was compared for the three isokinetic speeds of 60/180/240°/s for the 54 people irrespective of gender pre-operatively and six months post-operatively. The results of each limb at each speed are presented individually in tables 4.2-4.7. Secondly, as the data was normally distributed, paired sample T-tests were performed on the data to compare the strength values obtained pre-operatively with those obtained post-operatively with results shown in tables 4.8-4.12. Thirdly, the data is analysed based on gender shown in tables 4.13-4.17 and finally, the correlations between pre-operative and post-operative isokinetic scores are reported.

### **4.5 Part A: Isokinetic scores pre-operatively and post-operatively**

#### **4.5.1 Isokinetic scores pre-operatively**

This section identifies the mean scores achieved on both the operated and unoperated limb pre-operatively across the three speeds of 60/180/240°/s. Tables 4.2-4.4 show that for all speeds, the operated limb had decreased PT, PTBW, average PT and total work values compared to the unoperated limb but not TPT. These differences were statistically significant at 60°/s ( $p < .05$ ) but not 180°/s. At 240°/s, only PT and PTBW showed statistical significance.

**Table 4.2: Isokinetic scores pre-operatively for operated and unoperated limb at 60°/s**

Isokinetic Parameters	Unoperated limb Mean ±SD	Operated limb Mean ±SD	Sig (2 tailed) P value
<b>PT (Nm)</b>	<b>93.44 ±28.75</b>	<b>87.49 ±29.37</b>	<b>.00</b>
<b>PT/BW (%)</b>	<b>119.93 ±29.71</b>	<b>112.15 ±31.07</b>	<b>.00</b>
TPT (ms)	673.20 ±252.98	619.81 ±264.82	.13
Total work (J)	509.76 ±165.86	464.83 ±151.55	.00
Average PT (Nm)	85.95 ±27.48	80.10 ±27.52	.00

SD=standard deviation, PT=peak torque, PTBW=peak torque as a percentage of body weight, TPT=time to peak torque, Nm=newton metres, %=percentage, J=joules, ms=millisecond, °/s=degrees per second,

**Table 4.3: Isokinetic scores pre-operatively for operated and unoperated limbs at 180°/s**

Isokinetic Parameter	Unoperated limb Mean ±SD	Operated limb Mean ±SD	Sig (2 tailed) P value
PT (Nm)	63.40 ± 23.36	61.05 ± 22.39	.16
PT/BW (%)	81.29 ± 22.69	78.15 ±24.05	.13
TPT (ms)	320.18 ± 150.5	294.07 ± 134.29	.27
Total work (J)	347.43 ± 126.96	332.22 ± 137.83	.12
Average PT (Nm)	58.27 ±20.33	55.55 ± 20.76	.04

SD=standard deviation, PT=peak torque, PTBW=peak torque as a percentage of body weight, TPT=time to peak torque, Nm=newton metres, %=percentage, J=joules, ms=millisecond, °/s=degrees per second

**Table 4.4: Isokinetic scores pre-operatively for operated and unoperated limb at 240°/s**

Isokinetic Parameter	Unoperated limb Mean ±SD	Operated limb Mean ±SD	Sig (2 tailed) P value
PT (Nm)	61.65 ±20.37	57.39 ±19.16	.01
PT/BW (%)	78.63 ±19.25	73.42 ±19.94	.01
TPT (ms)	296.41 ±155.53	289.44 ±144.73	.73
Total work (J)	298.25 ±105.41	285.74 ±106.33	.20
Average PT (Nm)	54.53 ±17.64	52.09 ±13.44	.06

SD=standard deviation, PT=peak torque, PTBW=peak torque as a percentage of body weight, TPT=time to peak torque, Nm=newton metres, %=percentage, J=joules, ms=millisecond, °/s=degrees per second,

#### 4.5.2 Isokinetic scores post-operatively

Tables 4.5-4.7 show the mean (with standard deviation) isokinetic scores obtained post-operatively for both limbs across the three speeds. Similar to pre-operative results, the operated limb had decreased scores compared to the unoperated limb across all three speeds for PT, PTBW, average PT and total work with the differences statistically significant at 60°/s and 180°/s ( $p < .05$ ). For the faster speed of 240°/s, only PT and PTBW showed statistical significance differences ( $p < .05$ ).

**Table 4.5: Isokinetic scores post-operatively for operated and unoperated limb at 60°/s**

Isokinetic Parameter	Unoperated limb Mean ±SD	Operated limb Mean ±SD	Sig (2 tailed) P value
<b>PT (Nm)</b>	<b>112.98 ± 35.58</b>	<b>103.02 ±32.72</b>	<b>.00</b>
<b>PT/BW (%)</b>	<b>144.00 ±32.20</b>	<b>131.99 ±32.09</b>	<b>.00</b>
TPT (ms)	469.25 ±156.81	414.07 ±148.03	.01
Total work (J)	619.28 ±215.02	540.70 ±196.97	.00
Average PT (Nm)	105.53 ±34.44	95.02 ±33.35	.00

SD=standard deviation, PT=peak torque, PTBW=peak torque as a percentage of body weight, TPT=time to peak torque, Nm=newton metres, %=percentage, J=joules, ms=millisecond, °/s=degrees per second,

**Table 4.6: Isokinetic scores post-operatively for operated and unoperated limb at 180°/s**

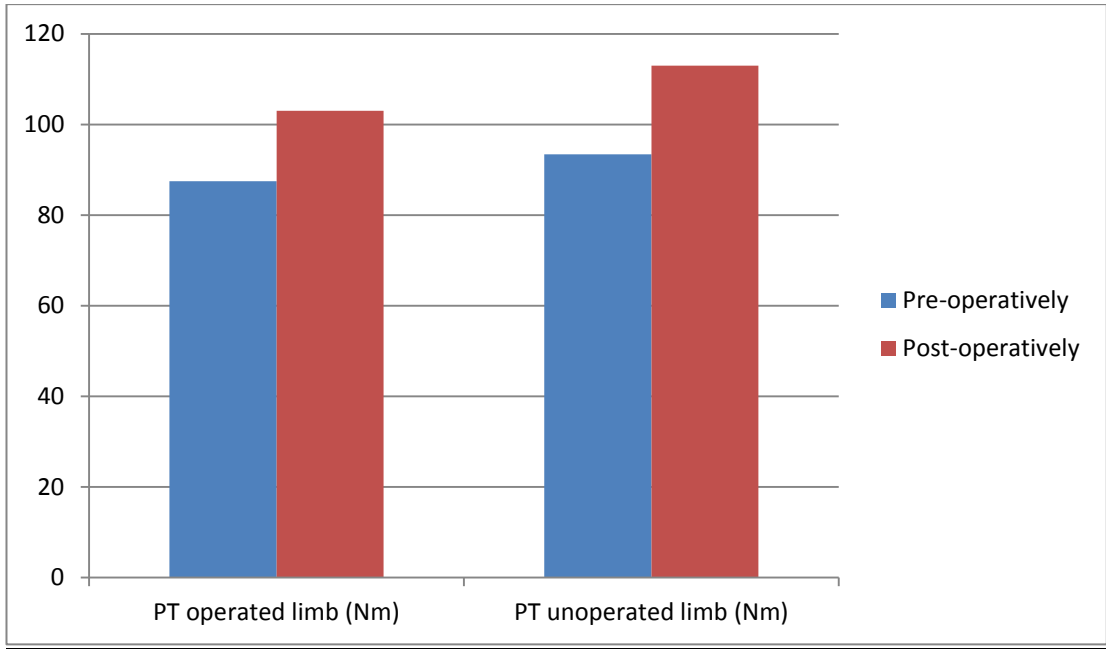
Isokinetic Parameter	Unoperated limb Mean ±SD	Operated limb Mean ±SD	Sig (2 tailed) P value
PT (Nm)	80.83 ± 25.31	76.94 ± 23.81	.02
PT/BW (%)	103.54 ± 24.12	98.79 ± 24.21	.02
TPT (ms)	245.74 ± 101.32	230.55 ± 113.77	.37
Total work (J)	457.02 ± 153.22	409.74 ± 141.04	.00
Average PT (Nm)	74.47 ± 23.82	71.04 ± 22.42	.02

SD=standard deviation, PT=peak torque, PTBW=peak torque as a percentage of body weight, TPT=time to peak torque, Nm=newton metres, %=percentage, J=joules, ms=millisecond, °/s=degrees per second,

**Table 4.7: Isokinetic scores post-operatively for operated and unoperated limb at 240°/s**

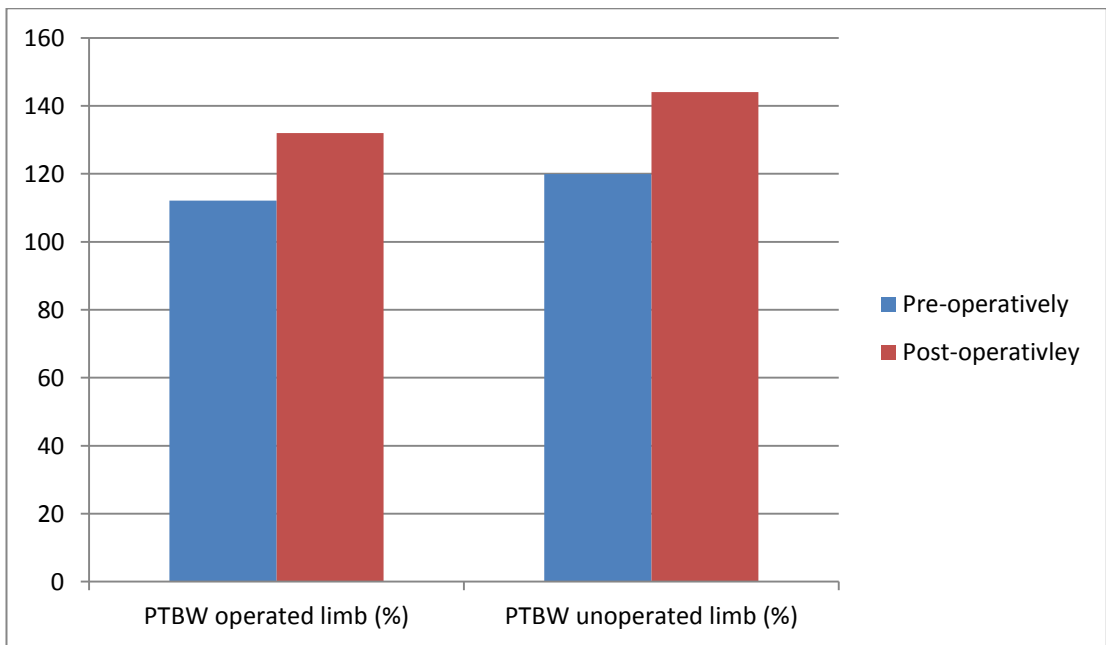
Isokinetic Parameter	Unoperated limb Mean ±SD	Operated limb Mean ±SD	Sig (2 tailed) P value
PT (Nm)	71.48 ± 20.69	68.24 ± 20.31	.03
PT/BW (%)	92.03 ± 21.37	87.58 ± 19.86	.01
TPT (ms)	253.70 ± 141.15	240.18 ± 133.2	.47
Total work (J)	361.05 ± 123.57	340.19 ± 127.58	.05
Average PT (Nm)	65.11 ± 19.51	62.62 ± 19.04	.07

SD=standard deviation, PT=peak torque, PTBW=peak torque as a percentage of body weight, TPT=time to peak torque, Nm=newton metres, %=percentage, J=joules, ms=millisecond, °/s=degrees per second



**Figure 4.1: Pre and post-operative PT for operated and unoperated limbs at 60°/s**

(statistical significant differences between pre and post-operative scores for both limbs  $p < .01$ , statistical significant difference between unoperated limb and operated limb  $p < .01$ )



**Figure 4.2: Pre and post-operative PTBW for operated and unoperated limbs at 60°/s**

(statistical significant differences between pre and post-operative scores for both limbs  $p < .01$ , statistical significant difference between unoperated limb and operated limb  $p < .01$ )

#### **4.6 Part B: Pre-operative versus post-operative isokinetic scores**

Tables 4.8 and 4.9 demonstrates the mean ( $\pm$ SD) pre-operative and post-operative hamstring strength data at 60°/s for the entire group (n=54 for operated limb and n=53 for unoperated limb\*\*\*). The data was compared using the paired sample T tests.

There was a statistically significant increase in PT scores at the six month post-operative assessment (103.02Nm $\pm$ 32.72) compared to the pre-operative data, with a mean increase of 15.52Nm (95% confidence interval 9.77-21.28Nm). Absolute scores including PT, PTBW, total work and average PT demonstrated a significant increase in the post-operative scores compared to the pre-operative data in both the operated and unoperated limbs. TPT also had statistically significant improvements with the time taken to reach PT decreasing following six months rehabilitation.

Relative deficits between limbs are expressed as the percentage difference in PT between the unoperated and operated limbs. The percentage deficits between the two limbs increased post-operatively but this was not found to be statistically significant.

**Table 4.8: Isokinetic scores pre-operatively versus post-operatively at 60°/s for the operated limb**

Isokinetic Parameter	Pre-op Mean $\pm$ SD	Six months post-op Mean $\pm$ SD	Sig (2 tailed) P Value
PT (Nm)	87.49 $\pm$ 29.37	103.02 $\pm$ 32.72	.00
PT deficits (%)	5.87 $\pm$ 15.56	7.52 $\pm$ 16.50	.57
PT/BW (%)	112.15 $\pm$ 31.07	131.99 $\pm$ 32.09	.00
TPT (ms)	619.81 $\pm$ 264.82	414.07 $\pm$ 148.03	.00
Total work (J)	464.83 $\pm$ 151.55	540.70 $\pm$ 196.97	.00
Average PT (Nm)	80.10 $\pm$ 27.52	95.02 $\pm$ 33.35	.00
Ham:Quad Ratios	55.00 $\pm$ 11.90	57.47 $\pm$ 14.34	.20

Pre-op=pre-operative, Post-op=post-operative, SD=standard deviation, PT=peak torque, PT deficit=relative deficit between the operated limb and unoperated limb, PTBW=peak torque as a percentage of body weight, TPT=time to peak torque, Nm=newton metres, %=percentage, J=joules, °/s=degrees per second, Ham:Quad ratios= Hamstring:Quadriceps ratios, ms=millisecond,

**Table 4.9: Isokinetic scores pre-operatively versus post-operatively at 60°/s for unoperated limb**

Isokinetic Parameter	Pre-op Mean ±SD	Six months post-op Mean ±SD	Sig (2 tailed) P Value
<b>PT (Nm)</b>	<b>93.44 ±28.75</b>	<b>112.98 ±35.58</b>	<b>.00</b>
<b>PT/BW (%)</b>	<b>119.93 ±29.71</b>	<b>144.00 ±32.20</b>	<b>.00</b>
TPT (ms)	673.20 ±252.98	469.25 ±156.81	.00
Total Work (J)	509.76 ±165.86	619.28 ±215.02	.00
Average PT (Nm)	85.95 ±27.48	105.53 ±34.44	.00
Ham:Quad Ratios	49.26 ±7.86	55.56 ±9.26	.00

Pre-op=pre-operative, Post-op=post-operative, SD=standard deviation, PT=peak torque, PTBW=peak torque as a percentage of body weight, TPT=time to peak torque, Nm=newton metres, %=percentage, J=joules, °/s=degrees per second, Ham:Quad ratios= Hamstring:Quadriceps ratios, ms=millisecond,

Tables 4.10 and 4.11 demonstrate the isokinetic scores recorded pre-operatively and six month post-operatively at 180°/s for both limbs. In both limbs, there was statistically significant increases ( $p < 0.001$ ) in absolute PT values, PTBW and total work values and average PT from pre-operatively to post-operatively for both limbs. Relative measures such as between limb PT deficits did not show a statistically significant improvement due to bilateral increase in absolute PT.

