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Validity and Reliability of the Clinician Rated Drop Vertical Jump Scale in Patients Following Anterior Cruciate Ligament Reconstruction

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Abstract

The purpose of this study was to evaluate the validity and reliability of the Clinician Rated Drop Vertical Jump Scale (CR-DVJS) in a population of patients following anterior cruciate ligament reconstruction (ACLR). Patients completed two drop vertical jump tasks at 6 and/or 12-months post-operative. One task was recorded using a motion capture system. Four individuals of varying clinical experience served as raters for the CR-DVJS. Rater scores of valgus collapse did not correlate strongly with motion capture measures of knee abduction moment or angle. However, CR-DVJS scores of trunk and knee flexion did demonstrate an association with 3D measures of trunk (rho=0.4-0.5) and knee (rho>0.5) flexion angle. Intraclass correlation coefficients suggested poor to good (0.4-0.9) inter-rater reliability of overall score, moderate (0.5-0.75) or good (0.75-0.9) intra-rater reliability, and good to excellent (0.75->0.9) within session test-retest reliability. Further studies are required to draw definitive conclusions prior to clinical implementation.

Keywords

Anterior cruciate ligament, ACL, anterior cruciate ligament reconstruction, rehabilitation, drop vertical jump, DVJ, validity, reliability

Co-Authorship Statement

This study was designed in collaboration with Dr. Dianne Bryant, Dr. Trevor Birmingham, Dr. Alan Getgood, and Greg Alcock as an extension of a larger ongoing multicenter randomized clinical trial. I was responsible for writing the amendment application to the previous ethics approval. I worked with the staff at Empower Health Research Inc. to create the study database and online assessment form. I created the secure site on Western's OWL platform. I was responsible for data collection with the assistance of clinicians involved in the study. Graduate research students in the Wolf Orthopaedic Biomechanics Laboratory (WOBL) completed the post processing of the motion capture data. I was responsible for data analysis and wrote the original draft of this thesis. Dr. Bryant provided me with suggestions and comments for the final thesis submission.

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Chapter 1

1 Introduction

Anterior cruciate ligament (ACL) injury is among the most common injuries of the knee joint.[1] It is a debilitating injury for most athletes and results in compromised function requiring extensive rehabilitation following repair. Reconstructive surgery is a standard treatment option to restore the structural integrity of the joint, although functional deficits can remain.[2] Despite extensive rehabilitation efforts, a portion of patients are not able to return to sport participation after injury[3] and the rate of re-injury is high.[4] New advancements in standard rehabilitation strategies, specifically those in the end stage of rehabilitation, may offer another method to track and provide feedback on progress, ultimately improving patient outcomes.

Nearly 75% of ACL injuries are non-contact in nature.[5] Research has focused on understanding this mechanism of injury to reduce overall rates of injury. Literature suggests deficits in neuromuscular and biomechanical control of the lower limb are a primary cause for injury.[2] Functional testing is becoming an increasingly popular tool in ACL research to assess movement patterns and has been used to identify several modifiable risk factors for ACL injury.[2,6] Specifically, landing mechanics of the knee, hip and trunk have proven to be important factors contributing to injury.[5,7] Furthermore, dynamic knee valgus during a drop vertical jump task is a predictive risk factor for ACL injury.[8]

The drop vertical jump (DVJ) is a functional task used to assess landing mechanics, arguably measured most accurately using three-dimensional (3D) motion analysis.[9] Unfortunately, this type of specialized equipment is not often accessible to clinicians and is not time or cost effective as part of standard rehabilitation.[10] The Clinician-Rated Drop Vertical Jump Scale (CR-DVJS) was developed as an alternative means to quantify landing mechanics within a clinical setting to identify risk factors for re-injury that therapists may elect to target prior to encouraging return to high-risk sports. [11] This study

is the first to evaluate the validity and reliability of the CR-DVJS in a population of patients following ACL reconstruction.

Chapter 2

2 Literature Review

2.1 The Knee Joint Anatomy

The knee joint is comprised of three main bones in the lower extremity which form three articulating surfaces. These articulations divide the knee joint into two parts. The patellofemoral joint is the articulation between the patella and the trochlea of the femur, and the tibiofemoral joint describes the articulation of the femoral and tibial condyles. [12]

The knee is classified as a hinge joint because its principal movements are flexion and extension. However, when the knee is in a flexed position rotation of the joint is also possible.[13] The stability of the joint during these fundamental movements is dependent on the surrounding structures. The quadriceps femoris muscle group, including the vastus lateralis, vastus medialis, vastus intermedius and rectus femoris, are the main extensors of the knee. The hamstrings (semitendinosus, semimembranosus, bicep femoris) are the primary flexors of the knee, although they are assisted by the gracilis, gastrocnemius and sartorius. The popliteus is responsible for medial rotation which initiates flexion from a fully extended position.[13]

The knee joint is also comprised of several passive stabilizers. The joint capsule is a fibrous layer which is attached to the margins of the articular surfaces and internally lined by a synovial membrane.[14] It connects superiorly with the suprapatellar bursa and posteriorly with the bursa under the medial head of the gastrocnemius. The joint is strengthened on either side by the lateral collateral ligament (LCL) and the medial collateral ligament (MCL). The patellar ligament and the medial and lateral patellar retinacula contribute to stabilization on the anterior surface. Posterior support is provided by the oblique popliteal ligament.[13,14]

Within the joint capsule are additional passive stabilizers. The semilunar cartilages (medial and lateral menisci) are located on the superior articular surface of the tibia.[14] Due to the difference in shape of the medial and lateral condyles of the tibia, the medial meniscus is larger and less curved than the lateral.[13] Together they act as a buffer to

forces placed through the knee and help stabilize the tibiofemoral joint by increasing the concavity of the tibia.[12] Finally, the two cruciate ligaments are an essential component of the joint stability. They are located in the center of the joint and provide a strong connection between the tibia and femur.[13] They cross each other obliquely and act to resist both anterior and posterior translation of the tibia.[12,13]

2.2 The Anterior Cruciate Ligament

The anterior cruciate ligament (ACL) originates from the lateral condyle within the intercondylar notch of the distal femur and passes obliquely to attach to the anterior intercondylar area of the proximaltibia.[13] Various literature sources report that the ACL is comprised of separate bundles. It is divided into two bundles (anteromedial and posterolateral) which are anatomically and functionally different. The anteromedial bundle is tight in flexion while the posterolateral bundle is tight in extension.[15] The ACL functions to prevent the anterior translation of the tibia relative to the femur and controls rotational movement of the tibia.[12] It provides 86% of the total resisting force to anteriorly directed forces on the tibia.[16] Additionally, it assists in preventing excessive knee extension, knee varus, and knee valgus movements.[17] The function of the ACL makes it essential for stability and control of the knee during dynamic tasks such as deceleration or an abrupt stop, pivoting, and landing.[12]

2.3 Mechanism of Injury

The ACL may be injured through means of contact or noncontact. Contact injuries occur far less frequently and are often unavoidable collisions during sporting activities. This contact places large external forces on the lower limb, either directly or indirectly, and often results in a valgus collapse of the knee.[18]

It has been reported that 70% of ACL injuries are the result of sport participation.[19] The highest incidence of ACL injury occurs during sports with pivoting and cutting maneuvers.[20,21] Most ACL injuries are noncontact in nature and occur during sudden deceleration such as when cutting, pivoting, or landing in sporting activity.[5,20,21]

Since noncontact injuries account for nearly 75% of ACL injuries,[5,18,22] several theories and risk factors surrounding noncontact mechanism of injury have been developed. Griffin et al[20] proposed four distinct categories of risk factors: environmental, anatomic, hormonal, and biomechanical. Within these categories, risk factors contributing to the mechanism of injury may be extrinsic or intrinsic. Extrinsic factors are external and are therefore modifiable by the athlete to reduce the risk of injury. These factors are classified as environmental and include equipment, bracing, playing surface, footwear, and type and level of sport. Intrinsic factors are internal and may or may not be modifiable. Nonmodifiable intrinsic factors include anatomical variables such as lower extremity alignment (knee angle and hip angle), joint laxity, and femoral notch size, as well as hormonal influence, sex and age. Modifiable intrinsic factors include body mass index, muscular strength, movement biomechanics, skill level, fatigue, and neuromuscular control.[5,17,23,24]

Modifiable intrinsic risk factors have been the predominant focus of recent research attempting to better understand the noncontact mechanism of injury. This is largely because it is hypothesized that deficits in neuromuscular control and biomechanical adaptations are the principal mechanism of both primary and secondary injury.[2] The most prevalent deficit observed involves a combination of knee valgus and internal tibial rotation.[25–27] This mechanism of valgus collapse, hip adduction and internal rotation has been referred to as the ligament dominant theory.[24] Other proposed theories include trunk dominance (poor trunk control during maneuvers), quadriceps dominance (increased quadriceps forces or reduced hamstring recruitment during maneuvers), and leg dominance (leg-to-leg asymmetries).[24]

2.4 Epidemiology

Anterior cruciate ligament injuries are among the most common and devastating musculoskeletal injuries sustained during sport and activity.[2] Of all musculoskeletal injuries, the knee is estimated to account for 19-23%[28] and of all knee injuries, up to 50% or more are injuries to the ACL.[1] Approximately 100,000 to 250,000 Canadians and Americans are annually effected by ACL injury.[29,30]

In a 10-year study conducted by Majewski et al[31], looking specifically at frequency of athletic knee injuries, 37% (6,434/17,397) of patients had sport injuries related to the knee joint. A total of 19,530 sport injuries were documented of which 39.8% were knee injuries. Of all knee injuries documented, ACL injuries had the highest incidence rate of internal knee injuries (20.3%), followed by medial meniscus injury (10.8%), MCL injury (7.9%), lateral meniscus injury (3.7%), LCL injury (1.1%), and PCL injury (0.65%). In total, internal knee injuries accounted for 44.8% of all knee joint injuries and the ACL was injured in 45.4% of cases.[31]

In a population-based study of 535,000 adults aged 13-90 years, knee injuries were found to be the most frequent musculoskeletal soft tissue injury, occurring in 37.2% (1040/2794). Data was collected for a 5-year period from January 1996 to December 2000 by the Edinburgh Orthopaedic Trauma Unit. Of the 1040 knee injuries, 212 (7.6%) were classified as ACL injuries second only to meniscal tear (22.4%). Overall, the incidence of ACL rupture was found to be 8.1/100,000 per year.[32]

Several national registries have used the number of surgical reconstructions to estimate the incidence of ACL injury. Although a good resource, it should be noted that not all ACL injuries are treated surgically so part of the patient population is not captured. Based on United States registries, it was estimated 100,000 to 150,000 ACL injured patients undergo reconstruction surgery annually.[33]

In 2014, Mall et al[34] published updated incidence and trends of ACL reconstruction in the United States. This study examined data collected between 1994 and 2006 using the National Hospital Discharge Survey and the National Survey of Ambulatory Surgery. The incidence of ACLR rose from 32.9 per 100,000 person-years in 1994 to a rate of 43.8 per 100,000 person-years in 2006.[34] More recently, Sanders et al[35] reported a 21-year population based study including 1841 individuals who were diagnosed with new-onset, isolated ACL injuries from January 1990 to December 2010. The overall age- and sex-adjusted annual incidence of ACL tears was reported as 68.6 per 100,000 person-years with significantly higher rates in males than females (81.7 vs 55.3 per 100,000, $P <$

0.001). Peak incidence in male patients was between 19 and 25 years, whereas in females the peak incidence was between 14 and 18 years.[35]

Incidence rates around the world vary slightly. Reports from the New Zealand's national registry collected between July 2000 and June 2005 state an incidence rate of 36.9 per 100,000 person-years for ACL surgeries. This study also reported the mean treatment costs of ACL surgeries to be $11,157.[36] Brazil reports from 2008 – 2014 indicate an overall incidence of 3.49 per 100,000 persons/year with a mean of $1,145 (US) per ACLR.[37] Finland and Sweden report somewhat higher incidence with 60.9[38] and 78[39] per 100,000 person-years respectively.

