# The Relationship between Lower Extremity Balance, Objective, and Subjective Outcome Measures in Patients with ACL – Deficient and ACL – Reconstructed Knees

**Dr. Tony Young**

**MBChB, PG Dip Surg Anat.**

This thesis is submitted in partial fulfilment for the Degree of

Master of Human Movement Science

**School of Medical and Applied Sciences**

**Division of Higher Education**

**CQUniversity**

**Australia**

September 2014

**Supervisors:**

- Assoc Prof. Peter Reaburn, School of Medical and Applied Sciences, CQUniversity
- Assoc Prof. Erik Hohmann,
    - Department of Orthopaedics, Rockhampton Hospital, Central Queensland Health
- Dr. Ross Clark
    - Faculty of Health Sciences, Melbourne Campus, The Daniel Mannix Building, Young Street, Level 1-1.05

**USE OF THIS THESIS**

The literary and intellectual rights of the author must also be respected. If any passages from this thesis are quoted or closely paraphrased in paper or written work prepared by the user, the source of the passage must be fully acknowledged in the work. Shall the user wish to publish a paper of written work containing passages copied or closely paraphrased from this thesis, this would in total constitute an infringing copy for the purpose of the copyright Act, he or she must first obtain prior written permission of the author to do so.

**DECLARATION**

I do solemnly declare that this thesis does not incorporate, without acknowledgement, any material previously submitted for a degree or diploma in any institution of higher education, and that to the best of my knowledge and belief, it does not contain any material previously published or written by another person except where due reference is made in the text.

This thesis does not contain any defamatory material.

The author and the supervisors did not receive any payments in carrying out the study, and there is no conflict of interest.

**Tony J. C. Young** Signature:________________________

Date: ___/___/____

**ACKNOWLEDGEMENTS**

I would like to take this opportunity to convey my most grateful thanks to my supervisors both in Melbourne and in Rockhampton. To Peter and Erik, for their untiring encouragement, sage advice and wisdom, I am grateful to you. Of course the project would not be possible without Ross's software finetuning and advice when things went wrong.

Furthermore, I would like to thank Dr. Du Toit for his understanding and allowing me to carry out my testings in the Orthopaedic Department, Rockhampton Hospital. I would also like to thank the Physiotherapy Department of Rockhampton hospital for kindly providing the excellent facilities afterhours for subject testing.

The study would not be possible without those who helped and believed in me. Thank you to Ms. Louie Gregg and Ms. Tracey Hansen for assisting with the subject recruitments. My trusty 'sidekicks' Dr. Grant Kingston, Dr. Maria Sathievelu, our senior physiotherapist, Ms. Sally Chapman, and Ms. Jenny Latcham, for their brave and tireless efforts in achieving the number of subject test sessions possible in such a short time frame.

To the medical students, staff and their family members who volunteered to be my 'test dummies' to trial the various tests before the real testings on participants, the study would not have been possible without your contributions.

Lastly, I would like to thank my long suffering wife, for her unwavering belief and forever staunch support of me, for supporting me through the tough times and being tolerant being apart for the two years interstate. I am forever grateful of the sacrifices she has made for this to happen.

*Fiedes servanda Est*

## ABSTRACT

The purpose of the present study was to examine the relationship between single limb standing balance as measured by total Centre of Pressure (CoP) pathlength in a fixed time interval using the Wii™ Balance Board, objective outcome measures of knee function as assessed by single-legged hopping test, vertical jump test, isometric muscle strength of both the quadriceps and hamstring muscle groups, and common subjective knee rating scales in participants with ACL- deficient and ACL- reconstructed knees. Fit and physically active participants were recruited from the Sports Injury Clinic in Rockhampton Hospital. Participants were recruited to the ACL Deficient (ACLD) group with a clinical diagnosis of ACL rupture confirmed by MRI (n = 25, male = 13; female = 12; mean age = 29.0 ± 9.6 years). Similarly the participants for the ACL Reconstructed (ACLR) group were identified as those who have had an ACL reconstruction at least six months prior to recruitment (n = 25, male = 18; female = 7; mean age = 29.3 ± 9.4 years). Pearson-product moment correlation analysis revealed that a statistically insignificant weakly negative correlations between the CoP measure and other independent variables in the ACLD group. Similarly statistically insignificant weak correlations were identified between the CoP measure and the variables examined in the ACLR group. The present findings indicated that no statistically significant relationship existed between CoP measure, subjective functional scores, and objective measures of muscle strength and power.

# TABLE OF CONTENTS

## LIST OF FIGURES



## LIST OF TABLES

# CHAPTER ONE: INTRODUCTION

Tears or rupture of the ACL are the most common injury to the ligaments of the knee (DeLee, 2009). In Australia, ACL injuries account for over 20% of all injuries in Australian Football at both professional and amateur level (Cochrane et al, 2007). The data from the Australian Institute of Health and Welfare (which included all ACL reconstructions performed in private and public sectors in Australia) suggested that 50,187 ACL reconstructions were performed between 2003 and 2008. This equates to just over 10,000 procedures per year (Janssen et al, 2011).

It is estimated that in the USA there are more than 200,000 ACL tears occurring annually in the general population (Erikson *et al*, 2014). Dragoo et al. (2012) showed the incidence of ACL tears in National Collegiate Athletic Association (NCAA) athletes to be 1.42 per 10,000 athletic exposures. This high incidence of ACL injuries is also observed in servicemen. For example, the Defence Services Medical Rehabilitation Unit admits approximately 400 patients with ACL- deficient and ACL- reconstructed knees per year for rehabilitation (Carter et al, 1997).

The knee joint is a complex system with its main purpose to accept, transfer, and to dissipate loads generated at the ends of the long mechanical lever arms of the both femur and tibia (Dye, 2003). To maintain a functional and stable system, the knee is reliant not only on the surrounding ligaments to provide sensate adaptive linkages, but also the neuromuscular interactions between the central nervous system and the periarticular muscles of the joint. This mechano-sensory interaction is referred to as proprioception and is critical to maintain balance (Howell et al, 2013).

Adaptive balance is upset when the knee joint ligaments rupture with a rupture of the Anterior Cruciate Ligament (ACL) the most common form of ligament rupture of the knee (Janssen et al, 2011). A successful reconstruction of the ACL must accomplish both the restoration of ligamentous stability and the restitution of proprioception (Dhillon et al., 2011). It has been theorised that the ACL serves both a proprioceptive and mechanical function to provide stability to the knee.

To clinically validate ACL reconstruction outcome measures, three rating scales are widely recognised and frequently used to assess knee functions following ACL reconstruction. These are the Lysholm Scoring System (Lysholm 1982), the Tegner Activity Rating Scales (Tegner, 1985), and the International Knee Documentation Committee (IKDC) (Hefti, 1993).

Many ACL reconstruction studies have employed a spectrum of methods to objectively measure the relative degree of success, with several investigations observing poor relationships between the clinical signs, knee assessment scores, and the patients' satisfaction and functional abilities (Barrett et al, 1991; Harter et al, 1998; Roberts, 2007). To date there are studies yielding contrasting results regarding the role of proprioception in ACL- deficient and ACL- reconstructed knees (Friden, 2001; Dhilion et al 2011). Thus more investigations are required to examine the role of postural control in knees that are ACL-deficient and in knees following an ACL reconstruction.

The simple task of standing requires synergistic actions of muscles in the lower limbs. Impaired standing balance manifests itself in reduced functional ability and increased risk of falling (Clark et al, 2009). Studies have concluded that assessment of standing balance can provide useful assessments such as risks of falls in the elderly (Pirrtola, 2006; Deutsch et al, 2008; Higgins et al, 2010). Thus, measuring Centre of Pressure (CoP) pathlength is one of the most effective assessment tools for measuring standing balance (Jarnlo, 2003). Centre of Pressure (CoP) pathlength is essentially the tracing of the sway paths as the person stands in single-limb stance. Researchers have identified that CoP is an important objective outcome measure that is too subtle to detect using subjective scales (Pirrtola, 2006). Pirrtola (2006) critically reviewed and extracted the findings of prospective studies in literature where force platform measurements have been used as predictors of falls among elderly populations. The researcher observed that the mean amplitude of the medial-lateral (ML) movement of the CoP with the eyes open and closed, and the root-mean-square value of the ML displacement of CoP were the indicators that showed significant associations with future falls. It is widely agreed that CoP recordings taken from a force platform is the gold standard measure of balance (Lee, 2012).

While the force platform provides useful data for assessing standing balance, it is not without its problems. The equipment is costly, cumbersome to transport and set up, the test is time consuming, and the test procedure requires considerable technical expertise. Such limitations make the integrated use of force platforms difficult in a clinical setting (Clarke et al, 2009). Development of subjective assessment tools such as Berg Balance Scale (a 14-item written scale designed to measure single limb standing balance of the older adult in a clinical setting) provides useful clinical data, but it has been shown to be imprecise in detecting subtle changes in single limb standing balance as noted in the systematic review carried out by Blum (2008). In her review of 21 studies examining the psychometric properties of the Berg Balance Scale with a stroke population, Blum (2008) noted excellent internal consistency, interrater reliability (Interrater Correlation Coefficient = 0.97), and test-retest reliability (ICC = 0.98). However, the author also concluded that the Berg Balance Scale was unable to capture subtle changes in balance in some studies. Furthermore, a previous investigation had found that the relationship between the measure of CoP pathlengths and subjective assessments could only be described as moderate (Frykberg et al, 2007). Previous studies have argued that the amalgamation of the two modes of measurements may yield vital information that cannot be obtained by either method alone (Adkin 2003; Blum 2008).

Given the above issues with the use of force platforms, there is a need to develop a portable, inexpensive balance assessment system that is widely available and can consistently provide valid and reliable CoP pathlengths measurements such as those observed with a force platform. The Wii™ Balance Board, part of the unique Wii Fit™ video exercise game by Nintendo®, fits all the above criteria. It uses Bluetooth technology and employs four pressure transducers in each corner to measure the user's CoP, as well as the amount of body sway similar to that of the force platform. It is inexpensive, portable, easy to use, reliable to produce consistent results and capable of providing instant feedback (Clark et al, 2011).

The Wii™ balance board has in recent times been incorporated into rehabilitation programmes for those with a neurological balance deficit, as well as in some elderly populations (Deutsch et al, 2008; Higgins et al, 2010, Holmes et al, 2013). Clark et al. (2009) compared the data produced using the Wii™ Balance Board and a laboratory-grade force platform in 30 participants aged in the 20's, healthy and injury free. The participants were asked to perform a combination of single and double leg standing balance tests. The researchers observed that the Wii™ Balance Board produced reliable data comparable to that produced by the force platform. In their analysis, in conjunction with the ICC values, standard error measurements, and minimal detectable change values were calculated to assess the concurrent validity between the Wii™ balance board and the force platform. The study concluded that the Wii™ Balance Board is both a valid and reliable tool to assess standing balance.

More recently, Holmes et al. (2013) evaluated the validity of the Nintendo® Wii™ Balance Board in their cohort of twenty participants with diagnosed idiopathic Parkinson Disease. The participants completed testing on two balance tasks with eyes both open and closed on a Wii™ Balance Board and a force platform. The researchers were able to observe and demonstrate excellent concurrent validity across all tasks with significant intraclass coefficient values of 0.96, 0.98, 0.92 and 0.94 with eyes open and closed. They concluded that the Wii™ Balance Board is a valid tool for quantification of postural stability among individuals with Parkinson Disease.

Wii™ Balance Board has also been utilised in other studies such as Pua et al. (2011). These researchers evaluated relationships between knee extensor strength, standing balance, and the interactions with subjective physical function. In their study, the investigators recruited 104 participants with end stage osteoarthritis waiting for a total knee replacement. Standing balance was measured by the CoP displacement during quiet standing on a Wii™ balance board, and isometric knee extensor strength was measured using an isokinetic dynamometer. They found that standing balance in the saggital plane was positively correlated to physical functions among participants with lower knee extensor strength. While the relationship is complex, the study recommended further studies to develop interventional strategies for patients with osteoarthritis.

Clinically, the use of Wii™ Balance Board does not just validly and reliably measure the CoP, it is also able to measure isometric muscle strength by calculating the force vectors when coupled with computer software. This ability allows clinicians to objectively assess both the CoP measure and isometric muscle strength using this inexpensive, portable and valid system (Clark et al, 2010). Thus the Wii™ Balance Board could provide great benefits in the clinical assessment of function in patients who are ACL- deficient or who have had an ACL reconstruction. The data produced by the Wii™ Balance board, supplemented by the subjective assessment scales such as IKDC, Tegner Activity Rating Scale, and Lysolm Functional Score, may thus yield a more complete representation of knee function in patients who are ACL deficient or rehabilitating from an ACL reconstruction.

In a typically busy hospital orthopaedic outpatient clinic, with time pressures and the lack of expensive instrumentation to measure muscle strength and knee function, clinicians currently rely solely on common assessment scales and clinical examination findings to assess knee function. To date, minimal research has examined correlations between commonly used outcome scores, objective knee function, objective testing of muscle strength and single limb standing balance via CoP.

## PURPOSE OF THE STUDY

The purpose of the present study was to examine the relationship between single limb standing balance as measured by the overall CoP pathlength in a fixed time interval, objective outcome measures of knee function and commonly used subjective knee rating scales in participants with ACL- deficient (ACLD) and ACL- reconstructed (ACLR) knees.

The following hypotheses were generated in relation to this study:

- There is a significant relationship between single limb standing balance, and subjective knee outcome scale scores in participants with ACL- deficient (ACLD) and ACL- reconstructed (ACLR) knees.
- There is a significant relationship between single limb standing balance and muscle strength measurements in participants with ACLD and ACLR knees.
- There is a significant relationship between objective functional tests (single legged hop and vertical jump) and single limb standing balance.

This study aims to highlight that:

- If the study reveals a significant relationship between the three commonly used rating scales, and single limb standing balance, it would suggest the need for single limb standing balance testing to be considered as a rehabilitative criterion.
- If no significant relationship is observed between the rating scales, functional tests and single limb standing balance, then other criteria may need to be evaluated as

criteria that may predict the ability for ACLD and ACLR patients to return to their daily and/or sports activities.

**ASSUMPTIONS**

The following assumptions were made in the present study:

1. Participation was voluntary from the participants.
2. Participants followed the given directions when answering the questionnaires.
3. Participants answered all questions honestly and by themselves.

The following exclusions were applied to this study:

1. Age group was delimited to 16 and 55 years of age
2. Physically active participants who play or train for sports on a regular three day per week basis were recruited for the study.
3. Participants were required to be residents of Central Queensland Health catchment area.
4. Potential participants were not considered if unable to comprehend the instructions or explanations given due to impaired intellectual/mental capacity, or a language barrier.
5. Potential participants who are highly dependent on medical care were not considered.
6. Participants who were unable to maintain balance in single leg stance, and thus a potential risk of injury to self were excluded.

The following limitations apply to the study:

1. Small sample size.
2. Reliance on participants' subjective responses to the function – based questionnaires.
3. Types of graft used in ACLR group were not specified.
4. ACLR group participants' operations were done by more than one surgeon.

*ACLD Group*: Group of voluntary participants with clinically diagnosed and MRI verified ACL deficient knee, with the index injury occurring more than six weeks prior to being recruited to the study.

*ACLR Group*: Group of voluntary participants who had undergone ACL reconstruction more than six months prior to being recruited to this study.

# CHAPTER TWO: LITERATURE REVIEW

This chapter presents the anatomical and functional roles of the ACL, examines the debate regarding neuromuscular properties of the ACL, examines the relationship between proprioception and balance as well as the research literature examining the relationships between single leg postural control, objective muscle strength tests and subjective functional scores.

## 2.1 ANATOMY AND BIOMECHANICAL FUNCTIONS OF ACL

Anatomically, the knee is a synovial joint connecting the distal ends of the femur and the proximal end of the tibia, with the patella articulating with the femur anteriorly. The hamstrings muscles are the major flexors of the knee, while the quadriceps muscle group extends the knee. The quadriceps muscle group has four parts which converge to form the quadriceps tendon that inserts into the patella (Canale & Beaty, 2007).

Knee ligaments contribute to the stability of the knee. These ligaments can be classified as extra-capsular and intra-articular. The major extra-capsular ligaments of the knee are the medial collateral ligament (MCL), and lateral collateral ligaments (LCL). These structures are tested when assessing the lateral stability of the knee. The main intra-articular ligaments are the anterior and posterior cruciate ligaments (ACL and PCL) that are essential for the antero-posterior stability of the knee joint (Dhillion et al, 2011). The ACL, combining with the medial and lateral supporting structures, maintains not only the stability in the saggital plane, but also contributes to the rotatory stability of a knee (Yoo et al, 2005; Howells et al, 2014). The ACL prevents posterior displacement of the femur on the tibia, and the PCL prevents anterior displacement of the femur on the tibia (Rockwood & Green, 2009). Apart from the simple flexion-extension movements, the knee also passively rotates when moving from flexion to full extension. The shorter, more highly curved lateral femoral condyle exhausts its articulation and is checked by ACL. In contrast, the larger and less curved medial femoral condyle continues its forward roll and skids backwards, assisted by tightening of the PCL. As the knee continues to reach full extension, the femur rotates internally, the tibia moves forward and internally rotates, the collateral ligaments tighten and the lateral femoral condyle impacts the posterior lateral tibial plateau (Canale & Beaty, 2007). This is known as the 'screw home' mechanism, and allows the knee to lock into a rigid structure that can support the body weight (McMinn, 1994).

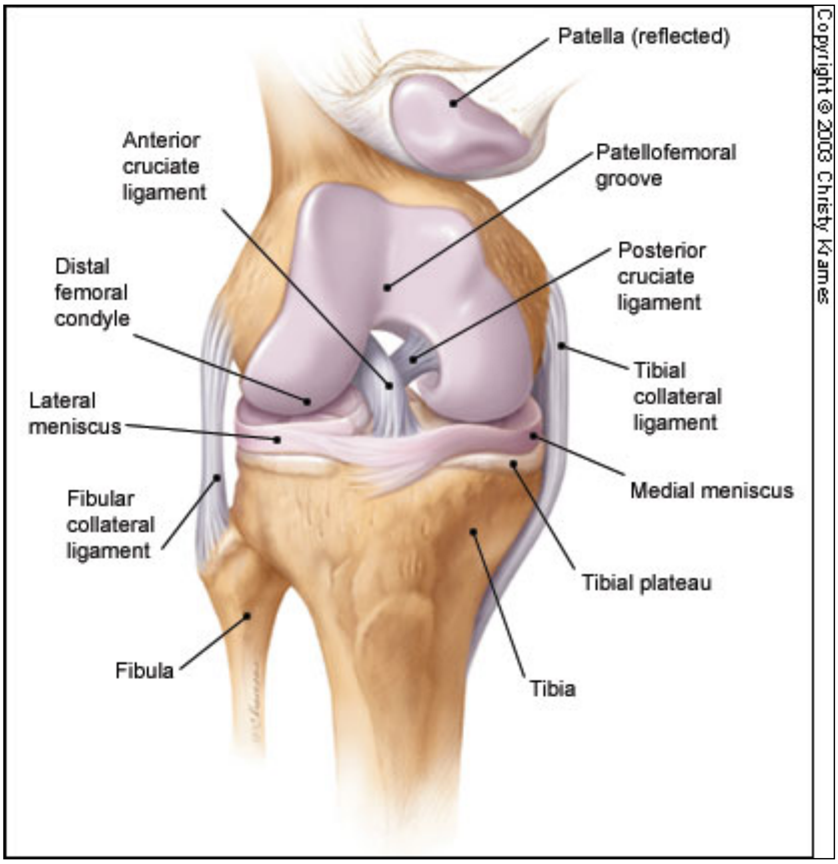


**FIGURE 1.** Anatomy of the knee.

Reprinted from Tandeter HB, Shvartzman P, Stevens MA. Acute Knee Injuries: Use of Decision Rules for Selective Radiograph Ordering. *Am Fam Physician* 1999; 60:2600.