**Table 4.10: Isokinetic scores pre-operatively versus post-operatively at 180°/s for the operated limb**

Isokinetic Parameter	Pre-op Mean ±SD	Six months post-op Mean ±SD	Sig (2 tailed) P value
PT (Nm)	61.05 ±22.39	76.94 ±23.81	.00
PT deficits (%)	1.77 ±23.40	3.78 ±15.15	.52
PT/BW (%)	78.15 ±24.05	98.79 ±24.21	.00
TPT (ms)	294.07 ±134.29	230.55 ±113.77	.00
Total work (J)	332.22 ±137.83	409.74 ±141.04	.00
Average PT (Nm)	55.55 ±20.76	71.04 ±22.42	.00
Ham:Quad Ratios	56.56 ±12.63	62.85 ±15.04	.01

Pre-op=pre-operative, Post-op=post-operative, SD=standard deviation, PT=peak torque, PT deficit=relative deficit between the operated limb and unoperated limb, PTBW=peak torque as a percentage of body weight, TPT=time to peak torque, Nm=newton metres, %=percentage, J=joules, °/s=degrees per second, Ham:Quad ratios= Hamstring:Quadriceps ratios, ms=millisecond,

**Table 4.11: Isokinetic scores pre-operatively versus post-operatively at 180°/s for unoperated limb**

Isokinetic Parameter	Pre-op Mean ±SD	Six months post-op Mean ±SD	Sig (2 tailed) P Value
PT (Nm)	63.40 ±23.36	80.83 ±25.31	.00
PT/BW (%)	81.29 ±22.69	103.54 ±24.12	.00
TPT (ms)	320.18 ±150.5	245.74 ±101.32	.00
Total work (J)	347.43 ±126.96	457.02 ±153.22	.00
Average PT (Nm)	58.27 ±20.33	74.47 ±23.82	.00
Ham:Quad Ratios	56.56 ±12.63	62.85 ±15.04	.01

Pre-op=pre-operative, Post-op=post-operative, SD=standard deviation, PT=peak torque, PTBW=peak torque as a percentage of body weight, TPT=time to peak torque, Nm=newton metres, %=percentage, J=joules, °/s=degrees per second, Ham:Quad ratios= Hamstring:Quadriceps ratios, ms=millisecond,

Tables 4.12 and 4.13 demonstrate the results of isokinetic scores recorded pre-operatively and post-operatively for both limbs at 240°/s. Similar to 180°/s, both limbs respectively has statistically significant increases in PT values, PTBW and

total work values and average PT ( $p < 0.001$ ) post-operatively compared to pre-operatively. Relative measures such as between limb deficits and hamstring:quadriceps ratios did not show a statistically significant improvement.

**Table 4.12: Isokinetic scores pre-operatively versus post-operatively at 240°/s for the operated limb**

Isokinetic Parameter	Pre-op Mean $\pm$ SD	Six months post-op Mean $\pm$ SD	Sig (2 tailed) P Value
PT (Nm)	57.39 $\pm$ 19.16	68.24 $\pm$ 20.31	.00
PT deficits (%)	5.34 $\pm$ 16.43	3.5 $\pm$ 15.81	.55
PT/BW (%)	73.42 $\pm$ 19.94	87.58 $\pm$ 19.86	.00
TPT (ms)	289.44 $\pm$ 144.73	240.18 $\pm$ 133.2	.03
Total work (J)	285.74 $\pm$ 106.33	340.19 $\pm$ 127.58	.00
Average PT (Nm)	52.09 $\pm$ 13.44	62.62 $\pm$ 19.04	.00
Ham:Quad Ratios	62.60 $\pm$ 13.44	67.59 $\pm$ 16.81	.06

Pre-op=pre-operative, Post-op=post-operative, SD=standard deviation, PT=peak torque, PT deficit=relative deficit between the operated limb and unoperated limb, PTBW= peak torque as a percentage of body weight, TPT=time to peak torque, Nm=newton metres, %=percentage, J=joules, °/s=degrees per second, Ham:Quad ratios= Hamstring:Quadriceps ratios, ms=millisecond,

**Table 4.13: Isokinetic scores pre-operatively versus post-operatively at 240°/s for the unoperated limb**

Isokinetic parameter	Pre-op Mean $\pm$ SD	Six months post-op Mean $\pm$ SD	Sig (2 tailed) P Value
PT (Nm)	61.65 $\pm$ 20.37	71.48 $\pm$ 20.69	.00*
PT/BW (%)	78.63 $\pm$ 19.25	92.03 $\pm$ 21.37	.00*
TPT (ms)	296.41 $\pm$ 155.53	253.70 $\pm$ 141.15	.08
Total work (J)	298.25 $\pm$ 105.41	361.05 $\pm$ 123.57	.00*
Average PT (Nm)	54.53 $\pm$ 17.64	65.11 $\pm$ 19.51	.00*
Ham:Quad Ratios	62.60 $\pm$ 13.44	67.59 $\pm$ 16.81	.06

Pre-op=pre-operative, Post-op=post-operative, SD=standard deviation, PT=peak torque, PTBW=peak torque as a percentage of body weight, TPT=time to peak

torque, Nm=newton metres, %=percentage, J=joules, °/s=degrees per second, Ham:Quad ratios= Hamstring:Quadriceps ratios

\*\*\* one patient had only their operated limb tested on return at six months

#### **4.7 Part C: Isokinetic scores by gender**

To allow for more accurate assessment of isokinetic scores and to account for physiological differences between males and females, the group scores were separated for gender. For clarity two parameters were used in this sub-analysis (PT and PTBW). These variables were selected as PTBW accounts for differences in body weight between genders while PT is the most commonly reported parameter (chapter two). These scores were analysed for the two most commonly reported speeds (chapter two) 60°/s and 180°/s.

Table 4.14 shows the results for females at 60°/s and 180°/s for PT and PTBW for both pre-operative and post-operative tests, while table 4.15 shows the results for males. For males and females, PT and PTBW values were lower in the operated leg than the unoperated both pre and post-operatively and at both 60 and 180°/s. For males, these differences were statistically significant at 60°/s pre and post-operatively, while for females statistical significant differences existed only at 180°/s pre-operatively.

**Table 4.14: Female isokinetic scores at 60 and 180°/s for operated and unoperated limb**

Isokinetic Score	Unoperated limb	Operated limb	Sig (2 tailed)
	Mean ±SD	Mean ±SD	P Value
Pre-op PT @60 (Nm)	69.82 ±14.53	64.41 ±12.77	.07
Pre-op PTBW @60 (%)	105.38 ±27.58	97.28 ±5.85	.08
Pre-op PT @180 (Nm)	48.70 ±8.98	42.96 ±8.95	.00
Pre-op PTBW @180 (%)	73.30 ±16.41	64.98 ±17.33	.00
Post-op PT @60 (Nm)	78.50 ±14.22	72.39 ±15.23	.06

Post-op PTBW @60 (%)	118.36 ±27.12	110.04 ±31.19	.11
Post-op PT @180 (Nm)	58.14 ±10.27	54.90 ±11.44	.11
Post-op PTBW @180 (%)	88.56 ±23.49	83.57 ±23.90	.13

Pre-op=pre-operative, Post-op=post-operative, SD=standard deviation, PT=peak torque, PTBW=peak torque as a percentage of body weight, Nm=newton metres, %=percentage, °/s=degrees per second, @60=testing at 60 degrees per second, @180= testing at 180 degrees per second.

**Table 4.15: Male isokinetic scores at 60 and 180°/s for operated and unoperated limbs**

Isokinetic Score	Unoperated limb	Operated limb	Sig (2 tailed)
	Mean ±SD	Mean ±SD	P Value
Pre-op PT @60 (Nm)	103.66 ±27.40	97.58 ±29.46	.02
Pre-op PTBW @60 (%)	126.21 ±28.69	118.78 ±32.37	.02
Pre-op PT @180 (Nm)	69.76 ±22.08	69.25 ±22.02	.79
Pre-op PTBW @180 (%)	84.74 ±24.30	84.36 ±24.48	.87
Post-op PT @60 (Nm)	127.50 ±31.64	115.91 ±29.38	.00
Post-op PTBW @60 (%)	154.79 ±27.99	141.23 ±28.02	.00
Post-op PT @180 (Nm)	90.38 ±23.63	86.23 ±21.46	.06
Post-op PTBW @180 (%)	109.85 ±21.87	105.20 ±21.57	.08

Pre-op=pre-operative, Post-op=post-operative, SD=standard deviation, PT=peak torque, PTBW=peak torque as a percentage of body weight, Nm=newton metres, %=percentage, °/s=degrees per second, @60= testing at 60 degrees per second, @180= testing at 180 degrees per second.

To establish the changes that occurred between pre-operative and post-operative testing for males and females separately, paired sample T-tests were performed. Tables 4.16 and 4.17 demonstrate the scores obtained on just the operated limb for

each gender at pre and post-operative testing. The results for the unoperated limb are contained in appendix H (Additional results). For the operated limb, there was statistically significant increases ( $p<.05$ ) for both PT and PTBW at both speeds.

**Table 4.16: Female pre-operative versus post-operative scores at 60 and 180°/s for operated limb**

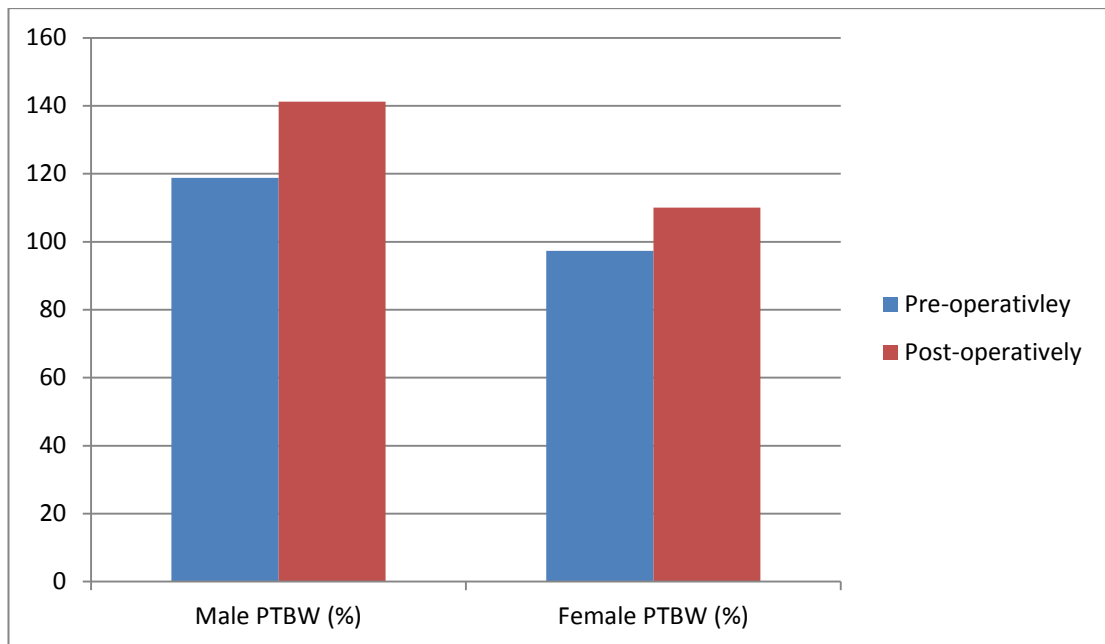
Isokinetic Score	Pre-op	Six months post-op	Sig (2 tailed)
	Mean $\pm$ SD	Mean $\pm$ SD	P Value
PT @60 (Nm)	64.41 $\pm$ 12.77	72.39 $\pm$ 15.23	.04
PTBW @60 (%)	97.28 $\pm$ 5.85	110.04 $\pm$ 31.19	.04
PT @180 (Nm)	42.96 $\pm$ 8.95	54.90 $\pm$ 11.44	.00
PTBW @180 (%)	64.98 $\pm$ 17.33	83.57 $\pm$ 23.90	.00

Pre-op=pre-operative, Post-op=post-operative, SD=standard deviation, PT=peak torque, PTBW=peak torque as a percentage of body weight, Nm=newton metres, %=percentage, °/s=degrees per second, @60=testing at 60 degrees per second, @180= testing at 180degrees per second.

**Table 4.17: Male pre-operative versus post-operative scores at 60 and 180°/s for operated limb**

Isokinetic Score	Pre-op	Six months post-op	Sig (2 tailed)
	Mean $\pm$ SD	Mean $\pm$ SD	P Value
PT @60 (Nm)	97.58 $\pm$ 29.46	115.91 $\pm$ 29.38	.00
PTBW @60 (%)	118.78 $\pm$ 32.37	141.23 $\pm$ 28.02	.00
PT @180 (Nm)	69.25 $\pm$ 22.02	86.23 $\pm$ 21.46	.00
PTBW @180 (%)	84.36 $\pm$ 24.48	105.20 $\pm$ 21.57	.00

Pre-op= pre-operative, Post-op= post-operative, SD= standard deviation, PT=peak torque, PTBW= peak torque as a percentage of body weight, Nm= newton metres, %=percentage, °/s=degrees per second, @60=testing at 60 degrees per second, @180= testing at 180 degrees per second



**Figure 4.3: Male and Female PTBW for the operated limb pre and post-operatively at 60°/s**

#### **4.8 Part D: Relationship between pre-operative scores and post-operative scores**

Pearson’s product moment of coefficient were assessed to determine the relationship between isokinetic scores obtained pre-operatively with those obtained six months post-operatively for the operated limb. The tables with these results are presented in Appendix H (Additional results). At 60°/s strong correlations ( $r > .5$ ) (Pallant, 2007) were identified between pre and post-operative PT at 60°/s ( $r=0.77$ ), PTBW ( $r=0.64$ ), Total work ( $r=0.68$ ) and ave PT ( $r=0.70$ ), while weak ( $r=0.1-0.29$ ) to moderate ( $0.3-0.49$ ) correlations were identified for PT deficits ( $r=0.28$ ), TPT ( $r=0.27$ ) and hamstring to quadriceps ratios respectively ( $r=0.31$ ). All correlations were found to be statistically significant of  $p < .05$ .