Incidence rates have also been found to vary by sex, sport and competition.[40–42] Beynnon et al[40] collected first-time noncontact ACL injury data between 2008 and 2012 from various college and high school sports teams. Incidence rates per 1000 athlete exposures were 0.112 for females and 0.063 for males, with females being twice as likely to injure after adjustment for sport and level of play (RR, 2.10; 95% CI, 1.34-3.27). Athletes at the college level were also at significantly higher risk of injury compared to the high school level (Adjusted RR, 2.38; 95% CI. 1.55-3.54).[40] Similarly, a meta-analysis reported females in basketball and soccer had a three times greater incidence than male players.[41] Although reports of sex incidence varies, it is generally accepted that females sustain a two to eight fold greater rate of injury than do males.[5] Female athletes have also been reported to be four times more likely to sustain a second ACL injury and six times more likely to sustain a contralateral injury following reconstruction than male athletes.[4]

Furthermore, the incidence rate of a second ACL injury after ACL reconstruction is consistently reported as higher in both the ipsilateral and contralateral knee.[4,43–45] Paterno et al[4] reported incidence rate as 15 times greater within 12 months following ALCR when compared to control subjects.[4] Another study tracked patients for 24 months after ACLR and return to sport and found the incidence rate of second ACL injury to be nearly six times greater than healthy controls (IRR, 5.71; 95% CI, 2..0-22.7; P=0.0003). Of the ACLR patients in this study, 20.5% sustained a contralateral injury and 9.0% sustained a re-tear of the original graft.[43]

2.5 Treatment

The optimal treatment plan following ACL injury is patient specific. The method of treatment depends on factors such as age, occupation, desired activity and level, and concomitant injuries.[17,46] The current standard of care for those hoping to return to athletic activity is surgical reconstruction followed by extensive rehabilitation.[2,46,47] Studies have reported operative management as the treatment option for 76% - 90% of ACL injuries.[42,48] Over time, the rate of ACLR has increased.[34,35]

Functional outcomes and the ability to return to pre-injury level of activity following ACLR vary across the literature.[2] Within the first year following surgery, reports are as low as half returning to sport,[49] although reports generally range from 60-80%.[49–51] Arden et al[52] completed a systematic review with meta-analysis of return to sport rates following ACLR. They reviewed sixty-nine articles reporting on 7556 participants. Findings suggest an average of 81% return to any sport, 65% return to pre-injury level of sport, and 55% returned to competitive level of sport.[52]

In 2018, Van Yperen et al[53] reported results of 50 patients who suffered ACL rupture between 1992-1996 and compared the 10 and 20 year outcomes of non-operative treatment and ACL reconstruction. This retrospective study matched 25 operative and 25 non-operative patients by age, sex, and Tegner activity score prior to injury. Those who were selected to receive operative treatment were those who demonstrated persistent instability after three months of non-operative treatment. Results from this 20-year follow-up conclude no significant difference in the prevalence of knee osteoarthritis between groups upon radiological assessment indicating future disease risk may not be influenced by treatment option. Functional outcomes including the Lysholm score, the International Knee Documentation Committee (IKDC) subjective and objective form, the Knee injury and Osteoarthritis Outcome Score (KOOS), and the one-legged hop test were also not statistically different. However, they did report significant differences in knee stability as demonstrated by the pivot-shift ($P<0.001$) and Lachman ($P=0.002$) test. Those who had received reconstruction surgery had greater joint stability.[53] These findings are consistent with the objective of ACL reconstruction to provide mechanical stability by repairing the damaged ligament. Thus, part of the rationale for operative management

includes increased mechanical stability which may be important for physical activity by supporting specific maneuvers that are known risk factors of injury.[2,47,54,55]

Non-operative management involves a direct course of rehabilitation and has also shown good short and long-term outcomes in select patients.[46,53,56] In 2017, Paterno[57] completed a review of non-operative patient care and determined a sub-set of the population may benefit from non-operative care based on reports of athletes successfully returning to pivoting and cutting sport without an intact ACL. This work suggests a screening process be developed to identify those likely to be successful non-operative patients. Fitzgerald et al[58] proposed a screening examination involving the single legged hop test, incidence of giving way, a self-reported global knee function rating, and the Knee outcome survey-Activity of Daily Living Scale (KOS-ADLS). A total of 93 patients were screened and 39 were identified as candidates for non-operative treatment. Of the 28 patients who underwent non-operative treatment, 22 returned to pre-injury level of activity without further instability or reported functional deficit. Snyder-Mackler et al[59] also suggest ACLR may not be the proper treatment option for all patients due to the lack of evidence demonstrating superiority of operative management.[59] Regardless of treatment option, risk of re-injury is high. Successful recovery and return to sport requires appropriate rehabilitation over a sufficient period of time.[55,60]

2.5.1 Rehabilitation

Rehabilitation is an essential part of the treatment process. The main goals are to regain the joint stability and muscle strength, assist patients in reaching optimal functional level, and reduce the risk of re-injury. Over time, the rehabilitation protocol for ACL injuries has been adapted to account for research advancements and to ensure the application of evidence-based practice. Specific examples of adaptations include the shift from post-operative casting, delayed weight bearing and limiting range of motion, to the current practice of earlier intervention, immediate range of motion and weight bearing. [61]

Original criterion-based ACL rehabilitation guidelines were published by the University of Delaware in 1996. In 2012, Adams et al[62] revised these guidelines to reflect the most current evidence on patient management for isolated ACL reconstruction. These

guidelines include milestone progressions and treatment protocols for each phase of the rehabilitation process. The immediate postoperative phase (week 1) focuses on active and passive range of motion (ROM) and active quadriceps contraction. The early postoperative phase (week 2) continues to increase flexion/extension and begins to incorporate weight-bearing activities. In the intermediate postoperative phase (week 3-5), muscular strength is improved, and balance and neuromuscular re-education exercises are introduced. The late postoperative phase (week 6-8) focuses on remaining impairments and restores full ROM, strength and a normal gait pattern. The transitional phase (week 9-12) continues to progress flexibility, strength and neuromuscular control, as well as focuses on cardiovascular fitness and unilateral strengthening through running progressions. Lastly, agility, plyometric, and sport-specific activities are added and functional testing is used at 4, 5, 6 and 12 months postoperative to determine a patient's readiness for return to sport activity.[62] These guidelines have been generally accepted, although slight variations across the literature do exist.[63] For instance, there is evidence suggesting earlier introduction of neuromuscular and proprioceptive re-education, which more recent protocols have incorporated.[64] Additionally, exact criteria for return to sport is still relatively inconclusive. Most resources suggest an evaluation of performance on a battery of clinical tests since there is currently no singular test to capture all essential component.[62]

Functional testing is a valuable tool for proper assessment of limb impairments during dynamic tasks and provides outcome measures to both the therapist and patient.[62] There is no evidence-based consensus however, as to which functional tests should be used.[65] Furthermore, there is an absence of standardized, objective criteria to accurately assess an athlete's ability to progress through end stage rehabilitation.[66] In a systematic review of 264 studies, Barber-Westin and Noyes[67] found only 13% noted objective criteria required for return to sport.[67]

In 2017, Gokeler et al[68] suggested a specific test battery to support decision making in the end stages of rehabilitation. The test battery included isokinetic strength tests, the single-leg hop tests, and a jump-landing task assessed with the Landing Error Scoring System (LESS). The LESS is a tool designed to identify potentially high-risk movement patterns

during a jump-landing task. It involves scoring the presence or absence of 17 items including specific trunk, hip, knee, ankle, and foot positioning. This tool has shown good interrater and intrarater reliability and there is evidence of its concurrent validity with three-dimensional (3D) motion analysis.[69] The test battery has not been assessed for predictive validity of re-injury but highlights the need for multifactorial framework to properly assess injury risk and readiness to return to sport [68]

The standardized series of single-leg hop tests is one of the most frequently reported functional tests.[62,65] This includes the single hop for distance, the triple hop for distance, the crossover hop for distance, and the 6-meter timed hop. Measures are averaged, and the limbs are compared using the limb symmetry index which is the performance of the involved limb as a percentage of the uninvolved limb. This test has shown to be a reliable and valid performance based outcome measure for ACL rehabilitation.[70]

Significant advancement in research over the last decade has suggested the importance of identifying deficits to the neuromuscular system and to movement mechanics during late stage rehabilitation. Incorporation of standardized and objective criteria may improve the ability to identify abnormal biomechanics associated with re-injury, which can then be targeted during rehabilitation.[71]

2.6 Biomechanical Assessment

Three-dimensional motion capture analysis is considered the gold standard to assess joint kinetics and kinematics during dynamic taks.[9,10,72] The primary movement patterns responsible for non-contact ACL injury during sport are landing and/or cutting maneuvers.[73,74] Poor biomechanical control of the lower limb due to neuromuscular deficiencies may predispose athletes to injury when performing these sporting movements.[8,75] 3D motion capture analysis has the ability to measure and identify potential mechanisms and risk factors associated with ACL injury during functional tasks.[76] However, there are several disadvantages and barriers to this resource such as the high cost and space required for the equipment, time consuming data collection and analysis, and technical skill/personnel required for the software.[10,77]

2.6.1 Landing Mechanics

Patient landing mechanics during dynamic tasks are regularly assessed as a means of quantifying dynamic knee control and identifying risk factors for potential injury. The drop landing and the drop vertical jump (DVJ) are among the most documented methods of assessing landing mechanics.[76,78] The DVJ is a functional test designed to replicate common sporting movements such as a basketball rebound or a volleyball block. Patients drop off a box ~31cm in height, land and immediately perform a maximum vertical jump.[79,80] This test has demonstrated high within-session reliability (ICC < 0.93)[80] as well as fair to excellent within-session and between-session reliability for the majority of kinetic and kinematic variables.[9,81] Test-retest reliability has also proven to be strong for several variables including knee abduction angle at initial contact, peak knee abduction angle at the deepest point of landing, and peak knee abduction moment.[82] Several other motion capture variables have correlated with abnormalities in landing mechanics which are associated with known modifiable neuromuscular risk factors for both initial and second ACL injury. Specific risk factors of focus have been dynamic knee valgus collapse, lateral trunk lean, trunk flexion, knee flexion and limb asymmetries.

2.6.1.1 Dynamic Knee Valgus

The concept of dynamic knee valgus collapse (combined valgus (or a knee abduction moment) and internal rotation) and its association to ACL injury has gained momentum within the last decade. Although the contribution of valgus forces to ACL injury is still controversial, growing evidence suggests valgus collapse plays a significant role in injury risk and prevention.[2,5]

Dynamic valgus collapse is a manifestation of poor frontal plane knee control during functional movement tasks.[83] The collapse mechanism involves specific movements in the lower limb including hip adduction and internal rotation, knee abduction, internal tibial rotation and ankle eversion.[4,6] These valgus loading movement patterns, when examined in cadaveric and computational model knee studies, have shown to collectively contribute to increased strain on the ACL thereby putting it at greater risk.[84–89] When the knee is in greater abduction, ligaments on the medial side of the knee are under more

strain than those on the lateral side. This imbalance may increase strain on the ACL by contributing to an anterior tibial shift with internal rotation.[84]

In a cadaveric study designed to simulate a single limb jump landing, 10 knees were tested for peak relative strain on the ACL under compressive loading with and without valgus moment. Results show strain was 30% larger when under compressive load in valgus and flexion compared to isolated flexion.[90] Furthermore, valgus loading has been shown to reach strain values high enough to rupture the ACL whereas sagittal plane joint forces alone did not.[88] An in vivo simulation of the drop vertical jump task found isolated abduction and combined abduction with internal tibial rotation produced the greatest change in ACL and MCL strain from the neutral position. The peak ACL strain was larger than the peak MCL strain when the rotational stimuli was applied.[89]

Similar reports of ACL strain resulting from valgus torque have also been assessed in vivo. During dynamic valgus collapse, a high external knee abduction moment about the knee has been reported. It has been established that knee abduction moment directly contributes to dynamic valgus and joint loading in the lower limb.[91] The valgus collapse landing pattern has been suggested to be ligament dominant technique as opposed to a muscle dominant technique which therefore places a larger load on the ACL.[92,93] Muscular strength, specifically co-contraction ability of the hamstrings and quadriceps, has been shown to contribute to the dynamic stability of the knee against valgus forces.[94]

In a comparison of 81 male and female athletes, female athletes landed a drop vertical jump with significantly greater total knee valgus as well as greater maximum knee valgus angles. The female athletes also demonstrated increased valgus angles in their non-dominant limb. Results suggest knee valgus is increased with lack of dynamic stability, which in turn may be responsible for the increased injury rates observed in females.[79]

In 2005, Hewett et al[95] discovered knee abduction moment predicted anterior cruciate ligament injury status with 73% specificity and 78% sensitivity. In this prospective cohort study, 205 female athletes were screened pre-season using a drop vertical jump task and 9 went on to sustain an ACL injury. Injured athletes had a 2.5 times greater knee abduction moment ($p<0.001$) than uninjured athletes. There was also a significant

difference in knee abduction angle ($p<0.05$) of injured athletes at both initial contact (8.4° greater; $p<0.01$) and maximum displacement (7.6° greater; $p<0.01$).[95] These findings were supported by another study conducted by Hewett et al[96] in 2009 that analyzed still video captures of landing and cutting tasks. During these tasks, athletes either sustained ACL injury or did not. Knee abduction angles were found to be the highest in ACL injured females. This difference was significantly greater than male ACL injured athletes and approached significance when compared to the uninjured female controls.[96]