The ACL is composed of longitudinally oriented bundles of collagen tissue arranged in fascicular subunits within larger functional bands. It consists of an anteromedial band, and a bulky posterolateral band (Diermann et al, 2009). The ACL is surrounded by synovium (the inside soft tissue lining of the knee producing small amount of fluid lubricating the knee), thus making it extrasynovial. The ACL inserts on the tibial plateau, medial to the insertion of the anterior horn of the lateral meniscus in a depressed area anterolateral to the anterior tibial spine (McMinn, 1994). The tibial attachment site is larger and more secure than the femoral site. It is typically 31 to 35 mm in length and 31 $mm^2$ in cross section (Canale & Beaty, 2007).

The ACL is the primary restraint to anterior tibial displacement, accounting for approximately 85% of the resistance to the anterior drawer test (where the tibia is pulled anteriorly on femur on clinical examination to assess stability of the knee in the anteroposterior plane) when the knee is flexed at 90 degrees (Canale & Beaty, 2007). Selective sectioning of the ACL has shown that the anteromedial band is tight in flexion, and provides the primary restraint when the knee is flexed (Canale and Beaty, 2007; Zantop et al, 2007). The posterolateral bulky portion of this ligament is tight in extension, thus providing the principal resistance for hyperextension (Hoppenfeld, 2009). Tension in the ACL is least at 30 to 40 degrees of knee flexion (Zantop et al, 2007). The ACL also functions as a secondary restraint on tibial rotation and varus-valgus angulation (angulation of lower leg away or towards the midline of the body) at full extension (Canale & Beaty, 2007; Gabriel et al, 2004).

## 2.2 SENSONEURAL FUNCTION OF ACL

In addition to its mechanical restraining function, the ACL also possesses an extensive sensory neural network (Dhillion et al, 2011). This neural network provides the anatomical basis for vital neuromuscular control including joint positional sense and motion, as well as muscular reflex stabilisation about the knee joint (Gomez- Barrena et al, 2008). This is referred to as proprioception.

There are several reports examining the presence of mechanoreceptors within the ACL (Lee et al, 2009). For example, Schutte et al. (1987) noted an extensive intra-ligamentous neural network in the cavaderic ACL specimens they obtained. Using a modified technique of Gairns gold chloride stain for neural elements, three types of mechanoreceptors and free nerve endings were identified. Two were of the slow adapting Ruffini type, and the third, a rapidly adapting receptor, the Pacinian corpuscle (Schutte et al, 1987). The rapidly adapting receptors register motion, and the slow adapting receptors detect speed and acceleration. The free nerve endings are found to be responsible for pain. In a series of studies, Kraupse et al. (1992 & 1995)` found that there was a functional connection between ACL mechanoreceptors and the posterior articular and sciatic nerves (Kraupse et al, 1992; Kraupse, 1995). The proprioceptive mechanism serves to protect the joint against excessive strain during activities and provides prophylaxis to recurrent injuries (Nagai et al, 2013; Taketomi, 2014).

## 2.3 SEQUALAE OF ACL RUPTURE AND ACL RECONSTRUCTION

Biomechanically, leaving a ruptured ACL untreated may result in antero-lateral rotatory instability, leading to excessive forward rotation of tibial plateau with excessive lateral opening of the joint, and excessive internal rotation of tibia on femur in flexion (Yoo et al, 2005). A subluxation of the tibia on femur will result as the knee extends (Rong, 1987). Leaving a ruptured ACL untreated can also result in repeated episodes of 'giving way' in which the knee fails under conditions of rotational stress (Tashiro et al, 2009). Non-operative management of the knee symptomatic of anterior cruciate deficiency has also been shown to lead to further rotatory instability, meniscal or chondral injury as well as premature joint degeneration (Noyes et al, 1983; Tashiro et al, 2009).

The goal of ACL reconstruction has always been to improve the patients' level of function, with minimal disability. In the past, the focus of ACL reconstruction has been on perfecting how to reconstruct a mechanically strong ligament (O'Neill, 2001; Canale & Beaty, 2007). However, researchers have also hypothesised that to achieve a successful ACL reconstruction, not only is there a need to maintain or develop the strength, range of motion and integrity of the ligament graft, but also a need for recovery of proprioception following ACL reconstruction (Barrett, 1991; Reider *et al*, 2003; Yoo et al, 2006; Roberts 2007; Ingersoll, 2008; Cooper 2011).

## 2.4 MEASURES OF RESTORATION OF FUNCTION AND ASSOCIATED DEBATES

Many ACL reconstruction studies have examined a variety of methods to objectively measure the relative degree of success of the procedure. Several investigations have observed poor correlations between the clinical signs, knee assessment measures, and the patients' satisfaction and functional abilities (Barrett *et al*, 1991; Harter et al, 1998; Roberts, 2000). For example, Barrett et al. (1991) assessed 45 patients who had undergone ACL reconstruction by a modified technique using bone-patellar tendon-bone graft (BPTB graft). Using standard knee scores and clinical ligament testing, the investigators reported that there was a poor correlation between the objective testing results, the patients' own opinions, and functional outcomes. However, employing similar techniques, other researchers have observed positive correlations between the improvement of proprioception in the knee, knee function and patients' satisfaction following ACL reconstruction (Kocher 2004; Roberts 2007).

Fischer-Rasmussen and Jensen (2000) examined the performance and proprioception of the knee joint in three groups of participants: ACL- deficient (ACLD) patients, ACL- reconstructed (ACLR) patients and a group of healthy participants acting as controls. The subjective function was evaluated using Lysholm Knee Score and Tegner Activity Rating Scale, the knee joint laxity was measured with Stryker's laxity tester with the knee flexed at 25 degrees and 70 degrees, and objective performance was assessed using results of one legged hop test as well as a triple jump distance. The researchers observed a significantly lower hop and triple jump distance in both the ACLD and ACLR groups when compared to the control group. They also reported a significantly decreased level of proprioception in both the ACLD and ACLR groups.

Other studies have drawn attention to both the sensory role of the ACL and the proprioceptive deficits following ACL injury (Corrigan et al, 1999; Pap et al, 1999; Roberts et al, 2000; Friden, 2001; Gomez- Barrena 2008). However a number of other investigations have not observed a significant difference when comparing patients' proprioceptive abilities to those of uninjured controls or the patient's own uninjured limb (MacDonald et al, 1996; Hooper et al, 2003; Mir et al, 2008, Taketomi et al, 2014). Furthermore, several published studies have documented significant improvement of pre-operative deficits in proprioception following ACL reconstruction (Fremerey et al, 2000; Roberts et al, 2000; Reider et al, 2003; Muaidi et al, 2009).

Thus, to date there are studies yielding contrasting results regarding the role of proprioception in ACL- deficient and ACL- reconstructed knees (Friden, 2001; Dhilion et al 2011). Bryant (2008) investigated the neuromuscular variables that related to the functional outcomes in 13 patients who had BPTB graft ACL reconstruction. Using the Cincinnati Knee Rating Scale to evaluate subjective knee function, and the median electromyographic (EMG) readings from Vastus Medialis and Vastus Lateralis as objective measurements, the data was compared with the same readings taken from the uninvolved limb. The researchers observed only a moderate correlation between the knee functionality and EMG readings. Gokeler et al. (2012) recently reviewed all currently available studies to establish any clinical relevance of proprioceptive deficits in ACLD or ACLR participants from English, Dutch and German electronic research databases. The literature search included studies published between January 1990 and June 2009. Of all 1161 relevant studies, only 24 met the inclusion criteria. The authors commented that most of the 24 studies failed to perform measurements of reliability of the test devices employed. They also noted four studies reported a moderate correlation between proprioception, strength, balance or single-legged hop test results. Thus, it appears that more investigations are required to examine the role of proprioception in ACLD and ACLR knees.

A number of previous studies have evaluated changes in proprioception in both the ACLD and ACLR participants (Carter et al, 1997; Iwasa et al, 2000; Hopper 2003; Mir et al, 2008; Muaidi et al, 2009). These researchers agreed that with current reconstructive methods, the restoration of mechanical stability is very successful (Woo et al, 2002; Sasaki et al, 2014). However, there continues to be an ongoing professional debate regarding the re-establishment of proprioceptive function in the injured knee following ACL reconstruction, and its relationship to both patients' and surgeons' perception of a successful outcome (Howells, 2013). Some researchers have noted that a patient's perception of a successful ACL reconstruction seems to more positively correlate with restored proprioception rather than with mechanical stability (Reider, 2003; Roberts, 2007).

## 2.5 PROPRIOCEPTION AND SINGLE LIMB STANDING BALANCE

With the advancement of technology available, the search for a valid tool to better assess knee function continues. Authors such as Boerbroom et al. (2008) measured the reliability and validity of methods commonly used to quantify proprioception. They examined the validity of Threshold to Detect Passive Motion (TTDPM). With 16 healthy volunteers lying on their side, with the tested leg strapped on an apparatus.(Figure 2), the apparatus held the leg in 20 degrees and/or in 40 degrees of flexion, while the hydraulic part of the apparatus passively moving the knee towards

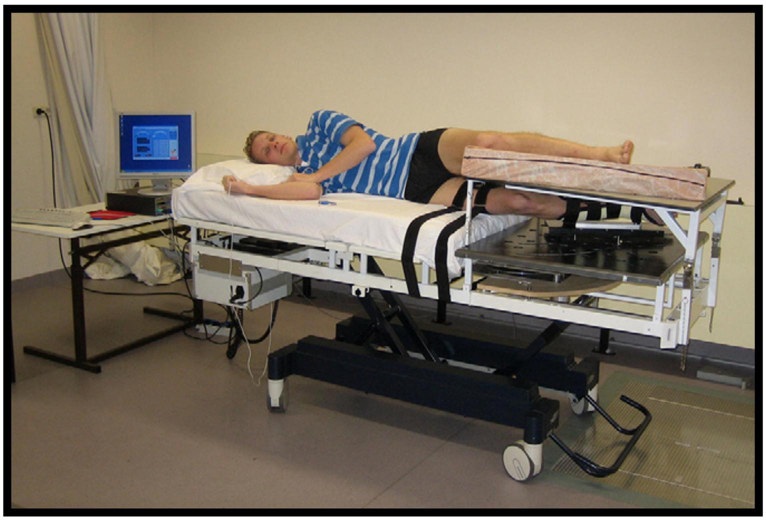

**Fig. 2: Apparatus to assess validity of TTDPM as used in Boerbrooms (2008) study**

extension or towards further flexion. By lying on their side, the researchers argued that any movements of the limb were eliminated at the pelvis and ankle, so that the only movement the participants could feel would be from the knee only. The participants were blind folded as well as with earphones to eliminate any visual or auditory cues (Figure 3). The participants were encouraged to push a button in their hand as soon as they could register the knee being flexed or extended. The authors noted that the threshold to detect passive motion were different depending on both the direction of motion and the starting position of the limb. They also observed that the threshold was lower when the knee was held in twenty degrees flexion and was moved passively towards extension, and when the knee was held in forty degrees flexion and was moved passively towards further flexion. Furthermore, they reported that this threshold rose with age. However, they concluded that TTDPM was a valid and reliable method to quantify proprioception in individuals.

**Fig. 3: Hydraulic apparatus as outlined in Boerbroom et al (2008) study**

Few studies have examined the relationship between the concept of proprioception and single limb standing balance. Research groups such as Lee et al. (2009), examined whether proprioception, muscle strength, and knee laxity were related to dynamic standing balance with ACLD knees. In their study, they employed an apparatus (see Figure 4) not dissimilar to that of Boerboom et al. (2008) to measure TTDPM as well as Passive Repositioning (PRP). They also performed quadriceps and hamstrings strength tests, single limb balance tests using a force platform (see Figure 5), as well as measuring amount of knee laxity using an instrument known as KT 1000. They concluded that knee laxity, PRP proprioception, and muscle strength did not correlate with single limb standing balance. However they observed a positive and significant correlation between TTDPM proprioception and single limb standing balance ($r = 0.579$, $p < 0.05$).

**Fig. 4: the apparatus designed in Lee *et al* (2009) to assess proprioception**

Cooper et al. (2005) completed an extensive literature review to investigate the effect of proprioceptive and balance exercises on outcomes following injury and surgical reconstruction of the ACL. They initially reviewed 1532 papers in the English speaking literature. These studies included randomised control trials, randomised trials, case series, cohort studies, and observational studies. Through their stringent criteria, only seven studies were analysed and of these five were randomised controlled trials and two retrospective analyses. They concluded that proprioceptive and balance exercises improve outcomes in people with ACLD knees. They also concluded that there was an improvement in proprioception, muscle strength, perceived knee joint function, and hop testing performance after these exercises. Finally, they concluded that further research on the effect of proprioceptive and balance exercise was required.

More recently, Howells et al. (2011) conducted a systematic review to determine whether lower limb postural control and static balance was restored in patients following ACLR when compared to healthy controls. Searching through a number of databases and having inclusion criteria, ten studies were identified for review.  These ten studies included 644 participants with a mean follow-up period of 29 months.  While there were marked discrepancies between the postural control protocols used, all studies evaluated a single-limb stance task and four studies measured postural control in bilateral stance. Howells et al. (2011) noted a limited number of studies had investigated postural control and static balance in ACLR participants. They concluded that there is a trend towards impaired static and dynamic postural control in patients following ACL reconstruction surgery.

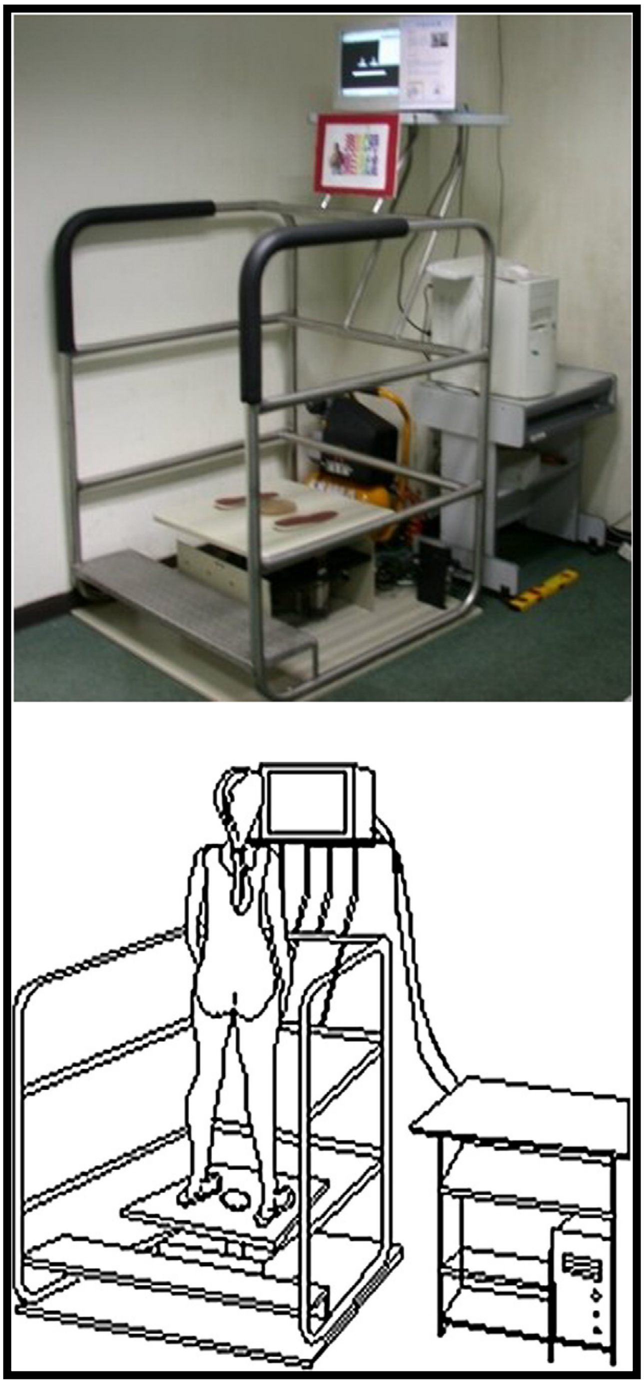

**Fig. 5: Force plate platform used in Lee et al. (2009) study**

To date, there are only limited number of studies available evaluating relationships between the CoP pathlength measure, objective and subjective function of the knee in ACLD and ACLR cohort of participants. Ageberg et al. (2005) evaluated the relationship between single limb stance, proprioception, leg strength and subjective function in a cohort of 36 participants. The participants were young males and females (mean = 26 years old), with no visual or vestibular disturbances, and no other known limb injuries other than a knee that is diagnosed to be ACL deficient. Knee laxity, proprioception, single limb standing balance and muscle strength were measured in these participants. The participants were instructed to stand on the force platform barefeet, with foot facing forward and the tested leg kept straight at the hip and the knee joints (see Figure 6). The opposite leg was flexed at 90 degrees at both the hip and knee joints, and the participants were asked to stand motionless for 20 seconds. This was repeated three times for each leg. Using an isokinetic dynometer, the leg muscle strength was measured, and estimation of subjective extremity function was obtained using a visual analogue scale. They reported that high knee laxity values were associated with higher values of excursion of CoP pathlengths in women but not in men, and those with low excursion values in single leg stance were those with better subjective function. In summary, with the current evidence

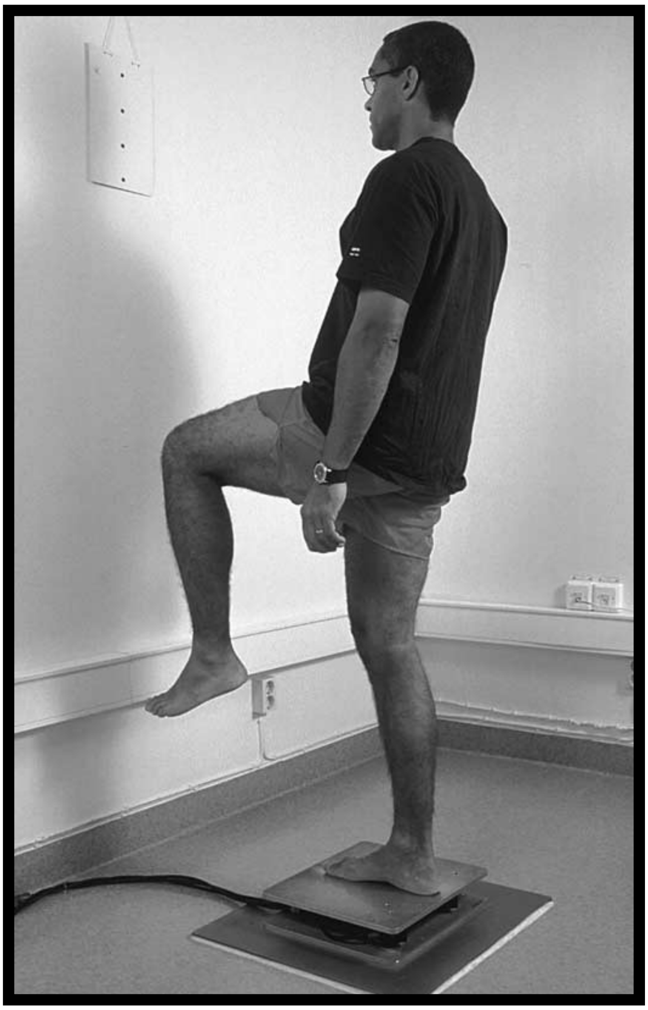

**Fig. 6: Force plate demonstration to assess single limb standing balance in Ageberg *et al*.**

available, there appears to be some relationship between single leg balance and overall knee function.

## 2.6 NINTENDO® Wii™ BALANCE BOARD

Employing a Wii™ Balance Board (WBB), Howell et al. (21013) more recently were able to compare static single leg postural control in their cohort of 45 participants who have undergone ACL reconstruction surgery to a group of healthy controls. The age-matched cohort included 30 men and 15 women were between six months to two years following a four strands hamstrings graft reconstruction of ACL. The researchers noted that when compared with the control group, the antero-posterior excursion of CoP pathlengths were significantly increased in the ACLR group for both the operated and non-operated leg. It was concluded that those who have had their ACL reconstructed exhibited reduced ability in both limbs to control the movement of the body in the anterior-posterior plane. The study also recommended that a Wii™ Balance Board may help clinicians to identify patients with deficits who may benefit from targeted neuromuscular training programmes.