At 180°/s, strong correlations existed for PT ( $r=0.77$ ), PTBW ( $r=0.60$ ), total work ( $r=0.58$ ) and average PT ( $r=0.63$ ) with statistical significance ( $p < .05$ ). Moderate correlations existed for PT deficits ( $r=0.42$ ) ( $p < .01$ ). At 240°/s, strong correlations existed for PT ( $r=0.78$ ), PTBW ( $r=0.63$ ), total work ( $r=0.59$ ) and average PT ( $r=0.76$ ) with statistical significance ( $p < .05$ ). Negligible correlations existed for PT deficits ( $r=0.07$ ).

In order to control for the effects of other factors that may have influenced the results, hierarchical multiple regression analysis (MRA) was performed on the data to establish the true effect of pre-operative strength on post-operative strength. This analysis technique was selected after consulting with the statistical consulting unit in the University of Limerick. MRA was used to assess the effect of pre-operative strength on post-operative strength controlling for 1) age at time of surgery, 2) length of time from initial injury to surgery and 3) the length of time from pre-operative isokinetic assessment.

Preliminary analysis was conducted to avoid violations of the assumptions of normality, linearity and multi-collinearity (Pallant, 2007). PT at 60°/s was the parameter identified as having the greatest correlations between pre and post-operative testing ( $r=0.77$ ) and preliminary analysis identified that PT correlated strongly with other testing variables such as PTBW, total work and average PT. Thus, MRA was performed on post-operative PT at 60°/s to establish the effect of pre-operative strength controlling for the above factors.

For post-operative hamstring PT, the results of MRA are shown in table 4.18. Results show that pre-operative strength together with the 1) age at time of surgery, 2) length of time from initial injury to surgery and 3) the length of time from pre-operative isokinetic assessment had a statistically significant effect on post-operative strength accounting for 63% of the variance with pre-operative strength alone accounting for 57%. In the model as a whole, pre-operative strength was the only factor which had a statistically significant beta value of 0.76,  $p<.001$ . Thus, pre-operative PT had the most significant influence on post-operative strength, more than age or time to surgery and was the only factor with a statistically significant influence.

Table 4.18: Results of hierarchical multiple regression of the effect of pre-operative PT on post-operative PT at 60°/s

Total Model variance (R square)	R square change	Beta value	Sig. (for all results)
0.64	0.58	0.76	0.000

## **4.9 Summary**

Statistically significant differences were present in the pre-operative scores between limbs for PT, PTBW, average PT and total work at 60°/s but not 180°/s. PT deficits of 5.87% existed pre-operatively. The mean reported PT and mean PTBW at 60°/s for the operated limb was 87.49Nm and 112.15% respectively.

Post-operatively, the operated limb had decreased scores compared to the unoperated limb across all three speeds for PT, PTBW, average PT and total work with the differences statistically significant at 60/s and 180°/s. PT deficits of 7.52% existed post-operatively. The mean reported PT and mean PTBW at 60°/s post-operatively for the operated limb was 103.02Nm and 131.99% respectively.

Statistically significant improvements in absolute scores including PT, PTBW and total work, were recorded on both limbs six months post-operatively compared to pre-operatively across all three speeds. No statistically significant changes were noted in PT deficits due to a bilateral increase in absolute scores.

When separating for gender, both males and females PT and PTBW values were lower in the operated leg than the unoperated leg both pre and post-operatively at both 60°/s and 180°/s. These differences were statistically significant for females pre-operatively at 180°/s and for males at pre and post-operative testing at 60°/s.

For males and females, statistically significant improvements were detected between six month post-operative and pre-operative testing for both limbs for PT and PTBW at 60 and 180°/s.

Strong correlations were identified for pre and six month post-operative PT, PTBW, Total work and ave PT across all three speeds.

## **Chapter 5: Results Part Two**

### **Results of Subjective Function**

#### **5.1 Introduction**

This chapter presents the results of participant self-reported questionnaires. It outlines the results of global knee function through the Tegner scale, isolated knee function as measured by the K-SES, and isolated hamstring function determined by the K-SES Ham. These results are subsequently correlated against the objective isokinetic scores to assess for relationships using Spearman's rank order coefficient.

The primary aim of this part of the study was to assess subjective knee function in the long term following ACLR using STG grafts recorded using the Tegner and K-SES scales. A secondary aim was to determine if a link existed between strength outcomes six months following surgery and current knee function to help establish the long term predictive effects of post-operative strengthening. The results of the subjective measures are first presented and these results are subsequently correlated against the objective isokinetic scores to assess for relationships using Spearman's rank order coefficient with hierarchical multiple regression performed to control for additional factors.

#### **5.2 Self-reported function questionnaires**

All participants (n=54), who agreed to participate in this study in March 2013 responded to the subjective questionnaires as described in Chapter three- the Tegner, K-SES and K-SES Ham. This was to obtain data on current subjective function at a median follow up time post ACLR of 3.66 years (range 1.47-6.24 years). This was performed to establish the long-term functional level, and the relationship between long-term subjective function and objective isokinetic scores obtained pre and post-operatively. As outlined in Chapter three, the K-SES is composed of four sections, A to D which are individually scored and grouped together to form K-SES total.

Table 5.1 shows the median results and ranges for the scores of the Tegner, K-SES sections A-D, and K-SES total.

**Table 5.1: Results for Tegner and K-SES**

<b>Outcome measure</b>	<b>Median (Range)</b>
Tegner	7.00 (3-10)
K-SES A	9.85 (3.43-10)
K-SES B	8.00 (1.8-10)
K-SES C	8.00 (1.17-10)
K-SES D	7.25 (0-10)
K-SES total	8.27 (2.41-10)

The median Tegner score of 7.0 reflects a range between recreational football, athletics, tennis, badminton, basketball, jogging to competitive tennis and basketball. A score of 9 indicates competitive football in lower divisions while a score of 10 indicates competitive football at national and international level.

For the K-SES, the higher the score, the higher the level of patient self-efficacy in performing the task described with scores out of a maximum of 10 points. The highest scores were consistently related to section A, which examined daily activities including going up stairs and gardening. The lowest scores were for section D which questioned future function and asked questions like “how sure are you that your knee will not give way again?”

### **5.3 K-SES Ham**

For the purposes of this study, a new addition to measure subjective hamstring function was made to the K-SES called the K-SES ham as described in chapter three. The median score for the K-SES Ham was 8.66 (range 0.5-10). Correlations between the three different outcome measures are shown in Appendix H (Additional results). K-SES Ham correlated moderately with all aspects of the original K-SES and strongly ( $r=0.57$ ) with K-SES total which was statistically significant ( $p<.001$ ). K-SES Ham correlated weakly with the Tegner scale ( $r=0.01$ ). Cronbach’s alpha coefficient of the K-SES total and K-SES ham was calculated to determine the internal consistency of the K-SES. Cronbach’s alpha coefficient for the K-SES total was identified as 0.92. Similar calculations of the K-SES ham alone identified a coefficient of 0.94. When the K-SES total and K-SES ham were combined,

Cronbach's alpha coefficient was 0.91 representing good internal consistency for the new combined scale.

#### **5.4 Relationship between functional measures and objective isokinetic testing**

Self-reported rating of performance using the Tegner scale, K-SES total and K-SES Ham were correlated against pre-operative and post-operative isokinetic scores to assess if a relationship existed between hamstring strength and global performance (Tegner), hamstring strength and knee performance (K-SES total), and hamstring strength and hamstring muscle function in isolation (K-SES Ham).

Questionnaire results were correlated against the two most commonly reported isokinetic parameters namely PT and PT deficits, across the two most commonly reported speeds of 60°/s and 180°/s (see chapter 2), plus PTBW due to the effect of weight and gender. The results for pre-operative testing are shown in table 5.2, while table 5.3 demonstrates the results for relationships for post-operative testing. Results by gender are shown in Appendix H (Additional results). Pre-operative PTBW correlated moderately ( $r=.299-.446$ ) with all functional measures at both 60°/s and 180°/s while weak ( $r<.3$ ) correlations existed between the PT/PT deficits scores and functional measures. Correlations between functional measures and other parameters including TPT and hamstring:quadriceps showed no consistent positive correlations Appendix H (Additional results).

**Table 5.2: Correlations between pre-operative isokinetic scores and functional measures at 60 and 180°/s**

<b>Outcome measure</b>	Pre-op PT @ 60°/s	Pre-op PTBW @60°/s	Pre-op PT deficits @60°/s	Pre-op PT @180°/s	Pre-op PTBW @180°/s	Pre-op PT deficits @180°/s
Tegner	0.11	0.29*	0.09	0.13	0.37**	-0.20
K-SES total	0.22	0.38**	-0.06	0.26	0.44**	-0.17

K-SES	0.25	0.36**	-0.27*	0.24	0.32*	-0.13
Ham						

Pre-op=pre-operative, PT=peak torque, PTBW=peak torque as a percentage of body weight, °/s=degrees per second, @60=testing at 60 degrees per second, @180=testing at 180 degrees per second, \*\*Correlation is significant at the 0.01 level (2 tailed), \*Correlation is significant at the 0.05 level (2 tailed)

**Table 5.3: Correlations between post-operative isokinetic scores and functional measures at 60 and 180 °/s**

<b>Outcome measure</b>	Post-op PT @ 60°/s	Post-op PTBW @60°/s	Post-op PT deficits @60°/s	Post-op PT @180°/s	Post-op PTBW @180°/s	Post-op PT deficits @180°/s
Tegner	0.02	0.09	0.22	0.03	0.13	0.14
KSES total	0.19	0.36**	-0.18	0.16	0.29*	0.09
KSES Ham	0.34*	0.49**	-0.39**	0.32*	0.46*	-0.17

Post-op=post-operatively, PT=peak torque, PTBW=peak torque as a percentage of body weight, °/s=degrees per second, @60=testing at 60 degrees per second, @180=testing at 180d degrees per second, \*\*Correlation is significant at the 0.01 level (2 tailed), \*Correlation is significant at the 0.05 level (2 tailed)

Table 5.4 shows the correlations between the self-reported measures and length of time following the ACL injury and subsequent reconstruction and age using Spearman's correlation coefficient. The Tegner scale had strong correlations with age at the time of surgery and age at follow-up, while K-SES total and K-SES ham had no correlations with age.

**Table 5.4: Correlations between functional measures and timelines**

Outcome measure	Length of injury pre-op	Length of time from pre-op test to surgery	Age at surgery	Age at follow-up	Time since surgery
Tegner	-0.30**	-0.51**	-0.49**	-0.51**	-0.09
K-SES tot	-0.11	-0.18	-0.10	-0.09	-0.09.
K-SES H	0.10	-0.02	0.08	0.13	0.13

Pre-op=pre-operatively. tot= total, H= hamstring section \*\*Correlation is significant at the 0.01 level (2 tailed), Correlation is significant at the 0.05 level (2 tailed), tot= total, H= hamstring section

In order to establish the true effect of post-operative strength on the K-SES total and K-SES Ham, while controlling for the influence of the timelines identified in Table 5.4 on the outcome measures, MRA was performed. PTBW was chosen as the post-operative strength measure to be used in the model as it correlated most consistently with KSES Total and KSES Ham using Spearman's rank order coefficient. Analysis was performed at only 60°/s for clarity and as it is the most widely reported speed in the literature (Chapter two). Additional analysis was not performed on the Tegner due to the weak correlations identified in Tables 5.2 and 5.3. This MRA was performed after controlling for 1) age at follow-up, 2) length of time from injury to surgery (injury time), 3) length of time from pre-operative assessment to surgery (pre-op time) and 4) time since surgery.

Analysis of K-SES and post-operative PTBW scores identified a complete model score of 22%  $F(5, 41) = 2.28$ ,  $p=0.06$ , with post-operative PTBW scores alone explaining additional variance of 9%,  $R$  square change = 0.09  $F(1, 41) = 4.85$ ,  $p=0.03$ . PTBW alone thus, accounted for small variances in long term K-SES function of just 9% but PTBW had the highest beta value of all the factors with 0.35 with statistical significance ( $p<.05$ ). PTBW was responsible for post-operative K-SES total scores more than age, time since surgery, injury time and pre-op time.

With regards to K-SES Ham, PTBW had a complete model score of 18%  $F(5, 45) = 1.92$ ,  $p=0.11$  with post-operative PTBW scores again explaining an additional variance of 9%,  $R^2_{change} = 0.09$ ,  $F(1, 45) = 4.73$ ,  $p=0.03$ . Similar to the K-SES total, PTBW had the highest beta value of all factors ( $\beta = 0.34$ ) and the only factor with statistical significance of  $p < 0.05$ .

Table 5.5: Hierarchical multiple regression of the effect of post-operative PTBW at 60°/s on outcome measures

Outcome measure	Total Model variance (R square)	R square change	Beta values	Beta Sig.
K-SES Total	0.22	0.09	0.35	$p=.03$
K-SES Ham	0.18	0.09	0.34	$p=.03$

Tables 5.2 and 5.3 showed that post-operative PTBW had the most consistent correlations to long term follow-up outcome measures with statistical significance of all the recorded strength parameters. Hierarchical regression analysis demonstrated that the influence of PTBW was diminished when other factors were controlled. However, PTBW was the only factor whose influence on post-operative outcomes was statistically significant.

Thus PTBW consistently correlated more with K-SES total and K-SES ham than PT alone and other factors such as age, injury length and pre-operative time and time since surgery. Conversely, the Tegner scale correlated more with age and timelines than strength and hamstring strength six months post-operatively had limited influence on long term Tegner activity levels.

## **5.5 Summary**

The primary aim of this aspect of the study was to identify the long term subjective function of patients after ACLR with STG grafts. . This study identified high levels of function with a median Tegner score of 7.0, a mean K-SES total of 8.27 and mean K-SES Ham of 8.66. The K-SES Ham used in this study to assess hamstring function showed good internal consistency and correlated strongly with K-SES total but weakly with the Tegner scale. A secondary aim of this aspect of the study was to establish the relationship between post-operative strength at six months with long term follow-up. In terms of isokinetic parameters, PTBW had consistent moderate correlations with the functional scores across both speeds whereas PT and PT deficits had no consistent correlation. PTBW had stronger correlations with K-SES total and K-SES ham than with the Tegner scale. Finally, the Tegner scale correlated with age whereas K-SES and K-SES Ham did not.

# **Chapter 6: Discussion**

## **6.1 Introduction**

This chapter provides a discussion of the results presented in chapters four and five and contextualises the results into the findings identified in chapter two and other published literature in this area. The results are interpreted and the clinical significance and implications of the findings for practice are discussed. This is performed in three parts to cover the primary aims of this study, which were to:

- examine the effect of ACLR with STG grafts on residual hamstring strength by identifying hamstring strength between limbs pre-operatively and at six months post-operatively across a wider range of isokinetic parameters than previously reported
- examine the relationship between pre-operative strength and post-operative strength
- establish patient's self-rating of their hamstring function and to establish the relationship between hamstring strength and subjective global knee and hamstring function

This study found that an ACLR using hamstring muscle grafting did not result in decreased isokinetic hamstring strength post-operatively compared to pre-operatively with scores improving post-operatively. It identified that small hamstring strength deficits existed in the operated limb both before and after ACLR when compared to the unoperated limb across a range of isokinetic parameters and there appears to be a strong relationship between pre-operative strength and post-operative strength. Patients after ACLR with hamstring grafting reported high levels of knee and hamstring self-efficacy at long term follow up and PTBW appears to be a more important predictor of function than previously reported.