2.6.1.2 Lateral Trunk Lean

Deficits in neuromuscular control of the trunk may lead to uncontrolled lateral trunk movements which influence the biomechanical positioning of the lower limb.[97] This is especially evident during dynamic tasks such as cutting and landing. In a prospective study assessing the correlation between trunk control and knee ligament injuries, twenty-five male and female athletes were positioned in a multidirectional, sudden force release apparatus. Findings determined that lateral trunk displacement was the strongest predictor of ligament injury.[98]

Poor lateral control of the trunk may increase strain on the ACL through mechanical and neuromuscular mechanisms.[97,99] During lateral trunk lean, the body's center of mass is transferred to the respective side which shifts the ground reaction force vector (GRFv) lateral to the knee joint center thereby creating a larger knee abduction moment. [97,99] In an analysis of still captures observed from video footage, it was determined that female athletes sustaining ACL injury demonstrate greater lateral trunk lean over one leg as well as greater knee abduction than male athletes and control females.[96] Additionally, a significant relationship between lateral trunk lean and knee abduction moment has been shown in a sample of 24 male and female athletes performing lateral reactive jumps.[100]

Furthermore, excessive lateral trunk lean may help to identify modifiable risk factors associated with ACL injury risk, including altered core proprioception as well as hip abductor weakness.[95] Increased core strength and proprioception improve the body's ability to prevent lateral lean and keep neutral trunk alignment.[101] Recent findings also suggest a trend towards negative correlation between dynamic knee valgus and trunk

endurance measured through plank and side plank tasks.[102] A common compensation for hip abductor weakness is contralateral pelvis elevation and ipsilateral lateral lean.[99] Studies have reported an association between hip muscle weakness and greater knee abduction moment and valgus angle during single leg tasks. This is likely due to the resultant compensatory trunk lateral lean.[103,104] The internal response to lateral trunk lean includes a larger hip adduction torque which then requires increased strength and recruitment of hip abductors to resist hip adduction and resultant dynamic valgus collapse.[105]

2.6.1.3 Trunk Flexion

Trunk positioning in the sagittal plane can influence the demands of the lower extremity and alter biomechanical risk factors commonly associated with ACL injury. [99,106] Trunk flexion causes the center of mass of the trunk to move forward which alters the moment about the hip and knee joints.[106] The resultant GRFv is shifted anteriorly which increases the extensor moment at the hip, but decreases the extensor moment at the knee which places less demand on the knee joint.[99]

Greater strain on the knee joint has been suggested when the center of mass is more posterior indicating a more erect landing posture. In an evaluation of 20 athletes performing a single legged landing, subjects who had sustained an ACL injury were found to have a more posterior center of mass relative to the base of support when compared to uninjured controls.[107] An overall decrease in the vertical ground reaction force, and thus force transmitted to the knee joint, has also been found in subjects completing a double leg drop landing with trunk flexion compared to no trunk flexion.[108]

In 2010, Pollard, Sigward, and Powers examined kinematics and ground reaction forces in 58 female subjects performing a drop landing task. Subjects were divided into two groups, high flexion and low flexion, based on combined sagittal plane knee and hip flexion angles. Subjects classified as low flexion demonstrated increased knee valgus angles ($p=0.02$) and decreased energy absorption at the hip ($p<0.001$).[109]

More recently, a 2016 study found similar results in a sample of 50 female athletes performing a drop vertical jump task. This study assessed the association between sagittal plane landing kinematics and neuromuscular activation patterns in the lower limb. These Findings suggested that landing with less hip flexion was associated with higher external knee abduction moment thereby putting the ACL at increased risk of injury.[110] Additionally, hip and knee flexion have been shown to increase with trunk flexion during landing which promotes a less erect landing posture.[108] During a flexed posture, hip extensor and knee flexor (gluteus maximus and hamstring) muscle groups are able to produce greater force due to an anterior pelvic tilt.[106] The increased force may result in reduced ACL loading by decreasing knee extension and valgus moment as well as increasing hip extension moment.[106] Furthermore, trunk flexion may protect against ACL strain as a result of quadricep induced anterior shear force acting on the tibia[99,106] since evidence suggests quadricep activation is reduced when there is increased trunk flexion during a drop landing. [108,109]

2.6.1.4 Knee Flexion

ACL injury has been frequently reported when the knee is in a position close to full extension[5,18] which suggests sagittal plane knee movements are important risk factors associated with ACL injury.

Findings from several studies on cadaveric and model knee joints have suggested strain on the ACL is greatly increased when loads are applied with the knee in a relatively extended position (0-45°) compared to a more flexed position.[111–113] The increased ACL strain in this position is a result of quadriceps contraction[106,112] as well as the inability of the hamstrings to adequately activate in their outer range to protect against anterior tibial translation.[106,114] Anterior shear force is the most direct loading mechanism of the ACL. A prediction model examining biomechanical and electromyographic analysis of subjects performing a vertical stop-jump task suggested that knee flexion moment had the greatest influence on proximal tibia anterior shear force. This model also indicated that knee flexion angle and vastus lateralis activity would significantly predict anterior shear force.[115]

This aligns with results of in vivo studies examining drop vertical jump performance in female athletes. These studies suggest landing in a more erect position with low knee flexion increases activation of the vastus lateralis which may place increased load on the ACL placing it at higher risk of injury.[109,110]

This is further supported by a 2016 study conducted by Leppanen et al to investigate the biomechanical characteristics of a vertical drop jump task. This study prospectively followed 171 female athletes after completing baseline testing to analyze six biomechanical variables. During the three year study period, 15 new ACL injuries were recorded. Findings suggest low peak knee flexion angle and high peak vertical ground-reaction force (vGRF) were associated with increased risk of ACL injury.[116]

2.6.1.5 Limb Asymmetry

Limb-to-limb asymmetries have been reported in unilateral and bilateral movement patterns within patients following ACLR. Limb asymmetry has been suggested to increase risk of ACL injury in both the re-constructed and contralateral side and may be predictive of ACL injuries.[2,95,117–119]

Biomechanical differences between limbs have been identified during drop vertical landing tasks up to four years post ACLR.[2] In 2007, Paterno et al[118] examined the landing and jumping kinetics of female athletes at least two years post reconstruction who had been released for full return to play. In this case control study, 14 females a mean of 27 months post-operative were compared to 18 female controls. Participants completed three DVJ trials to collect kinetic data. Results in female ACLR patients demonstrate increased loading rate ($p<0.001$) and vGRF ($p=0.001$) at landing on the uninvolved limb when compared to both the involved limb and control group limb. The involved limb also demonstrated a significantly lower ability to generate force during takeoff ($p=0.03$).[118]

A similar unloading pattern has been shown in recent (2018) work completed by Meyer et al comparing knee kinematics of 17 ACLR individuals to 28 healthy controls during a drop vertical jump. This study found a significant difference in knee sagittal plane energy absorption during a drop vertical jump task. ACLR patients had 25% lower values in

their involved limb compared to their uninvolved limb (p=0.010) and 18% lower values in their involved limb compared to controls (p=0.018).[120] Findings suggest limb asymmetry in vGRF and loading within ACLR patients may be a result of a compensation strategy during bilateral landing to unload the involved limb as well as avoid high vertical impact forces.[118,120,121] Another possibility for limb loading asymmetry may be a deficit in quadriceps strength of the involved limb, which would further explain the decreased force production observed at takeoff.[118,120]

In 2015, Schmitt et al[122] investigated the effect of asymmetry of quadricep femoris strength on knee landing mechanics during a drop vertical jump task in patients following ACLR. Seventy-seven ACLR patients were sub-divided into either a high quadriceps or low quadriceps strength symmetry group. The low quadricep group demonstrated worse asymmetry in all variables compared to the high quadricep and control group; whereas there were no differences observed between the high quadricep group and the control group. Following ACLR, quadricep strength asymmetry, defined by the involved limb as <85% strength of the uninvolved limb, resulted in reduced peak knee external flexion moments and vGRF in the involved limb, as well as increased vGRF and higher peak loading rates in the uninvolved limb. In this study, quadriceps strength in the ACLR group predicted limb symmetry during landing after controlling for factors including graft type, meniscus injury, knee pain and patient symptoms.[122] However, slightly different results were observed in a study of similar design consisting of similar patients who performed a single-leg drop landing. This study also divided ACLR patients (n=103) into high and low-quadriceps subgroups using a calculated quadriceps index for isometric quadriceps strength. Motion capture data was collected to compare differences in landing mechanics with 47 control participants, as well as between limbs of ACLR patients. When performing the single-leg drop landing, both high- and low-quadricep groups demonstrated greater limb asymmetry in knee flexion excursion (p<0.001; p=0.02), peak trunk flexion angle (p<.001; p=0.03), and peak knee extension moment (p<0.001; p=0.005) when compared to the control group. The low quadricep group demonstrated greater asymmetry compared to the high quadricep group for these three measures.[123] Thus, both studies identify greater asymmetrical patterns in the presence of lower quadricep strength symmetry. When a difference in limb strength exists, the stronger limb

may land more posterior to the other which is evident through foot placement. Additionally, one limb may take off or land prior to the other.[93]

2.7 The Clinician-Rated Drop Vertical Jump Scale

The Clinician-Rated Drop Vertical Jump Scale (CR-DVJS) is a Beta version tool designed to evaluate biomechanical parameters observed during a drop vertical jump task. It is intended for clinical use during rehabilitation of patients following ACL reconstruction. It was developed to allow clinicians to formulate an objective measurement of the drop jump performance thereby facilitating rehabilitation aimed at improving landing mechanics and tracking patient progress.

The CR-DVJS was developed through expert consensus using a modified Delphi approach. Agreement was ≥ 92.9% for both the scale and the accompanying booklet which includes instructions with visual examples, a rationale, and possible interpretation for each scale component.[11] The scale includes brief instructions (Appendix A). The full instruction booklet is included in Appendix B.

The CR-DVJS records whether each limb is affected or unaffected and provides an overall score for each side. It uses a 10-point scale ranging from 0 – 9 according to the DVJ performance with zero indicating perfect completion of the task. It includes two main components to identify joint positioning and compensatory movement patterns associated with ACL injury risk. The first being the level of *knee valgus collapse* (none, some, moderate, extreme), which denotes the greatest indication of performance, and the second being the presence of *other undesirable movements* (lateral trunk lean, insufficient trunk flexion, insufficient knee flexion, asymmetry). As described in the instruction booklet, the clinician observes at least three repeated DVJ tasks and should check the appropriate corresponding boxes on the scale to complete a final score. It is advised to assess the jump from varying positions to observe the movement in different planes.[11]

2.8 Summary

The ACL is one of the most frequently injured structures in the knee, often requiring surgical reconstruction and extensive rehabilitation. Despite current surgical procedures

and rehabilitation techniques, rates of re-injury in both the ipsilateral and contralateral knee remain quite high. Additionally, many athletes are unable to return to their previous level of physical activity/sport and the optimal return to sport guidelines have yet to be determined.

Researchers have identified neuromuscular imbalances and biomechanical deficits present after ACL injury and reconstruction that are associated with re-injury risk. Biomechanical assessment to evaluate the kinetics and kinematics of a functional task, such as the drop vertical jump, have been shown to be an effective way to identify high risk patients. 3D motion analysis is the current gold standard for biomechanical assessment but is not accessible or feasible for standard clinical use.

Current rehabilitation protocols are lacking standardized and objective criteria to evaluate functional tasks and the risk of re-injury in the end stage of rehabilitation. Patients would benefit from clinicians' ability to identify and target high risk movement patterns. The CR-DVJS was developed as a more accessible and feasible tool for clinicians to evaluate patient biomechanics during a drop vertical jump task. However, the scale has yet to be assessed for evidence of validity and reliability.

Chapter 3

3 Objectives

The objective of this study was to evaluate the measurement properties of the Clinician Rated Drop Vertical Jump Scale in patients following anterior cruciate ligament reconstruction. Specifically, we evaluated concurrent validity, inter-rater reliability, intra-rater reliability, and test-retest reliability. We hypothesized a strong association (rho > 0.5) between observer scores of scale components and 3D measures of performance as well as good scale reliability (ICC $\geq$ 0.7).

Chapter 4

4 Methodology

The following study was a sub-study of an ongoing randomized control trial (NCT02018354) conducted by researchers at the Fowler Kennedy Sport Medicine Clinic. This study included only patients recruited from this center following institutional approval by the Health Sciences Research Ethics Board (HSREB) at Western University (Appendix C). Patients were presented with an updated Letter of Information (Appendix D) and gave informed consent to participate in the sub-study.