In their study, Abujaber et al (2015) evaluated the validity of the WBB during dynamic tasks in 35 individuals before or within one year of total knee joint arthroplasty. The purpose of the study was to determine the concurrent validity of force measurement acquired from the WBB as compared to the laboratory grade force plates. The participants performed a sit-to- stand and return-to-sit task in two conditions. First subjects performed the task with both feet placed on single WBB. Secondly the task was repeated with each foot on an individual force plate. They reported that both the force plates and the WBB exhibited excellent agreement for all outcome measurements (ICC = 0.83 – 0.99). They concluded that the WBB may serve as a valid, suitable and low cost alternative to expensive, laboratory force plates for measuring weight bearing asymmetry in clinical settings.

There is a constant evolution of methods to assess knee function from proprioception, to the concept of stabilometry, the study of postural control in standing stance. The role of proprioception in knee function is fiercely debated in the literature, and there is limited data available on incorporating stabilometry in assessing knee function. From the few studies currently available, there may be a relationship between single leg standing balance, leg muscle strength and subjective function of the knee. There needs to be more studies examining such possible relationships.

Coupled with appropriate software, the Wii™ balance board has established to be a valid and accurate tool to assess leg balance (Clark et al, 2010; Abujaber et al, 2015). It is versatile to not only measure CoP pathlengths, but also to measure muscle strength in quadriceps and hamstrings. It is portable, inexpensive and can potentially be available to every orthopaedic outpatient clinic to assess knee functions of ACLD and ACLR patients.

**CHAPTER THREE: INTENDED JOURNAL ARTICLE FOR *THE AMERICAN JOURNAL OF SPORTS MEDICINE***

**The Relationship between Lower Extremity Balance, Objective, and Subjective Outcome Measures in Patients with ACL – Deficient and ACL – Reconstructed Knees**

***Corresponding Author:***

Dr. Tony Young

E-mail: t.young8@me.com

***Second Author:***

Associate Professor Peter Reaburn

School of Medical and Applied Sciences, Division of Higher Education, CQUniversity, Rockhampton, QLD, AUSTRALIA, 4702.

E-mail: p.reaburn@cqu.edu.au

***Third Author***

Associate Professor Erik Hohmann

Department of Orthopaedics, Rockhampton Hospital, Queensland Health

E-mail: Erik_Hohmann@health.qld.gov.au

## ABSTRACT

**Background:**

Few studies have examined the relationship between single limb standing balance using Centre of Pressure (CoP) pathlength, objective tests, and subjective functional outcome measures in knees that are either ACL deficient or have had an ACL reconstruction.

**Hypothesis/Purpose:**

The purpose of the present study was to examine the relationships between the total CoP pathlengths when participants are standing on the affected leg, objective outcome measures of knee function as assessed by the single-legged hopping test, single leg vertical leap test, isometric muscle strength of both the quadriceps and hamstring muscle groups, and commonly used subjective knee rating scales in subjects with ACL- deficient (ACLD) and ACL- reconstructed (ACLR) knees.

**Study Design:**

Case – Control Study

**Methods:**

Fit and physically active participants were recruited from the sports injury clinic in the hospital where the study took place. The participants are recruited to the ACLD group with a clinical diagnosis of ACL rupture confirmed by MRI (n = 25, male = 13; female = 12; mean age = 29.0 ± 9.6 years). In ACLR group, the participants were identified as those who have had an ACL reconstruction at least six months prior to the recruitment (n = 25, male = 18, female = 7; mean age = 29.3 ± 9.4 years). Using the Wii™ Balance Board, the total Centre of Pressure (CoP) Pathlength was

used as the CoP measure, with the participants performing single limb standing balance. The strength readings of the quadriceps and the hamstrings were also obtained employing the Wii™ Balance Board. Single-legged hop and single vertical leap tests results were also obtained as objective functional measurements, the participants also completed the Tegner, the Lysholm and the IKDC subjective functional outcome measures.

**Results:**

In the ACLD group, weak negative correlations were noted between CoP measure, objective tests, and the three subjective functional outcome measures. There were statistically significant strong correlations between the variables examined in the ACLD group. The quadriceps strength measure was strongly correlated to the single legged hop distance reading ($r(23) = 0.70$, $p < 0.05$). There were strong correlations between the single-legged hop distances and the single leg vertical leap distances ($r(23) = 0.80$, $p < 0.05$); between the single-legged hop distances and the Tegner subjective score values ($r(23) = 0.50$, $p < 0.05$), and between the single-legged hop distances and the IKDC values ($r(23) = 0.55$, $p < 0.05$). Similarly, the single leg vertical leap measure was strongly correlated with all three subjective functional outcome measures in the present study. There was also a strong correlation noted between the Lysholm subjective functional outcome measure and the IKDC subjective functional outcome measure.

In the ACLR cohort of participants, weak correlations were revealed between the CoP measure and other independent variables examined at the $p$ level of 0.05. Moreover, we noted that the quadriceps strength measure was strongly correlated with the hamstrings strength measure ($r(23) = 0.57$, $p < 0.05$), and the single-legged hop measure ($r(23) = 0.63$, $p < 0.05$). A strong correlation was demonstrated between the single-legged hop measure and the single leg vertical leap measure (($r(23) = 0.58$, $p < 0.05$). Similarly, a strong correlation was also observed between the Tegner subjective functional outcome measure and the IKDC functional outcome measure ($r(23) = 0.89$, $p < 0.05$).

There was a statistically significant moderate correlation between quadriceps strength measure and single leg vertical leap measure ($r(23) = 0.44$, $p < 0.05$).

**Conclusions:**

Neither group demonstrated a statistically significant relationship between the CoP measure, objective muscle strength tests, objective functional tests and the subjective functional outcome measures. Single limb standing balance cannot be used as the lone criterion to predict the ability for ACLD and ACLR patients to return to their daily and/or sports activities.

**Clinical Relevance:**

Coupled with appropriate software, the Wii™ balance board is able to not only assess CoP pathlengths, but also to measure muscle groups strength in the lower limbs.

## INTRODUCTION

Single limb standing balance asymmetry is prevalent in a wide range of clinical populations, such as those who have had lower limb surgery, or those with neurological deficits (Clark, 2011). It requires the continuous adjustment of muscle activity and joint position to retain the body's centre of gravity over the base of support (Clark et al, 2009). Very few studies have used Centre of Pressure (CoP) pathlengths to assess function in ACL deficient (ACLD) individuals and those who have had ACL reconstruction (ACLR).

Few studies have examined the relationship between proprioception and single limb standing balance. Research groups such as Lee et al. (2009) have examined whether proprioception, muscle strength and knee laxity are related to dynamic standing balance in individuals with ACLD knees. In their study, they measured Threshold for Detection of Passive Motion (TTDPM) as well as Passive Repositioning (PRP). They also performed quadriceps and hamstrings strength tests, single limb balance tests using a force platform (see Figure 3), and knee laxity using a KT 1000. They concluded that knee laxity, PRP proprioception, and muscle strength did not correlate with standing balance. However they observed a strong and statistically significant relationship between TTDPM proprioception and single limb standing balance ($r = 0.579$, $p < 0.05$).

To investigate the effect of proprioceptive and balance exercises on outcomes following injury and surgical reconstruction of the ACL, Cooper et al (2005) conducted a systematic review examining more than 1500 papers in the English literature. These studies included randomised control trials, randomised trials, case series, cohort studies, and observational studies. Seven studies were analysed after satisfying the set of stringent inclusion criteria. The researchers concluded that proprioceptive and balance exercises improve outcomes in people with ACLD knees. Furthermore, the authors concluded that there was an improvement in proprioception, muscle strength, perceived knee joint function, and hop testing measures after proprioceptive and balance exercises. They also noted that only one study included in their review investigated proprioceptive exercise following ACL reconstruction. There were benefits noted in the proprioceptive group for measures of strength and proprioception, although no benefits were noted for any measures of activity. The authors commented that in the longer term, it would be desirable that outcome measures that assess whether people have returned to participate in their desired societal roles are incorporated into future studies. The authors concluded that further research on the effect of proprioceptive and balance exercise was required.

To date, there are few studies examining the relationships between single limb standing balance, leg muscle strength, and subjective function tests in a young, active population who either have had the ACL torn, or have had an ACL reconstruction. No study to date has investigated the relationships between single leg standing balance and simple function tests such as the distance of a single-legged hop or the height of the single-legged vertical leap in these two populations.

Hence the purpose of the present study was to determine if there was a significant relationship between the CoP measure, and subjective knee outcome scale scores in participants with ACLD and ACLR knees. We also aim to determine if there was a significant relationship between the CoP measure, objective functional tests and muscle strength measurements in participants of both groups. Means and standard deviations of the participants' physiological characteristics and each dependent variable were calculated. The Pearson product-moment correlation coefficients ($r$) were calculated to examine the relationships between the CoP measure, objective, and subjective outcome measures. An alpha level of $p < 0.05$ was used to determine statistical significance.

**METHODS AND MATERIALS**

The project has been approved by the Human Research and Ethics Committee of the Health Service District, as well as the University Human Research Ethics Review Panel. All participants signed a written informed consent form prior to commencement of all testing sessions (see Appendix B).

The research took place with the support of the Department of Orthopaedics at the base hospital within the district health catchment area. Moreover, those who have had the ACL reconstruction performed are also followed up through the outpatient process. Referrals are either made through the emergency department of the district health hospital, surrounding peripheral hospitals, or via the General Practitioner of the injured athlete.

**Participants**

Fit and physically active participants (play or train for sports on a regular three-days a week basis) who are 16 years and older were recruited from the Department of Orthopaedics Sports Injury Clinic at base hospital. In the ACLD group, a total of 25 (13 males, 12 females) participants were recruited with a mean age of 29.0 ± 9.6 years, mean height of 1.7 ± 0.1 m and a mean body mass of 76.3 ± 9.4 kg. In the ACLR group, 25 (18 males, 7 females) participants with a mean age of 29.3 ± 9.4 years, mean height of 1.75 ± 0.1 m, a mean body mass of 79.7 ± 17.8 kg, and at a mean of 40.4 ± 52.1 months since their respective operations were included.

**Fig. 7: Wii™ Balance Board setup to measure CoP pathlengths**

**PROCEDURES**

Based on the research published by Clark et al. (2010), the project utilised the Nitendo® Wii™ Balance Platform to compute the overall Centre of Pressure (CoP) pathlength on both the affected, and non- affected leg (control) as a measure of postural control.

***Centre of Pressure Pathlengths (CoP)***

Participants stood on the Wii™ balance board with both legs and with hands by their sides. They were then asked to stand on the affected leg in the marked centre of the board for 30 seconds (see Figure 7) with the other leg lifted and the knee flexed at 90 degrees on the board, followed by the non- affected leg for the same amount of time. The tasks were performed with the eyes open with the participants asked to focus on one point on the wall. This ensured participants' safety as outlined in the Ethics approval. One minute's rest was allowed between tests. Each test was repeated five times for each leg, with the highest and the lowest values of the data eliminated, and the remaining three values used to obtain the mean for data analysis.

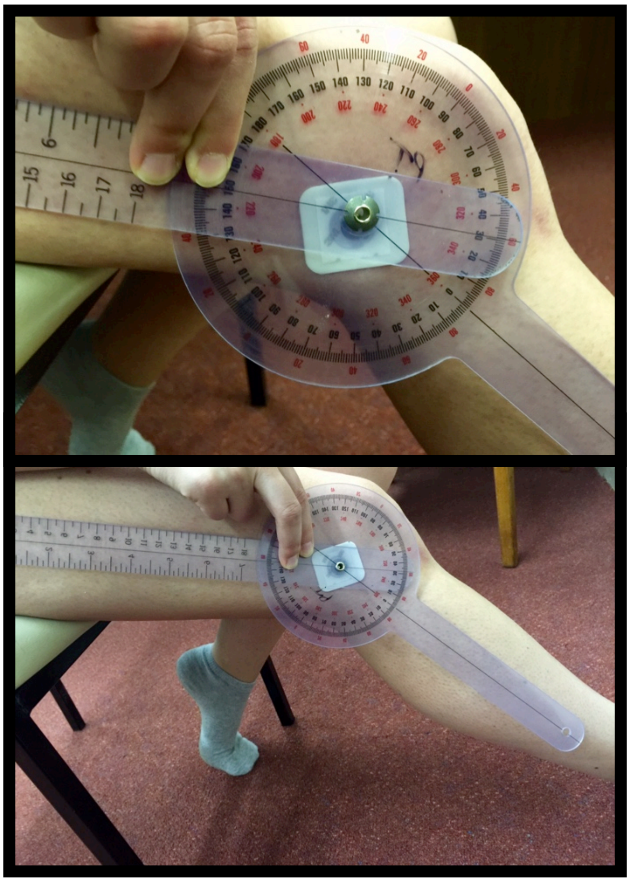

**Fig. 8: Verfication of Angle with a Goniometer**

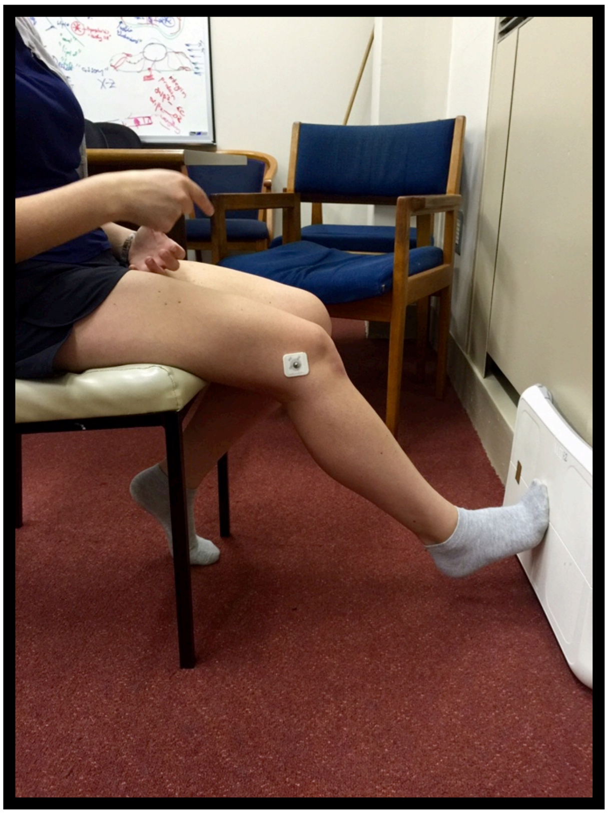

**Fig. 9: Wii™ Balance Board setup to measure isometric strength of the quadriceps in study**

The data recorded from the Wii™ Balance Board were interpolated to 100Hz before being filtered using an undecimated wavelet-based filter (Symlet 8) with a low pass frequency of 12 Hz as per protocol used in Clark et al (2010). As per Clark et al. (2010), the CoP measure used in this study was the total CoP pathlength in a fixed time intervals, the results are analogous to a measure of the average CoP velocity, as recommended by

Salvati et al. (2009) to be a valid and reliable measure of single limb standing balance.

***Quadriceps Isometric Strength***

The participants sat in an armless chair with arms by their sides holding on to edge of the chair, and lower back against the back of the chair. The Wii™ Balance Board was placed against the wall (Fig. 9) and the participants asked to push against centre of the board with the affected leg for as hard as they could for six seconds with the knee maintaining 30 degrees flexion as measured by goniometer similar to the protocol used in Carpenter et al (2006). For the safety of the participants, the back legs of the chair were bolted to the floor, and two research assistants stood behind and pushing against the chair to avoid it from tipping back during the exercise. One minute of passive rest was taken between each of the five trials. The process was repeated for the non-affected leg. The highest and lowest values from the five trials were eliminated and the mean value obtained from three other trials used for data analysis. This was performed to remove the potential for outlying data to influence the results.

***Hamstrings Isometric Strength***

The isometric strength of hamstring muscle group was tested as shown in Figure 10. The Wii™ balance board was placed on the floor in front of the participants. The participants sat in an armless chair with arms by the sides holding onto the edge of the chair. A goniometer was used to ensure 90 degrees angle of the hip flexion as per Leelarthaepin (1992). Using the affected leg, the subject was asked to flex the knee to 30 degrees as verified by the goniometer. The participants then

**Fig. 10: Wii™ Balance Board setup to measure hamstrings isometric strength**

used the heel of the foot to push down against the marked centre of the board for six seconds without flexing the trunk as per Carpenter et al. (2006). After a minute of passive rest, the process was repeated with the non- affected leg. This was repeated five times for each leg. The highest and lowest values of the five trials were eliminated to remove the potential of outlying data influence the result, and a mean value was obtained from the middle three scores. This was performed to remove the potential for outlying data to influence the results.

***Single-Legged Vertical Leap***

The participants were asked to perform a single-legged vertical jump test as measures of lower extremity power. Similar to Leard et al (2007), the participants were first asked to stand on the affected leg. Once they were able to achieve and maintain balance standing on one leg, the subject would then jump single legged as high as they can as shown in Figure 11. The height (cm) was recorded from the Vertec system. Following one minute of standing passive rest, the participants were asked to stand on the other leg and to perform the same action. This process was alternated five times. The height of the jump was measured by the Vertec system (cm) with the highest and lowest measures discarded, and the remaining three readings of

**Fig. 11: Vertical jump station using the Vertec system**

**Fig. 12: Single legged hop demonstration for participants in the study**

jump heights (cm) averaged for data analysis.

***Single-Legged Hop***

The participants were asked to stand on the affected leg. Once able to achieve balance, the participants were asked to jump forward as far as they can on the affected leg as outlined in Ross et al. (2002, see Figure 12). The distance of the jump (cm) was measured, and a minute break allowed before the participants perform the same task standing on the non-affected leg. This process was repeated five times for each leg, with the highest and lowest measurements (cm) removed, and the middle three measurements averaged to obtain the mean (cm) for data analysis.

***Questionnaires***

Each subject was asked to fill in the knee outcome scores from the Lysholm, Tegner, and IKDC subjective outcome questionnaires. The investigator was on hand to answer any queries the participants may have regarding the questionnaires.

## DATA ANALYSIS

Means and standard deviations of the participants' physiological characteristics and each dependent variable were calculated. Pearson product-moment correlation coefficients (r) were calculated to examine the relationships between the CoP measure, objective, and subjective outcome measures. An alpha level of $p < 0.05$ was used to determine statistical significance. The CoP measure used in this study was the total CoP pathlength as per Clark et al. 2010. Given that the trials were for a fixed time interval, these CoP pathlength results in the study are analogous to a measure of average CoP velocity (pathlength per time interval tested). Therefore the total CoP pathlength was adopted as it is known to be a reliable and valid measure of standing balance. (Salavati et al. 2009)

**RESULTS**

As shown in Table 1, there was a significant difference between the ACLR and ACLD groups for both the mean distance of single leg hop and vertical single leg leap. The distance for both single leg hop and vertical leap were statistically significantly greater in the ACLR group than the ACLD group.

| | ACLD group | ACLR group | Differences between Two Group |
|---|---|---|---|
| **CoP measurements (cm)** | 110.7 ± 30.7 | 105.0 ± 25.3 | |
| **Quadriceps Strength (kg)** | 47.8 ± 30.6 | 59.3 ± 36.1 | |
| **Hamstrings Strength (kg)** | 11.5 ± 5.0 | 11.9 ± 5.9 | |
| **Single-legged hop (cm)** | 107.1 ± 46.5 | 136.2 ± 33.8* | $p = 0.02$ |
| **Vertical single leg jump (cm)** | 16.1 ± 8.0 | 20.6 ± 6.4* | $p = 0.01$ |
| **Tegner** | 3.2 ± 1.6 | 5.1 ± 2.0* | $p = 0.03$ |
| **Lysholm** | 63.4 ± 15.7 | 80.4 ± 18.5* | $p = 0.01$ |
| **IKDC** | 53.1 ± 18.3 | 74.1 ± 18.6* | $p = 0.02$ |

**Table 1: Summary of results of each station for both groups. * denotes difference between two group is statistically significant at $p < 0.05$**

As shown in Table 1, there was a significant difference between the two groups in Tegner, Lysholm and IKDC scores. There was also statistically significant difference between the two groups in single-legged hop distance, and vertical single leg leap height.