## **6.2 Population**

The sample size of n=54 compares favourably to other studies of this type with samples of less than this frequently reported (Ko et al 2012 n=23, Ardern et al 2010 n=50, Vairo et al 2007 n=14, Keays et al 2003 n=31). The mean age of 26.90 years is

consistent with other studies (Keays et al 2007, Burks et al 2005, Elmlinger et al 2006, Keays et al 2002) and generally reflects the mean age of population who undergo ACLR surgery in a clinical setting (systematic review ages from 208 to 34 years..

Females have been excluded in other studies of this nature (Ko et al 2012, Kim et al 2011) due to their influence on group mean results. In this study, females were included as it was felt this more accurately represented the population of individuals undergoing ACLR surgery in our setting. Subjects are not homogenous in nature with different levels of activity, age and occupation, which although could influence the comparison of scores, more accurately reflects the general population as opposed to focusing purely on elite or high level athletes. This was generally the case in previous studies (chapter two-systematic review), where participants were described as “majority non-athletes”, “recreational three times a week”, “active participants” or “young and active”. Thus, the population included in this study is similar to previous studies in terms of activity and numbers but differences will always be present among human populations. This study had a mean Tegner activity score of 7.0 reflecting an active population engaged in recreational sport and competitive non-contact sports.

### **6.3 Aim No. 1: To establish if hamstring muscle strength deficits exist pre-operatively and six months post-operatively after ACLR**

#### **6.3.1 Pre-operative PT and PT deficits at 60°/s**

Mean PT deficits of less than 10% were identified between limbs across all speeds both pre-operatively. Inter-limb differences of less than 10% are generally considered negligible in relation to isokinetic testing (Xergia et al., 2011) and thus deficits in this study would not be considered as clinically significant. The hamstring PT deficits identified pre-operatively in this study (5.87% at 60°/s) (Table 4.8) are comparable to other studies reporting deficits of 1% (Keays et al., 2007), 1.1% (Keays et al., 2003) and 8.6% (Anderson et al., 2002). These results suggest that small deficits in hamstring muscle strength generally exist in the injured limb pre-operatively. The results of this and other studies would imply that hamstring muscle strength is not dramatically affected by the initial injury compared to the other side as only small deficits exist between limbs. This is unlike quadriceps inhibition and

quadriceps weakness which has been reported after knee injury (Suter et al., 1998). It was not possible in this study to determine if these deficits existed before the initial ACL injury or were a consequence of the injury due to study design as this was not a prospective study.

### **6.3.2 Post-operative PT and PT deficits at 60°/s**

At six months post-operatively, this study identified statistically significant but again clinically small deficits in PT between limbs at 60°/s of just 7.52% (Table 4.8). This suggests that ACLR using STG grafts achieves satisfactory outcomes in hamstring strength when solely compared to the opposite limb. While post-operative hamstring PT deficits have been recorded previously in systematic reviews at longer term follow-up (Xergia et al., 2011, Dauty et al., 2005), studies that report results at six months following ACLR with STG grafts are more limited in number (Keays et al., 2007, Anderson et al., 2002). Previous systematic reviews (Xergia et al., 2011, Dauty et al., 2005) compared the strength outcomes of BPTB and hamstring grafts at two year follow-up but did not report any absolute scores. The PT deficit between limbs at six months in this study is similar to those reported by Keays et al. (2007) of 10% but considerably lower than Anderson et al. (2002) at 19%. Strength deficits of less than 10% have been used as one of the guiding factors for returning athletes to sport along with full range of motion, swelling and healing times (Hartigan et al., 2010). In terms of healing times, six months is often the time for a return to sport (Keays et al., 2001) and thus results in this study would indicate that hamstring strength deficits between limbs at six months after ACLR were satisfactory for return to sport once all other factors were satisfied.

At six months after ACLR this study identified an increased group mean PT value at 60°/s compared to pre-operatively (103.2Nm v 87.49Nm). Crucially, in this study absolute PT improved six months following surgery despite STG grafting. This is the first study which has reported an improvement in absolute PT after surgery compared to pre-operatively as previous studies (Keays et al., 2003, Anderson et al., 2002) had reported decreased absolute PT scores at six months following surgery compared to pre-operative testing.

This may be explained by possible changes that may have occurred in hamstring muscle tissue either pre and/or post-operatively. Strength gains post-operatively may

be explained by compensatory hypertrophy of the remaining biceps femoris and semimembranosus muscles (Eriksson et al., 2001) or from possible regeneration of the semitendinosus tendons (Janssen et al., 2013). It has been identified that the semitendinosus and gracilis tendons have the ability to regenerate with a new insertion either proximal or distal to the joint line (Todokoro et al., 2004, Takeda et al., 2006). A hypothesis for this regeneration is the possible formation of a haematoma in the space left by the harvesting the tendons. This space is filled with fibroblast cells that proliferate and produce collagen which matures into hamstring tendon (Janssen et al., 2013). However, while studies have previously identified tendon regeneration following surgery, no study has associated this tendon regeneration with increased strength levels compared to pre-operatively suggesting that this alone wouldn't account for improved PT scores.

Strength gains and muscle hypertrophy may have been achieved pre-operatively as all patients were given an individual home exercise programme pre-operatively after initial assessment depending on the initial scores and time to surgery. The aim of the pre-operative assessment was to maximise strength and function before surgery and educate the patients on the post-operative rehabilitation. Exercise plans were individualised but focused on ensuring proper straight leg raise technique and encouraging closed kinetic chain activities including squatting and exercise bike. Thus, it was expected that strength levels identified at the pre-operative assessment would be increased by the time of surgery. Previous studies which tested patients pre-operatively did so on the day before surgery (Anderson et al 2002) or the week before (Keays et al 2003) and thus did not allow time for pre-operative strength gains and subsequently demonstrated decreases in hamstring PT six months post-operatively. In this study, it is then possible that patients had strengthened their hamstring muscle beyond the level identified in the pre-operative isokinetic test by the time surgery arrived thus affecting post-operative comparisons. Even accounting for this, it still promotes the benefit of pre-operative testing as patients were statistically stronger at six months post-operatively than at a median timeframe of 10.14 weeks pre-operatively. Additionally, multiple regression analysis identified that the length of time from pre-operative assessment to surgery did not have significant correlation to post-operative strength thus limiting the influence of this factor on post-operative outcomes.

The improved value for between limb post-operative PT deficits and absolute PT scores identified in this study compared to others (Keays et al., 2007, Anderson et al., 2002) may also be attributed to the rehabilitation and testing protocol used in this study, which allowed for early detection of scores and deficits at three and four months post-operatively (See Appendix G- ACL rehabilitation protocol). By identifying deficits early in the rehabilitation process, it allowed for variation of the strengthening programme to address certain scores thus ensuring that deficits of less than 10% were achieved at six months testing. This may have had the effect of increased patient motivation during a long programme of rehabilitation, which has shown to affect patient outcomes after ACLR linked to the basis of patient self-efficacy (Everhart et al., 2013). The small deficits identified in this study may provide justification for earlier and more frequent testing in the rehabilitation process, which was not reported in other studies. It also served to inform the patients as to the expected targets and effectiveness of existing home exercise programme. While, the rehabilitation could be hypothesised for improvements in strength, it has to be acknowledged that differences in absolute PT between studies may also be explained by the heterogeneous populations used in studies. It is only by matching for weight and gender that accurate comparisons can be made across different studies.

### **6.3.3 PT deficits at 180 and 240°/s**

At the faster speeds of 180 and 240 °/s, clinically small PT deficits of less than 10% (table 4.10 and 4.12) were also present pre and post-operatively. This suggests that the initial ACL injury did not result in speed-specific reductions in muscle performance, although no other study was identified that reported PT deficits at these faster speeds pre-operatively for comparison. Post-operatively, small deficits despite hamstring tissue harvesting may be explained by a strengthening programme that focused on slow speed strength training at the early acute phase and higher speed functional exercise after three months of rehabilitation to cover the complete velocity spectrum. Without a control group, it is difficult to fully determine whether hamstring strength recovery was due to rehabilitation alone or due to the tissue healing over time. However, the difference in PT deficits reported in previous studies

at six months (Keays et al., 2007, Anderson et al., 2002) compared to this study with the same timeframe suggests that some factor other than time and tissue healing would account for the variances. The use of faster speeds has been suggested to relate to higher functional demands (Anderson et al., 2002), and this study provides pilot data for future studies as to what is to be expected pre-operatively and at six months post-operatively following ACLR.

#### **6.3.4 PTBW**

The mean identified pre-operative absolute hamstring PT for the operated limb of 87.49Nm at 60°/s in this study is similar to 84Nm (Anderson et al., 2002) while is lower than 99Nm (Keays et al., 2007) and 105Nm (Keays et al., 2003). At six months, a group mean PT value at 60°/s of 103.02 Nm was identified which is higher than previously reported (chapter two) and compares to 96.3Nm (Keays et al., 2003) and a considerably lower value of 77Nm (Anderson et al., 2002). Differences will always be present between studies due to the heterogeneity across study populations. Accordingly, absolute scores in isolation are limited unless PT values are normalised to body weight (PTBW) and gender which can allow for accurate comparisons across groups and profiles, but previous studies have not reported this parameter. By reporting both the absolute PT and PTBW figures, this study provides pilot data for future studies and clinicians to compare hamstring muscle strength across a range of speeds with this being the first study to report absolute PT values both pre-operatively and post-operatively at 60, 180 and 240 °/s.

Since no data for PTBW six months following ACLR exists, comparisons for this value need to be made against other populations. As identified in chapter two, the Biodex System 3 dynamometer provides expected values of PTBW for males of between 155.4- 209.2%, while for females a PTBW range of slightly lower (149.4- 176.4%) is expected at 60°/s. Crucially, while this normative data exists, no study has previously examined this data specifically in relation to patients after ACLR. The mean PTBW identified post-operatively was 131.99% for the operated limb demonstrating an improvement in strength with rehabilitation from 112.15% pre-operatively. The highest mean PTBW reported in this study was in the unoperated leg six months following surgery with a value of 144%, which shows that even the best PTBW values recorded across the whole group at either time frame, still fell

outside the expected ranges for either males or females. This result would suggest that hamstring strength is lower than one would expect based on normative data, even in the uninjured leg, and despite improvements pre-operatively. This is similar to the findings in chapter two, where reported PT values appeared lower than expected compared to normative data, and as such small deficits against a weak opposite limb may over-estimate the effect of rehabilitation.

Low PT and PTBW scores may be explained by general deconditioning that may occur in both limbs before surgery due to reduced activity, which although improved with rehabilitation has not reached normative values. Thus, low scores in the opposite control limb may explain why such low deficits are detected between limbs pre-operatively as the basis of comparison is inherently flawed. It may also identify that patients with low hamstring PTBW values are more susceptible to ACL injury in the first instance as suggested in females (Hewett et al., 2001). Only one other study (Vairo et al., 2008) has previously reported absolute PTBW values at 60°/s of 51.7% 21 months following surgery, which is considerably lower than scores expected or reported above. It is difficult to interpret the reasons for such low scores in the study by Vairo et al. (2008), which could possibly be accounted for by different testing equipment or possible inversion of PTBW scores. Overall, this would suggest that hamstring strength in patients following completion of ACL surgery and rehabilitation still did not achieve hamstring strength as expected for their gender and weight compared to the general population. One may expect hamstring PT's (and by consequence PTBW) to be lower in the operated leg following surgery due to the harvesting of hamstring muscle tissue (as outlined in chapter two) but this does not account for lower than expected scores in the non-affected leg.

None of these patients were tested before they ruptured their ACL so it is not possible to definitely say whether these patients had bilateral low hamstring PTBW values before their injury. However, it would appear that this may be the case as the uninjured limb was also tested pre-operatively as a control, supporting the case for hamstring strengthening as part of ACL prevention programmes (Bien, 2011).

Stratifying for gender also demonstrates variations that occur in group PTBW results. As stated, females have been identified as at greater risk of ACL injury (Paterno et al., 2012) but are often excluded in other studies of this nature (Ko et al., 2012, Kim

et al., 2011) due to the influence of gender on the group's mean results lowering the male average. In this study, females were included, which is a more accurate representation of the population of individuals undergoing ACLR surgery in our clinical setting. The mean PTBW for females pre-operatively and post-operatively was considerably lower than expected (Dvir, 1995) and lower than male PTBW even after taking gender into account which is supported by other studies (de Jong et al., 2007, Gobbi et al., 2004). This suggests that female patients may require a more intensive hamstring strengthening regime during the rehabilitation phase to optimise hamstring strength for ACL injury prevention (Hewett et al., 2001) as they are not developing their strength to appropriately match their weight.

### **6.3.5 Additional testing parameters**

In addition to understanding the strength of the hamstring muscle group, this study also examined the speed of contraction (TPT) and the balance between hamstring strength and quadriceps strength (hamstring:quadriceps ratios). The hamstring muscles work synergistically with the ACL to prevent anterior tibial translation (Arderm et al., 2010, Vairo et al., 2008, Anderson et al., 2002) and thus it is important to understand the speed that the hamstring muscle group can activate and the balance between the posterior pull of the hamstring and anterior pull of the quadriceps muscle groups.

The results of TPT and hamstring:quadriceps ratios showed no deficits compared to the opposite limb pre or post-operatively. TPT represents the time taken during a muscle contraction to reach maximum PT and thus the ability of a muscle to generate force quickly. It has been suggested that programmes that improve TPT values and hamstring activation should be included as part of ACL prevention programmes in females (Bien, 2011). Unlike PT and PTBW, TPT had consistently statistically significant better scores in the operated limb compared to the unoperated limb at pre and post-operative testing across all speeds. Better TPT scores in the operated limb may be associated with familiarity with the testing pattern as the unoperated limb was always tested first followed by the operated limb. TPT was consistently faster for both limbs at six months post-operatively than compared to pre-operatively. This may be explained by increased familiarity of the patients with the testing procedure after repeated testing and six months of rehabilitation. It is interesting however, that

despite deficits between limbs in all other parameters, TPT scores had no deficits pre or post-operatively, suggesting that ACL injury and semitendinosus grafting did not lead to a reduction in the acceleration speed of the hamstring group. No previous study was detected which reported TPT at six months post-operatively to allow for comparisons with this study again providing original data as a reference point for future studies.