4.1 Eligibility

Participant eligibility was determined by eligibility criteria in accordance with recruitment for the ongoing randomized trial. Specifically, patients were eligible if they (1) were between age 15-25 years; (2) had an ACL deficient knee with instability defined by at least two of the following – grade 2 pivot shift or higher, participation in a pivoting sport at a competitive level, and/or generalized ligamentous laxity; (3) were willing to undergo ACL reconstructive surgery.

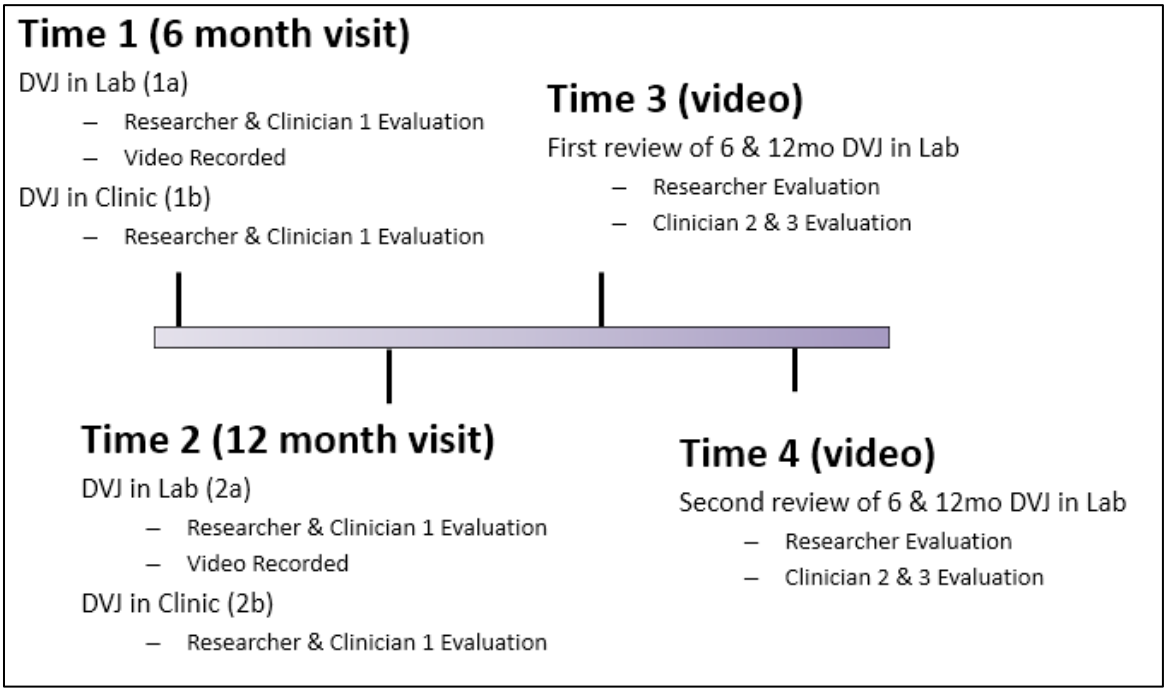
Patients were ineligible if they had (1) a previous ACL reconstruction on either knee; (2) bilateral ACL insufficiency; (3) asymmetric varus knee alignment greater than three degrees; (4) a multi-ligament injury where two or more ligaments required surgical repair or reconstruction; (5) an articular cartilage defect that required treatment other than debridement; (6) were unable to speak, understand, or read English; (7) a psychiatric illness or cognitive impairment that precluded informed consent; (8) were unwilling to participate.

4.2 Study Design

Patients completed study testing during their 6 and/or 12-month post-operative follow-up visit. During each visit the patient completed two drop vertical jump (DVJ) tasks; the first in the Wolf Orthopaedic Biomechanics Laboratory (WOBL) using the motion capture analysis system and standard video recording, and the second in the Fowler Kennedy

Sport Medicine Clinic (FKSMC) physiotherapy gym. Sessions took place approximately 30 minutes apart, during which time they completed additional testing. A total of four examiners of varying experience evaluated knee landing biomechanics and served as raters for the Clinician Rated Drop Vertical Jump Scale (CR-DVJS). Figure 1 displays the study design.

Figure 1: Study Design



4.3 New Test: Clinician Rated Drop Vertical Jump Scale

The CR-DVJS is a Beta version tool developed through expert consensus using a modified Delphi approach. This study was the first to examine the measurement properties of the tool and to use it in a clinical setting to assess drop vertical jumps completed by patients following ACL reconstruction.

When using this tool, the standardized protocol outlined in the Instruction Booklet for the CR-DVJS was followed. The rater observed five repeated drop vertical jumps on a verbal "go" signal – three from the front and then two from each side to observe the movements in varying planes. The scale was completed by checking off the appropriate boxes based on the observed joint positioning and compensatory movements during the initial contact

through to the deepest point of the first landing. All movements were recorded, even if they were only observed once.

Prior to data collection, the Researcher and Clinician 1 reviewed the instruction booklet to verify definitions of each of the scale components. They independently evaluated at least three practice DVJ tasks to become familiar with the tool. The Researcher received additional training with two FKSMC physiotherapists uninvolved in the study to ensure proper identification of joint positioning and compensatory movements. The designated expert clinicians (Clinician 2 and 3) did not receive training aside from individually reading the Instruction Booklet.

Paper CR-DVJS evaluations were kept in a secure location until the end of data collection when results could be inputted by the author electronically. Electronic CR-DVJS evaluations were stored in a secure web-based data management system (EmPower Health Research, Inc, www.empowerhealthresearch.ca). Observations were not discussed or shared between evaluators to control for experimenter bias.

4.3.1 Drop Vertical Jump

The drop vertical jump protocol defined in the Instruction Booklet for the CR-DVJS was followed. Patients were instructed to start by standing on a 30cm box, feet shoulder-width apart (~35 cm) with the toes overhanging the edge. Patients were then instructed to drop off the box with both feet at the same time, land on both feet, and perform a maximum vertical jump landing within the designated area. This area was defined in WOBL by the two force plates. In the FKSMC physiotherapy clinic, this area was defined by a taped square pattern on the floor identical in size to the WOBL force plate measurements. Trials were excluded and repeated if the patient did not land in the designated area during either landing phase of the task. The same box was used in both locations to standardize the testing protocol. All patients received the same set of verbal instructions prior to completing each DVJ task. They were allowed one practice jump without evaluation or recording to ensure they understood the instructions and could perform the task.

4.3.2 Standard Video Recorded Footage

A Nixon Coolpix B500 camera was used to video record patient testing in the lab (WOBL). To comply with the scale instructions, a total of five drop vertical jumps were recorded – three from the front and one from each side. Videos were reviewed by raters once in real time to best simulate an in-person visit and complete the CR-DVJS evaluation. Clinician 2 and 3 independently reviewed the video footage in a designated location on two separate occasions at least two weeks apart to avoid recall. The Researcher reviewed video footage once at least one month following the original in person evaluation. The CR-DVJS evaluation was directly inputted by each rater into the online form on Empower while observing the video footage. Each of these raters were provided a unique username and password to access each patient's form by searching the anonymous patient ID number. Video footage was stored in OWL – a secure online system which was only accessible by the raters involved in the research project. Each rater had a password protected account set up through OWL to access videos within files listed by patient ID number.

4.4 Gold Standard Assessment

4.4.1 Motion Capture System

The gold standard assessment was collected using an 11-camera three-dimensional motion analysis system (Cortex, Motion Analysis Corporation, Santa Rosa, CA, USA) and three floor-mounted force plates (Advanced Mechanical Technology, Watertown, MA, USA). The system was calibrated each morning by WOBL research students to ensure synchronization of the cameras with each other and with the force plates. Patients were fitted with twenty-nine adhesive reflective markers placed on anatomical landmarks. Markers were placed by the author and consistent WOBL research students. Static trials were collected to determine relative marker orientation, body mass, and virtual joint centers. After performing three static trials of patients standing for three seconds on the drop jump box, four markers were removed from the patient. These markers were used to determine the virtual joint centers and were located on the medial

knee joint lines and the medial malleoli. A total of five drop vertical jumps were then performed by the patient. Kinematic and kinetic data were recorded at 120 Hz and 1200 Hz respectively. Trials were repeated if the patient landed with their feet off the force plate on either landing phase of the task.

4.4.2 Motion Capture Post Processing

Research students and volunteers working in WOBL as part of the on-going larger RCT tracked all patient trials. The three static trials were used to determine virtual hip, knee and ankle joint centers as well as relative marker orientation and body mass. Specific software was used to create body segments between markers (Skeleton Builder engine within Cortex) and to scale body segment masses according to each individual (Mass Model Editor). Variables of interest were then calculated within Cortex and graph data was exported. Exported data was processed using a Butterworth filter with an input frequency of 12 Hz while force plate data was filtered at 100 Hz. The data was then supplied to the author to be sorted for variables of interest to be used in the current project.

4.5 Sample Size

The sample size was calculated *a priori* for reliability using an ICC of at least 0.75, an alpha of 0.05, beta of 0.2, and a confidence interval width of 0.2. It was determined that 75 patients were necessary if there were two raters. Our aim was to recruit 75 patients.

4.6 Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics version 25 (IBM Corp., Armonk NY). The weighted kappa extension was added to the software to complete our analyses.

4.6.1 CR-DVJS Variables

From the DVJ's completed in WOBL, there were a total of four CR-DVJS scores generated for each patient (two in-person and two via standard video recording). From the DVJ's completed in the physiotherapy clinic, there were two CR-DVJS scores

generated per patient. We used intraclass correlation coefficients (ICC) to estimate absolute agreement between scores. An ICC of <0.5 was classified as poor reliability, 0.5-0.75 as moderate, 0.75-0.9 as good, and >0.9 as excellent.[124]

We also evaluated the validity of the individual scale components of knee valgus collapse, trunk flexion, and knee flexion, compared with observations made using the motion capture system. We used Spearman's rank order correlation to estimate magnitude of association. A correlation coefficient of 0.1 was classified as weak, 0.3 as moderate, and >0.5 was considered a strong correlation.[125,126]

4.6.2 Motion Capture Variables

We generated the following variables from the motion capture: peak knee abduction moment (KAM) produced during the initial landing phase of the DVJ task (normalized to patient body weight and height), knee abduction angle, knee flexion angle, and trunk flexion angle.

4.6.3 Concurrent Validity

To investigate concurrent validity, we compared CR-DVJS observations from the in-person assessment in the biomechanics laboratory (Researcher and Clinician 1) with the motion capture measurements. We estimated the magnitude of the association between the CR-DVJS component and the corresponding variable generated by the motion capture system. Specifically, we estimated the magnitude of the association between the CR-DVJS rating of "dynamic knee valgus" and the peak knee abduction moment (KAM) and knee abduction angle (KAA); the CR-DVJS component of "insufficient trunk flexion" and trunk flexion angle (TFA); the CR-DVJS component "insufficient knee flexion" and the knee flexion angle (KFA). We hypothesized that if the CR-DVJS was valid, then the rating on the CR-DVJS and the corresponding variable generated by the motion capture system should be highly correlated (rho>0.5).

In addition, the data for each motion capture variable was sorted according to the scoring on the corresponding CR-DVJS component to observe differences between groups. KAM and KAA data were grouped by scored level of dynamic knee valgus (none, some,

moderate, extreme). TFA and KFA data were sorted into two groups (sufficient/insufficient) determined by scoring of trunk and knee flexion respectively. We hypothesized that mean values from motion capture data would differ between groups indicting the ability of the scale to accurately discriminate between each level of valgus and the presence or absence of flexion motions. Specifically, the mean of KAM and KAA should increase with each level of dynamic valgus, and the mean of KFA and TFA should be lower when classified as insufficient.

4.6.4 Inter-rater Reliability

To investigate inter-rater reliability, we calculated ICC for absolute agreement between overall scores on the CR-DVJS for the affected and unaffected limb at 6 and 12 months post-operative. A two-way mixed effects model was used to examine the two in-person raters in the lab (Researcher and Clinician 1), and between each of the experts assessments and the researcher's video assessment. The video assessment was used to maintain consistency with the expert analysis. A two-way random effects model was used to examine agreement between the two expert raters' (Clinician 2 and 3) first video assessment.

The largest component of the scale, dynamic knee valgus, was also analyzed between each pair of raters (Researcher and Clinician 1; Clinician 2 and 3; Researcher and Clinician 2; Researcher and Clinician 3). The agreement between scoring the level of knee valgus as none, some, moderate, or extreme, was calculated for the affected and unaffected limb using a weighted Kappa. This analysis was completed using a 4x4 crosstabulation between each pair of raters.

4.6.5 Intra-rater Reliability

To investigate intra-rater reliability of the expert clinicians, we calculated two-way mixed effects ICC for absolute agreement between the two overall scores per affected/unaffected limb at 6 and 12 months. These two scores were completed by the rater (Clinician 2 and 3) on separate occasions at least two weeks apart but were an evaluation of the same DVJ task. This was accomplished using the standard video recorded footage from the lab and the online platform OWL.