**ACLD Group**

In our data analysis, negative correlations existed between the CoP and other independent variables examined. There was a weak negative correlation between the CoP measurements and the quadriceps strength readings; between the CoP measurements and the single-legged hop distances; between the CoP and the Tegner subjective functional outcome measure; as well as the CoP measurements and the single leg vertical leap values. There was a very weak negative correlation between the CoP measurements and Lysholm subjective functional outcome measure *(r*(23) = -0.08, *p* < 0.05; and between the CoP measurements and IKDC subjective functional outcome measure (*r*(23)

**Table 2: Correlation Matrix ACLD Group**

| | CoP | Quadriceps | Hamstrings | Single Legged Hop | Single Leg Vertical Leap | Tegner | Lysholm | IKDC |
|---|---|---|---|---|---|---|---|---|
| CoP | 1 | | | | | | | |
| Quadriceps | -0.27 | 1 | | | | | | |
| Hamstrings | -0.15 | 0.09 | 1 | | | | | |
| Single Legged Hop | -0.24 | 0.70* | 0.03 | 1 | | | | |
| Single Leg Vertical Leap | -0.27 | 0.45* | 0.09 | 0.80* | 1 | | | |
| Tegner | -0.29 | 0.21 | 0.05 | 0.50* | 0.51* | 1 | | |
| Lysholm | -0.08 | -0.04 | 0.05 | 0.47* | 0.68* | 0.41 | 1 | |
| IKDC | 0.03 | 0.09 | -0.03 | 0.55* | 0.64* | 0.45* | 0.59* | 1 |

***Correlation is significant at *p* < 0.05**

= 0.03, *p* < 0.05).

We noted some statistically significant strong correlations between the variables examined in the ACLD group. The quadriceps strength measure was strongly correlated to the single legged hop distance reading (*r*(23) = 0.70, *p* < 0.05). There were strong correlations between the single-legged hop distances and the single leg vertical leap distances (*r*(23) = 0.80, *p* < 0.05); between the single-legged hop distances and the Tegner subjective score values (*r*(23) = 0.50, *p* < 0.05), and between the single-legged hop distances and the IKDC values (*r*(23) = 0.55, *p* < 0.05). Similarly, the single leg vertical leap measure was strongly correlated with all three subjective score values in the present study as shown in table 2. There was also a strong correlation noted between the Lysholm subjective functional outcome measure and the IKDC subjective functional outcome measure.

There was a statistically significant moderate correlation between the single-legged hop measure and the Lysholm subjective functional outcome measure ($r(23) = 0.47$, $p < 0.05$); Similarly, the Tegner subjective score measure was moderately correlated to the Lysholm subjective functional outcome measure ($r(23) = 0.41$, $p < 0.05$), and to the IKDC measure ($r(23) = 0.45$, $p < 0.05$).

A weak correlation was observed between the quadriceps strength measure and the Lysholm subjective score measure ($r(23) = 0.21$, $p < 0.05$). Very weak correlations were noted between some independent variables in the ACLD group. Hamstring strength measure showed very weak correlations to all other independent variables apart from CoP measures in the ACLD group as shown in Table 2.

**ACLR Group**

In the ACLR group, the data analysis revealed that the correlations between the CoP measure and to all the other independent variables were weak and statistically insignificant as shown in Table 3. A moderate correlation was noted between the CoP measure and the single-legged hop measure ($r(23) = 0.33$, $p < 0.05$), however it was not statistically significant.

The quadriceps strength measure was noted to be strongly correlated with the hamstrings strength measure ($r(23) = 0.57$, $p < 0.05$), and the single-legged hop measure ($r(23) = 0.63$, $p < 0.05$). A strong correlation was demonstrated between the single-legged hop measure and the single leg vertical leap measure (($r(23) = 0.58$, $p < 0.05$). Similarly, a strong correlation was also observed between the Tegner subjective functional outcome measure and the IKDC functional outcome measure ($r(23) = 0.89$, $p < 0.05$).

We noted a statistically significant moderate correlation between two independent variables in this group of cohorts in the study. The quadriceps strength measure was moderately correlated to the single leg vertical leap measure ($r(23) = 0.44$, $p < 0.05$). The hamstring strength measure to the single leg vertical leap measure was also moderately correlated ($r(23) = 0.35$, $p < 0.05$), however it was not statistically significant. Similarly, the single leg vertical leap measure was moderately correlated with

**Table 3: Correlation Matrix ACLR Group**

| | CoP | Quadriceps | Hamstrings | Single Legged Hop | Single Leg Vertical Leap | Tegner | Lysholm | IKDC |
|---|---|---|---|---|---|---|---|---|
| CoP | 1 | | | | | | | |
| Quadriceps | 0.23 | 1 | | | | | | |
| Hamstrings | 0.18 | 0.57* | 1 | | | | | |
| Single-Legged Hop | 0.33 | 0.63* | 0.20 | 1 | | | | |
| Single Leg Vertical Leap | 0.12 | 0.44* | 0.35 | 0.58* | 1 | | | |
| Tegner | 0.17 | 0.23 | 0.08 | 0.46* | 0.39 | 1 | | |
| Lysholm | 0.16 | 0.07 | 0.26 | 0.02 | 0.11 | 0.33 | 1 | |
| IKDC | 0.20 | 0.05 | 0.22 | -0.04 | 0.01 | 0.48* | 0.89* | 1 |

***Correlation is significant at $p < 0.05$**

the Tegner subjective functional outcome measure ($r(23) = 0.39$, $p < 0.05$), and the Tegner subjective functional outcome measure showed a moderate correlation to the Lysholm subjective functional outcome measure ($r(23) = 0.33$, $p < 0.05$), however neither were statistically significant.

The quadriceps strength measure showed weak to very weak correlations to the three subjective functional outcome measures in this group. Similarly, there was generally weak correlation between hamstrings strength measure and the three subjective functional variables, as shown in Table 3".

**DISCUSSION**

The purpose of the present study was to examine the relationships between single limb standing balance, muscle strength, and subjective function tests in a physically well, active population who have ACLD knees or have had an ACL reconstruction. Furthermore, no study to date has investigated the relationship between the total CoP pathlength in a fixed time interval, and simple function tests such as the distance of a single-legged hop, or the height of a single leg vertical jump in participants with knees that are ACL deficient or have had an ACL reconstruction.

Neither of the two cohorts demonstrated statistically significant relationships between the CoP measure and other independent variables examined. These findings were similar to those of Lee et al. (2009) who measured quadriceps and hamstrings peak torque at a number of angular velocities using expensive and clinically difficult to access isokinetic dynamometry in a cohort of 12 young participants (mean age of 23.1 years) with unilateral ACL deficient knees. Similar to our findings using inexpensive and clinically accessible strength measures, they reported no correlations between single limb standing balance and the peak torque of both the quadriceps and hamstring muscle groups.

In contrast to our findings in the present study, Pua et al. (2011) examined the relationship between single limb standing balance in the anteroposterior plane using Wii™ Balance Board and knee extensor strength. Single limb standing balance was measured by the CoP displacement during quiet standing on a Wii™ balance board, and isometric knee extensor strength was measured using an isokinetic dynamometer. They observed a positive relationship between single limb standing balance and physical function as measured using the Short Form 36 (SF-36) general health survey in their cohort of elderly participants with end stage knee osteoarthritis. They also observed an inverse relationship between the single limb standing balance and physical function association in the participants with higher knee extensor strength.

In the study done by Ageberg et al. (2005), the authors employed similar methodologies to the present study and was not able to observe significant relationships between muscle strength and the

CoP measure in their cohort of fit and active population of 36 men and women whose knees were ACL deficient. Furthermore, in the same study, the authors further analysed the data from the participants separately by gender, and was not able to uncover any statistically significant relationship between muscle strength and the CoP measure. Clinically the findings from Lee et al (2009), Ageberg et al (2005), and current study may have implications in an outpatient setting. All three studies were unable to derive a relationship between the CoP measure and the strength of quadriceps and hamstrings muscle groups. This would suggest further studies involving larger samples may be required to verify these findings.

In the present study, no statistically significant relationships were observed between the CoP measure and subjective functional outcome measures such as Lysholm, Tegner and IKDC. Ageberg et al. (2005) used visual analogue scale score (VAS) to assess relationships between CoP and subjective functions in their cohort of participants with documented ACL injury. They reported lower amplitude values of CoP pathlengths correlated with better subjective extremity function. In other words, those who demonstrated higher value of CoP excursion in single limb standing balance on a forceplate, also reported poorer results on the VAS. In the present study, VAS was not used to evaluate the level of subjective knee function as the panel wished to focus on the three commonly employed subjective functional outcome scales.

In both cohorts, the quadriceps strength measure was strongly correlated to both the single-legged hop and single leg vertical leap measures. It was also strongly correlated to the hamstring strength measure in the ACLR group. The single-legged hop measure was strongly correlated to the single leg vertical leap measure in both groups. Both the single-legged hop and single leg vertical leap are seen as objective functional measurements, some would consider the two measures to be measurements of muscular power of the lower extremity, whereas others see the two as measurable coordinated activities (Ross et al, 2002; Leard et al, 2007). Thus it was expected that there would be a relationship between the muscle strength of the lower limb and the associated power produced in the involved limb, and the two measurements of single limb power would be related positively in both groups.

The Tegner and the Lysholm functional outcome measures showed strong correlations to the IKDC measure in both groups, however the correlations between the Tegner and the Lysholm functional outcome measures in both groups were statistically insignificant. All three subjective measures of knee function are used frequently and are valid, reliable, responsive and sensitive to change over time (Briggs et al. 2009). Hence it was expected that the correlations between the Tegner and the IKDC, also the Lysholm and the IKDC were strong in both groups. We were unable to explain the statistically insignificant relationship noted in this study between the Tegner and Lysholm subjective functional outcome measures.

The present study has a number of limitations. Firstly, we were not able to recruit more than the suggested 36 participants in either group identified by a power calculation to achieve 80% statistical power. Secondly, the participants were not matched for their characteristics such as age, height, body mass, or BMI. The district health catchment from which the cohort was recruited encompasses a vast geographic area that can require in some cases, more than eight hours of commute to and from the hospital. The potential participants were mostly full-time employees working in the peripheries of the Health District catchment. Without any incentives for these potential participants to travel to the hospital for testing, the inconvenience of travel time and distance meant that the subject response rate was low in the ACLD and ACLR groups. Thirdly, the patient cohort in the study was extracted from the hospital waiting list and theatre audit database for the lead investigator. Due to the low rate of response of recruitment of potential participants in either group, we also sought potential participants from other orthopaedic surgeons working also in the catchment area. In the present cohort, while the senior author performed most of the operations, a small number of ACL reconstructions were performed by other orthopaedic surgeons in the unit. Other surgeons would use different operative techniques for the same procedure. Different operative techniques, tourniquet time, types of graft fixation and types of graft harvested for the ACL reconstruction may lead to variability with the data obtained, particularly in the ACLR group. There are many techniques and choices of grafts to reconstruct the ACL. Techniques such as single, double or even triple bundles are used to reconstruct the ACL. Types of graft include the bone-patellar-bone graft, hamstring graft, allograft and synthetic graft (Spindler et al, 2004). There is a distinct lack of empirical research demonstrating the effect or lack of effect of types of surgical technique and ACL graft on single limb standing balance (Lee et al 2009). Hence in the present study, we did not consider these factors and were not 'graft type specific' in our inclusion criteria for the participants in ACLR group.

The study used the total CoP pathlength in a fixed time interval as the CoP measure. This approach was basing on the previous research by Clark et al. (2010). However, while the software has been updated since, at the time of the study was performed, the software was unable to further discern the pathlengths in either anteroposterior (AP) and medial-lateral (ML) directions. Future studies could further refine the data and examine relationships between the AP and ML CoP measures and other independent variables.

Another limitation may be that we used auditory or visual cues in our CoP testing. The participants in the present study were instructed to solely focus on a spot provided on the wall in the quiet physiotherapy gymnasium while data was collected. Eliminating the visual cues using blindfolding may have resulted in potential falls and injuries to our participants. This practice would be unsafe and posed a small but real falls risk to our participants. Moreover, it was a condition of ethical approval that we would not use a blindfold.

Finally, the data collection from cohort of participants was also open to inter-observer difference. In the present study, different but trained operators performed data collections at each testing station. Due to a lack of resources, and limited availability of venues for testing purposes, we were not able to assign the same data collector for every specific testing station. While each data collector was university-qualified and well instructed in each method of testing in each station, inter-observer error may have been present leading to variability of measurements.

**CONCLUSION**

The present study showed no statistically significant relationship between the CoP measure, objective functional tests and subject functional scores in our cohort of participants with either ACL-deficient or ACL reconstructed knees. Based on this finding, the CoP values obtained in an outpatient clinic would not truly reflect the status of knee function in fit and active patients with ACL-deficient knees or who have undergone reconstruction of ACL in the last six months. Given the limitations of the present study, more in depth investigations involving larger number of participants, more specific requirement on graft choices, software able to further differentiate CoP pathlengths in AP and ML directions, and more stringent criteria regarding participants selection would be recommended to further explore possible relationships between these variables.

## REFERENCES


1. Adkin AL, Frank JS, Jog MS. (2003). Fear of Falling and Postural Control in Parkinson's Disease. *Mov Disord*, *18*(5), 496 – 502.

2. Ageberg E, Roberts D, Holmstrom E, et al. (2005). Balance in Single-Limb Stance in Patients with Anterior Cruciate Ligament Injury: Relation to Knee Laxity, Proprioception Muscle Strength, and Subjective Function. *Am J Sports Med*, *10*, 1527-35.

3. Ageberg E, Zatterstrom R, Friden T, Moritz U. (2001). Individual Factors Affecting Stabilimetry and One Leg Hop Test in 75 Healthy Participants, aged 15 – 44. *Scand J Med Sci Sports*, *11*(1), 47 – 53

4. Barber SD, Noyes FR, Mangine RE, De Maio M. (1992). Rehabilitation after ACL Reconstruction: Function Testing. *Sports Med Rehab*, *15*(8), 969 – 974.

5. Blum L, Korner- Bittensky N. (2008). Usefulness of the Berg Balance Scale in Stroke Rehabilitation: A Systematic Review. *Phys Ther*, *88*(5), 559 – 566.

6. Boerboom AL, Huizinga MR, Kaan WA, Stewart RE, Hof AL, Bulstra SK, Diercks RL. (2008). Validation of a method to Measure the Proprioception of the Knee. Gait & Posture, 610 - 614

7. Booher LD, Hench KM, Worrell TW, Stikeleather J. (1993). Reliability of Three Single Leg Hope Tests. *J Sports Rehab*, *2*, 165 – 170.

8. Briggs KK, Lysholm J, Tegner Y, Rodkey WG, Kocher MS, Steadman JR. (2009). The Reliability, Validity, and Responsiveness of the Lysholm Score and Tegner Activity Scale for Anterior Cruciate Ligament Injuries of the Knee, 25 Years Later. *Am J Sports Med*, *37*(5), 890 – 897.

9. Bryant AL, Kelly J, Hohmann E. (2007). Neuromuscular Adaptations and Correlates of Knee Functionality Following ACL Reconstruction. *J Orthop Res*, *26*, 126 – 135.

10. Campbell MJ. (2006). *Statistics at Square Two (*2nd ed*)*. BMJ Books, Blackwell.

11. Carpenter MR, Carpenter RL, Peel L, Zukley LM, Angelopoulou KM, Fischer I, Angelopoulos J, Rippe JM. (2006). The Reliability of Isokinetic and Isometric Leg Strength Measures Among Individuals with Symptoms of Mild Osteoarthritis. J Sports Med Phys Fitness, 46(4), 585 – 9.

12. Canale ST, & Beaty, JH. (2007). *Campbell's Operative Orthopaedics (*11th ed*)*, Mosby.

13. Clark RA, Bryant AL, Pua Y, McCrory P, Bennell K, Hunt M. (2010). Validity and Reliability of the Nintendo® Wii™ Balance Board for Assessment of Standing Balance. *Gait & Posture, 31*, 307 – 310.

14. Clark RA, McGough R, Paterson, K. (2011). Reliability of an Inexpensive and Portable Dynamic Weight Bearing Asymmetry Assessment System Incorporating Dual Nintendo® Wii™ Balance Boards. *Gait & Posture, 34*, 288 – 291.

15. Cochrane, JL, Lloyd DG, Buttfield A, Seward H, McGivern J. (2007). Characteristics of Anterior Cruciate Ligament Injuries in Australian Football. *J Sci Med Sport*, *10*, 96 – 104.

16. Cooper RL, Taylor NF, Feller JA. (2005). A Systematic Review of the Effect of Proprioceptive and Balance Exercises on People with an Injured or Reconstructed Anterior Cruciate Ligament. *Res Sports Med*, *13*, 163 – 178.

17. Corrigan JP, Cashman WF, Brady MP. (1992). Proprioception in the Cruciate Deficient Knee. *J Bone Joint Surg Br*, *74*, 247 – 250.

18. DeLee JC, Drez D, and Miller MD. (2009). *DeLee and Drez's Orthopaedic Sports Medicine (*3rd ed*)*, Saunders.

19. Deustch JE, Borberly M, Filler J, Huhn K, Guarrera- Bowlby P. (2009). Use of A Low- Cost, Commercially Available Gaming Console (Wii™) for Rehabilitation of an Adolescent with Cerebral Palsy. *Phys Ther*, *88*(10), 1196 – 1207.

20. Diermann N, Schumacher T, Scahnz S, Raschke MJ, Petersen W, Zantop T. (2009). Rotational Instability of the Knee: Internal Tibial Rotation Under a Simulated Pivot Shift Test. *Arch Orthop Trauma Surg*, *129*, 353 – 358.

21. Dhillon MS, Bali K, Prabhakar S. (2011). Proprioception in Anterior Cruciate Ligament Deficient Knees and Its Relevance in Anterior Cruciate Ligament Reconstruction. *Indian J Orthop*, *45*, 294-300.

22. Erickson BJ, Harris JD, Fillingham YA, Frank RM, Bush-Joseph CA, Bach BR, Cole BJ, Verma NN. (2014). Anterior Cruciate Ligament Reconstruction Practice Patterns by NFL and NCAA Football Team Physicians, *Arthroscopy*, *30*(6), 731 - 738

23. Fischer-Rasmussen T, Jensen PE. (2000). Proprioceptive Sensitivity and Performance in Anterior Cruciate Ligament- Deficient Knee Joints. *Scand J Med Sci Sports*, *10,* 85 – 89.

24. Frykberg GE, Lindmark B, Lanshammar H, Borg J. (2007). Correlation between Clinical Assessment And Force Plate Measurement of Postural Control After Stroke. *J Rehab Med*, *39*(6), 448 – 453.

25. Haas BM, Burden AM. (2000). Validity of Weight Distribution and Sway Measurements of the Balance Performance Monitor. *Physiother Res Int*, *5*(1), 19 – 32.

26. Higgins HC, Horton JK, Hodgkinson BC, Muggleton SB. (2010). Lessons Learned: Staff Perceptions of The Nintendo® Wii™ As a Health Promotion Tool Within an Aged- Care And Disability Service. *Health Promotion Journal of Australia*, *21*(3), 189 – 195.

27. Holmes JD, Jenkins ME, Johnson AM, Hunt MA, Clark RA. (2013). Validity of the Nintendo® Wii™ Balance Board for The Assessment of Standing Balance in Parkinson's Disease. *Clin Rehabil*, *27*(4), 361-6.

28. Hoppenfeld S, deBoer P & Buckley R. (2009). *Surgical Exposures in Orthopaedics – The Anatomic Approach (*3rd ed*)*. Lippincott, Williams & Wilkins.

29. Hohmann E, Bryant AL. (2005). Biomechanics of ACL Rupture and Deficiency, Surgical Repair, Rehabilitation and Post – Surgical Evaluation. *Sports Science Sports Medicine Reviews*, 75 – 86.

30. Howells BE, Ardern CL, Webster KE. (2011). Is Postural Control Restored Following Anterior Cruciate Ligament Reconstruction? A Systematic Review. *Knee Surg Sports Traumatol Arthrosc*, *19*, 1168-77.

31. Howells BE, Clark RA, Ardern CL, Bryant AL, Feller JA, Whitehead TS, Webster KE. (2013). The Assessment of Postural Control and the Influence of A Secondary Task in People with Anterior Cruciate Ligament Reconstructed Knees Using a Nintendo® Wii™ Balance Board. *Br J Sports Med*, *47*(14), 914-9.