Different ratios have been proposed when considering hamstring and quadriceps function, including concentric:concentric ratios and eccentric hamstrings:concentric quadriceps (Holcomb et al., 2007) otherwise known as the functional ratio. Eccentric testing is more difficult to perform by the participant and has been associated with a risk of hamstring injury (Croisier et al., 2008), which results in concentric ratios more frequently obtained, as was the case in this study. One study (Myer et al., 2009) identified concentric ratios of less than 0.55 as their cut off point for increased ACL injury risk while another (Croisier et al., 2008) examined the ratios that predicted hamstring muscles strain and identified a concentric ratio of 0.55 (55%) or more as necessary to reduce risk of injury. In this study the pre-operative ratio was identified as 0.55 (55%) in the operated limb and 0.57 post-operatively suggesting a satisfactory result in rehabilitation if the opposite limb is the sole reference point for comparison. Hamstring to quadriceps ratios were not reported in absolute terms in any of the studies reviewed in chapter two. This ratios importance in hamstring injury is unclear with conflicting results evident in the literature (Copland et al., 2009, Petersen and Holmich, 2005). Like any relative measure, the basis of comparison is critical as low quadriceps scores may explain good ratios but it was beyond the scope of this study to examine quadriceps strength.

#### **6.4 Aim No. 2: To establish the relationship between pre and post-operative isokinetic strength results**

This study identified a strong relationship between pre-operative and post-operative scores across all speeds and that post-operative scores improved from pre-operative testing. This would suggest that high absolute PT values pre-operatively are associated with better PT values post-operatively. The literature in this area (chapter two) has focused on the relative PT deficits between limbs when analysing outcomes. This study identified low to moderate correlations between pre and post-operative

values for percentage PT deficits between limbs. This would suggest a low percentage PT deficit between limbs pre-operatively has limited effect on what the percentage PT deficit between limbs will be post-operatively. This is in contrast to studies into quadriceps strength (Eitzen et al., 2009), which found that large pre-operative quadriceps deficits were associated with large post-operative deficits (>20%). A possible explanation is that in the study by Eitzen et al. (2009) patients were stratified during analysis according to pre-operative deficits, however similar stratification in this study did not reveal any relationship with only eight patients having large deficits pre-operatively (>20%).

This is the first study to examine the relationship between pre and post-operative hamstring strength. Possible reasons for the lack of research into pre-operative hamstring strength may have been a traditional focus on quadriceps strength (Xergia et al., 2011), and a limited ability to perform pre-operative testing. This may be due to constraints on time for both patient and therapist, which reduces the volume of studies which perform pre-operative testing with a recent systematic review of pre-operative quadriceps strength identifying only three suitable studies for inclusion (Silkman and McKeon, 2012).

This study identified a mean PT improvement of 15.52Nm between the two time lines (approx. 18%) but as already identified, the PTBW scores achieved post-operatively were lower than expected for normative data. A possible solution to this may be longer and more intensive periods of rehabilitation pre-operatively as it appears that pre-operative strength has a direct and strong link with post-operative strength. Other factors may also affect post-operative strength outcomes including patient compliance with their home exercise programme and knee self-efficacy (Thomee et al., 2006) but it was beyond the scope of this study to examine such factors during rehabilitation itself. Correlations may also be due to having a distinct client group who had incidentally similar scores pre and post-operatively, however, it would appear that good pre-operative scores can relate to good post-operative scores.

Post-operatively, in the initial acute phase, hamstring strengthening exercises are often contra-indicated (as was the case for the first four weeks in this study's protocol) due to the fragile nature of the donor site which limits the time frame for optimal strength gains. In contrast, during the sub-acute pre-operative period no such

restrictions often exist once the initial inflammatory phase has settled and the patient has regained full pain free range of motion. During this period, it could be recommended that progressive strengthening programmes could be performed to optimise strength pre-operatively, which could lead to improved PT's post-operatively. This would need increased therapist time and input pre-operatively, and possibly delaying surgery until strength gains were achieved. For some patients, this may be undesirable as they may want surgery as soon as is feasible but they may need to be informed that rehabilitation after ACL injury begins before surgery for best post-operative outcomes. Ultimately, the reference point for what is acceptable strength pre-operatively needs to be defined, either as good as the other limb, as good as the general population or possibly the same as expected on return to sport and future studies are needed to establish this.

### **6.5 Aim No. 3: Establish the long term subjective function levels after ACLR and the relationship between hamstring strength and subjective function**

The final aim of this study was to determine the relationship between self-reported function following ACLR and hamstring strength before and after ACLR at a mean follow up of 3.66 years post-surgery. This study identified that patients after ACLR with STG grafts reported high levels of subjective global, knee and hamstring function as measured by the Tegner scale, K-SES and K-SES Ham scales. Moderate correlations existed between hamstring PTBW strength pre-operatively and post-operatively with self-reported knee and hamstring function.

#### **6.5.1 Functional measure results**

The use of subjective rating scales provides an insight into how the patient feels about his/her knee function rather than what he/she can actually do. The Tegner score provided an indication of how many individuals were involved in sporting activity. A score of three equated to recreational or competitive swimming, five equated to recreational sport like jogging or competitive cycling while seven or above equals competitive sport. All patients scored a three or more with 36 scoring a 6 or more (Tegner scale appendix D). The Tegner scale was used as a measure of global knee function with a median score of 7.0 identified in this study.

The Tegner scale is widely reported with other previous studies reporting mean post-operative values of 5.7 and 6.4 at one and two years respectively (Ko et al., 2012) 6.0 at five years (Lautamies et al., 2008) and 5.03 at 2.75 years (Kim et al., 2011). Ko et al. (2012) identified scores of 6-7 as common in patients after ACLR which is similar to this study.

As the Tegner scale rates a wide level of function from disability to elite international performance across a small range of 0-10, it is by nature not sensitive to change with an inherent ceiling as the majority of patients will report a level of competitive sport (a score of seven) as they may not have the ability or opportunity to participate in elite or international sport (scores of 8-10). Also, in Ireland, patients participating at a level of national or international level usually have their own medical team and will not attend a public physiotherapy setting as was the case in this study. Thus, scores of seven in our patient group represent at or near their highest level of functioning after surgery. While the Tegner scale records the actual sporting level, it is not sensitive to detect if participants felt they were performing at a certain level as well as they performed before surgery. Overall however, it suggests that patients after ACLR with hamstring grafts report high levels of function in terms of subjective global functional performance. Unfortunately, scores were not obtained pre-operatively due to study design to identify baseline activity levels, which would have allowed an assessment of changes that may have occurred over time.

The K-SES provides a wider range of subjective knee function across various levels of activity. This study identified high levels of subjective knee function with an overall median score for the K-SES total identified at 8.27. Thomee (2006) identified a median K-SES total score of 6.8 in patients 12 months following surgery. The longer median follow-up time period in this study (3.66 years versus 12 months) may account for the higher scores reported in our study, as patients may have become more confident about their knee function with increased activity, with scores of 8.27 suggesting high levels of knee self-efficacy.

Section A of the K-SES related to activities of daily living and, patients reported the highest mean score for this section (9.85). Interestingly, the lowest scores were reported for section D (7.25) which related to knee function in the future, which suggests that although patients may return to a high level of sport, leisure and physical

activity, a fear of re-injury remains prevalent. Thus, fear of injury may be as important a factor in determining return to sport as strength deficits, timelines, swelling and range of motion (Arderm et al., 2013, Arderm et al., 2012).

The measurement of hamstring function subjectively has not previously been described and this author is unaware of any such measure that assesses patients' satisfaction or confidence about their hamstring muscle function. Despite previous studies identifying hamstring weakness after surgery, none have examined the consequences of this on patients own personal performance and whether they were concerned about injuring their hamstring or causing pain, This is an original feature of this study as it is the first study to attempt to establish how patients react to the harvesting of the hamstring muscle tissue through the K-SES Ham.

The K-SES Ham correlated moderately to strongly with the original sections of the K-SES, with good internal consistency similar to other results (Thomee et al., 2006) suggesting that the K-SES Ham provided a satisfactory measure of subjective hamstring function. The results of the K-SES Ham would suggest that harvesting of hamstring muscle tissue, at long term follow-up, does not lead to low levels of patient self-efficacy in relation to how the hamstring muscle performs. This is somewhat surprising given that the hamstring section questioned patients regarding hamstring pain or discomfort during a range of activities including playing sport and sudden acceleration and deceleration. It has been suggested that semitendinosus plays a greater role at deeper knee flexion angles rather than less acute knee flexion angles (Arderm and Webster, 2009). This may account for why harvesting the semitendinosus tendon does not appear to affect self-reported performance of hamstring function as the activities assessed using these scales would not involve deep knee flexion. Patients may be concerned that harvesting hamstring muscle tissue will lead to decrease in sporting performance. From this study, it would appear that ACLR with STG grafts results in good outcomes for patients in terms of subjective performance helping to support it as the current choice of graft during ACLR (Granan et al., 2009).

### **6.5.2 Relationship between isokinetic scores and functional measures**

The Tegner scale had no consistent correlation with PT, PT deficits or PTBW at either 60 or 180°/s at either timeline. It would then appear that hamstring strength

either pre or post-operatively appeared to have limited effect on post-operative global knee function. This again is possibly explained by limitations of the Tegner score such that the Tegner score was not very sensitive to changes in functional level and thus had limited movement regardless of hamstring strength.

Moderate correlations were identified between post-operative strength scores and the K-SES total K-SES Ham (Table 5.3) but not the Tegner scale. Separate analysis conversely showed moderate to strong correlations between age (at surgery and follow up) and timelines with the Tegner but not the K-SES scales (Table 5.4).

It would thus appear that the Tegner scale is more affected by age and the length of time a person waits for surgery than hamstring strength, while the K-SES appears to be affected by other factors. A possible explanation for this relationship between the Tegner scale and age is due to an inherent limitation in the Tegner scale as it primarily measures knee function by sporting activity levels while the K-SES covers a broader aspect of knee function. It may be suspected that participants will take part in less strenuous sporting activities as they get older and thus a negative correlation between current age and sporting activity would be expected.

Of interest, the time since surgery did not correlate with knee function ( $r=0.091$ ), which may be explained by a conflict between patients who are getting older as time passes since surgery and reducing activity and those younger patients who may be increasing activity as they get more confident about their knee with the passing of time from surgery. It has been shown that fear of re-injury decreases as time progressed after ACLR (Chmielewski et al., 2008). Finally, the length of time from pre-operative assessment to surgery had strong negative correlations with the Tegner scale. A possible explanation for this may be that the longer a patient waits for surgery, the more accustomed they get to lower levels of activity secondary to disability, inactivity and fear of injury and do not return to higher levels after surgery.

It may also reflect inappropriate testing parameters and limitations in the isokinetic testing. It has been suggested by other authors (Keays et al., 2003) that other parameters such as muscle reaction time such as TPT and recruitment patterns may be more appropriate testing parameters of hamstring muscle performance rather than PT alone, and that these parameters may be relate better to global function. However,

separate analysis of the relationship between TPT ratios and the Tegner scale did not reveal any relationship. Future studies may need to examine other factors such as eccentric strength to determine if it plays more of a role than concentric strength (with concentric strength ratios showing no correlation) in improving outcomes due to its relationship to the functional ratio described previously.

PTBW had consistent moderate correlations with the K-SES total and K-SES Ham both pre and post-operatively, whereas PT and PT deficits which are the most widely used and reported results in the literature did not show any consistent correlation with knee or hamstring function. This would imply that rehabilitation needs to focus on regaining strength that is appropriate for a person's individual physical characteristics rather than just comparing PT between limbs. Other studies have previously identified a positive relationship between post-operative isokinetic hamstring strength deficits and objective functional knee tests but this author found no other study which reported correlations between absolute PT or PTBW values and subjective function. Hierarchical multiple regression analysis found that PTBW had a limited correlation with long term follow up of knee self-efficacy after controlling for other factors including age and time since surgery. It would appear that factors beyond the variables recorded in this surgery are ultimately responsible for long term knee self-efficacy, including possible psychological factors such as fear and/or anxiety reflecting the lower than average scores in section D (future function) and future studies need to examine these.

It is surprising that only low to moderate correlations existed between hamstring strength and knee function given the known synergistic effect of hamstring muscle function on knee stability and risk of ACL injury (Hewett et al., 2001). A possible hypothesis is that hamstring strength may relate more to risk of re-injury rather than subjective performance and may not be an issue unless a threshold point is reached and surpassed when injury could occur. The clinical implications of this may be that optimising hamstring strength after ACLR may play a greater role in ACL injury prevention rather than improving subjective performance which largely seems to be independent of hamstring strength values.

In relation to hamstring function in isolation, it appears that strength alone does not appear to be the primary factor in determining self-efficacy. Hamstring self-efficacy

has not been previously examined in the literature. Studies have focused on objective causative factors for primary hamstring injuries (Freckleton and Pizzari, 2013) and recurrent hamstring injuries (de Visser et al., 2012) with conflicting results. Although previous ACLR has been associated with a higher risk of recurrent hamstring strains (de Visser et al., 2012), patients in this study did not report dissatisfaction with their hamstring function. This study examined current subjective hamstring function and did not examine injury rates since surgery. Possibly, patients may have had a hamstring injury since surgery which had resolved by the time of the questionnaire but if so, it did not appear to have any detrimental effects on how they currently feel about their hamstring function.

## **6.6 Clinical Implications**

The clinical implications of these results depend on the reference point to judge successful outcome. If the opposite limb is the sole reference point as has been the case previously, then these results suggest excellent outcomes in hamstring muscle strength with high levels of knee and hamstring function reported supporting hamstring grafting during ACLR. However, if current normative data is used, then muscle strength is not being optimised in this or previous studies (chapter two). Future studies need to further examine the importance of PTBW in both ACL and hamstring injury prevention to fully establish its clinical significance, namely to establish if low PTBW values are a consequence or precursor to ACL surgery. Also, it needs to be established if the current normative data is reflective of the general population or is possibly artificially higher due the client groups used e.g. sporting groups (Hadzic et al., 2013). Previous studies have focused on PT and PT deficits but it appears that these have limited effect on self-reported outcomes unlike PTBW and this parameter needs to be more widely reported.

## **6.7 Limitations**

The primary limitation of this study was that it was retrospective in nature with follow up of over five years which accounts for the decrease in numbers from the initial assessment. Although the sample size of n=54 compares favourably to other studies of this type, with smaller numbers of participants frequently reported in the

literature (range 14-50) (Ko et al., 2012, Ardern et al., 2010, Vairo et al., 2008, Keays et al., 2003). Decreased participant numbers can be an issue with retrospective studies (Ardern et al., 2010). It has been stated (Keays et al., 2003), that the ACL population is young and migratory, making it difficult to ensure follow up which may explain the decrease in numbers in patients who were available for testing at six months following ACLR but were unable to complete the longer term follow up subjective questionnaires. Also, the participants who responded may reflect those patients who were more diligent to their rehabilitation process or who felt most satisfied with the service provided, and thus may have reflected a more positive bias in questionnaire responses. Conversely, participants who felt their rehabilitation was not successful may not have wished to participate, although no patient expressed those views.