For the research student, agreement was analyzed between the original in-person lab evaluation and the evaluation of the video footage using ICC. This type of intra-rater reliability assessed agreement between each method of observation to determine if there was a difference in the researcher's in-person and video scores.

4.6.6 Within Session Test-retest Reliability

To investigate within session test-retest reliability, we calculated two-way mixed effects ICC for absolute agreement between the overall scores per affected/unaffected limb of the lab and clinic evaluations. This was analyzed at 6months and 12 months for both the Researcher and Clinician 1.

Chapter 5

5 Results

5.1 Participant Demographics

A total of 20 patients completed testing at six months follow-up and an additional 17 patients completed testing at twelve months only for a total of 37 patients at twelve months follow-up. Demographic characteristics are displayed below (Table 1).

Table 1. Baseline demographics of anterior cruciate ligament (ACL) reconstructed patients completing drop vertical jump testing

Characteristics	6 month Participants (n = 20)	12 month Participants (n = 37)
Sex, n (%) Male	9 (42.9)	15 (40.5)
Mean Age ± SD (yrs)	19.8 ± 2.5	19.1 ± 2.5
Mean Height ± SD (cm)	172.8 ± 8.6	171.8 ± 8.8
Mean Weight ± SD (kg)	74.1 ± 10.6	73.2 ± 13
BMI ± SD (kg/m^2)	24.8 ± 3.1	24.7 ± 3.5
Operative Limb, n (%) Left	8 (38.1)	21 (56.8)

5.2 Concurrent Validity

All 20 patients at six months were included in analysis. Clinician 1 scored 34 patients at 12 months to include in analysis while all 37 patients were included for the researcher analysis.

5.2.1 Dynamic Knee Valgus

There was a generally weak to moderate correlation between scored level of valgus collapse and the motion capture measurements (Table 2 and 3). Knee abduction angle demonstrated a statistically significant moderate and strong correlation in the affected limb at the six-month time point for the Researcher and Clinician 1 respectively.

Results did not demonstrate the expected stepwise increase of mean values per scoring group of none to extreme level of dynamic valgus collapse. Both peak knee abduction moment (Table 4) and knee abduction angle (Table 5) had similar means across all scores for the researcher and clinician 1 at 6 and 12-month follow-up. Although no significant differences between groups were observed, the mean of the extreme valgus group was generally higher than the mean of the no valgus group.

Table 2. Spearman's rho correlation of peak knee abduction moment and scored level of valgus collapse on the CR-DVJS at 6 and 12 months post-operative

	6 months		12 months	
	Correlation coefficient	**p-value**	**Correlation coefficient**	**p-value**
Researcher				
Affected Limb	0.26	0.28	0.36	0.03
Unaffected Limb	0.26	0.28	0.39	0.02
Clinician 1				
Affected Limb	0.09	0.70	0.18	0.30
Unaffected Limb	0.37	0.10	0.28	0.11

Table 3. Spearman's rho correlation of knee abduction angle and scored level of valgus collapse on the CR-DVJS at 6 and 12 months post-operative

	6 months		12 months	
	Correlation coefficient	**p-value**	**Correlation coefficient**	**p-value**
Researcher				
Affected Limb	0.48	0.03	-0.02	0.90
Unaffected Limb	0.32	0.17	-0.15	0.93
Clinician 1				
Affected Limb	0.67	0.001	-0.13	0.45
Unaffected Limb	0.36	0.11	0.08	0.66

Table 4. Peak knee abduction moment by scored level of valgus collapse on the CR-DVJS at 6 and 12 months post-operative

	6 months				12 months			
	n	**Mean (SD)**	**Min**	**Max**	**n**	**Mean (SD)**	**Min**	**Max**
Researcher Scores								
Affected Limb								
None	1	20.3 (-)	20	20	5	15.4 (7)	6	23
Some	7	15.0 (12)	-0.2	34	14	24.1 (27)	-5	87
Moderate	7	18.4 (18)	5	54	15	25.9 (13)	0.7	59
Extreme	5	24.3 (9)	13	36	3	28.6 (13.1)	17	42
Unaffected Limb								
None	1	0.7 (-)	0.7	0.7	4	12.8 (8)	5	21
Some	7	20.7 (18)	5	60	14	9.7 (13)	-3	47
Moderate	8	17.4 (9)	1	35	17	20.5 (17)	-7	60
Extreme	4	18.8 (8)	6	27	2	46.8 (34)	23	71
Clinician 1 Scores								
Affected Limb								
None	1	20.3 (-)	20	20	3	13.3 (8)	6	22
Some	7	18.8 (19)	-0.2	54	10	24.5 (27)	7	87
Moderate	8	17.6 (18)	5	36	15	26.0 (15)	-5	50
Extreme	4	19.6 (20)	9	32	6	21.5 (21)	0.7	59
Unaffected Limb								
None	1	0.7 (-)	0.7	0.7	3	15.5 (7)	7	21
Some	6	14.8 (7)	5	24	10	6.7 (9)	-3	24
Moderate	6	22.5 (19)	1	60	16	21.7 (16)	-2	60
Extreme	7	19.5 (8)	6	27	5	26.5 (32)	-7	71

Note: A negative value indicates adduction moment rather than abduction.

Table 5. Knee abduction angle by scored level of valgus collapse on the CR-DVJS at 6 and 12 months post-operative

	6 months				12 months			
	n	**Mean (SD)**	**Min**	**Max**	**n**	**Mean (SD)**	**Min**	**Max**
Researcher Scores								
Affected Limb								
None	1	4.0 (-)	4	4	5	-2.1 (4)	-8	2
Some	7	1.5 (8)	-7	19	14	7.2 (8)	-4	24
Moderate	7	10.6 (10)	-5	26	15	4.2 (8)	-8	20
Extreme	5	9.9 (3)	5	14	3	-2.4 (3)	-5	0.8
Unaffected Limb								
None	1	1.6 (-)	2	2	4	6.9 (8)	-0.5	16
Some	7	1.4 (4)	-3	7	14	4.5 (9)	-6	26
Moderate	8	3.8 (7)	-6	16	17	4.9 (7)	-9	23
Extreme	4	9.2 (10)	0.8	20	2	2.0 (3)	-0.3	4
Clinician 1 Scores								
Affected Limb								
None	1	4.0 (-)	4	4	3	-0.8 (2)	-1	2
Some	6	0.8 (7)	-7	12	10	7.2 (10)	-8	24
Moderate	6	5.2 (8)	-5	19	15	5.1 (8)	-8	20
Extreme	7	14.0 (6)	7	26	6	-0.4 (4)	-5	6
Unaffected Limb								
None	1	1.6 (-)	2	2	3	5.7 (9)	-0.5	16
Some	7	0.5 (5)	-6	7.4	10	2.7 (6)	-6	16
Moderate	7	5.0 (7)	-0.6	16	16	5.5 (7)	-2	23
Extreme	5	7.8 (9)	0.8	20	5	5.4 (13)	-9	26

Note: A negative value indicates adduction angle rather than abduction.

5.2.2 Trunk Flexion

There was a moderate correlation between trunk flexion angle and scoring of trunk flexion (Table 6).

Results are consistent with the hypothesis of lower mean TFA for those with observed insufficient trunk flexion (Table 7). There was a difference in TFA between those scored as sufficient/insufficient by either rater at both time points. This difference was statistically significant at 12 months post-operative for the researcher (p=0.002) and clinician 1 (p=0.001).

Table 6. Spearman's rho correlation of trunk flexion angle and scored trunk flexion sufficiency on the CR-DVJS at 6 and 12 months post-operative

	6 months		12 months	
	Correlation coefficient	**p-value**	**Correlation coefficient**	**p-value**
Researcher				
Affected Limb	0.45	0.05	0.49	0.002
Unaffected Limb	0.45	0.05	0.49	0.002
Clinician 1				
Affected Limb	0.20	0.39	0.39	0.03
Unaffected Limb	0.20	0.39	0.38	0.03

Table 7. Trunk flexion angle by scored trunk flexion sufficiency on the CR-DVJS at 6 and 12 months post-operative

	6 months				12 months			
	n	**Mean (SD)**	**Min**	**Max**	**n**	**Mean (SD)**	**Min**	**Max**
Researcher Scores								
Affected Limb								
Sufficient	3	85.0 (8)	76	91	16	81.8 (17)	45	103
Insufficient	17	60.4 (21)	25	96	21	64.8 (14)	36	86
Unaffected Limb								
Sufficient	3	85.0 (8)	76	91	16	81.8 (17)	45	103
Insufficient	17	60.4 (21)	25	96	21	64.8 (14)	36	86
Clinician 1 Scores								
Affected Limb								
Sufficient	2	77.0 (1)	76	78	9	82.8 (11)	64	97
Insufficient	18	62.7 (22)	25	96	25	67.6 (18)	36	103
Unaffected Limb								
Sufficient	2	77.0 (1)	76	78	9	82.8 (11)	64	97
Insufficient	18	62.7 (22)	25	96	25	67.6 (18)	36	103

5.2.3 Knee Flexion

There was a strong correlation between knee flexion angle and scoring of knee flexion (Table 8).

Results are consistent with the hypothesis of lower mean KFA for those with observed insufficient knee flexion (Table 9). There was a difference in KFA between those scored

as sufficient/insufficient by either rater at both time points. This difference was statistically significant at 12 months post-operative (p=0.0001). It was also significantly different between all but one 6-month comparison (R Aff: p=0.008; R Unaff: p=0.001; C1 Aff: p=0.087; C1 Unaff: p=0.027).

Table 8. Spearman's rho correlation of knee flexion angle and scored knee flexion sufficiency on the CR-DVJS at 6 and 12 months post-operative

	6 months		12 months	
	Correlation coefficient	**p-value**	**Correlation coefficient**	**p-value**
Researcher				
Affected Limb	0.55	0.01	0.65	<0.0001
Unaffected Limb	0.60	0.006	0.66	<0.0001
Clinician 1				
Affected Limb	0.47	0.04	0.64	<0.0001
Unaffected Limb	0.47	0.04	0.67	<0.0001

Table 9. Knee flexion angle by scored knee flexion sufficiency on the CR-DVJS at 6 and 12 months post-operative

	6 months				12 months			
	n	**Mean (SD)**	**Min**	**Max**	**n**	**Mean (SD)**	**Min**	**Max**
Researcher Scores								
Affected Limb								
Sufficient	3	92.7 (11)	84	105	10	101.6 (15)	77	122
Insufficient	17	67.2 (14)	49	104	27	74.5 (13)	47	95
Unaffected Limb								
Sufficient	3	97.7 (6)	91	103	10	102 (12)	84	115
Insufficient	17	65.2 (14)	41	95	27	76.5 (12)	51	93
Clinician 1 Scores								
Affected Limb								
Sufficient	3	85.6 (2)	84	88	12	98.6 (15)	77	122
Insufficient	17	68.5 (16)	49	105	22	74.1 (13)	47	95
Unaffected Limb								
Sufficient	3	90.1 (13)	76	103	12	99.3 (12)	84	115
Insufficient	17	66.6 (15.9)	41	99	22	75.7 (12.4)	51	93

5.3 Reliability

5.3.1 Inter-rater Reliability

The scores of all 20 six-month patients were analyzed. Number of patients analyzed at 12 months varied due to missing data from either clinician absence or video error. For the researcher – clinician 1 comparison, 34 patients were included in analysis. For all other comparison rater groups, 36 patients were analyzed. The overall score on the CR-DVJS demonstrated moderate (0.5-0.75) or good (0.75-0.9) reliability between raters at both six months and twelve months post-operative (Table 10).

The agreement between raters scoring the level of dynamic knee valgus collapse (Table 11) also demonstrated moderate to good (0.4-0.8) reliability between the Researcher and Clinician 1 and the two expert clinicians. Agreement between the researcher and expert clinicians was slightly lower demonstrating fair to moderate (0.2-0.6) reliability.