32. Janssen KW, Orchard JW, Driscoll TR, van Mechelen W. (2011). High Incidence and Costs for Anterior Cruciate Ligament Reconstructions Performed in Australia from 2003- 2004 to 2007- 2008: Time for An Anterior Cruciate Ligament Register by Scandinavian Model? *Scan J Med Sci Sports*, 1 – 7.

33. Johnson DS, Smith RB. (2011). Outcome Measurement in the ACL Deficient Knee – What's the Score? *Knee*, *8*(1), 51 – 57.

34. Kocher MS, Steadman JR, Briggs KK, Sterett WI, Hawkins RJ. (2004). Relationships Between Objective Assessment of Ligament Stability and Subjective Assessment of Symptoms and Functions After Anterior Cruciate Ligament Reconstruction. *Am J Sports Med*, *32*, 629 – 634.

35. Kues JM, Rothstein JM, Lamb RL. (1994). The Relationship Among Knee Extensor Torques Produced During Maximal Voluntary Contractions Under Various Test Conditions. *Phys Ther*, *74*(7), 674 – 683.

36. Leard JS, Cirillo MA, Katsnelson E, Kimiatek DA, Miller TW, Trebincevic K, Garbalosa JC. (2007). Validity of Two Alternative Systems for Measuring Vertical Jump Height. *J Strength Cond Res,* 21(4), 1296 – 9.

37. Lee HM, Cheng CK, Liau JJ. (2009). Correlation between Proprioception, Muscle Strength, Knee Laxity, and Dynamic Standing Balance in Patients with Chronic Anterior Cruciate Ligament Deficiency. *The Knee*, *16*, 387 – 391.

38. Leelarthaepin B. *Assessment of Physical Fitness: a practical approach.* Sydney: Leelar Biomedicalscience Services, 1992.

39. MacDonald PB, Hedden D, Pacini O, Sutherland K. (1986). Proprioception in Anterior Cruciate Ligament Deficient and Reconstructed Knees. *Am J Sports Med*, *24*, 774 – 778.

40. McMinn RMH. (1994). *Last's Anatomy: Regional and Applied* (5th ed). Elsevier.

41. Mir SM, Hadian MR, Talebian S, Nasseri N. (2008). Functional Assessment of Knee Joint Position Sense Following Anterior Cruciate Ligament Reconstruction. *Br J Sports Med*, *42*, 300 – 303.

42. Muaidi QI, Nicholson LL, Refshauge KM, Adams RD, Roe JP. (2009). Effect of ACL Injury and Reconstruction on Proprioceptive Acuity of Knee Rotation in the Transverse Plane. *Am J Sports Med*, *37*(8), 1618 – 1626.

43. Nagai T, Sell TC, House AJ, Abt JP, Lephart SM. (2013). Knee proprioception and Strength and Landing Kinematics During a Single-Leg Stop-Jump Task. *J Athl Train, 48*(1), 31-8.

44. Pap G, Machner A, Nebelung W, Awiszus F. (1999). Detailed Analysis of Proprioception in Normal and ACL Deficient Knees. *J Bone Joint Surg Br*, *81*, 764 – 768.

45. Petschnik R, Baron R, Albrecht M. (1998). The Relationship Between Isokinetic Quadriceps Strength and Hop Tests for Distance and One – Legged Vertical Jump Following Anterior Cruciate Ligament Reconstruction. *J Orthop Sports Phys Ther*, *28*(1), 23 – 31.

46. Pirrtola M, Era P. (2006). Force Platform Measurements as Predictors of Falls Among Older People – A Review. *Gerontology*, *52*(1), 1 – 16.

47. Pua YH, Liang Z, Ong PH, Bryant AL, Lo NN, Clark RA. (2011). Associations of Knee Extensor Strength and Standing Balance with Physical Function in Knee Osteoarthritis. *Arthritis Care Res*, *63*(12), 1706-14.

48. Rannest J et al. (1998). Proprioception of Cruciate Ligaments: Receptor Mapping in an Animal Model. *Arch Orthop Trauma Surg*, *19*(3), 159 – 163.

49. Reider B, Arcand MA, Lee HD, Mroczek K, Abulencia A, Stroud CC, Palm M, Gilbertson J, Staszak P. (2003). Proprioception of the Knee Before and After Anterior Cruciate Ligament Reconstruction. *Arthroscopy*, *19*(1): 2 – 12.

50. Roberts D, Ageberg E, Andersson G, Friden T. (2007). Clinical Measurements of Proprioception, Muscle Strength and Laxity in Relation to Function in the ACL- Injured Knee. *Knee Surg Sports Traumatol Arthrosc*, *15*, 9 – 16.

51. Ross, MD, Langford, B, Whelan PJ. (2002). Test-Retest Reliability of Four Single-Leg Horizontal Hop Tests. *J Streng Cond Res.* 16(4), 617 – 622.

52. Salavati M, Hadian MR, Mazaheri M, Negahban H, Ebrahimi I, Talebian S, et al. (2009). Test-retest Reliability of Centre of Pressure Measures of Postural Stability During Quiet Standing in a Group with Group with Musculoskeletal Disorders Consisting of Low Back Pain, Anterior Cruiciate Ligament Injury and Functional Ankle Instability. *Gait Posture*, 29(3), 460 – 464.

53. Sasaki N, Farraro KF, Kim KE, Woo SL. (2014). Biomechanical Evaluation of The Quadriceps Tendon Autograft for Anterior Cruciate Ligament Reconstruction: A Cadaveric Study. *Am J Sports Med,* 42(3), 723-30

54. Spindler KP, Kuhn JE, Freedman KB, Matthews CE, DIttus RS, Harrell FE. (2004). Anterior Cruciate Ligament Reconstruction Autograft Choice: Bone-Tendon-Bone Versus Hamstring. *Am J Sports Med,* 32(8), 1986 – 1994.

55. Swinscow TDV, & Campbell MJ. (2002). *Statistics at Square One (*9th ed*).* BMJ Books, Blackwell.

56. Tegner Y, Lysholm J. (1985). Rating Systems in the Evaluation of Knee Ligament Injuries. *Clin Orthop*, *198*, 43 – 49.

57. Woo SL, Kanamori A, Zeminski J, Yagi M, Papageorgiou C, Fu FH. (2002). The Effectiveness of Reconstruction of the Anterior Cruciate Ligament with Hamstrings and Patellar Tendon: A Cadaveric Study Comparing Anterior Tibial and Rotational Loads. *J Bone Joint Surg Am*, *84*, 907 – 914.

58. Yoo JD, Papannagari R, Park SE, DeFrate LE, Gill TJ, Li G. (2005). The Effect of Anterior Cruciate Ligament Reconstruction on Knee Joint Kinematics under Simulated Muscle Loads. *Am J Sports Med*, *33*, 240 – 246.

59. Young DW, McDonald C, Heggen T, Fitzpatrick J. (1997). An Evaluation of the Specificity, Validity, and Reliability of Jumping Tests. *J Sports Med Phys Exercise*, *37*(4), 240 – 255.

# CHAPTER FOUR: SUMMARY AND CONCLUSIONS

## 4.0 SUMMARY

In soft tissue knee reconstructive surgery, topics relating to ACL reconstruction are some of the most widely researched. While the biomechanical contribution of ACL in knee stability is fully elucidated, there are distinctly divergent opinions regarding its neuromuscular role especially following ACL reconstruction surgery despite the vast amount of research in this area in the current literature.

There is a growing body of literature postulating the somatosensory effect of ACL on postural control (Howells et al, 2011). To date, few studies have inspected the relationships between static single limb standing balance as measured by the CoP pathlength, leg muscle strength, and subjective function tests in a fit and active population who either have had an injury to the ACL, or have had an ACL reconstruction. Furthermore, no study to date has scrutinized the relationships between the CoP measure and simple function tests such as the distance of a single-legged hop or the height of the single-legged vertical leap.

In order to determine the relationships between postural control, leg muscle strength, objective and subjective knee functional tests, the present study specifically hypothesized:

1. There is a significant relationship between the CoP measure, and subjective knee outcome scale scores in participants with ACL- deficient (ACLD) and ACL-reconstructed (ACLR) knees.
2. There is a significant relationship between the CoP measure and muscle strength measurements in participants with ACLD and ACLR knees.
3. There is a significant relationship between objective functional tests (single-legged hop and vertical jump) and the CoP measure.

Two groups of fit and physically active participants were recruited and stratified into two groups. One group have had a confirmed diagnosis of rupture to ACL, and the other group who have undergone reconstruction surgery to ACL at least six months prior to recruitment. The participants underwent measurements of height, weight, BMI, as well as a series of testing stations evaluating the CoP, quadriceps and hamstrings strength, simple objective functional tests and questionnaires. Descriptive, and correlation statistics were analysed to examine the relationships for all variables of interest in both groups.

## 4.1 MAJOR FINDINGS

This study did not identify any statistically significant relationship between the CoP measure and leg muscle strength in either group. The study did not demonstrate any statistically significant relationship between the CoP measure and objective functional tests (single-legged hop and single-legged vertical leap. The present study also did not observe any statistically significant relationship between the CoP measure and subjective knee functional outcomes (Lysholm, Tegner, and IKDC).

We noted some statistically significant strong correlations between the variables examined in the ACLD group. The quadriceps strength measure was strongly correlated to the single legged hop distance reading ($r(23) = 0.70$, $p < 0.05$). There were strong correlations between the single-legged hop distances and the single leg vertical leap distances ($r(23) = 0.80$, $p < 0.05$); between the single- legged hop distances and the Tegner subjective score values ($r(23) = 0.50$, $p < 0.05$), and between the single-legged hop distances and the IKDC values ($r(23) = 0.55$, $p < 0.05$). Similarly, the single leg vertical leap measure was strongly correlated with all three subjective score values in the present study as shown. There was also a strong correlation noted between the Lysholm subjective functional outcome measure and the IKDC subjective functional outcome measure.

There was a statistically significant moderate correlation between the single-legged hop measure and the Lysholm subjective functional outcome measure ($r(23) = 0.47$, $p < 0.05$); Similarly, the Tegner subjective score measure was moderately correlated to the Lysholm subjective functional outcome measure ($r(23) = 0.41$, $p < 0.05$), and to the IKDC measure ($r(23) = 0.45$, $p < 0.05$).

In the ACLR group, we noted that the quadriceps strength measure was noted to be strongly correlated with the hamstrings strength measure ($r(23) = 0.57$, $p < 0.05$), and the single-legged hop measure ($r(23) = 0.63$, $p < 0.05$). A strong correlation was demonstrated between the single-legged hop measure and the single leg vertical leap measure (($r(23) = 0.58$, $p < 0.05$). Similarly, a strong correlation was also observed between the Tegner subjective functional outcome measure and the IKDC functional outcome measure ($r(23) = 0.89$, $p < 0.05$).

We noted a statistically significant moderate correlation between two independent variables in this group. The quadriceps strength measure was moderately correlated to the single leg vertical leap measure ($r(23) = 0.44$, $p < 0.05$).

# CHAPTER FIVE: FUTURE RESEARCH RECOMMENDATIONS

A number of research questions emerged as a result of the findings of the present study. These include:

1. The study did not scrutinize the possibility that the role of gender may have on the relationships of the variables examined. Hence a similar study design investigating the relationships between the same factors as the present study between genders in ACLD and ACLR groups. The future research may examine whether there is any relationships in young, active males and females who have had either an ACL rupture, or have undergone a recent reconstruction to ACL.

2. The study used the total CoP pathlength in a fixed time interval as the CoP measure as per Clark et al. (2010), the software version used in the testings was not able to discern the pathlengths in anteroposterior (AP) and medial-lateral (ML) directions. Since the conclusion of the study, the software has gone through several updates and iterations. It is now able to examine the amount of body sway in single limb stance in both AP and ML directions.

3. This study was not 'graft specific' in the ACLR group as discussed in previous chapter. It would be of great interest to examine if there is any relationship between these factors in cohort of ACLR participants with bone patellar tendon bone (BPTB) graft, and compare with ACLR group with hamstring graft.

4. Same study could be used in patients who have undergone total knee joint replacement arthroplasty. In the procedure of a knee replacement arthroplasty, the ACL is completely excised. It would be of great interest to see if there is any relationship between single leg balance, muscle strength, simple function tests and subjective knee outcome scores.

## REFERENCES

Abujaber S, Gillispie, G, Marmon A, Zeni J. (2015). Validity of the Nintendo® Wii™ Balance Board to Assess Weight Bearing Asymmetry During Sit-to-Stand and Return-to-Sit Task. *Gait & Posture*, 41, 676 - 682.

Adkin AL, Frank JS, Jog MS. (2003). Fear of Falling and Postural Control in Parkinson's Disease. *Mov Disord*, *18*(5), 496 – 502.

Ageberg E, Roberts D, Holmstrom E, et al. (2005). Balance in Single-Limb Stance oin Patients with Anterior Cruciate Ligament Injury: Relation to Knee Laxity, Proprioception Muscle Strength, and Subjective Function. *Am J Sports Med*, *10*, 1527-35.

Ageberg E, Zatterstrom R, Friden T, Moritz U. (2001). Individual Factors Affecting Stabilimetry and One Leg Hop Test in 75 Healthy Participants, aged 15 – 44. *Scand J Med Sci Sports*, *11*(1), 47 – 53

Bandy WD, McLaughlin S. (1993). Intra-machine and Inter-machine Reliability for Selected Dynamic Performance Tests. *J Orthop Sports Phys Ther*, *18*(5), 609 – 613.

Barber SD, Noyes FR, Mangine RE, De Maio M. (1992). Rehabilitation after ACL Reconstruction: Function Testing. *Sports Med Rehab*, *15*(8), 969 – 974.

Barber SD, Noyes FR, Mangine RE, McCloskey JW, Hartman W. (1990). Qualitative Assessment of Functional Limitations in Normal and Anterior Cruciate Ligament Deficient Knees. *Clin Orthop*, *255*, 204 – 214.

Barber-Westin SD, Noyes FR, McCloskey JW. (1999). Rigorous Statistical Reliability, Validity and Responsiveness Testing of the Cincinnati Knee Rating System in 350 Participants with Uninjured, Injured, or Anterior Cruciate Ligament Reconstructed Knees. *Am J Sports Med*, *27(4)*, 402 – 416.

Barrett DS. (1991). Proprioception and Function after Anterior Cruciate Reconstruction. *J Bone Joint Surg Br*, *73*(5), 53 – 56.

Bengtsson J, Mollberg J, Werner S. (1996). A Study for Testing the Sensitivity and Reliability of the Lysholm Knee Scoring Scale. *Knee Surg Sports Traumatol Arthroscop*, *4*(1), 27 – 31.

Blum L, Korner- Bittensky N. (2008). Usefulness of the Berg Balance Scale in Stroke Rehabilitation: A Systematic Review. *Phys Ther*, *88*(5), 559 – 566.

Boerboom AL, Huizinga MR, Kaan WA, Stewart RE, Hof AL, Bulstra SK, Diercks RL. (2008). Validation of a method to Measure the Proprioception of the Knee. Gait & Posture, 610 - 614

Booher LD, Hench KM, Worrell TW, Stikeleather J. (1993). Reliability of Three Single Leg Hope Tests. *J Sports Rehab*, *2*, 165 – 170.

Borsa PA, Lephart SM, Irrgang JJ, et al. (1997). The Effects of Joint Position and Direction of Joint Motion on Proprioceptive Sensibility in Anterior Cruciate Ligament Deficient Athletes. *Am J Sports Med*, *25*, 336 – 340.

Briggs KK, Kocher MS, Rodkey WG, Steadmann RJ. (2006). Reliability, validity, and Responsiveness of the Lysholm Knee Score and Tegner Activity Scale for Patients with Meniscal Injury of the Knee. *J Bone Joint Surg Am*, *88*(4), 698 – 705.

Briggs KK, Lysholm J, Tegner Y, Rodkey WG, Kocher MS, Steadman JR. (2009). The Reliability, Validity, and Responsiveness of the Lysholm Score and Tegner Activity Scale for Anterior Cruciate Ligament Injuries of the Knee, 25 Years Later. *Am J Sports Med*, *37*(5), 890 – 897.

Briggs KK, Steadman, JR, Jay CJ, Hines SL. (2009). Lysholm Score and Tegner Activity Level in Individuals with Normal Knee. *Am J Sports Med*, *37*, 898 – 901.

Bryant AL, Kelly J, Hohmann E. (2007). Neuromuscular Adaptations and Correlates of Knee Functionality Following ACL Reconstruction. *J Orthop Res*, *26*, 126 – 135.

Campbell MJ. (2006). *Statistics at Square Two (*2nd ed*).* BMJ Books, Blackwell.

Canale ST, & Beaty, JH. (2007). *Campbell's Operative Orthopaedics (*11th ed*)*, Mosby.

Carpenter MR, Carpenter RL, Peel L, Zukley LM, Angelopoulou KM, Fischer I, Angelopoulos J, Rippe JM. (2006). The Reliability of Isokinetic and Isometric Leg Strength Measures Among Individuals with Symptoms of Mild Osteoarthritis. J Sports Med Phys Fitness, 46(4), 585 – 9.

Carter ND, Jenkinson TR, Wilson D, Jones, DW, Torode AS. (1999). Joint Position Sense and Rehabilitation in the Anterior Cruciate Ligament Deficient Knee.. *Br. J Sports Med*, *31*, 209 – 212.

Clark RA, Bryant AL, Pua Y, McCrory P, Bennell K, Hunt M. (2010). Validity and Reliability of the Nintendo Wii Balance Board for assessment of Standing Balance. *Gait & Posture, 31*, 307 – 310.

Clark RA, McGough R, Paterson, K. (2011). Reliability of an Inexpensive and Portable Dynamic Weight Bearing Asymmetry Assessment System Incorporating Dual Nintendo Wii Balance Boards. *Gait & Posture, 34*, 288 – 291.

Cochrane, JL, Lloyd DG, Buttfield A, Seward H, McGivern J. (2007). Characteristics of Anterior Cruciate Ligament Injuries in Australian Football. *J Sci Med Sport*, *10*, 96 – 104.

Cooper RL, Taylor NF, Feller JA. (2005). A Systematic Review of the Effect of Proprioceptive and Balance Exercises on People with an Injured or Reconstructed Anterior Cruciate Ligament. *Res Sports Med*, *13*, 163 – 178.

Corrigan JP, Cashman WF, Brady MP. (1992). Proprioception in the Cruciate Deficient Knee. *J Bone Joint Surg Br*, *74*, 247 – 250.

DeLee JC, Drez D, and Miller MD. (2009). *DeLee and Drez's Orthopaedic Sports Medicine (*3rd ed*)*, Saunders.

Deustch JE, Borberly M, Filler J, Huhn K, Guarrera- Bowlby P. (2009). Use of A Low- Cost, Commercially Available Gaming Console (Wii™) for Rehabilitation of an Adolescent with Cerebral Palsy. *Phys Ther*, *88*(10), 1196 – 1207.

Diermann N, Schumacher T, Scahnz S, Raschke MJ, Petersen W, Zantop T. (2009). Rotational Instability of the Knee: Internal Tibial Rotation Under a Simulated Pivot Shift Test. *Arch Orthop Trauma Surg*, *129*, 353 – 358.

Dhillon MS, Bali K, Prabhakar S. (2011). Proprioception in Anterior Cruciate Ligament Deficient Knees and Its Relevance in Anterior Cruciate Ligament Reconstruction. *Indian J Orthop*, *45*, 294-300.

Dye SF. (1996). The Knee as a Biologic Transmission with an Envelope of Function: A Theory. *Clin Orthop*, *325,* 10 – 18.

Dye SF. (2003). Functional Morphological Features of the Human Knee: An Evolutionary Perspective. *Clin Ortho Relat Res*, *410*, 19 – 24.

Erickson BJ, Harris JD, Fillingham YA, Frank RM, Bush-Joseph CA, Bach BR, Cole BJ, Verma NN. (2014). Anterior Cruciate Ligament Reconstruction Practice Patterns by NFL and NCAA Football Team Physicians, *Arthroscopy*, *30*(6), 731 - 738

Fischer-Rasmussen T, Jensen PE. (2000). Proprioceptive Sensitivity and Performance in Anterior Cruciate Ligament- Deficient Knee Joints. *Scand J Med Sci Sports*, *10,* 85 – 89.