Another limitation is that patients were tested at various points before surgery, due to when the participant was referred for assessment or participant preference to delay surgery due to personal commitments. It was logistically impossible to assess patients the day before or day of surgery as the testing equipment was not on the same site as the surgery. Patients were all given exercise programmes following pre-operative testing to perform at home before surgery. Some patients may have been more compliant with their exercises than others, which may have resulted in altering the pre-operative isokinetic results by the time surgery occurred. Ideally, assessing patients the day of surgery, day before surgery or a series of pre-operative testing would help eliminate this anomaly.

Also, the angle of PT was not used in this study due to the wide range of parameters already recorded and the desire to focus on full ranges of motion. This parameter has been recognised by many authors (Ardern and Webster, 2009, Tashiro et al., 2003, Makihara et al., 2006) to be influenced by harvesting of the semitendinosus tendon although the clinical and functional significance of this has not been fully established (Ko et al., 2012). Together with this, this study did not examine the effect of medial hamstring grafting on tibial rotation strength and its relationship to function as discussed by others (Tashiro et al., 2003) and testing that isolates medial hamstring strength may provide more insight into the effects of hamstring grafting on knee rotatory strength. This occurred due to the time constraints to perform extra testing and to limit the number of variables for analysis.

Finally, the use of subjective testing only may have limited a full interpretation of hamstring function and the effect of hamstring muscle grafting. This was done both due to need identified to examine subjective function as identified in chapter one and also due to the logistical difficulty of getting patients to attend for objective tests at up to six years following surgery. Thus, postal questionnaires were deemed the most appropriate method of long term follow-up assessment. Future studies would benefit from performing both subjective and objective tests to assess their relationship to each other and other factors including strength.

## **6.8 Recommendations for future trials**

Future studies in this area would benefit from prospective testing involving a series of pre-operative tests and longer post-operative follow up to determine the optimal time frames for maximum strength outcomes following ACLR. A comparison between early and later isokinetic testing would be beneficial to determine if early isokinetic testing was indeed responsible for improved outcomes at six months as suggested in this study. This study has identified strong correlations between pre-operative strength and post-operative strength. Future studies are needed to determine if there should be a baseline level of strength achieved before surgery is performed to ensure optimal strength outcomes post-operatively. Finally, the use of PTBW values and its relationship to post-operative outcomes needs to be further examined and it needs to be established if low PTBW values are associated with increased risk of injury or are a consequence of injury.

## **Chapter Seven: Conclusions**

This study has identified through the systematic review that the reporting of hamstring strength after ACLR had previously focused on narrow parameters such as PT deficits, with limited understanding of the effect of pre-operative strength and the relationship between strength and self-reported function. This main study has broadened the evidence that exists into the effect of hamstring grafting during ACLR on residual hamstring strength and function. It has identified that pre-operatively and six months post-operatively after ACLR surgery, clinically small deficits in hamstring strength existed between limbs. Post-operative hamstring strength scores improved consistently at six month testing compared to pre-operatively demonstrating that harvesting of the hamstring muscle tissue had no deleterious effects on muscle strength. Strong correlations existed between pre-operative and post-operative hamstring strength which promotes the need for pre-operative hamstring strength training for optimal post-operative strength gains.

Patients after ACLR reported high levels of global, knee and hamstring function promoting hamstring grafting as a graft choice. The levels of function reported had low correlations to commonly reported strength testing parameters such as PT and PT deficits but did correlate moderately to PTBW suggesting PTBW has a bigger influence on post-operative outcomes than PT. PTBW values achieved in this study did not return to reported normative values, as also seen in other studies, and this may have implications for risk of future injury. PTBW values were lower than expected pre and post-operatively and the relationship between PTBW and initial injury has not been established.

Thus, hamstring grafting appears to be an acceptable choice for ACLR with good patient outcomes in terms of hamstring strength and function but future studies need to examine PTBW to ensure that the best outcomes are achieved in order to minimise the risk of future injury.

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Appendix A

**Mid-Western Regional Hospital Complex**  
**SCIENTIFIC RESEARCH ETHICS COMMITTEE PROTOCOL**

**THIS FORM MUST BE TYPE WRITTEN AND SUBMITTED TO THE SCIENTIFIC RESEARCH ETHICS COMMITTEE TOGETHER WITH 14 COPIES OF BOTH THE FORM AND SUPPORTING INFORMATION. YOU MUST ALSO SUBMIT ONE ADDITIONAL COPY ELECTRONICALLY, TYPED IN MS WORD (WORD '97 OR LATER), VIA EMAIL TO [joanne.oconnor@hse.ie](mailto:joanne.oconnor@hse.ie)**

**1 GENERAL**

**Title of Study:**

Hamstring muscle function following anterior cruciate ligament reconstruction with semitendinosus and gracilis autografts

**Date of submission:**

09/09/2012

**Name of principal investigator and department:**

Colum Moloney, Chartered Physiotherapist  
Mr. Dermot O' Farrell, Consultant Orthopaedic Surgeon

**Telephone No:**

061-482151, 0863067177

**Signature of principal investigators: Colum Moloney**

**2 INVESTIGATING PERSONNEL (If the Principal Investigator is not a Consultant, the project must be supervised by a Consultant)**

**PRINCIPAL INVESTIGATOR**

Colum Moloney

**DEPARTMENT**

Physiotherapy Department,  
MWRH, Limerick

**OTHER INVESTIGATORS**

Dr. Amanda Clifford

**DEPARTMENT**

Department of Clinical  
Therapies, University of  
Limerick

Kieran O'Sullivan

Department of Clinical  
Therapies, University of  
Limerick

**Is each investigator a registered medical practitioner?**

No. Colum Moloney, Amanda Clifford and Kieran O'Sullivan are Chartered Physiotherapists.

**Have the investigators any vested interest in the outcome of the study?**

No.

**What payments, monetary or otherwise, if any are to be made to any of the investigators, either directly or indirectly?**

None.

**What payments, monetary or otherwise, if any, are to be made to any person or institution providing facilities to be used for the purpose of the project?**

None

**3 ENCLOSURES WHICH MUST ACCOMPANY THIS APPLICATION:**

**(i) A draft Patient Information Sheet, giving information under the following headings:**

Title	Confidentiality
Introduction	Compensation
Procedures	Voluntary participation
Benefits	Stopping the study
Risks	Permission
Exclusion from participation	Complaints procedures
Alternative treatment	Further information

**The Patient Information Leaflet should be brief and in language which is easily understood.**

Please see Appendix B

- (ii) A copy of the draft Consent Form, which should provide for signature by the Investigator, and an independent witness, as well as the Patient and, if the Patient is not in a position to sign, by a consentor, parent or guardian acting on behalf of the patient. The draft Consent Form should cover (a) the fact that the Patient has read and understands the Patient Information Sheet, (b) the voluntary nature of participation by the Patient including the freedom to withdraw, (c) access to the Patient's medical notes if relevant, (d) permission to inform the Patient's GP, (e) agreement by the Patient to notify the Investigator of any side effects arising during the study, and (f) agreement by the Patient to take part in the study.**

Please see Appendix C

- (iii) An appropriate letter of indemnity.**

Full time employee of HSE and automatically covered by Hospital insurance as per risk management

- (iv) Medicines Board approval covering the relevant drugs, the investigator and the participating institution.**

N/A

**Please send all these papers, with the Protocol, to:**

**The Chairman  
Scientific Research Ethics Committee  
Limerick Regional Hospital, Dooradoyle, Limerick**

#### **4 TITLE OF PROJECT**

**Please indicate the Project Title:**

Hamstring muscle function following anterior cruciate ligament reconstruction with semitendinosus and gracilis autografts

**Proposed Start Date:**

September 2012 on receipt of ethical approval

#### **5 SUPPORT**

**Is there any financial or other support by a drug company or other outside commercial organisation?**

No

**If so, which organisation and does it agree to abide by the IPHA guidelines?**

N/A

**What funding arrangements have been made for the conduct of additional diagnostic tests being carried out in the study?**

N/A

#### **6 OBJECTIVE**

**(a) What hypothesis is it intended to test?**

The aims of this research are two-fold:

Primarily: To establish if hamstring strength deficits exist on isokinetic testing following ACL reconstruction using hamstring autografts using a public health system rehabilitation protocol.

Secondly: To investigate the relationship between pre-operative and post-operative hamstring strength following ACL surgery as a predictor of strength results and to compare postoperative results along a timeline of 12 months. Together with this, demographic variables such as weight, height, age, sex, length of injury prior to surgery, sporting level and occupation will be recorded as influencing factors. Subjective opinion of knee and hamstring function will be assessed through a postal questionnaire (See Appendix D, E, F).

It is hypothesised that hamstring muscle strength will be reduced on the affected leg following ACL reconstruction despite rehabilitation. It is also hypothesised that post-operative relative and absolute strength deficits on the affected side may be as a result of pre-operative weakness and not primarily due to donor site morbidity.

A secondary aim of this study is to establish a reference point for expected hamstring strength pre and post-surgery which will help to inform future research into optimizing rehabilitation techniques following ACL reconstruction.

**(b) What is the value of the study to the patient(s) or volunteers?**

There will not be any immediate benefit to the people who consent to their data being used in this study, as these individuals have all received their test results already and have finished their rehabilitation.

The findings of this study will be used to identify any recommendations for the current rehabilitation programme being used in the physiotherapy department of the Mid-Western Regional Hospital and thus help to improve the treatment and hence outcomes of patients following future ACL reconstruction. It will also give an insight into ACL rehabilitation within an Irish context

**7 CONDUCT OF PROJECT**

**Will the conduct of the project conform to the principles of the Declaration of Helsinki (the latest version of which can be found on the World Medical Association website, at: [www.wma.net](http://www.wma.net) )?**

Yes

**8 DESIGN OF THE STUDY**

**Describe briefly, including proposed methods for the analysis of the results.**

This study involves patients who been referred to the physiotherapy department over the past 5 years post ACL surgery and who been strength tested pre-operatively and again at 3, 6 and 12 months post-operatively on the Biodex System 3 isokinetic dynamometer. This current study involves a retrospective data mining analysis of tests performed on patients, who have already undergone ACL reconstruction between 2007 and 2011 and who have already finished their physiotherapy rehabilitation and attended all their orthopaedic appointments.

Through patient consent obtained by post or telephone, data already obtained from these isokinetic strength tests will be analysed and interpreted -approximately 130 tests. Analysis will be performed through statistical analysis software, specifically looking at comparisons for hamstring peak torques, hamstring to quadriceps ratios and time to peak torque. Intrinsic and extrinsic factors will be explored as potential influencing variables.

I also intend to obtain and analyse patients own subjective interpretation of their hamstring and global function following ACL reconstruction through a postal questionnaire (see appendix D, E, F).

## **9 SCIENTIFIC BACKGROUND**

**If this investigation has been done previously with human subjects, why repeat it?**

Patients after ACL reconstruction have high incidences of osteoarthritis, pain, chronic functional impairment and ACL re-injury (Lohmander et al., 2007, Paterno et al., 2012, Beynnon et al., 2005) and many do not return to previous sport/activity levels (Ardern et al., 2011). Despite advances many people do not return to their previous sporting level. Muscle strength is often tested following ACLR and has been identified as a key variable for guiding return to sport (Renstrom et al., 2008). Studies have identified chronic long term hamstring weakness in people following ACLR with hamstring grafting (Coombs and Cochrane, 2001, Ageberg et al., 2009, Emlinger et al., 2006) which can increase the risk of ACL rupture in women (Hewitt et al., 2001), and further hamstring injury (Croisier et al., 2008).

While long term studies have been performed, few studies have specifically examined hamstring strength pre-operatively and again at crucial time points following ACLR e.g. at six months post ACL, the time frame at which a decision for return to sport is often made (See MWRH ACL Rehab Protocol Appendix G). In studies where this has been performed sample sizes have been often low e.g. Keays et al. (2001) n=31. Together with this, no studies have specifically looked at ACLR rehabilitation in an Irish population given its unique sporting demands.

Data mining of this large sample size will provide an essential reference point for expected hamstring strength and provide a foundation for future research and help inform others as to optimal rehabilitation protocols. It would also provide the first insight into ACLR rehabilitation in an Irish context.

**If it has not been done with humans before, has the problem been worked out as fully as possible in animals, analytically, technically and to assess possible toxic effects?**

N/A

## **10 ETHICAL PROBLEMS**

**Please itemise here any ethical problems which you perceive to be associated with the research project:**

No ethical problems are anticipated once informed consent has been achieved.

## **11 SUBJECTS AND CONTROLS**

**How will the subjects and controls (if any) be selected and what wider population will they be representative of?**

All patients who have had primary ACL reconstruction performed by Mr. O Farrell, Consultant Orthopaedic Surgeon during 2007-2011 inclusive will be identified for inclusion in this research study. Patients will be

identified through records from the MWRH hospital inpatient enquiries (HIPE), and from physiotherapy records. Patients who have undergone isokinetic strength testing pre-operatively and also 3/6/12 months after surgery at the physiotherapy department in the MWRH, and who knowingly followed the existing physiotherapy rehabilitation protocol will be included. A lower age limit of 16 years old will be applied. No upper age limit.

Patients who have undergone multiple ligamentous surgery will be excluded. Patients who underwent ACL reconstruction using patellar tendon autografts will be excluded. Any patient who did not complete the requisite number of isokinetic tests will be excluded. The sample size will not discriminate on basis of sex or race.

**Will participants or controls undergo independent medical examination, before, during or after the project?**

No. All physical examinations have already been performed and this research aims to analyse data that already has been collected. Records of all objective isokinetic tests will be available for reference or review.

**What is the nature and extent of the medical examination that participants and controls are to undergo before participating in this project?**

No participant will be required to undergo any further medical examinations for inclusion on this project.

**How will the health of the participants and controls be monitored during and after the project?**

All participants have already completed the rehabilitation following their surgery and have attended any physiotherapy and orthopaedic consultant appointments as requested or desired and as such will not necessitate future monitoring of their health outside of normally accepted medical practice.

**If a placebo group is to be used, will the group receive the best standard of therapy?**

No placebo group.

**Will pregnancy be excluded?**

Any patients who identified themselves as being pregnant did not undergo isokinetic testing while pregnant and thus are excluded if they did not meet the inclusion criteria as already set out above.

**How many subjects and controls will be involved, and in what age groups?**

Approximately 300 have been assessed for inclusion and approximately 130 participants are expected to meet inclusion criteria.

**Have sample size calculations been checked with an expert statistician?**

Not yet but the sample size for this study is expected to be greater than previous similar studies such as Coombs and Cochrane (2001) which had 12 participants and Ardern et al. (2010) which included 50 participants.

**Where the analysis involves investigating differences between groups, please give details of the sample size calculations, including the minimum clinically important difference which you wish to be able to detect (e.g. "a sample of 25 patients and 25 controls will be sufficient to detect a difference of 20mm Hg between groups, with a power of 90% and a significance level of 5%").**

A similar study by Keays et al. (2001) found a statistically significant 10% deficit in hamstring strength 6 months following surgery in a study of 31 patients. This current study would be aiming to use a sample size considerably higher than this, thus allowing for improved statistical power. Coombs and Cochrane (2001) in a study of 12 patients identified an average knee flexor deficit of 23% up to 12 months post-surgery while Ardern et al. (2010) in a study of 50 patients identified deficits of 3-27% over 2 years post-surgery.