Table 10. Inter-rater reliability of overall CR-DVJS score per limb at 6 and 12 months post-operative

Rater Group	6 months		12 months	
	ICC (95% CI)	**p-value**	**ICC (95% CI)**	**p-value**
Researcher – Clinician 1				
Affected Limb	0.79 (0.55 – 0.91)	<0.0001	0.78 (0.53 – 0.89)	<0.0001
Unaffected Limb	0.90 (0.75 – 0.96)	<0.0001	0.85 (0.64 – 0.93)	<0.0001
Clinician 2 – Clinician 3				
Affected Limb	0.64 (0.27 – 0.84)	0.001	0.64 (0.41 – 0.80)	<0.0001
Unaffected Limb	0.41 (-0.02 – 0.71)	0.031	0.52 (0.20 – 0.73)	<0.0001
Researcher – Clinician 2				
Affected Limb	0.77 (0.51 – 0.90)	<0.0001	0.52 (0.24 – 0.72)	<0.0001
Unaffected Limb	0.78 (0.53 – 0.91)	<0.0001	0.46 (0.17 – 0.68)	0.002
Researcher – Clinician 3				
Affected Limb	0.75 (0.46 – 0.89)	<0.0001	0.57 (0.30 – 0.76)	<0.0001
Unaffected Limb	0.58 (0.21 – 0.81)	0.001	0.64 (0.40 – 0.80)	<0.0001

Table 11. Inter-rater reliability of CR-DVJS valgus collapse score per limb at 6 and 12 months post-operative

Rater Group	6 months		12 months	
	Weighted Kappa (95% CI)	**p-value**	**Weighted Kappa (95% CI)**	**p-value**
Researcher – Clinician 1				
Affected Limb	0.65 (0.41 – 0.89)	< 0.0001	0.61 (0.41 – 0.82)	< 0.0001
Unaffected Limb	0.84 (0.66 – 1.02)	< 0.0001	0.71 (0.52 – 0.91)	< 0.0001
Clinician 2 – Clinician 3				
Affected Limb	0.52 (0.26 – 0.78)	< 0.0001	0.56 (0.36 – 0.75)	< 0.0001
Unaffected Limb	0.22 (-0.05 – 0.48)	0.125	0.43 (0.23 – 0.64)	< 0.0001
Researcher – Clinician 2				
Affected Limb	0.56 (0.34 – 0.79)	< 0.0001	0.36 (0.15 – 0.58)	0.001
Unaffected Limb	0.59 (0.39 – 0.80)	< 0.0001	0.32 (0.07 – 0.56)	0.005
Researcher – Clinician 3				
Affected Limb	0.50 (0.23 – 0.79)	0.001	0.43 (0.21 – 0.65)	< 0.0001
Unaffected Limb	0.25 (0.02 – 0.48)	0.055	0.38 (0.16 – 0.59)	0.001

5.3.2 Intra-rater Reliability

The overall scores of 20 patients at 6 months and 36 patients at 12 months were analyzed to determine intra-rater reliability of each expert clinician. One patient at the 12-month visit was missing because there was no video recording for the experts to evaluate. Results of intra-rater reliability for both time points are reported (Table 12). Clinician 2 demonstrated good (0.75-0.9) reliability while Clinician 3 demonstrated moderate (0.5-0.75) reliability. There was moderate agreement (0.5-0.75) between the researcher's in-person lab evaluation and video footage evaluation.

Table 12. Intra-rater reliability of overall CR-DVJS score per limb at 6 and 12 months post-operative

Rater	6 months		12 months	
	ICC (95% CI)	p-value	ICC (95% CI)	p-value
Clinician 2				
Affected Limb	0.85 (0.67 – 0.94)	< 0.0001	0.84 (0.70 – 0.91)	< 0.0001
Unaffected Limb	0.85 (0.66 – 0.94)	< 0.0001	0.79 (0.64 – 0.89)	< 0.0001
Clinician 3				
Affected Limb	0.72 (0.41 – 0.88)	< 0.0001	0.71 (0.50 – 0.84)	< 0.0001
Unaffected Limb	0.50 (0.11 – 0.77)	0.005	0.59 (0.33 – 0.77)	< 0.0001
Researcher				
Affected Limb	0.58 (0.12 – 0.82)	< 0.0001	0.70 (0.50 – 0.84)	< 0.0001
Unaffected Limb	0.53 (0.15 – 0.78)	0.004	0.76 (0.58 – 0.87)	< 0.0001

5.3.3 Within Session Test-retest Reliability

Twenty patients at 6 months and 36 patients at 12 months completed testing in both the lab and gym area for the analysis of test-retest reliability of the overall scores on the CR-DVJS. One patient refused to complete a second jump in the physiotherapy gym. Clinician 1 was absent from four 12-month patient visits so only 32 patients were included in that analysis. The overall score per limb on the CR-DVJS demonstrated good (0.75-0.9) to excellent (>0.9) within session test-retest reliability (Table 13).

Table 13. Within session test-retest reliability of overall CR-DVJS score per limb at 6 and 12 months post-operative

Rater	6 months		12 months	
	ICC (95% CI)	p-value	ICC (95% CI)	p-value
Researcher				
Affected Limb	0.84 (0.64 – 0.94)	< 0.0001	0.89 (0.73 – 0.94)	< 0.0001
Unaffected Limb	0.84 (0.64 – 0.94)	< 0.0001	0.87 (0.74 – 0.93)	< 0.0001
Clinician 1				
Affected Limb	0.95 (0.86 – 0.98)	< 0.0001	0.81 (0.65 – 0.91)	< 0.0001
Unaffected Limb	0.96 (0.91 – 0.99)	< 0.0001	0.90 (0.80 – 0.95)	< 0.0001

Chapter 6

6 Discussion

This study is the first to evaluate the measurement properties of the CR-DVJS. As such, it is the first to provide evidence of the scale's validity and reliability. The results are generally consistent with the study's hypotheses, although slightly lower than anticipated.

6.1 Concurrent Validity

6.1.1 Dynamic Knee Valgus

Since knee abduction is a known factor contributing to knee valgus, knee abduction moment and knee abduction angle were used as the gold standard for measuring frontal plane knee movements. The measured knee abduction moment and angle were expected to be associated with the scoring of dynamic knee valgus. Previous literature has reported high abduction moment and angle with increased valgus collapse. Therefore, patients demonstrating the most extreme level of knee valgus during the drop vertical jump task should have the highest reported measures of knee abduction moment and angle. Similarly, if raters can accurately observe and report level of knee valgus, scores should reflect motion capture measures. We would expect to see a difference in mean knee abduction moment and angle which increases with each level of valgus scoring (none < some < moderate < extreme).

Results were generally not statistically significant and did not demonstrate a strong (rho > 0.5) correlation between measures as expected. The relationship between scored level of valgus collapse and both motion capture measures was very weak to moderate. The only exception was the strong correlation observed between KAA and the affected limb scores at the six-month follow-up for both raters (rho=0.48, p=0.03; rho=0.67, p=0,001). Surprisingly, a negative relationship was observed at the 12-month follow-up for KAA measures. This may be a result of the greater than expected number of patients demonstrating varus rather than valgus motion, which may be attributed to rehabilitation strategies to correct jumping mechanics. In addition, there was no difference or pattern in mean knee abduction moment and angle per scoring group. Standard deviation of mean

values was generally high, indicating a wide spread of measures in each category. Furthermore, there is large overlap of max and min values between groups. Extreme max and min values suggest there may be outliers in the group – if a patient was scored incorrectly this would drastically affect the mean and standard deviation. Outliers were detected in some scoring groups; however, these values are more likely a result of low sample size. Increasing overall sample size would decrease this random sampling error. Increasing the number of patients demonstrating each level of valgus collapse would allow for better comparisons between levels.

This suggests the scale could not accurately identify level of valgus. However, when comparing the lowest (none) and highest (extreme) scored groups the mean abduction moment was higher in the extreme group. Although these differences did not reach significance, the trend suggests it may be easier for raters to distinguish between none and extreme levels rather than four levels; especially when distinguishing between 'some' and 'moderate' levels.

6.1.2 Trunk Flexion

Trunk flexion angle (TFA) was used as the gold standard measurement of trunk flexion. TFA was expected to be strongly associated with the scoring of the trunk flexion component of the CR-DVJS. Furthermore, patients demonstrating insufficient trunk flexion as scored on the CR-DVJS were expected to have decreased TFA.

Results agree with hypotheses and demonstrate lower mean TFA for those scored as insufficient at both time points. There is no difference between limbs because trunk flexion is independent of injury status. The difference between those scored as sufficient and insufficient was statistically significant at the 12-month time point for both the researcher and clinician. The lack of statistical significance at the 6-month time point is likely a result of sample size since only 2-3 patients were recorded as having sufficient trunk flexion compared to 17-18 as insufficient. Furthermore, the high max value of insufficient flexion suggests incorrectly categorized patients may be affecting the mean and SD thereby contributing to the lack of significance. However, true outliers were not detected in this group. It should also be noted the insufficient max value is higher for the

clinician at 12-month follow-up, so not all patients were identified as expected despite the statistical significance. The relationship between TFA and the Researcher's scores produced a moderate correlation (rho>0.5) at both time points (rho=0.45, p=0.05; rho=0.49, p=0.002). The correlation was not as strong when TFA was compared to Clinician 1 scores. Although less susceptible to outliers, it seems incorrect identification of the highest TFA reduced the strength of this relationship. Overall, results suggest clinicians can use the CR-DVJS to accurately distinguish between sufficient and insufficient trunk flexion.

6.1.3 Knee Flexion

Knee flexion angle (KFA) was used as the gold standard measurement of knee flexion. KFA was expected to be strongly associated with the scoring of the knee flexion component of the CR-DVJS. Furthermore, patients demonstrating insufficient knee flexion as scored on the CR-DVJS were expected to have decreased KFA.

The strongest correlation (0.47-0.67) was observed between KFA and scoring of knee flexion. This suggests the knee flexion CR-DVJS component is most accurately identified by observers. Results agree with hypotheses and demonstrate lower mean KFA for those scored as insufficient at both time points. The difference between those scored as sufficient and insufficient was statistically significant at the 12-month time point for both the researcher and clinician. It was also statistically significant at all but one 6-month comparison of the affected limb for the clinician. This comparison has a much larger max value again suggesting incorrectly identified patients may have acted as outliers thereby skewing mean and SD. Few patients were recorded as sufficient but minimum values are still above mean values of those recorded as insufficient. There is a consistent difference in mean values between the affected and unaffected limb. The motion analysis can detect a more precise difference between limbs that may appear symmetrical to the observer. However, although less accurate, results suggest the CR-DVJS can be used to distinguish insufficient/sufficient knee flexion.

6.2 Reliability

6.2.1 Inter-rater Reliability

Inter-rater reliability was examined between four pairs of raters. Results indicate moderate to good (0.5 – 0.9) reliability between raters. These results were consistent within rater pairs between the two follow-up visits suggesting no difference in the inter-rater reliability of observing patients at 6 months or 12 months post-operative.

There was an exception indicating poor reliability (0.41) between Clinicians 2 and 3 for the unaffected limb at the six-month follow-up. Slightly lower reliability (0.46) was also observed between the Researcher and Clinician 2 at 12-month follow-up for the unaffected limb. Although most ICC values are within the moderate range, CI are wide which makes it difficult to draw exact conclusions. The lower boundary of the 95% CI indicates poor reliability (<0.5) for many comparisons, while the upper indicates good to excellent (>0.75).

The strongest reliability was observed between the Researcher and Clinician 1. This may be a result of the initial training and mutual understanding of the tool. Clinician 2 and 3 did not receive verbal instruction or discuss the use of the tool. Thus, it is possible the accompanying instruction manual was interpreted differently between clinicians resulting in lower agreement. These findings highlight the importance of instruction clarity despite the clinician's level of experience. The difference in user interpretation may also account for the lower agreement observed between the researcher and expert clinicians. However, it is also possible there was a difference in the ability to identify movements due to level of clinical experience. Furthermore, raters were only allowed to review video footage once in real time to best simulate the clinical experience. Adjusting instructions to allow for multiple viewings would likely improve level of agreement.

Since the level of dynamic knee valgus collapse has the strongest influence of the overall scale score, a weighted kappa was used to assess the agreement between raters on this component. The strongest reliability was again observed between the Researcher and Clinician 1 indicating good (0.61-0.84) results. There was moderate (0.43-0.56) reliability with one account of fair (0.22) reliability between Clinician 2 and 3 for the

unaffected limb at the six-month follow-up. Results comparing the researcher and expert clinicians demonstrate fair to moderate (0.25-0.59) reliability which is much lower than anticipated. These results may reflect a difference in the specific skill required to properly identify and categorize level of valgus collapse.

Overall results provide evidence of inter-rater reliability of the CR-DVJS score although, the wide confidence intervals and lower agreement of the valgus component suggest results should be interpreted with caution. Individuals with varying level of clinical experience demonstrate moderate agreement when using the CR-DVJS. To improve agreement between clinicians, more clear instructions and a strong understanding of tool use may be required.

6.2.2 Intra-rater Reliability

Intra-rater reliability of the overall score per limb was examined for each expert clinician. Clinician 2 demonstrated good (0.79-0.85) reliability while Clinician 3 demonstrated moderate (0.5-0.72) reliability.