Fremerey RW, Loberhoffer P, Born I, et al. (2000). Proprioception After Rehabilitation and Reconstruction in Knees with Deficiency of the Anterior Cruciate Ligament- A Prospective, Longitudinal Study. *J Bone Joint Surg Br*, *82*(6), 801 – 806.

Friden T, Roberts D, Ageberg E, Walden M, Zatterstrom R. (2001). Review of Knee Proprioception and the Relation to Extremity Function After an Anterior Cruciate Ligament Rupture. *J Orthop Sports Phys Ther*, *31*(10), 567 – 576.

Frykberg GE, Lindmark B, Lanshammar H, Borg J. (2007). Correlation between Clinical Assessment And Force Plate Measurement of Postural Control After Stroke. *J Rehab Med*, *39*(6), 448 – 453.

Gabriel MT, Wong EK, Woo SL, Yagi M, Debski RE. (2004). Distribution of In Situ Forces in the Anterior Cruciate Ligament in Response to Rotatory Loads. *J Orthop Res*, *22,* 85 – 89.

Gaunt BW, Curd DT. (2011). Anthropometric and Demographic Factors Affecting Distance Hopped and Limb Symmetry Index for the Crossover Hop for Distance in High School Athletes. *J Orthop Sports Phys Ther*, *31*(3), 145 – 151.

Gokeler A, Benjaminse A, Hewett TE, Lephart SM, Enegebretsen L, Ageberg E, Engelhardt M, Arnold MMP, Postema K, Otten E, Dijkstra P. (2012). Proprioceptive Deficits after ACL injury: Are They Clinically Relevant? *Br J Sports Med*, *46,* 180 – 192.

Gomez – Barrena E, Bonsfills N, Martin JG, Ballesteros-Massos R, Foruria A, Nunez-Molina A. (2008). Insufficient Recovery of Neuromuscular Activity Around the Knee After Experimental Anterior Cruciate Ligament Reconstruction. *Acta Orthop*, *79*(1), 39 – 47.

Greenberger HB, Paterno MV. (1994). The Test- Retest Reliability of a One Legged Hop Test for Distance in Healthy Adults. *J Orthop Sports Phys Ther*, *19*, abstract.

Haas BM, Burden AM. (2000). Validity of Weight Distribution and Sway Measurements of the Balance Performance Monitor. *Physiother Res Int*, *5*(1), 19 – 32.

Higgins HC, Horton JK, Hodgkinson BC, Muggleton SB. (2010). Lessons Learned: Staff Perceptions of The Nintendo Wii As a Health Promotion Tool Within an Aged- Care And Disability Service. *Health Promotion Journal of Australia*, *21*(3), 189 – 195.

Hogervorst T, Brand RA. (1998). Current Concepts Review – Mechanoreceptors in Joint Function. *J Bone Joint Surg Am*, *80*: 1365 – 1378

Holmes JD, Jenkins ME, Johnson AM, Hunt MA, Clark RA. (2013). Validity of the Nintendo Wii® Balance Board for The Assessment of Standing Balance in Parkinson’s Disease. *Clin Rehabil*, *27*(4), 361-6.

Hoppenfeld S, deBoer P & Buckley R. (2009). *Surgical Exposures in Orthopaedics – The Anatomic Approach (*3rd ed*)*. Lippincott, Williams & Wilkins.

Hohmann E, Bryant AL. (2005). Biomechanics of ACL Rupture and Deficiency, Surgical Repair, Rehabilitation and Post – Surgical Evaluation. *Sports Science Sports Medicine Reviews*, 75 – 86.

Howells BE, Ardern CL, Webster KE. (2011). Is Postural Control Restored Following Anterior Cruciate Ligament Reconstruction? A Systematic Review. *Knee Surg Sports Traumatol Arthrosc*, *19*, 1168-77.

Howells BE, Clark RA, Ardern CL, Bryant AL, Feller JA, Whitehead TS, Webster KE. (2013). The Assessment of Postural Control and the Influence of A Secondary Task in People with Anterior Cruciate Ligament Reconstructed Knees Using a Nintendo® Wii™ Balance Board. *Br J Sports Med*, *47*(14), 914-9.

Hu HS, Whitney SL, Irrgang JJ, Janosky J. (1992). Test retest Reliability of the One – Legged Vertical Jump and The One Legged Hop Tests. *J Orthop Sports Phys Ther*, *15*, abstract.

Ingersoll CD, Grindstaff TL, Pietrosimone BG, Hart JM. (2008). Neuromuscular Consequences of Anterior Cruciate Ligament Injury. *Clin Sports Med*, *27*, 283 – 304.

Iwasa J, Ochi M, Adachi N, et al. (2000). Proprioceptive Improvement in Knees with Anterior Cruciate Ligament Reconstruction. *Clin Orthop*, *381*, 168 – 176.

Janssen KW, Orchard JW, Driscoll TR, van Mechelen W. (2011). High Incidence and Costs for Anterior Cruciate Ligament Reconstructions Performed in Australia from 2003- 2004 to 2007-2008: Time for An Anterior Cruciate Ligament Register by Scandinavian Model? *Scan J Med Sci Sports*, 1 – 7.

Johnson DS, Smith RB. (2011). Outcome Measurement in the ACL Deficient Knee – What's the Score? *Knee*, *8*(1), 51 – 57.

Kennedy JC, Alexander IJ, Hayes KC. Nerve Supply of the Human Knee and Its Functional Importance. *Am J Sports Med* 1982; 10: 329 – 355.

Kennedy JC, Weinberg HW, Wilson AS. The Anatomy and Function of the Anterioior Cruciate Ligament as Determined by Clinical and Morphological Studies. *J Bone Joint Surg Am* 1974; 56: 223 – 235.

Kocher MS, Steadman RJ, Briggs KK, Zurakowski D, Sterett WI, Hawkins RJ. (2002). Determinants of Patient Satisfaction with Outcome After Anterior Cruciate Ligament Reconstruction. *J Bone Joint Surg Am*, *84*, 1560 – 1572.

Kocher MS, Steadman JR, Briggs KK, Sterett WI, Hawkins RJ. (2004). Relationships Between Objective Assessment of Ligament Stability and Subjective Assessment of Symptoms and Functions After Anterior Cruciate Ligament Reconstruction. *Am J Sports Med*, *32*, 629 – 634.

Krauspe R, Schmidt M, Schaible HG. (1992). Sensory Innervation of the ACL: An Electrophysiological Study of the Response Properties of Single Identified Mechanoreceptors in the Cat. *J Bone Joint Surg Am*, *74*, 390 – 397.

Krauspe R, Schmitz F, Zoller G, Drenckhahn D. (1995). Distribution of Neurofilament Positive Nerve Fibres and Sensory Endings in the Human Anterior Cruciate Ligament. *Arch Orthop Trauma Surg*, *114,* 194 – 198.

Kues JM, Rothstein JM, Lamb RL. (1994). The Relationship Among Knee Extensor Torques Produced During Maximal Voluntary Contractions Under Various Test Conditions. *Phys Ther*, *74*(7), 674 – 683.

Leard JS, Cirillo MA, Katsnelson E, Kimiatek DA, Miller TW, Trebincevic K, Garbalosa JC. (2007). Validity of Two Alternative Systems for Measuring Vertical Jump Height. *J Strength Cond Res,* 21(4), 1296 – 9.

Lee BI. (2009). Immunochemical Study of Mechanoreceptors in the Tibial Remnant of Anterior Cruciate Ligament Remnant of Ruptured Human Knees. *Knee Surg Sports Traumatol Arthrosc*, *17*(9), 1095 – 1101.

Lee HM, Cheng CK, Liau JJ. (2009). Correlation between Proprioception, Muscle Strength, Knee Laxity, and Dynamic Standing Balance in Patients with Chronic Anterior Cruciate Ligament Deficiency. *The Knee*, *16*, 387 – 391.

Leelarthaepin B. *Assessment of Physical Fitness: a practical approach.* Sydney: Leelar Biomedicalscience Services, 1992

Lysholm J, Gillquist J. (1982). Evaluation of Knee Ligament Surgical Results with Special Emphasis on Use of Sccoring Scale. *Am J Sports Med*, *10*, 150 – 154.

MacDonald PB, Hedden D, Pacini O, Sutherland K. (1986). Proprioception in Anterior Cruciate Ligament Deficient and Reconstructed Knees. *Am J Sports Med*, *24*, 774 – 778.

Marx RG. (2009). Knee Rating Scales. *Arthroscopy*, *19*(10), 1103 – 1108.

Marx RG, Jones EC, Allen AA, Altchek DW, O'Brien SJ, Rodeo SA, Williams RJ, Warren RF, Wicklewicz TL. (2001). Reliability, Validity and Responsiveness of Four Knee Outcome Scales for Athletic Patients. *J Bone Joint Surg Am*, *83*(10), 1459 – 1469.

McMinn RMH. (1994). *Last's Anatomy: Regional and Applied* (5th ed). Elsevier.

Mir SM, Hadian MR, Talebian S, Nasseri N. (2008). Functional Assessment of Knee Joint Position Sense Following Anterior Cruciate Ligament Reconstruction. *Br J Sports Med*, *42*, 300 – 303.

Moir G, Button C, GHlaister M, Stone MH. (2004). Influence of Familiarisation of the Reliability of Vertical Jump and Acceleration Sprinting Perforamnce in Physically Active Men. *J Strength Cond Res*, *18*(2), 276 – 280.

Monaco E, Labianca L, Counteduca F, De Carli A, Feretti A. (2007). Double Bundle or Single Bundle Plus Extraarticular Tenodesis in ACL Reconstruction? A CAOS Study. *Knee Surg Sports Traumatol Arthrosc*, *15*(10), 1168 – 1174.

Muaidi QI, Nicholson LL, Refshauge KM, Adams RD, Roe JP. (2009). Effect of ACL Injury and Reconstruction on Proprioceptive Acuity of Knee Rotation in the Transverse Plane. *Am J Sports Med*, *37*(8), 1618 – 1626.

Nagai T, Sell TC, House AJ, Abt JP, Lephart SM. (2013). Knee proprioception and Strength and Landing Kinematics During a Single-Leg Stop-Jump Task. *J Athl Train, 48*(1), 31-8.

Noyes FR, Barber SD, Mooar PA. (1989). A Rationale for Assessing Sports Activity Levels and Limitations in Knee disorders. Clin Orth, 246 – 249.

Noyes FR, Mooar PA, Matthews DS, (1983). The Symptomatic Anterior Cruciate Deficient Knee. Part 1: The Long- Term Disability in Athletically Active Individuals. *J Bone Joint Surg Am*, *65*, 154 – 162.

Ochi M, Iwasa J, Uchio Y, Adachi N, Sumen Y. (1999). The Regeneration of Sensory Neurons in the Reconstruction of the Anterior Cruciate Ligament. *J Bone Joint Surg Br*, *81*, 902 – 906.

O'Neill DB. (2001). Arthroscopically Assisted Reconstruction of the Anterior Cruciate Ligament: a Follow- Up Report. *J Bone Joint Surg Am*, *183*, 1329 – 1332.

Pap G, Machner A, Nebelung W, Awiszus F. (1999). Detailed Analysis of Proprioception in Normal and ACL Deficient Knees. *J Bone Joint Surg Br*, *81*, 764 – 768.

Petschnik R, Baron R, Albrecht M. (1998). The Relationship Between Isokinetic Quadriceps Strength and Hop Tests for Distance and One – Legged Vertical Jump Following Anterior Cruciate Ligament Reconstruction. *J Orthop Sports Phys Ther*, *28*(1), 23 – 31.

Pirrtola M, Era P. (2006). Force Platform Measurements as Predictors of Falls Among Older People – A Review. *Gerontology*, *52*(1), 1 – 16.

Pua YH, Liang Z, Ong PH, Bryant AL, Lo NN, Clark RA. (2011). Associations of Knee Extensor Strength and Standing Balance with Physical Function in Knee Osteoarthritis. *Arthritis Care Res*, *63*(12), 1706-14.

Rannest J et al. (1998). Proprioception of Cruciate Ligaments: Receptor Mapping in an Animal Model. *Arch Orthop Trauma Surg*, *19*(3), 159 – 163.

Reider B, Arcand MA, Lee HD, Mroczek K, Abulencia A, Stroud CC, Palm M, Gilbertson J, Staszak P. (2003). Proprioception of the Knee Before and After Anterior Cruciate Ligament Reconstruction. *Arthroscopy*, *19*(1): 2 – 12.

Roberts D, Ageberg E, Andersson G, Friden T. (2007). Clinical Measurements of Proprioception, Muscle Strength and Laxity in Relation to Function in the ACL- Injured Knee. *Knee Surg Sports Traumatol Arthrosc*, *15*, 9 – 16.

Roberts D, Friden T, Stomberg A, Lindstrand A, Moritz U. (2000). Bilateral Proprioceptive Defeccts in Patients with A Unilateral Anterior Cruciate Ligament Reconstruction: A Comparison Between Patients and Healthy Individuals. *J Orthop Res*, *18*, 565 – 571.

Rong GW, Wang YC. (1987). The Role of Cruciate Ligaments in Maintaining Knee Joint Stability. *Clin Orthop*, *215*, 65 – 71.

Ross, MD, Langford, B, Whelan PJ. (2002). Test-Retest Reliability of Four Single-Leg Horizontal Hop Tests. *J Streng Cond Res.* 16(4), 617 – 622.

Salavati M, Hadian MR, Mazaheri M, Negahban H, Ebrahimi I, Talebian S, et al. (2009). Test-retest Reliability of Centre of Pressure Measures of Postural Stability During Quiet Standing in a Group with Musculoskeletal Disorders Consisting of Low Back Pain, Anterior Cruiciate Ligament Injury and Functional Ankle Instability. *Gait Posture*, 29(3), 460 – 464.

Sargeant DA. (1921). The Physical Test of A Man. *Am Phys Ed Rev*, *26*, 188 – 194.

Sasaki N, Farraro KF, Kim KE, Woo SL. (2014). Biomechanical Evaluation of The Quadriceps Tendon Autograft for Anterior Cruciate Ligament Reconstruction: A Cadaveric Study. *Am J Sports Med, 42*(3), 723-30

Schutte MJ, Dabezies EJ, Zinny ML, Happel LT. (1987). Neural Anatomy of the Human Anterior Cruciate Ligament. *J Bone Joint Surg Am*, *69*, 243 – 247.

Sgalione NA, Del Pizzo W, Fox JM, Friedman MJ. (1996). Critical Analysis of Knee Ligament Rating Systems. *Am J Sports Med*, *23*(6), 660 – 667.

Swinscow TDV, & Campbell MJ. (2002). *Statistics at Square One (*9th ed*).* BMJ Books, Blackwell.

Taketomi S, Inui H, Sanada T, Nakamura K, Yamagami R, Masuda H, Tanaka S, Nakagawa T. (2014). Remnant-Preserving Anterior Cruciate Ligament Reconstruction Using a Three-Dimensional Fluoroscopic Navigation System. Knee Surg Relat Res, *26*(3), 168-76.

Tandeter HB, Shvartzman P, Stevens MA. (1999). Acute Knee Injuries: Use of Decision Rules for Selective Radiograph Ordering. *Am Fam Physician*, *60*, 2600.

Tashiro Y, Okazaki K, Miura H, Matsuda S, Yasunaga T, Hashizume M, Nakanishi Y, Iwmoto Y. (2009). Quantitative Assessment of Rotatory Instability after Anterior Cruciate Ligament Reconstruction. *Am J Sports Med*, *37*, 909 – 916.

Tegner Y, Lysholm J. (1985). Rating Systems in the Evaluation of Knee Ligament Injuries. *Clin Orthop*, *198*, 43 – 49.

Williams GN, Chmielewski T, Rudolph KS, Buchanan T, Snyder-Mackler L. (2001). Dynamic Knee Stability: Current Theory and Implications for Clinicians and Scientists. *J Orthop Sports Phys Ther*, *31*(10), 546 – 566.

Woo SL, Kanamori A, Zeminski J, Yagi M, Papageorgiou C, Fu FH. (2002). The Effectiveness of Reconstruction of the Anterior Cruciate Ligament with Hamstrings and Patellar Tendon: A Cadaveric Study Comparing Anterior Tibial and Rotational Loads. *J Bone Joint Surg Am*, *84*, 907 – 914.

Yoo JD, Papannagari R, Park SE, DeFrate LE, Gill TJ, Li G. (2005). The Effect of Anterior Cruciate Ligament Reconstruction on Knee Joint Kinematics under Simulated Muscle Loads. *Am J Sports Med*, *33*, 240 – 246.

Young DW, McDonald C, Heggen T, Fitzpatrick J. (1997). An Evaluation of the Specificity, Validity, and Reliability of Jumping Tests. *J Sports Med Phys Exercise*, *37*(4), 240 – 255.

Zantop T, Herbort M, Raschke MJ, Fu FH, Petersen W. (2007). The Role of the Anteromedial and Posterolateral Bundles of the Anterior Cruciate Ligament in Anterior Tibial Translation and Internal Rotation. *Am J Sports Med*, *35*, 223 – 227.

## APPENDIX A: AUTHOR GUIDELINES

# AJSM Manuscript Submission Guidelines

The *American Journal of Sports Medicine* (AJSM) is the official publication of the American Orthopaedic Society for Sports Medicine.

The editor of AJSM, Bruce Reider, can be contacted via e-mail at breider@ajsm.org.

Manuscripts must not be under simultaneous consideration by any other publication, before or during the peer-review process. Papers presented at AOSSM meetings must be submitted to the Journal for first rights of refusal. Authors are responsible for submitting papers of presentations directly to the Journal. Articles published in AJSM may not be published elsewhere without written permission from the publisher.

Manuscripts should cite any other work by one or more of the co-authors that is relevant to the subject matter of the current submission or that used any of the same participants, animals, or specimens being reported in the current submission. This includes manuscripts that are currently under preparation, are being considered by journals, are accepted for publication, or already published. In any of these cases, the relationship to the current submission should be made clear.

All review articles (such as systematic review, meta- analysis) submitted will be considered for the Current Concepts section. Authors with ideas for current concepts should contact the associate editor, Timothy Foster, MD, to find out if AJSM has recently published a review article on that topic of if there is a similar submission in progress. Contact Dr Foster at currentconcepts@ajsm.org to inquire about your idea or submit already completed papers directly to the journal at http://ajsm-submit.highwire.org.

### SUBMISSIONS

Authors should register on our online submission site at http://ajsm-submit.highwire.org/ to submit manuscripts.

When manuscripts have been received by the editorial office, the corresponding author will be sent an acknowledgment giving an assigned manuscript number, which should be used with all subsequent correspondence for anything related to that particular manuscript.

The following items are required on submission:

1. Blinded manuscript including the abstract and figures legends. No identifying information should appear in the uploaded manuscript. Please remove author names, initials, and institutions. State or country names may be used, but do not include specific locations such as cities or regions.
2. Journal Contributor Publishing Agreement and AJSM Author Disclosure Statement. These forms are available for download from the author area of the submission site. The corresponding author must complete the forms and return them to AJSM by e-mail or upload them online as a PDF or Word file using the “upload legal documents” option. As an alternative to the AJSM disclosure form, authors may submit the ICMJE disclosure form *along with* the AJSM supplemental form available on our website.
3. A copy of the IRB or other agency approval (or waiver) if animal participants or human participants or tissues or health information were used. This information should be

uploaded with the disclosure and publishing forms and not as a supplemental file.

Cover letter, acknowledgments, and suggested reviewers are optional. If a paper has more than 5 authors, a cover letter detailing the contributions of all authors should be included in the appropriate box on the submission page. Only those involved in writing the paper should be included in the author line. Others should be listed as a footnote or acknowledgment. While there is no limit on the number of authors, no more than 12 will be listed on the masthead of the published article; additional authors will be listed at the end of the article.

## MANUSCRIPT FORMATS

Manuscript pages should be double-spaced with consecutive page numbers and continuous line numbers. The abstract should be included with the manuscript as well as being entered in the Metadata section (except for case reports, which do not require abstracts). Manuscripts should be 6000 words or fewer (including abstract and references). There are also limitations on figures, tables, and references; see guidelines below. The system handles most common word processing formats; however, Word and PDF are preferred.