**12 DRUGS**

**(i) If drugs are to be used, do the drugs that are the subject of the investigation have Medicines Board approval for use in a clinical trial?**

N/A

**(ii) Drugs**

**(a) Please state all drugs involved in the study:**

N/A

**(b) Are these drugs being supplied by a drug company?**

N/A

**(c) Are the drugs used in the normal course of medical treatment?**

N/A

**(iii) Pharmacy Support**

**(a) Has the Hospital Pharmacist been informed?**

N/A

**(b) Where will supplies of drugs be kept?**

N/A

**(c) It is recommended that a copy of the Trial Codes be kept in Pharmacy. Do you object? If so, why?**

N/A

**(iv) What efforts will be made to exclude unknown drugs or other unknown medication in patients or volunteers?**

N/A

**(v) Substances to be given to subjects**

N/A

**(a) Describe any special diet, isotopic tracers, or other information related to this study.**

N/A

**(b) State routes of administration, amount and effect expected.**

N/A

### **13 RADIOACTIVE SUBSTANCES**

**If radio isotopes are to be used, you are required to register the project with the Radiation Protection Adviser (St James's Hospital). Are radio isotopes to be used in this study?**

N/A

**If radio isotopes are to be used, please indicate that approval has been obtained from the IRPP (and please provide a copy of the Authority Certificate).**

N/A

### **14 SAMPLES TO BE TAKEN FROM THE SUBJECT**

**(Venepuncture, arterial, urine, biopsy etc)**

**(a) State type of sample, frequency and amount**

N/A

**(b) Would the samples(s) be taken especially for this investigation or as part of normal patient care?**

N/A

### **15 PROCEDURES**

**Describe the exact procedures which will be applied to each subject.**

Isokinetic tests have already been performed on the Biodex System 3 Isokinetic dynamometer in the physiotherapy department in the Mid-Western Regional Hospital. For each test participant that meets inclusion criteria as set out earlier, a consent form (See Appendix C) and questionnaire (Appendix D,E,F) will be posted to each individual for reply within one month to consent or refuse the use of their test results in this research.

For patients who consent, the test results for values for hamstring and quadriceps peak torque, average peak torque, time to peak torque, hamstring to quadriceps ratios and range of motion will be recorded across three speeds of 60/180/240 degrees per second.

Demographic variables of age, sex, height, weight, occupation, leg dominance, length of injury and sport will also be recorded for each participant.

Statistical analysis will be performed using SPSS statistical analysis software.

## **16 DISCOMFORT AND ADVERSE EVENTS**

**What discomfort or interference, however slight, with their activities may be suffered by all or any of the subjects?**

None anticipated.

**Indicate how adverse events are to be notified and evaluated.**

If for any reason, a participant becomes concerned about any aspect of the study, he/she will be advised to contact the principal investigator (CM) directly. Each participant will be given the relevant email address and physiotherapy department number (on subject information leaflet).

## **17 SAFETY AND RISKS**

**Please give details of any potential hazards or side-effects, or other risks to subjects or to controls from investigative or therapeutic procedures or from withholding of therapy (this information must also be included in the Patient Information Sheet - see 3 (i)).**

None anticipated.

## **18 INFORMATION TO PATIENTS' GENERAL PRACTITIONERS**

**(a) Please indicate briefly the information that will be given to GPs about the involvement of their patients in the research project (for drug studies, this should include the name of the active drug, the possible mode of action, and known side effects).**

There will be no changes to a patient's usual routine or medical care.

There are no medical concerns associated with this study and therefore contact with the G.P. will not be necessary.

**(b) GPs may know of reasons why patients should not participate in the Study and a letter should be sent to the GP to ask whether he/she knows of any such reasons. Please confirm that such a letter will be sent.**

All participants have already underwent all physical tests and operations and this project will have no effect on a participants routine or medical care and the necessity for a GP letter is not foreseen.

## **19 VOLUNTEERS**

**(a) Are any payments to be made to volunteers? If so, please give details.**

No

**(b) Where it is proposed to recruit medical students or student nurses as volunteers, the supervising authorities must be informed. If applicable, please confirm that the supervising authorities have been so informed.**

N/A

## **20 CONSENT**

**Written consent of patients is required in all cases. Please confirm that such consent will be obtained (see 3(ii)).**

All participants that have met the inclusion criteria will be sent a consent form (see appendix) to the current address that is recorded on the hospital patient database. In the event of no responses, participants may be contacted by phone once to obtain if verbal consent can be obtained.

## **21 PATIENT INFORMATION SHEET**

**(a) A written Information Sheet about the Trial should be given to all participants before they are asked to give written consent (see 3(i)). This Information Sheet should be submitted to the Scientific Research Ethics Committee with this Protocol before approval can be given to the Study.**

**Is the draft Information Sheet attached?**

Yes: Please see appendix

**The Patient should be given the opportunity to take away and consider the Information Sheet and sign the consent form later. If this is not practical, the Patient should at least be given sufficient time to read and discuss it with relatives if he/she wishes to do so. Any discussion about the Trial between Patient and Investigator should be in person and not by telephone.**

Participants will be given one month to read and reply to the consent form and information sheet and may contact the principal investigator (CM) if any concerns or questions arise.

**Where Patients entering a Trial are under 16 years of age, you will be required to obtain the consent of both the Patient and the Patient's parents or guardian(s). If applicable, please indicate that such consent will be obtained:**

No participants under 16 years of age will be included.

**22 THE PRINCIPAL INVESTIGATOR IS RESPONSIBLE FOR INFORMING COLLEAGUES AND OTHER GROUPS WHO MAY BE INVOLVED OR AFFECTED BY THE RESEARCH.**

**Has this been done?**

Yes

(version dated 28 March 2002)

## Appendix B

### Information Leaflet

**Mr. DERMOT O FARRELL,  
Consultant Orthopaedic Surgeon,  
Regional Orthopaedic Hospital,  
Croom,  
Limerick**

Dear

I am writing to you to obtain your consent for participation in a research study.

#### **Aim:**

The aim of this study is to examine the effect of anterior cruciate ligament reconstruction using hamstring grafts on hamstring muscle strength and function following surgery.

#### **Procedure:**

People who had anterior cruciate ligament reconstruction surgery during 2007 and 2011 have been selected to be included in a research study. Before and during your rehabilitation following surgery you underwent Isokinetic strength testing in the Physiotherapy department in the Mid-Western Regional Hospital. We hope to analyse the information obtained on leg muscle strength to assess the effect that ACL surgery has on hamstring muscle strength.

Through the questionnaire provided we also want to get your opinion on the current state of your knee and hamstring muscle following surgery.

#### **Benefits:**

Analysis of your test results and the information you provide in the questionnaire may help us to improve the rehabilitation of future people who may injure their ACL and undergo an ACL reconstruction.

#### **Risks:**

There is no risk involved in this study and will have no negative effect on any future interaction with the physiotherapy department or hospital.

**Compensation:**

There will be no financial cost or reward for participating in this study.

**Confidentiality and voluntary participation:**

Your identity shall remain anonymous and confidential. All data recorded will not be traceable back to you and will be available to the research team only. Your name will not be published next to your data at any time during the study. You are not obliged to participate in the study. You may withdraw from the study at any time without giving a reason and you will not be penalised in any way.

**Further Information:**

If you are happy to be part of this study, please sign the consent form and fill in the questionnaires provided and return all documents in the stamped addressed envelope provided. If you require any additional information, please do not hesitate to contact Colum Moloney, Physiotherapy Department, 061-482151, [colum.moloney@hse.ie](mailto:colum.moloney@hse.ie)

**Complaint Procedure:**

If you have any concerns or complaints about this study and wish to contact someone independent, you may contact The Chairperson of the Mid-Western Ethics Committee.

The Chairperson  
Scientific Research Ethics Committee,  
Limerick Regional Hospital,  
Dooradoyle,  
Limerick.

Appendix C

**Consent Form**

Physiotherapy Department,  
Mid-Western Regional Hospital,  
Dooradoyle,  
Limerick

**Participant Consent Form**

Hamstring muscle function following anterior cruciate ligament reconstruction with hamstring grafts

Please read the following statements and place a tick in the box to indicate that you agree with the statement.

---

I have read and clearly understand all the detail provided on the subject information sheet.

I understand what the study is about, what is expected of me as a volunteer and why the study is being carried out.

I clearly understand that my participation is voluntary and that I can withdraw from this study at any time without explanation.

I agree to participate in this study AND have filled in and returned the enclosed questionnaires in the stamped addressed envelope provided

---

**If you are happy with the above statements and agree to participate in this study, please sign below and return all forms in the enclosed stamped addressed envelope provided.**

Participant: \_\_\_\_\_ Date: \_\_\_\_\_

Witness: \_\_\_\_\_

## Appendix D

	<b>Tegner Activity Score</b>	<b>ID ____</b>
Competitive sport	Football (national and international elite)	10
Competitive sport	Football (lower divisions), ice hockey, wrestling, gymnastics	9
Competitive sport	Squash, badminton, athletics (jumping), downhill skiing	8
Competitive sport	Tennis, athletics (running), motorcross/speedway, basketball, cross country	7
Recreational sport	Football, ice hockey, squash, athletics (jumping), cross-country	
Recreational sport	Tennis, badminton, basketball, downhill skiing, jogging (5x/week)	6
Work	Heavy labour (building etc.)	5
Competitive sport	Cycling, cross country skiing	
Recreational sport	Jogging (uneven ground >2x/week)	
Work	Moderately heavy labour (truck driver, heavy domestic work)	4
Recreational sport	Cycling, cross country skiing, jogging (even ground >2x/week)	
Work	Light labour	3
Competitive sport	Swimming	
Recreational sport	Swimming	
Walking	In forest possible	
Work	Very light labour	2
Walking	Uneven ground possible but forest impossible	
Work	Sedentary	1
Walking	Even ground only	
Work	Sick leave or disability allowance/pension because of knee problems	0

**If possible can you state the month and year that you had the injury to your anterior cruciate ligament: \_\_\_\_\_**

(In the event that you had a repeat ACL injury or injury to the opposite side, state the month and year for the first injury only)

**Have you had any other knee injury to either leg since your surgery for the above injury?**

**Yes\_\_ No\_\_\_\_**

**If yes, please describe: \_\_\_\_\_**

**Overall total (Tegner) – (0 – 10) Tegner Activity Score [52]** Rating systems in the evaluation of knee ligament injuries. Tegner Y, Lysholm J. *Clinical Orthopaedics and Related Research* 1985;198:43-49

Appendix E

The Knee-Self Efficacy Scale (K-SES)  
Instrument

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ID\_\_\_\_\_

For People who have sustained an Anterior Cruciate  
Ligament Injury

A Questionnaire on:

How certain you are about your ability to manage different  
activities *right now*

And

How certain you are about your knee function *in the  
future*

You should only give *your perception of* how certain *you  
are about your ability* to manage the activities and not  
how well you actually can perform the activities.

If never have tried the activity, you should say what you  
believe your ability is.

# Self-Efficacy of Knee function in patients with an ACL injury

Version 4, Copyright PiaThomeé 2003

## A. Daily Activities

Mark the box with the number that best represents how certain you are about the activity right now despite pain/discomfort.

0 = Not certain at all                      10 = Very

certain

How certain are you about:

	0	1	2	3	4	5	6	7	8	9	10
1) Taking a walk in a wooded area or rough ground											
2) Climbing up and down the stairs											
3) Going out dancing											
4) Jumping along the beach											
5) Running after small children											
6) Running after the bus/train											
7) Working in the garden											

## B. Sports and Leisure Activities

Mark the box with the number that best represents how certain you are about the activity right now despite pain/discomfort.

0 = Not certain at all                      10 = Very  
certain

How certain are you about:

	0	1	2	3	4	5	6	7	8	9	10
1) Cycling long distances											

2) Going cross-country skiing whilst on holidays?												
3) Going horse-riding												
4) Swimming												
5) Hiking in the mountains during an adventure trip												

### C. Physical Activities

Mark the box with the number that best represents how certain you are about the activity right now despite pain/discomfort.

0 = Not certain at all                      10 = Very certain

How certain are you about:

	0	1	2	3	4	5	6	7	8	9	10
1) Squatting											
2) Jumping sideways from one leg to the other											
3) Going for an intense work out a short time after an injury											
4) Performing a one-leg hop on the injured leg											
5) Moving around on an unsteady surface i.e. a boat out on the water											
6) Doing a fast twisting movement											

### D. Your Knee function in the future

Mark the box with the number that best represents how certain you are about the activity in the future.

0 = Not certain at all                      10 = Very certain

	0	1	2	3	4	5	6	7	8	9	10
1) How certain are you that you can participate at the same activity level as before											
2) How certain are you that you will not have new knee injuries											
3) How certain are you that your knee will not "give way"											
4) How certain are you that your knee will not get worse than before surgery											

Appendix F

The Knee-Self Efficacy Scale (K-SES)

Instrument

(K-SES Ham)

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ID\_\_\_\_\_

For People who have sustained an Anterior Cruciate  
Ligament Injury

A Questionnaire on:

How certain you are about your ability to manage different  
activities *right now*

And

How certain you are about your knee function *in the  
future*

You should only give *your perception of* how certain *you  
are about your ability* to manage the activities and not  
how well you actually can perform the activities.

If never have tried the activity, you should say what you  
believe your ability is.

## Self-Efficacy of Hamstring function in patients with an ACL injury

E: Hamstring function

Mark the box with the number that best represents how certain you are about the activity right now without pain/discomfort in your affected hamstring muscle

0 = Not certain at all                      10 = Very certain

How certain are you about:

	0	1	2	3	4	5	6	7	8	9	10
1) How certain are you about participating in activities of daily living without hamstring pain/discomfort											
2) How certain are you about participating in sporting activities without hamstring pain/discomfort?											
3) How certain are you about performing a squat without hamstring pain/discomfort?											
4) How certain are you about performing a one-leg hop on the injured leg without hamstring pain/discomfort?											
5) How certain about you about performing sudden acceleration/deceleration movements without hamstring pain/discomfort?											
6) How certain are you about performing twisting movements without hamstring pain/discomfort?											

## Appendix G

### Physiotherapy Management of Hamstring Graft Anterior Cruciate Ligament Reconstruction Mr O' Farrell's Protocol

Therapist Copy

#### Preoperatively (Dooradoyle)

- Explain Procedure and necessary commitment to Rehabilitation Process
  
- Isokinetic Testing
  - 60, 180, 240 deg/sec Bilaterally
  - Full range into terminal extension
  - 5 repetitions at each speed
  - Concentric quadriceps Vs Concentric hamstrings
  
- Exercise prescription as per objective knee and Isokinetic Assessment
- Avoid high impact exercise.
- Choose progressive resisted strengthening, stretching and/ or closed chain exercise.