However, confidence intervals were again wide and ranged from moderate (0.64) to excellent (0.94) for Clinician 2 and from poor (0.11) to good (0.88) for Clinician 3. Lower ICC values were observed in Clinician 3 scores of the unaffected limb.

A version of intra-rater reliability was assessed for the researcher's in-person lab evaluation and video footage evaluation. There was moderate agreement (0.53 – 0.76) of the overall scores but agreement was slightly stronger at the 12-month time point as a result of increased sample size.

6.2.3 Within Session Test-retest Reliability

The results from the Researcher overall scores indicate good (0.84 – 0.89) within session test-retest reliability. However, 95% confidence intervals are wide reflecting our low sample size. The lower boundary of the confidence intervals for the 6-month time point is slightly lower (0.64), but all upper boundaries indicate excellent (0.93 – 0.94) reliability.

Results from analysis of Clinician 1 overall scores indicate excellent (0.90 – 0.96) within session test-retest reliability except for the affected limb at the 12-month time point (0.81). This also demonstrated the widest CI with the lower boundary at 0.65 (moderate). All other CI support good to excellent reliability.

6.3 Limitations

A limitation of this study is the small sample size. Specifically, increasing sample size would reduce the likelihood of random sampling error, improving the probability of achieving a sample representative of the population. This would also serve to reduce the magnitude of the effect of extreme values on agreement statistics, like weighted Kappa, and improve our certainty of both the within and between subject variability, which would improve the precision of our ICCs. Finally, with such a small sample size, we were unable to precisely estimate the values from the motion capture system.

Another limitation is the applicability since the study was conducted at a tertiary care centre located in Southwestern Ontario (FKSMC) with expert surgeons and clinicians. ACLR rehabilitation at this facility specifically addresses patient jumping and landing mechanics. Thus, it is possible those receiving this treatment protocol may have had improved movement patterns compared to those receiving treatment elsewhere. However, we did not specifically collect this data to address this issue.

Evidence of the validity of the tool is also limited by the capabilities of the current gold standard. Although 3D motion capture analysis is considered the gold standard of measuring lower body biomechanics during dynamic tasks, it has several limitations which should be acknowledged. Factors including marker placement, estimations of joint center, and skin/soft tissue movement artifacts have been shown to reduce the accuracy and precision of calculated joint angles and moments.[127,128] Furthermore, the system only allows for measuring specific kinematic and kinetic variables that act as surrogates of specific movement patterns. While these variables don’t exactly measure the motion of interest, they are the best possible measure available. In addition, there is not an exact measure corresponding to the overall score on the CR-DVJS, but several components accounting for the score could be analyzed. Two of the components, trunk lean and

asymmetry, could not be analyzed for the purposes of this study. Trunk lean was not frequently observed in patients nor could we determine the angle that created a visible trunk lean. Asymmetry, although more clearly defined in the CR-DVJS manual, could not be accurately defined in calculations since it is unknown what difference between limbs is visible to the human eye. Without providing evidence for all components of the CR-DVJS, it is difficult to draw conclusions surrounding the validity of the overall score.

Although the CR-DVJS manual was provided to all raters involved in the study, it is evident some scale instructions could be defined more objectively by supplying measurement ranges or visual prompts. Raters' interpretation of the instructions directly influences the tool use which is then reflected in outcome scores. For instance, it is left to the discretion and judgement of the rater to determine what "insufficient" flexion looks like. The check boxes on either side also leave some room for error in interpretation. For example, checking the side that the patient trunk is leaning toward, the side leading or landing during asymmetrical jumping patterns, or one side for trunk flexion. The difference in training and clarity of instructions between the raters make it difficult to determine if there is a difference in scoring ability based on level of experience. Furthermore, the expert clinicians scores were not compared to the gold standard due to the different method of assessment. Although the Researcher's scores via video were used to estimate the level of inter-rater reliability between experts, we could not determine whether there was a difference in skill of using the tool between raters. Agreement could have been affected by raters' inconsistent interpretation of instructions, differences in skill, method of observation, or truly low intra-rater reliability of the researcher. In addition, it is possible intra-rater reliability of the expert clinicians may have been improved by recall bias despite completing assessments a designated two weeks apart. Test-retest is limited to conclusions within session as opposed to a standard retest after a period of time without change. Although it was assumed there was no change in the jumping pattern within the same day, or it is possible fatigue may have altered mechanics for some patients. It is also possible patients experienced a learning effect and became more confident completing the drop vertical jump task. Thus, order bias may have influenced results of the within session test-retest since patients always completed the task in the lab first and the physiotherapy clinic second.

Chapter 7

7 Conclusion

This study provides moderate evidence of concurrent validity, inter-rater reliability, and intra-rater reliability as well as good evidence of test-retest reliability of the CR-DVJS. Raters were more accurate in ratings of trunk and knee flexion than level of knee valgus collapse.

7.1 Future Direction

Future studies are required to provide further evidence of the tool validity and reliability. A similar study should be conducted with an increased sample size to reduce the likelihood of random sampling error thereby improving the ability to precisely estimate the CR-DVJS's association with motion capture variables.

Furthermore, increasing sample size would improve the precision of agreement measures. Improving the ability to capture all movement patterns included on the CR-DVJS, would allow for more direct comparisons between components. A reliability study should be conducted to determine the agreement of each component of the tool, since more than one combination of components can result in the same final score.

True test-retest reliability should also be examined. Rather than completing two test sessions in different locations during the same day, patients should return to complete the second testing session on a separate day. This would also reduce the potential effect of patient fatigue and learning compared to the within session design. Limiting physical exertion and monitoring fatigue prior to task completion may also be beneficial to improve study design and quality of the results.

Each method of assessment (video vs in-person) should also be further investigated. Specifically, it may be determined if one method is more accurate and/or reliable, as well as how this may be affected by different viewing instructions. For instance, whether repetitive viewing in real-time, pausing and continuing viewing, or slow-motion viewing can improve agreement or association.

Additionally, an in-person assessment, rather than a video assessment, by an expert clinician would allow for better conclusions regarding the effect of skill on ability to use the tool. Without prior knowledge of whether a difference exists between in-person and video assessment we could not determine the accuracy of video assessment. An in-person lab assessment by a beginner, novice, and expert clinician would demonstrate whether increased skill can improve accuracy with the motion capture system.

The accompanying instruction manual should be reviewed among clinicians in a qualitative manner to improve clarity and hence, effectiveness of tool use. Feedback from raters of this study, as well as others in the field should be incorporated into a revised instruction manual and tested. This includes simple visual and layout feedback as well as more clear definitions of components and instructions to increase consistency of ratings.

Lastly, a large prospective study may be conducted to determine whether CR-DVJS score can predict ACL re-rupture. Once there is strong evidence of tool validity and reliability clinical implementation will assist with decision making and monitoring of progress during ACL rehabilitation. This will enhance ACL rehabilitation by providing an accessible and feasible option to quantify DVJ performance within a clinical setting.

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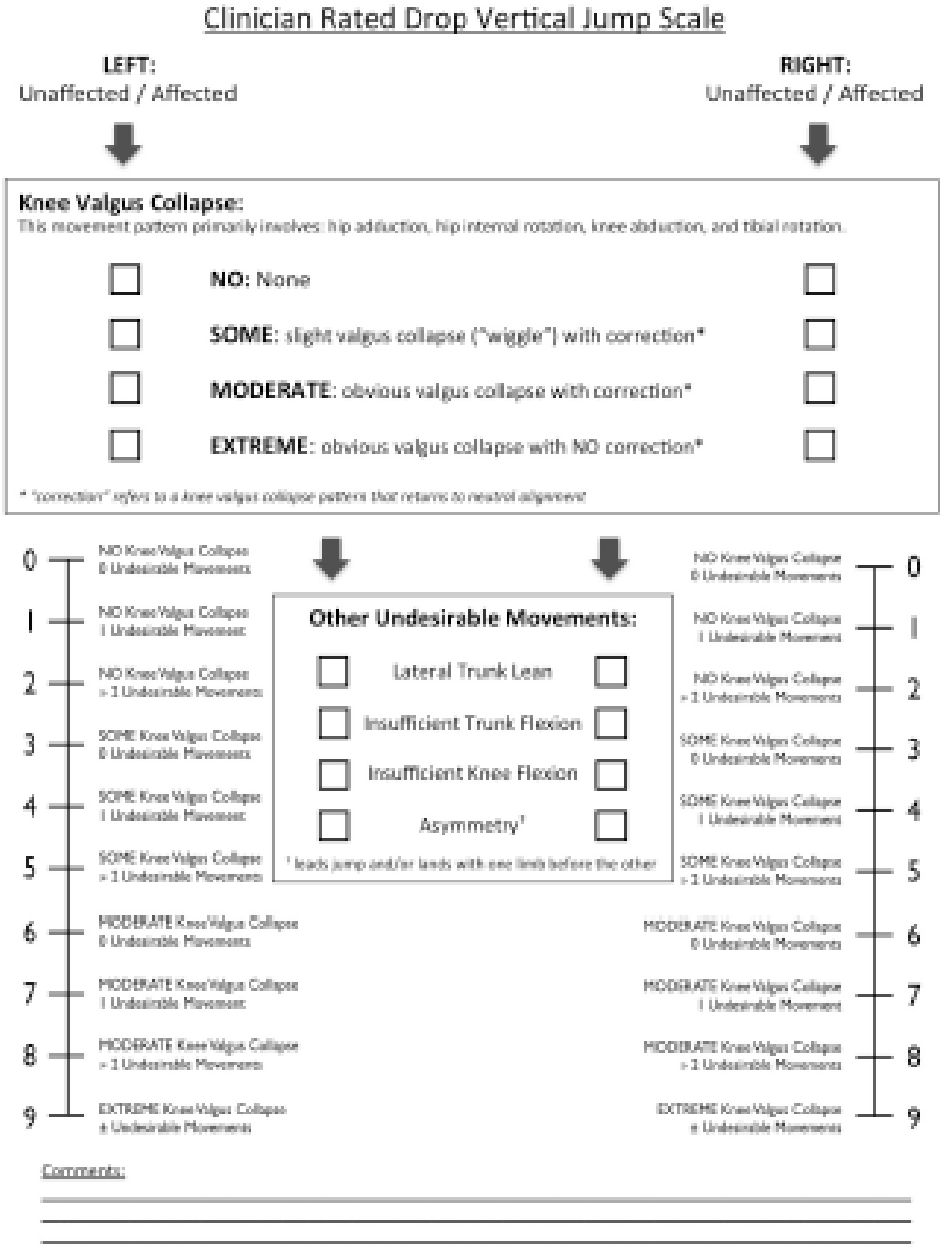
Appendices

Appendix A: Clinician Rated Drop Vertical Jump Scale Sheet



Instructions:* This scale is for clinician use to quantify performance of a drop vertical jump. It is intended to help evaluate change in performance following therapy.

Clinicians observe at least 3 repeated landings, check the appropriate boxes for *Knee Valgus Collapse and Other Undesirable Movements* for both left and right limbs, then circle the corresponding scale numbers (left and right of page).

[1]Asymmetry: Observed as leading with one limb to initiate movement, or making initial contact with one limb prior to the other.

Drop Vertical Jump: The patient stands on a box of approximately 30 cm, feet shoulder-width apart (~35 cm), with the ball of each foot on the edge of the box. The patient then drops off the box with both feet at the same time, lands on both feet, and then performs a maximum vertical jump as quickly as possible (similar to jumping for a basketball), landing again in the same spot as the initial landing[1].

The extent of knee valgus collapse, and other undesirable movements, are evaluated from initial contact through to the deepest point during the initial landing, prior to the maximal jump.

Example of sequence of DVJ. A) Start position; B) Drop; C) Deepest point during initial landing; D) Maximal jump; E) Second landing and completion of jump.

* For more detailed instructions and example pictures, please consult the Clinician Rated Drop Vertical Jump Scale Instruction Booklet.

1. Ford KR, Myer GD, Hewett TE. Valgus knee motion during landing in high school female and male basketball players. MSSE 2003;35(10):1745-1750

Appendix B: Instruction Booklet for the Clinician Rated Drop Vertical Jump Scale

Clinician Rated Drop Vertical Jump Scale

Instruction Booklet

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Clinician Rated Drop Vertical Jump Scale

INTRODUCTION

The purpose of this booklet is to provide instructions for how to use the Clinician Rated Drop Vertical Jump Scale (see Appendix 1 for the scale). A summary of the instructions also appears on the back of the scale. This booklet includes examples of what to observe when using the scale, and provides *instructions*, a brief *rationale* and potential *interpretation* for each component.