## MANUSCRIPT PREPARATION

### Abstract

Abstracts should summarize the contents of the article in 350 words or less. The abstract should be structured in the following format:

**Background:** In one or two sentences, summarize the scientific body of knowledge surrounding your study and how this led to your investigation.

**Hypothesis/Purpose:** State the theory(ies) that you are attempting to prove or disprove by your study or the purpose if no hypothesis exists.

**Study Design:** Identify the overall design of your study. See list below.

**Methods:** Succinctly summarize the overall methods you used in your investigation. Include the study population, type of intervention, method of data collection, and length of the study.

**Results:** Report the most important results of your study. Only include positive results that are statistically significant, or important negative results that are supported by adequate power. Report actual data, not just *P* values.

**Conclusion:** State the answer to your original question or hypothesis. Summarize the most important conclusions that can be directly drawn from your study.

**Clinical Relevance:** If yours was a laboratory study, describe its relevance to clinical sports medicine.

**Key Terms:** Include at least 4 key terms for indexing. When submitting an article, you will be asked to choose from a list of terms that are used for assigning reviewers. These terms can be used in the manuscript as well. The list can be found at http://ajsm-submit.highwire.org/submission/ editexpertise

**What is known about the subject:** Please state what is currently known about this subject to place your study in perspective for the reviewers.

**What this study adds to existing knowledge:** Please state what this study adds to the existing knowledge.

The last two items are for reviewers only and are not included in the word count, but should appear at the end of the abstract in the uploaded text.

### Study Designs

**Meta-analysis:** A systematic overview of studies that pools results of two or more studies to obtain an overall answer to a question or interest. Summarizes quantitatively the evidence regarding a treatment, procedure, or association.

**Systematic Review:** An article that examines published material on a clearly described subject in a systematic way. There must be a description of how the evidence on this topic was tracked down, from what sources and with what inclusion and exclusion criteria.

**Randomized Controlled Clinical Trial:** A group of patients is randomized into an experimental group and a control group. These groups are followed up for the variables / outcomes of interest.

**Crossover Study Design:** The administration of two or more experimental therapies one after the other in a specified or random order to the same group of patients.

**Cohort Study:** Involves identification of two groups (cohorts) of patients, one which did receive the exposure of interest, and one which did not, and following these cohorts forward for the outcome of interest.

**Case-Control Study:** A study that involves identifying patients who have the outcome of interest (cases) and patients without the same outcome (controls), and looking back to see if they had the exposure of interest.

**Cross-Sectional Study:** The observation of a defined population at a single point in time or time interval. Exposure and outcome are determined simultaneously.

**Case Series:** Describes characteristics of a group of patients with a particular disease or who have undergone a particular procedure. Design may be prospective or retrospective. No control group is used in the study, although the discussion may compare the results to other published outcomes.

**Case Report:** Similar to the case series, except that only one or a small group of cases is reported.

**Descriptive Epidemiology Study:** Observational study describing the injuries occurring in a particular sport.
**Controlled Laboratory Study:** An in vitro or in vivo

investigation in which 1 group receiving an experimental treatment is compared to 1 or more groups receiving no treatment or an alternate treatment.

**Descriptive Laboratory Study:** An in vivo or in vitro study that describes characteristics such as anatomy, physiology, or kinesiology of a broad range of participants or a specific group of interest. Authors should choose the design that best fits the study.

The Editor will make the final determination of the study design and level of evidence based on the Center for Evidence Based Medicine guidelines.

### Text

In general, follow the standard IMRAD (Introduction, Materials and Methods, Results, Discussion) format for

writing scientific articles. The author is responsible for all statements made in the work, including copyeditor changes, which the author will have an opportunity to verify. Authors with limited fluency in English should have the paper reviewed or edited by a native English speaker to ensure clear presentation of the work. **Papers including human or animal participants must include a statement of approval by appropriate agencies in the text, and a copy of the approval letter must be uploaded with the submission. If approval was not required, authors must upload a waiver statement from the appropriate agency.** For case reports, include a letter from the patient granting permission for his/her information to be included in the publication.

Reports on surgery, except in rare instances, require a minimum follow-up of 2 years.

Use generic names of drugs or devices. If a particular brand was used in a study, insert the brand name along with the name and location of the manufacturer in parentheses after the generic name when the drug or device is first mentioned in the text.

Use metric units in measurements (centimeter vs inch, kilogram vs pound).

Abbreviations should be used sparingly. When abbreviations are used, give the full term followed by the abbreviation in parentheses the first time it is mentioned in the text, such as femur-ACL-tibia complex (FATC).

Use of a CONSORT flow diagram is recommended to illustrate the grouping and flow of patients in all clinical studies, whether randomized clinical trials or otherwise.

Statistical methods should be described in detail. Actual *P* values should be used unless less than .001. Reporting of 95% confidence intervals is encouraged.

### Acknowledgment

Type the acknowledgments in the box provided on the submission page; do not include it in the manuscript. This information will be added to the accepted manuscript at the time of publication. Give credit to technical assistants and professional colleagues who contributed to the quality of the paper but are not listed as authors. Please briefly describe the contributions made by persons being acknowledged. **Note: anyone who has contributed to the preparation of the submitted text must be included on the author disclosure form, under Statement of Authorship, and disclosures included there.**

### References

References should be double-spaced in alphabetical order and numbered according to alphabetical listing. Except for review articles, references should be limited to 60. If references are not in alphabetical order the uploaded file will be REJECTED and will have to be resubmitted with the references in the correct form. When author entries are the same, alphabetize by the first word of the title. In general, use the Index Medicus form for abbreviating journal titles and the *AMA Manual of Style* (10th ed) for format. *Note:* References must be retrievable. Do not include in the reference list meeting presentations that have not been published. Data such as presentations and articles that have been submitted for publication but have not been accepted must be put in the text as unpublished data immediately after mention of the information (for example, “Smith and Jones (unpublished data, 2000) noted ...”). Personal communications and other references to unpublished data are discouraged. For review purposes, unpublished references that are closely related to the submitted paper or are important for understanding it should be uploaded as supplemental files.

References will be linked to Medline citations for the reviewers. Authors can include articles that are in Epublish mode. To ensure that these Epub references are linked correctly, please provide the PMID number from Medline at the end of the reference. For example: Emery CA, Meeuwisse WH. Injury rates, risk factors, and mechanisms of injury in minor hockey. *Am J Sports Med*. 2006 Jul 21; [Epub ahead of print] PMID: 16861577

### Figures and Tables

Figures and tables should not exceed 3 journal pages. One journal page equals 1 large table or figure, 2 medium-sized tables or figures, or 4 small tables or figures. Medium-sized tables and figures will be a page width and half the length of the page; small tables and figures are 1-column width and take up half the length of the page or less.

Any material that is submitted with an article that has been reproduced from another source (that is, has been copyrighted previously) must conform to the current copyright regulations. It is the author’s responsibility to obtain written permission for reproduction of copyrighted material and for providing the editorial office with that documentation before the material will be reproduced in the Journal.

**All image files for figures should be labeled with the Figure number (label each part if figures include multiple parts, eg, 2A, 2B).** Be sure to include figure legends in the text. The figure legend should include descriptions of each figure part and identify the meaning of any symbols or arrows. Terms used for labels and in the legend must be consistent with those in the text.

Color will be used in the Journal where needed (eg, histology slides or surgical photographs). All other figures, such as bar graphs and charts, should be submitted in black and white.

Figures for papers accepted for publication must meet the image resolution requirements of the publisher, Sage Publications. Files for line-based drawings (no grayscale) should ideally be submitted in the format they were originally created; if submitting scanned versions, files should be 1200 dots per inch (dpi). Color photos should be submitted at 600 dpi and black-and-white photos at 300 dpi.

Charts and graphs can be submitted in the original form created (eg, Word, Excel, or PowerPoint). Photographs or scanned drawings embedded in Word or PowerPoint are not acceptable for publication. If figures are embedded in the submitted manuscript for ease of reading they should also be submitted as separate files for use in the publication process.

All photographs of patients that disclose their identity must be accompanied by a signed photographic release granting permission for their likeness to be reproduced in the article. If this is not provided, the patient's eyes must be occluded to prevent recognition.

For tables, the system accepts most common word processing formats. Tables should be numbered consecutively and have a title that describes the content and purpose of the table. Tables should enhance, not duplicate, information in the text.

### Videos

Use of supplementary video is encouraged. Videos may be submitted with a manuscript and, if approved by the editor, will be posted online with the article when published. Video submission is strongly encouraged for manuscripts reporting surgical, examination, or exercise techniques or injury mechanisms. For more information about the format requirements for videos, please review the Video Format Guide. For detailed information pertaining to copyright and permissions requirements, view the Video Permission and Fair Use Quick Guide. For videos with identifiable participants, participants will need to sign the Audio-Visual Likeness Release form. It is the author's responsibility to submit signed release forms, if necessary, for each video.

## ACCEPTED MANUSCRIPTS

Once an article is accepted and typeset, authors will be required to carefully read and correct their manuscript proofs that have been copyedited by the publisher. Any extensive changes made by authors on the proofs will be charged to authors at the rate of $2 a line. Authors are responsible for ordering reprints of their articles; a reprint order form is provided with the page proofs. Completed articles will be published on our website before print publication.

### NIH-Supported Studies

Authors of studies funded by grants from the National Institutes of Health can deposit a copy of their accepted final peer- reviewed manuscript and associated figure/table files (pre- typeset versions) to the NIH database after a 12-month embargo period from the time their article is published in AJSM.

## APPENDIX B: RESEARCH PROJECT PROPOSAL CQUNIVERSITY

### Research Title

The Relationship between Lower Extremity Balance, Objective, and Subjective Outome Measures in Patients with ACL – Deficient and ACL- Reconstructed Knees.

### Supervisors

Associate Professor Peter Reaburn – p.reaburn@cqu.edu.au

Associate Professor Erik Hohmann – Erik_Hohmann@health.qld.gov.au

Dr. Ross Clark – Ross.Clark@acu.edu.au

### Introduction

The knee joint is a complex system, where its main purpose is to accept, transfer, and to dissipate loads generated at the ends of the long mechanical lever arms of the femur and tibia.[1] To maintain such a functional stable system, the knee is not only reliant on the various ligaments to provide sensate adaptive linkages, but also the neuromuscular interactions between the central nervous system and the periarticular muscles. This mechano-sensory interaction is referred to as proprioception.[2]

Such adaptive balance is upset when ligaments rupture as in those with rupture of the Anterior Cruciate Ligament (ACL). It has been theorised that ACL serves both a proprioceptive and mechanical function to provide stability to the knee joint.[2]

Hence a successful reconstruction of the ACL must accomplish both the restoration of ligamentous stability, and the restitution of proprioception.[3,4]

### Aim

To investigate the relationship between balance, the objective, as well as subjective outcome measures in participants with an ACL – deficient and ACL – reconstructed knee.

### Ethics

The research would be subject to approval by the Human Research and Ethics Committee of the Central Queensland Health Services District (CQHSD), as well as CQ University Human Research Ethics Committee.

## Research Site

The research would take place with the support of the Department of Orthopaedics at Rockhampton Hospital. Rockhampton Hospital is the secondary referral hospital for the Central Queensland district serving a population of approximately 150,000.

Rockhampton Orthopaedics receive referrals for patients with suspected ACL deficient knees, at the same token also judiciously track those with ACL reconstruction performed in the outpatient setting.

## Methodology

Basing on Clark's (RA Clark, *Gait and Posture 2010*)[5], we will look to utilise the Nitendo® Wii™ Balance Platform. It will aid to compute the Centre of Pressure (COP) pathlength on the affected, and non- affected leg as a measure of proprioception. The findings obtained will then be correlated to not only the objective measures (isometric strength of the quadriceps, hamstring muscles, and function hopping tests, single leg squat test using the Wii™ platform as a measure of lower extremity strength), but also the subjective measures (using common knee outcome scores such as Lysholm, Tegner, IKDC, and Cincinnati).

Patients will be recruited from the Department of Orthopaedics Sports Injury Clinic at Rockhampton Hospital. This clinic caters for approximately 80% of the sporting community of Central Queensland. It covers mostly sports injuries of the knees and shoulders. Referrals are either made through the Emergency Department of Rockhampton Hospital or surrounding peripheral hospitals, or via the General Practitioner of the injured athlete. ACL – reconstructed patients are followed up through this clinic.

## Analysis

The Means and standard deviations will be calculated for the dependent variables. The Pearson's product moment correlation coefficients will be employed to establish the strength of the relationships between balance, objective, and subjective outcome measures. A level of significance of $p < 0.05$ is selective in all analysis to limit the chance of Type I error to 5%. All analysis will be conducted using SPSS (Version 12.0.1, Chicago, IL) for Windows.

Proposed Research Timeframe

| Time | Schedules |
|---|---|
| **Mid September 2010** | Enrolment in Research in Higher Degrees Programme at CQ University |
| **September 2010/Early October 2010** | 1. Applications for Ethics Approval to CQU and Rockhampton Human Ethics Committees lodged<br>2. To Melbourne to familiarise with the softwares required for the project |
| **October to January 2010** | 1. Awaiting for Ethics Approval<br>2. Set up outpatient clinics to accommodate for subject testing<br>3. Finalise setting up of softwares |

| | |
|---|---|
| **February 2011/March 2011** | Commence Testing and Data Gathering |
| **July 2011/August 2011** | Completion of data collection |
| **September 2011** | Data Analysis Commence |
| **October 2011/November 2011** | Write ups, presentations at conferences, journal publications |
| **January 2012** | Drafting of thesis |
| **March/April 2012** | Submit thesis |

References


1. Dye, SF. The Knee as a Biologic Transmission with an Envelope of Function, A Theory. *Clin Orthop Rel Research* 1996; **323**: 10 – 18
2. Mir, SM, Hadian MR, Talebian S, et al. Functional Assessment of Knee Joint Position Sense Following Anterior Cruciate Ligament Reconstruction. *Br J Sports Med* 2008; **42**: 300 – 303
3. Reider B, Michel A, Mroczek K, et al. Proprioception of the Knee Before and After Anterior Cruciate Ligament Reconstruction. *ArthrosCoPy* 2003; **19**(1): 2 – 12
4. Gomez-Barrena E, Bonsfills N, Martin JG et al. Insufficient Recovery of Neuromuscular Acitivity Around the Knee After Experimental Anterior Cruciate Ligament Reconstruction. *Acta Orthopaedica* 2008; **79**(1): 39 – 47
5. Clark RA, Bryant AL, McCrory et al. Validity and Reliability of the Nintendo Wii Balance Board for Assessment of Standing Balance. *Gait & Posture* 2010; **31**: 307 - 310
6. Moezy A, Olyaei G, Hadian M, et al. A Comparative Study of Whole Body Vibration Training and Conventional Training on Knee Proprioception and Postural Stability after Anterior Cruciate Ligament Reconstruction. *Br J Sports Med* 2008; **42**: 373 – 385
7. Swinscow TDV, Campbell MJ. Statistics at Square One. 10th Edition, BMJ Books, Blackwell Publishing. ISBN 978-0-7279-1552-8
8. Campbell MJ. Statistics at Square Two. 2nd Edition, BMJ Books, Blackwell Publishing. ISBN 978-1-4051-3490-3

## APPENDIX C: LETTER OF SUPPORT DEPARTMENT OF ORTHOPAEDICS, ROCKHAMPTON HOSPITAL

Queensland Government
Queensland Health

***CENTRAL QUEENSLAND HEALTH SERVICE DISTRICT***
***ORTHOPAEDIC CLINIC***

| | |
|---|---|
| Enquiries to: | Department of Orthopaedics |
| Telephone: | (07) 4920 6536 |
| Facsimile: | (07) 4920 7232 |
| Our Ref: | FDT:rm |

18th November 2010

Dear Dr Young

With regard to your e-mail, I would like to confirm that on behalf of the Orthopaedic Department, permission and access is permitted to allow you to access clients and conduct the research required for your proposal.

Access to computers, library facilities and medical records will also be provided to support you in this matter. I understand that Professor Hohmann has the necessary permission for his research proposals.

If you need any further information please do not hesitate to contact me on the above number.

Yours Sincerely

Dr Francois Du Toit
Director of Orthopaedics
Department of Orthopaedics
Central Queensland Health Service

| Office | Postal | Phone | Fax |
|---|---|---|---|
| Department of Orthopaedics<br>Central Queensland Health Service District | Rockhampton Hospital<br>Canning Street<br>ROCKHAMPTON QLD 4700 | (07) 4920 6775 | (07) 4920 6263 |

## APPENDIX D: CENTRAL QUEENSLAND HOSPITAL HREC APPROVAL FOR STUDY

Queensland Government

**CENTRAL QUEENSLAND HUMAN RESEARCH ETHICS COMMITTEE**

Queensland Health


**Enquiries:** Rodney Boddice
**Telephone:** 07 4920 5765
**Facsimile:** 07 4920 6335
**Email:** rod_boddice@health.qld.gov.au
**Our Ref:** HREC# 11/QCQ/09



Dr Tony Young
26 Prudence Parade
Alamanda Estate
POINT COOK VIC 3030


Dear Dr Young

**HREC Reference number:** HREC/11/QCQ 09

**Project Title:** The Relationship between Lower Extremity Balance, Objective, and Subjective Outcome Measures in Patients with ACL – Deficient and ACL – Reconstructed Knees

Thank you for submitting the above project for ethical and scientific review. This project was first considered by the Central Queensland Health Service District Human Research Ethics Committee (HREC) meeting held on 31 March 2011 and again on 26 May 2011. Following discussion you were invited to attend the meeting on 28 July 2011 to discuss your application. I thank you for providing the addendum as discussed in the July meeting.

This HREC is constituted and operates in accordance with the National Health and Medical Research Council's (NHMRC) *National Statement on Ethical Conduct in Human Research (2007), NHMRC and Universities Australia Australian code for the Responsible Conduct of Research (2007)* and the *CPMP/ICH Note for Guidance on Good Clinical Practice.*

I am pleased to advise that the Human Research Ethics Committee has granted approval of this research project effective from 28 July 2011. The documents reviewed and approved include:

| Document | Version | Date |
|---|---|---|
| Amended NEAF | Version 7 | July 2011 |
| Amended Consent Form | | July 2011 |
| Amended Information Sheet – ACL – R Group | | July 2011 |
| Amended Information Sheet – ACL – D Group | | July 2011 |
| Information Sheet Demonstration Pictures | | May 2011 |
| Study Protocol | | May 2011 |
| 2000 IKDC Knee Forms | | May 2011 |
| Cincinnati Scoring System (Noyes Score) | | May 2011 |
| Letter of Support from Dr Francois Du Toit | 1 | 18 November 2010 |
| Approval letter from CQUniversity | 1 | 4 July 2011 |


*OFFICE:*
*Level 2, CQU Building*
*36 East Street*
*ROCKHAMPTON Q 4700*

*POSTAL :*
*PO Box 871*
*ROCKHAMPTON*

*PHONE*
*(07) 4920 5765*

*FAX:*
*(07) 4920 6335*

# APPENDIX E: CQ UNIVERSITY HREC APPROVAL

Secretary, Human Research Ethics Committee
Ph: 07 4923 2603
Fax: 07 4923 2600
Email: ethics@cqu.edu.au

4 July 2011

Dr Tony Young
26 Prudence Parade
Alamanda Estate
Point Cook VIC 3030

Dear Dr Young

**HUMAN RESEARCH ETHICS COMMITTEE CONDITIONAL APPROVAL: PROJECT H11/05-096, *THE RELATIONSHIP BETWEEN LOWER EXTREMITY BALANCE, OBJECTIVE, AND SUBJECTIVE OUTCOME MEASURES IN PATIENTS WITH ACL - DEFICIENT AND ACL - RECONSTRUCTED KNEES***

The Human Research Ethics Committee is an approved institutional ethics committee constituted in accord with guidelines formulated by the National Health and Medical Research Council (NHMRC) and governed by policies and procedures consistent with principles as contained in publications such as the joint Universities Australia and NHMRC *Australian Code for the Responsible Conduct of Research.* This is available at http://www.nhmrc.gov.au/publications/synopses/_files/r39.pdf.