#### Post-Operatively

##### **Week One (Instruction prior to D/C as Croom Inpatient)**

- Commence ROM exercises 0-110 deg flexion within pain limits
  - Push flexion using CPM or active assisted exercises
  - Push extension in prone lying with weight if necessary
  - Rest heel on roll - allow to fall into hyperextension
  
- Crutch Walking PWB to FWB as tolerated. Stair climbing prior to discharge
  
- Control swelling as appropriate (Cryocuff etc)
  
- Static Hamstrings
- Static Quadriceps
- Inner Range Quads
- Straight Leg Raise

## **Week 2 (OPD Dooradoyle 1<sup>st</sup> Visit)**

- Continue ROM exercises
  - Push extension in prone
  - Assisted active flexion/Isometric hamstrings using wall/heel slides
- IRQ with 3lbs weight multi-reps
- SLR 0-3lbs, lag dependant
- Gait re-education with one crutch. Progress to full weight bearing without crutches if tolerated and if good gait pattern achieved
- Heel lifts
- Stepping forward & backward  $\pm 30$  deg trunk incline
- Rocker board
- Hamstring and calf stretches

## **Week 3 (OPD Dooradoyle 2<sup>nd</sup> Visit)**

- ROM – Flexion c. 115 to Terminal Extension
- SLR/SLR with Ext Rot/ SLR with abd. with 5lbs weight multi-reps
- Heel Lifts
- Stepper - closed chain
- Wobble board/Neuromuscular re-education
- Single leg stance on affected leg
- Standing Quadriceps, Hamstrings and Calf stretches

## **Week 4 (OPD Dooradoyle 3<sup>rd</sup> Visit)**

- Continue SLR / SLR with ER/ SLR with Abd, with 5lbs multireps
- Commence stationary bicycle, high saddle, low resistance
- Commence mini squats to 30 multireps
- Correct any outstanding gait problems
- Continue stretches as above
- Continue wobble board, SLS and proprioception as above. Progress as tolerated
- Continue stepper, closed chain exercise, progress as tolerated

## **Week 5 (OPD Dooradoyle 4<sup>th</sup> Visit)**

- Continue SLR / SLR with ER/ SLR with Abd, with 5lbs multireps
- Continue stationary bicycle, high saddle, mid resistance
- Progress repetitions of mini squats
- Continue stretches as above
- Continue wobble board, SLS and proprioception as above. Progress as tolerated
- Continue stepper, closed chain exercise, progress as tolerated
- Commence Bilateral Hamstring strengthening with 5lbs multireps
- Commence unilateral step-downs/SLS mini-squats

### **At 6-8 weeks (OPD Dooradoyle r/v from clinic)**

Review of HEP

Address any outstanding problems with HEP

Commence through arc quadriceps strengthening exercises with 5lbs 0- 90

Discuss swimming, gym programme as appropriate with individual patients

### **12 weeks (OPD Dooradoyle)**

Isokinetic Testing

60, 180, 240 deg/sec

Full flexion to terminal extension

5 reps at each speed

Concentric quadriceps Vs concentric hamstrings

If isokinetic strength is 70-80 % of unaffected leg

Commence

- Light jogging. Straight lines and increasing speeds when tolerated progress to multidirectional training
- Lateral shuffles
- Jumping; Vertical and horizontal jump tests. Single and double leg testing
- Progress weights specific to isokinetic findings. Particularly agonist/ antagonist ratios
- Agility Drills
- Proprioceptive training
- Progress to sport specific training as tolerated

### **Isokinetic testing at 4 months**

- 60, 180, 240 deg/sec
- Full flexion to terminal extension
- Concentric Quadriceps Vs concentric Hamstrings
- 5 repetitions **at** each speed
- Full review prior to return to contact sport. Must be within specific isokinetic Values. Pain free, controlled swelling and tolerating sport specific training

**Review at 6 and 12 months post-operatively**

- Isokinetic testing as above
- Monitor for any problems

**Appendix H: Additional Results**

Tables H.1 and H.2 demonstrate the results of pre-operative versus post-operative isokinetic testing at 60 and 180°/s for females and males. Statistically significant changes occurred at both speeds for both genders

**Table H.1: Female pre-operative versus post-operative scores at 60 and 180°/s for unoperated limb**

Isokinetic Score	Pre-op	Six months post-op	Sig (2 tailed)
	Mean ±SD	Mean ±SD	P Value
PT @60 (Nm)	69.82 ±14.53	78.50 ±14.22	.03
PTBW @60 (%)	105.38 ±27.58	118.36 ±27.12	.03
PT@180 (Nm)	48.70 ±8.98	58.14 ±10.27	.00
PTBW@180 (%)	73.30 ±16.41	88.56 ±23.49	.00

Pre-op=pre-operative, Post-op=post-operative, SD=standard deviation, PT=peak torque, PTBW=peak torque as a percentage of body weight, Nm=newton metres, %=percentage, °/s=degrees per second, @60= testing at 60 degrees per second, @180= testing at 180degrees per second.

**Table H.2: Male pre-operative versus postoperative scores at 60 and 180°/s for unoperated limb**

Isokinetic Score	Pre-op	Six mths post-op	Sig (2 tailed)
	Mean ±SD	Mean ±SD	P Value
PT @60	103.66 ±27.40	127.50 ± 31.64	.00
PTBW @60	126.21 ± 28.69	154.79 ± 27.99	.00
PT@180	69.76 ± 22.08	90.38 ± 23.63	.00
PTBW@180	84.74 ± 24.30	109.85 ± 21.87	.00

Pre-op=pre-operative, Post-op=post-operative, mths=months, SD=standard deviation, PT=peak torque, PTBW=peak torque as a percentage of body weight, Nm=newton metres, %=percentage, °/s=degrees per second, @60= testing at 60 degrees per second, @180= testing at 180degrees per second

Tables H.3-H.5 show the results for correlations between pre-operative and post-operative isokinetic parameters as detailed in chapter four.

**Table H.3: Correlations between pre-operative and post-operative isokinetic parameters at 60°/s for operated leg**

Isokinetic Parameter	Six mth PT	Six mth Deficit	Six mth PTBW	Six mth TPT	Six mth Total work	Six mth Ave PT	Six mth H:Q Ratios
Pre-op PT	0.77**	-	-	-	-	-	-
Pre-op Deficit		0.28*	-	-	-	-	-
Pre-op PTBW			0.64**	-	-	-	-
Pre-op TPT				0.27*	-	-	-
Pre-op total work					0.68**	-	-
Pre-op ave PT						0.70**	-
Pre-op H:Q ratios							0.31*

°/s=degrees per second, six mth=six months post-operatively, PT=peak torque, six month deficit=PT deficit between operated and unoperated limbs, PTBW=peak torque as a percentage of body weight, TPT=time to peak torque, ave PT=average PT, H:Q ratios=hamstring:quadriceps ratios, pre-op=pre-operatively, \*\*Correlation is significant at the 0.01 level (2 tailed), \*Correlation is significant at the 0.05 level (2 tailed)

**Table H.4: Correlations between pre-operative and post-operative isokinetic parameters at 180°/s for operated leg**

Isokinetic Parameter	Six mth PT	Six mth Deficit	Six mth PTBW	Six mth TPT	Six mth Total work	Six mth Ave PT	Six mth Ratios
Pre-op PT	0.77**	-	-	-	-	-	-
Pre-op Deficit		0.42**	-	-	-	-	-
Pre-op PTBW			0.60**	-	-	-	-
Pre-op TPT				-0.73	-	-	-
Pre-op total work					0.58**	-	-
Pre-op ave PT						0.63**	-
Pre-op H:Q ratios							0.15

°/s=degrees per second, PT=peak torque, six mth=six months post-operatively, six month deficit=PT deficit between operated and unoperated limbs, PTBW=peak torque as a percentage of body weight, TPT=time to peak torque, ave PT=average PT, H:Q ratios=hamstring:quadriceps ratios, pre-op=pre-operatively, \*\*Correlation is significant at the 0.01 level (2 tailed), \*Correlation is significant at the 0.05 level (2 tailed)

**H.5: Correlations between pre-operative and post-operative isokinetic parameters at 240°/s for operated leg**

Isokinetic Parameter	Six mth PT	Six mth Deficit	Six mth PTBW	Six mth TPT	Six mth Total work	Six mth Ave PT	Six mth Ratios
Pre-op PT	0.78**	-	-	-	-	-	-
Pre-op Deficit		0.08	-	-	-	-	-
Pre-op PTBW			0.64**	-	-	-	-
Pre-op TPT				0.28*	-	-	-
Pre-op total work					0.59*	-	-
Pre-op ave PT						0.76**	-
Pre-op H:Q ratios							0.20

°/s=degrees per second, PT=peak torque, six mth=six months post-operatively, six month deficit=PT deficit between operated and unoperated limbs, PTBW=peak torque as a percentage of body weight, TPT=time to peak torque, ave PT=average PT, H:Q ratios=hamstring:quadriceps ratios, pre-op=pre-operatively, \*\*Correlation is significant at the 0.01 level (2 tailed), \*Correlation is significant at the 0.05 level (2 tailed)

**Table H.6: Correlations between functional measures**

<b>Outcome measure</b>	<b>Tegner</b>	<b>K-SES A</b>	<b>K-SES B</b>	<b>K-SES C</b>	<b>K-SES D</b>	<b>K-SES total</b>	<b>K-SES Ham</b>
<b>MEAN SCORE</b>							
Tegner	1	0.31*	0.46*	0.30**	0.25	0.34*	0.01
K-SES A	-	1	0.78**	0.73**	0.66**	0.86**	0.45**
K-SES B	-	-	1	0.77**	0.71**	0.89**	0.48**
K-SES C	-	-	-	1	0.79**	0.93**	0.57**
K-SES D	-	-	-	-	1	0.88**	0.44**
K-SES TOTAL	-	-	-	-	-	1	0.56**
K-SES HAM	-	-	-	-	-	-	1

\*\*Correlation is significant at the 0.01 level (2 tailed), \*Correlation is significant at the 0.05 level (2 tailed)

**Table H.7: Correlations between pre-operative isokinetic scores and functional measures at 60 and 180°/s for females**

<b>Outcome measure</b>	<b>Pre-op PT @60°/s</b>	<b>Pre-op PT deficits @60°/s</b>	<b>Pre-op PTBW @60°/s</b>	<b>Pre-op PT @180°/s</b>	<b>Pre-op PT deficits @180°/s</b>	<b>Pre-op PTBW @180°/s</b>
Tegner	-0.01	-0.04	0.38	0.06	-0.42	0.63*
K-SES total	0.03	0.42	0.37	0.30	-0.22	0.65**
K-SES Ham	0.21	0.00	0.34	0.26	-0.41	0.41

Pre-op=pre-operatively, PT=peak torque, PTBW= peak torque as percentage of body weight, °/s=degrees per second, @60=testing at 60 degrees per second, @180=testing at 180 degrees per second, \*\*Correlation is significant at the 0.01 level (2 tailed), \*Correlation is significant at the 0.05 level (2 tailed)

**Table H.8: Correlations between post-operative isokinetic scores and functional measures at 60 and 180°/s for females**

<b>Outcome measure</b>	Six mth PT @60°/s	Six mth PT deficits @60°/s	Six mth PTBW @60°/s	Six mth PT @180°/s	Six mth PT deficits @180°/s	Six mth PTBW @180°/s
Tegner	-0.14	0.15	0.29	-0.07	0.27	0.38
K-SES total	0.30	-0.44	0.51*	0.34	0.22	0.54*
K-SES Ham	0.61*	-0.67**	0.52*	0.62**	-0.11	0.53*

Six mth=six months post-operatively, PT=peak torque, PTBW= peak torque as percentage of body weight, °/s=degrees per second, @60=testing at 60 degrees per second, @180=testing at 180 degrees per second, \*\*Correlation is significant at the 0.01 level (2 tailed), \*Correlation is significant at the 0.05 level (2 tailed)

**Table H.9: Correlations between pre-operative isokinetic scores and functional measures at 60 and 180°/s for males**

<b>Outcome measure</b>	Pre-op PT @60°/s	Pre-op PT deficits @60°/s	Pre-op PTBW @60°/s	Pre-op PT @180°/s	Pre-op PT deficits @180°/s	Pre-op PTBW @180°/s
Tegner	0.25	0.13	0.26	0.23	0.06	0.36*
K-SES total	0.26	-0.30	0.36*	0.25	-0.12	0.37*
K-SES Ham	0.25	-0.37*	0.39*	0.19	-0.02	0.26

Pre-op=pre-operatively, PT=peak torque, PTBW=peak torque as a percentage of body weight, °/s=degrees per second, @60=testing at 60 degrees per second,

@180=testing at 180 degrees per second, \*\*Correlation is significant at the 0.01 level (2 tailed), \*Correlation is significant at the 0.05 level (2 tailed)

**Table H.10: Correlations between post-operative isokinetic scores and functional measures at 60 and 180°/s for males**

<b>Outcome measure</b>	Six month PT @60°/s	Six mth PT deficits @60°/s	Six mth PTBW @60°/s	Six mth PT @180°/s	Six mth PT deficits @180°/s	Six mth PTBW @180°/s
Tegner	.05	.305	.057	.153	.109	.095
KSES total	.11	-.046	.224	.087	.086	.138
KSES Ham	.288	-.273	.418**	.295	-.184	.414**

Six mth=six months post-operatively, PT=peak torque, PTBW=peak torque as a percentage of body weight, °/s=degrees per second, @60=testing at 60 degrees per second, @180=testing at 180 degrees per second, \*\*Correlation is significant at the 0.01 level (2 tailed)

**Table H.11: Correlations between pre-operative isokinetic scores and functional measures at 60 and 180°/s for TPT and hamstring:quadriceps ratios**

<b>Outcome measure</b>	Pre-op TPT @60°/s	Pre-op ham:quad ratios @60°/s	Pre-op TPT @180°/s	Pre-op ham:quad ratios @180°/s
Tegner	-0.09	0.08	-0.14	0.19
K-SES total	-0.42**	0.13	-0.22	0.22
K-SES Ham	-0.24	0.13	-0.19	0.11

Pre-op=pre-operative, TPT=time to peak torque, ham:quad=hamstring:quadriceps ratios, °/s=degrees per second, @60=testing at 60 degrees per second, @180=testing at 180 degrees per second, \*\*Correlation is significant at the 0.01 level (2 tailed)

**Table H.12 Correlations between post-operative isokinetic scores and functional measures at 60 and 180°/s for TPT and hamstring:quadriceps ratios**

<b>Outcome measure</b>	Post-op TPT @60°/s	Post-op ham:quad ratios @60°/s	Post-op TPT @180°/s	Post-op ham;quad ratios @180°/s
Tegner	0.05	-0.26	-0.06	-0.23
K-SES total	-0.14	-0.74	-0.12	-0.11
K-SES Ham	0.05	0.10	-0.07	0.21

Post-op=post-operative, TPT=time to peak torque, ham:quad=hamstring;quadriceps ratios, °/s=degrees per second, @60=testing at 60 degrees per second, @180=testing at 180 degrees per second,