On 28 June 2011, the committee met and considered your application. The project was assessed as being greater than low risk, as defined in the National Statement. The committee is pleased to tell you that they have granted conditional approval for your research *The Relationship between Lower Extremity Balance, Objective, and Subjective Outcome Measures in Patients with ACL - Deficient and ACL - Reconstructed Knees* (Project Number H11/05-096). There are a number of conditions to be met:

a) *Although it was not picked up at the May meeting, members noticed that your supervisors are also listed as principal or associate researchers, and also as other relevant personnel. The committee is unsure whether this is an error and asks for clarification as this may present the potential for challenging the student's contribution.*
b) *Please provide a copy of approval from the Rockhampton Health Service District HREC*

The period of ethics approval will be from date of compliance with the conditions above to 20 June 2012. The approval number is H11/05-096; please quote this number in all dealings with the Committee. HREC wishes you well with the undertaking of the project and looks forward to receiving the final report and statement of findings.

**PLEASE NOTE: It is important that** you do NOT commence any aspects of the project involving human participants until you have lodged with the Human Research Ethics Committee the required information and/or acceptance of the outlined conditions.

Central Queensland University CRICOS Provider Codes: QLD - 00219C, NSW - 01315F, VIC - 01624D

**APPENDIX F: CONSENT FORM FOR STUDY**

# Department of Orthopaedic Surgery, Rockhampton Hospital

## The Relationship between Lower Extremity Balance, Objective, and Subjective Outcome Measures in Patients with ACL – Deficient and ACL – Reconstructed Knees

## CONSENT FORM

**I consent to participation in this research project and agree that:**

1. An information Sheet has been provided to me that I have read and understood;
2. I have had any questions I had about the project answered to my satisfaction by the Information Sheet and any further verbal explanation provided;
3. I understand that my participation or non-participation in the research project will not affect my treatment.
4. I understand that I have the right to withdraw from the project at any time without penalty;
5. I understand the research findings will be included in the researchers' publication(s) on the project and this may include conferences and articles written for journals and other methods of dissemination stated in the Information Sheet;
6. I agree that the results of the study may be published providing that I am not identified in any way.
7. I am aware that a plain English statement of results will be available at my request;
8. I agree that I am providing informed consent to participate in this project.

Signature: ________________________________________ Date: __________________

Full Name: ______________________________________________________________________

| | YES | NO |
|---|---|---|
| 1. I wish to have a plain English statement of results posted to me at the address I provide below. | | |
| 2. I give permissions for photographs and digital images of me to be used in any publication(s) from the research project | | |

Postal Address: ________________________________________________________________________

Email Address: ________________________________________________________________________

**APPENDIX G: PARTICIPANTS CLEARANCE FORM FOR PHYSCIAL TESTINGS**

# Department of Orthopaedic Surgery, Rockhampton Hospital

**The Relationship between Lower Extremity Balance, Objective, and Subjective Outcome Measures in Patients with ACL – Deficient and ACL – Reconstructed Knees**

**PARTICIPANTS CLEARANCE FORM FOR PHYSICAL TESTINGS**

I, Professor Erik Hohmann, Orthopaedic Consultant, Department of Orthopaedics Surgery, Rockhampton Hospital, approve ______________________________________________________, to undertake the series of tests involved with Dr. Tony Young's research project titled *"The Relationship between Lower Extremity Balance, Objective, and Subjective Outcome Measures in Patients with ACL – Deficient and ACL – Reconstructed Knees."*

Signature:_______________________________________ Date:_________________

**APPENDIX H: INFORMATION SHEET FOR ACLD GROUP**

# Department of Orthopaedic Surgery, Rockhampton Hospital

**The Relationship between Lower Extremity Balance, Objective, and Subjective Outcome Measures in Patients with ACL – Deficient and ACL – Reconstructed Knees**

**INFORMATION SHEET**

**ACL – D Group**

You are invited to participate in a study to determine the functionality of your knee, sense of your balance, as well as strength of your thigh muscles before the anterior cruciate ligament of your knee is reconstructed. Before agreeing to take part in this study, it is important that you read and understand the description of the study. One researcher will also explain the study to you, and testing session to ensure you understand.

This study will be performed by Dr. Tony Young, the orthopaedic registrar, and Associate Professor Erik Hohmann of Department of Orthopaedics, Rockhampton Hospital.

This study also forms the major part of Dr. Young's Master of Human Movement Science degree in CQUniversity.

## PURPOSE OF THE STUDY

The objective of the study is to assess your sense of balance, the functionality of your knee, as well as testing the strength of your thigh muscles, we would like to compare your results with other participants who have had the anterior cruciate ligament of the knee surgically reconstructed. This will give us a subjective and objective outcome of strength and stability in your knee. This will help us to evaluate if there is any difference in sense of balance, thigh strength and stability between the two groups.

## PRIOR TO THE PROCEDURE

We will ask you to stand on your affected leg on the Wii™ Balance Board for thirty seconds with arms by your side and with eyes open.  This is to help us to assess your baseline leg strength, and if you are not able to perform this particular task, we will not be able to continue with further tests as we believe that there is a higher than acceptable risk of you sustaining further injury from performing these tests.

**STUDY PROCEDURE**

The following is an outline of the study including what you are required to do if you choose to participate.  Please feel free to ask the researcher if you do not understand.

In this study, you will be asked to do the following during your clinic appointment:

1. Stand on your 'bad' leg (the side of the knee needing ACL reconstruction) on a platform shown in Fig. A for 30 seconds at a time, this will be repeated five times with a break of one minute in between, the data produced will be recorded.
2. We will then ask you to stand on your other leg (Fig. B), and repeat the same test, this is also repeated five times;
3. Sit in the chair facing the platform as shown in Fig. C, and push hard against the platform, with it leaning against the wall for six seconds.  This measures your quadriceps strength.  You will be asked to do this five times, this will alternate on both legs with a break of one minute in between;
4. Sit in the chair with the platform placed as shown in Fig. D, you will then push into the platform with your heel as hard as you can for six seconds.  This again will repeated five times for each leg with a break of one minute in between;
5. We will then measure how high you could jump from standing on either leg, we will record the height of your jump to assess your muscle strength, you will be asked to do this five times on each leg in alternate fashion with a break of one minute in between;
6. You will be asked to hop forward on one leg as far as you can, the distance will be measured, and this is to be repeated five times on both legs in alternate fashion with a break of one minute in between;
7. We will ask you to complete 4 health questionnaires regarding your knee to assess your pain and ability to perform daily activities, with the help of an examiner if required.

**POSSIBLE RISKS & DISCOMFORTS**

During the study, you may experience some discomfort such as muscle lethargy, as it is encouraged that maximal effort be exerted for these tests.  You may also develop delayed onset of muscle soreness due to maximal testing of strength involved.  This however can be alleviated with icepacks applied to the sore region, and also by reducing your level of activity for a few days after the test.  Any risk or harm will be minimised by adhering to standard techniques.

You may lose balance and fall off the platform during the balance testing, or fall when jumping on either leg, please be assured that you will be fully supervised at all times to minimise this risk, however shall you fall, we will take you to the Emergency Department here to be fully assessed.

Additionally, all results will be collected by qualified personnel.

**CONFIDENTIALITY**

Any information that is obtained in this study, and that can be identified with you will remain strictly confidential. Only the researchers involved with the study will have access to your personal records. Individual data will not be identified in any published material.

**PARTICIPATION IN THE STUDY**

If you decide to participate in this study, you are free to withdraw your consent and discontinue participation at any time, for any reason without prejudice. Should you choose to withdraw from the study, we would appreciate some notice in advance.

**FEEDBACK**

Written summary of results from this study in plain English can be made available upon your request.

**INFORMED CONSENT**

If you decide to participate in the study you will be required to complete the 'Informed Consent Form', and the researcher will keep the consent form for our records.

**INQUIRIES**

If you have any questions, please contact:

Dr. Tony Young

Rockhampton Hospital

Department of Orthopaedic Surgery

Ph: (07) 4720 7565

**Please contact Central Queensland University's Office of Research (Tel: 07 4923 2607; E-mail: research-enquiries@cqu.edu.au; Mailing address: Building 32, Central Queensland University, Rockhampton QLD 4702) should there be any concerns about the nature and/or conduct of this research project.**

## APPENDIX I: INFORMATION SHEET FOR ACLR GROUP

CQUniversity AUSTRALIA

# Department of Orthopaedic Surgery, Rockhampton Hospital

**The Relationship between Lower Extremity Balance, Objective, and Subjective Outcome Measures in Patients with ACL – Deficient and ACL – Reconstructed Knees**

**INFORMATION SHEET**

**ACL – R Group**

You are invited to participate in a study to determine the functionality of your knee, sense of your balance, as well as strength of your thigh muscles before the anterior cruciate ligament of your knee is reconstructed. Before agreeing to take part in this study, it is important that you read and understand the description of the study. One researcher will also explain the study to you, and testing session to ensure you understand.

This study will be performed by Dr. Tony Young, the orthopaedic registrar, and Associate Professor Erik Hohmann of Department of Orthopaedics, Rockhampton Hospital.

This study also forms the major part of Dr. Young's Master of Human Movement Science degree in CQUniversity.

**PURPOSE OF THE STUDY**

The objective of the study is to assess your sense of balance, the functionality of your knee, as well as testing the strength of your thigh muscles, we would like to compare your results with other participants who have not yet had the anterior cruciate ligament of the knee surgically reconstructed. This will give us a subjective and objective outcome of strength and stability in your knee. This will help us to evaluate if there is any difference in sense of balance, thigh strength and stability between the two groups.

**PRIOR TO THE PROCEDURE**

We will ask you to stand on your affected leg on the Wii™ Balance Board for thirty seconds with arms by your side and with eyes open. This is to help us to assess your baseline leg strength, and if you are not able to perform this particular task, we will not be able to continue with further tests as we believe that there is a higher than acceptable risk of you sustaining further injury from performing these tests.

**STUDY PROCEDURE**

The following is an outline of the study including what you are required to do if you choose to participate. Please feel free to ask the researcher if you do not understand.

In this study, you will be asked to do the following during your clinic appointment:

1. Stand on your 'reconstructed' leg (the side of the knee needing ACL reconstruction) on a platform shown in Fig. A for 30 seconds at a time, this will be repeated five times with a break of one minute in between, the data produced will be recorded.
2. We will then ask you to stand on your other leg (Fig. B), and repeat the same test, this is also repeated five times;
3. Sit in the chair facing the platform as shown in Fig. C, and push hard against the platform, with it leaning against the wall for six seconds. This measures your quadriceps strength. You will be asked to do this five times, this will alternate on both legs with a break of one minute in between;
4. Sit in the chair with the platform placed as shown in Fig. D, you will then push into the platform with your heel as hard as you can for six seconds. This again will repeated five times for each leg with a break of one minute in between;
5. We will then measure how high you could jump from standing on either leg, we will record the height of your jump to assess your muscle strength, you will be asked to do this five times on each leg in alternate fashion with a break of one minute in between;
6. You will be asked to hop forward on one leg as far as you can, the distance will be measured, and this is to be repeated five times on both legs in alternate fashion with a break of one minute in between;
7. We will ask you to complete 4 health questionnaires regarding your knee to assess your pain and ability to perform daily activities, with the help of an examiner if required.

**POSSIBLE RISKS & DISCOMFORTS**

During the study, you may experience some discomfort such as muscle lethargy, as it is encouraged that maximal effort be exerted for these tests. You may also develop delayed onset of muscle soreness due to maximal testing of strength involved. This however can be alleviated with icepacks applied to the sore region, and also by reducing your level of activity for a few days after the test. Any risk or harm will be minimised by adhering to standard techniques.

You may lose balance and fall off the platform during the balance testing, or fall when jumping on either leg, please be assured that you will be fully supervised at all times to minimise this risk, however shall you fall, we will take you to the Emergency Department here to be fully assessed.

Additionally, all results will be collected by qualified personnel.

**CONFIDENTIALITY**

Any information that is obtained in this study, and that can be identified with you will remain strictly confidential. Only the researchers involved with the study will have access to your personal records. Individual data will not be identified in any published material.

**PARTICIPATION IN THE STUDY**

If you decide to participate in this study, you are free to withdraw your consent and discontinue participation at any time, for any reason without prejudice. Should you choose to withdraw from the study, we would appreciate some notice in advance.

**FEEDBACK**

Written summary of results from this study in plain English can be made available upon your request.

**INFORMED CONSENT**

If you decide to participate in the study you will be required to complete the 'Informed Consent Form', and the researcher will keep the consent form for our records.

**INQUIRIES**

If you have any questions, please contact:

Dr. Tony Young

Rockhampton Hospital

Department of Orthopaedic Surgery

Ph: (07) 4720 7565

**Please contact Central Queensland University's Office of Research (Tel: 07 4923 2607; E-mail: research-enquiries@cqu.edu.au; Mailing address: Building 32, Central Queensland University, Rockhampton QLD 4702) should there be any concerns about the nature and/or conduct of this research project.**

## APPENDIX J: INFORMATION SHEET FOR INVESTIGATORS

Subject ID: ________________________________________

Gender: M□ F□

Date of Birth: ____/____/________ (DD/MM/YYYY)

Height:__________ cm Weight:________ kg

Affected Leg: L□ R□

**STATION 1: Balance**

| Side | COP Measurement | Mean |
|---|---|---|
| LEFT | | |

| Side | COP Measurement | Mean |
|---|---|---|
| RIGHT | | |

**STATION 2: Quads & Hamstrings Strength**

| Side | Quads Peak Strength | Mean |
| --- | --- | --- |
| LEFT | | |

| Side | Quads Peak Strength | Mean |
| --- | --- | --- |
| RIGHT | | |

| Side | Hamstring Strength | Mean |
| --- | --- | --- |
| LEFT | | |

| Side | Hamstring Strength | Mean |
| --- | --- | --- |
| RIGHT | | |

**STATION 3: Single Legged Hop**

| Side | Distance (cm) | Mean |
|---|---|---|
| LEFT | | |

| Side | Distance (cm) | Mean |
|---|---|---|
| RIGHT | | |

**STATION 4: Single Legged Vertical Jump**

| Side | Height (cm) | Mean |
|---|---|---|
| LEFT | | |

| Side | Height (cm) | Mean |
|---|---|---|
| | | |

RIGHT

## APPENDIX K: DEMONSTRATION PICTURES FOR BOTH GROUPS

# Department of Orthopaedic Surgery, Rockhampton Hospital

**The Relationship between Lower Extremity Balance, Objective, and Subjective Outcome Measures in Patients with ACL – Deficient and ACL – Reconstructed Knees**

**Fig. A**

**Fig. B**

Fig. C

Fig. D

## APPENDIX L: SAMPLE OF AUTOMATED LYSHOLM & TEGNER ACTIVITY SCALE

### Lysholm Knee Questionnaire / Tegner Activity Scale

**Name:** ______ ______ **Date:** ______
First Last

**Physician:** ______

**1. Limp:**

- a) None
- b) Slight or periodical
- c) Severe and constant

**2. Support:**

- a) None
- b) Stick or crutch
- c) Weight-bearing impossible

**3. Locking:**

- a) No locking and no catching sensations
- b) Catching sensation but no locking
- c) Locking occasionally
- d) Locking frequently
- e) Locked joint on examination

**4. Instability:**

- a) Never giving way
- b) Rarely during athletics or other severe exertion
- c) Frequently during athletics or other severe exertion (or incapable of participation)
- d) Occasionally in daily activities
- e) Often in daily activities
- f) Every step

**5. Pain:**

- a) None
- b) Inconstant and slight during severe exertion
- c) Marked during severe exertion
- d) Marked on or after walking more than 2 km
- e) Marked on or after walking less than 2 km
- f) Constant

**6. Swelling:**

- a) None
- b) On severe exertion
- c) On ordinary exertion
- d) Constant

**7. Stair-climbing:**

- a) No problems
- b) Slightly impaired
- c) One step at a time
- d) Impossible

**8. Squatting:**

- a) No problems
- b) Slightly impaired
- c) Not beyond 90°
- d) Impossible

### APPENDIX M: IKDC 2000 QUESTIONNAIRE FORM

## 2000 IKDC SUBJECTIVE KNEE EVALUATION FORM

Your Full Name_______________________________________________________

Today's Date: ______/_______/______ Date of Injury: ______/________/_____

Day Month Year Day Month Year

**SYMPTOMS*:**

*Grade symptoms at the highest activity level at which you think you could function without significant symptoms,

even if you are not actually performing activities at this level.

1. What is the highest level of activity that you can perform without significant knee pain?

4❑Very strenuous activities like jumping or pivoting as in basketball or soccer

3❑Strenuous activities like heavy physical work, skiing or tennis

2❑Moderate activities like moderate physical work, running or jogging

1❑Light activities like walking, housework or yard work

0❑Unable to perform any of the above activities due to knee pain

2. During the past 4 weeks, or since your injury, how often have you had pain?

10 9 8 7 6 5 4 3 2 1 0

Never ❑ ❑ ❑ ❑ ❑ ❑ ❑ ❑ ❑ ❑ ❑ Constant

3. If you have pain, how severe is it?

10 9 8 7 6 5 4 3 2 1 0

No pain ❑ ❑ ❑ ❑ ❑ ❑ ❑ ❑ ❑ ❑ ❑ Worst pain imaginable

4. During the past 4 weeks, or since your injury, how stiff or swollen was your knee?

4❑Not at all

3❑Mildly

2❑Moderately

1❑Very

0❑Extremely

5. What is the highest level of activity you can perform without significant swelling in your knee?

4❑Very strenuous activities like jumping or pivoting as in basketball or soccer

3❑Strenuous activities like heavy physical work, skiing or tennis

2❑Moderate activities like moderate physical work, running or jogging

1❑Light activities like walking, housework, or yard work

0❑Unable to perform any of the above activities due to knee swelling

6. During the past 4 weeks, or since your injury, did your knee lock or catch?

0❑Yes 1❑No

7. What is the highest level of activity you can perform without significant giving way in your knee?

4❑Very strenuous activities like jumping or pivoting as in basketball or soccer

3❑Strenuous activities like heavy physical work, skiing or tennis

2❑Moderate activities like moderate physical work, running or jogging

1❑Light activities like walking, housework or yard work

0❑Unable to perform any of the above activities due to giving way of the knee

**Page 2 – 2000 IKDC SUBJECTIVE KNEE EVALUATION FORM**

**SPORTS ACTIVITIES:**

8. What is the highest level of activity you can participate in on a regular basis?

4❑Very strenuous activities like jumping or pivoting as in basketball or soccer

3❑Strenuous activities like heavy physical work, skiing or tennis

2❑Moderate activities like moderate physical work, running or jogging

1❑Light activities like walking, housework or yard work

0❑Unable to perform any of the above activities due to knee

9. How does your knee affect your ability to:

Not difficultat all

Minimally difficult
Moderately Difficult
Extremely difficult
Unable to do
a. Go up stairs 4❑ 3❑ 2❑ 1❑ 0❑
b. Go down stairs 4❑ 3❑ 2❑ 1❑ 0❑
c. Kneel on the front of your knee 4❑ 3❑ 2❑ 1❑ 0❑
d. Squat 4❑ 3❑ 2❑ 1❑ 0❑
e. Sit with your knee bent 4❑ 3❑ 2❑ 1❑ 0❑
f. Rise from a chair 4❑ 3❑ 2❑ 1❑ 0❑
g. Run straight ahead 4❑ 3❑ 2❑ 1❑ 0❑
h. Jump and land on your involved leg 4❑ 3❑ 2❑ 1❑ 0❑
i. Stop and start quickly 4❑ 3❑ 2❑ 1❑ 0❑

**FUNCTION:**

10. How would you rate the function of your knee on a scale of 0 to 10 with 10 being normal, excellent function
and 0 being the inability to perform any of your usual daily activities which may include sports?
FUNCTION PRIOR TO YOUR KNEE INJURY:
Couldn't perform No limitation
daily activities 0 1 2 3 4 5 6 7 8 9 10 in daily
❑ ❑ ❑ ❑ ❑ ❑ ❑ ❑ ❑ ❑ ❑ activities
CURRENT FUNCTION OF YOUR KNEE:
Cannot perform No limitation
daily activities 0 1 2 3 4 5 6 7 8 9 10 in daily
❑ ❑ ❑ ❑ ❑ ❑ ❑ ❑ ❑ ❑ ❑ activities