The drop vertical jump (DVJ) is a functional task relevant to anterior cruciate ligament (ACL) injury and rehabilitation. The DVJ is similar to rebounding a basketball, blocking in volleyball or jumping in soccer, among other sporting movements. When quantified in a biomechanics lab with motion analysis equipment, it is an indicator of ACL injury risk, especially in young females when greater dynamic knee valgus motion, knee abduction loads and limb-to-limb asymmetry are observed[1]. The present scale is intended to help clinicians quantify performance on the DVJ, without requiring motion analysis equipment, and evaluate change following therapy.

OVERALL INSTRUCTIONS

The clinician should observe at least *three* (more if required) repeated DVJ's while standing in different positions so as to observe movements in all three planes (frontal, sagittal and transverse), looking for joint positions and possible compensatory movements. Based on the repeated jumps, the clinician should check the appropriate boxes on the scale for i) *Knee Valgus Collapse*, and ii) *Other Undesirable Movements*, for both the left and right limbs, then circle the corresponding scale numbers to determine the overall performance for each limb (Appendix 1). Even if a joint position or compensatory movement is observed only once, it should be recorded.

Drop Vertical Jump Protocol

The patient is instructed to stand on a box of approximately 30 cm in height (e.g. a small plyo-box), with feet shoulder-width apart (~35 cm), with the ball of each foot on the edge of the box (e.g. toes overhanging edge). The patient then drops off the box with both feet at the same time, lands on both feet, and then performs a maximum vertical jump as quickly as possible (similar to jumping for a basketball), landing in the same approximate spot as the initial landing[2]. *The extent of dynamic knee valgus collapse and other undesirable movements should be evaluated from initial contact through to the deepest point during the initial landing, prior to the maximal jump.* An illustration of the sequence of phases in the DVJ is presented in Figure 1.

FIGURE 1. Example DVJ. Sequences include: (A) Start position; (B) Drop; (C) Deepest point during initial landing; (D) Maximal jump; and E) Second landing and completion of jump.

KNEE VALGUS COLLAPSE

➢ *Instruction*

The dynamic knee valgus collapse pattern includes the following movements: hip adduction and internal rotation, knee abduction, and ankle eversion[3,4]. These movements have a resultant external knee abduction moment directing the distal tibia away from the midline (Figure 2).

The Clinician Rated DVJ Scale has clinicians distinguish between four levels of dynamic knee valgus collapse. These include: NO (none); SOME (slight valgus collapse ("wiggle") with correction); MODERATE (obvious valgus collapse with correction); and EXTREME (obvious valgus collapse with NO correction). The term "correction" refers to a knee valgus collapse pattern that returns to neutral alignment. Figure 3 illustrates these four categories of valgus collapse.

➢ *Rationale*

The dynamic knee valgus collapse pattern is suggested to indicate a ligament dominant (rather than a muscular dominant) landing technique that produces a large external knee abduction moment about the knee and a large load on the ACL[4,5].

➢ *Interpretation*

When this pattern is observed, a suggested rehabilitation goal is to decrease medial knee motion to promote a muscle dominant landing technique and decrease risk for ACL (re)injury[4].

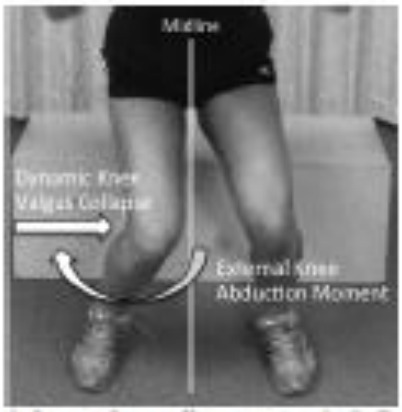

FIGURE 2. Example of the dynamic knee valgus collapse pattern including hip adduction and internal rotation, knee abduction, and ankle eversion. This pattern produces an external knee abduction moment.

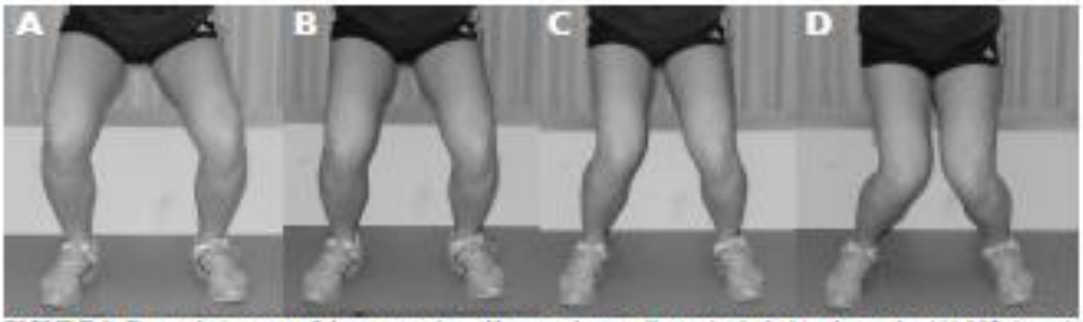

FIGURE 3. Example images of the categories of knee valgus collapse included in the scale. (A) NO (none); (B) SOME; (C) MODERATE; and (D) EXTREME knee valgus collapse

UNDESIRABLE MOVEMENTS

While dynamic knee valgus collapse is of primary concern during the DVJ, other undesirable movements are suggested to be important[6]. Therefore, the clinician should also evaluate excessive lateral trunk lean, insufficient forward trunk flexion, insufficient knee flexion and asymmetry using the Clinician Rated DVJ Scale.

Lateral Trunk Lean

- *Instruction*

When evaluating whether a patient exhibits lateral trunk lean, the clinician should observe performance in the frontal plane and whether the patient is in a neutral alignment (Figure 4A), or is shifting the trunk over one limb (Figure 4B).

➢ *Rationale*

Studies suggest that at the time of ACL injury, the trunk is frequently erect[8,9,10] and displaced laterally[8], which results in less flexion in the lower extremity (esp. hip and knee)[11,12,13]. The consequences are increased load on the ACL and increased risk for injury.

➢ *Interpretation*

Lateral trunk lean is more easily observed with single leg performance; however, it is important to consider in any landing, as it can be an indicator of hip abductor weakness[8] and possibly weak core proprioception[7]. These should therefore be considered as targets of rehabilitation intervention. Note that shifting the trunk over a weaker limb could result in an increase in dynamic knee valgus collapse ipsilaterally.

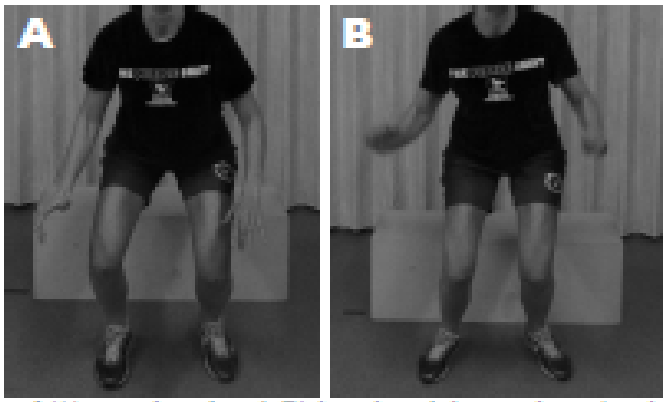

FIGURE 4. Example of (A) neutral trunk and (B) lateral trunk lean to the patients' right side during the DVJ. Note that in image (B) the participant is shifting weight over the right hip (right shoulder and hip dropped) and is also demonstrating a dynamic valgus collapse

Insufficient Trunk Flexion

➢ *Instruction*

The clinician should evaluate performance for insufficient trunk flexion in the sagittal plane. When observing decreased trunk flexion during the DVJ, the clinician should also check for accompanying decreased knee and hip flexion, as often when landing with an erect trunk (Figure 5A), the patient will also exhibit less knee and hip flexion, in comparison to a more flexed trunk[11,12,13] (Figure 5B).

➢ *Rationale*

Hip and knee moments are influenced by sagittal plane trunk motion[8]. A more erect position (Figure 5A) results in greater loads at the knee[8,11,12,13], while landing with the trunk in a more flexed position (Figure 5B) reduces loads at the knee and potentially ACL strain, while increasing hip and knee flexion angles during landing[11,12,13].

➢ *Interpretation*

If a patient is landing in a trunk erect position, technique training to increase trunk flexion is recommended.

FIGURE 5. Examples of sagittal plane trunk positions during the DVJ: (A) erect trunk position with hip and knee joints demonstrating only slight flexion; and (B) greater trunk flexion accompanied by greater hip and knee flexion

Insufficient Knee Flexion

➢ *Instruction*

The clinician should evaluate performance for insufficient knee flexion in the sagittal plane. Cues to look for when observing insufficient knee flexion are a flat-footed straight-leg landing, usually with an associated loud contact noise[3]. Figure 6 portrays an example of straight-leg landing (A) and a more flexed landing (B).

➢ *Rationale*

At the time of ACL injury, the knee is frequently reported to be in a position close to full extension[9], a position at which contraction of the quadriceps increases strain on the ACL[34] and the hamstrings cannot adequately protect the ACL[4,15,36].

➢ *Interpretation*

Insufficient knee flexion may suggest quadriceps dominance or poor hamstring strength and recruitment[4,5], which should therefore be a focus of rehabilitation.

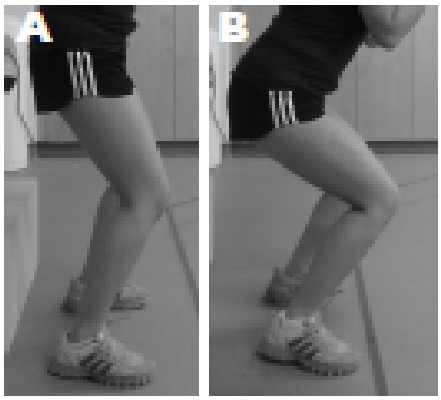

FIGURE 6. Example images of knee flexion observed in the sagittal plane, (A) flat-footed, straight-leg landing depicting insufficient knee flexion; and (B) a more flexed position allowing the hamstrings to activate and reduce anterior tibial translation and strain on the ACL

Asymmetry

- *Instruction*

When observing performance of the DVJ for asymmetry, the clinician should be watchful for patients leaving the box with one limb prior to the other and/or landing with one limb prior to the other (Figure 7). Another cue is a foot placement with one foot posterior to the other (the posterior limb is suggested to be the stronger limb)[4] (Figure 8).

- *Rationale*

Limb-to-limb asymmetries are also risk factors for ACL injury[1]. Asymmetries in landing and jumping forces following return to sport after ACL reconstruction exist as long as 2 years after surgery[17]. Lingering asymmetries can increase the risk for re-injury of the reconstructed ACL and to the contralateral limb[6,17].

Interpretation

Lower limb asymmetry is suggested to indicate that the patient is exhibiting leg dominance, or residual injury deficits[4], and a focus of rehabilitation should therefore be on correcting the observed imbalance between limbs.

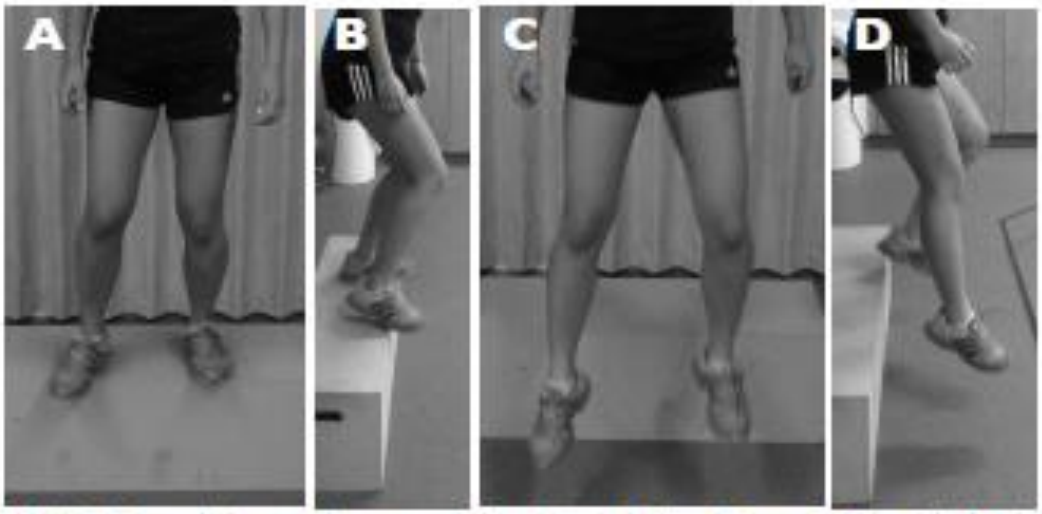

FIGURE 7. Example images of asymmetry: The subject is leading the jump with the right foot by unweighting it first as seen in (A) frontal, and (B) sagittal views; Subject will likely land, or make initial contact with the right foot first as seen in (C) frontal, and (D) sagittal views

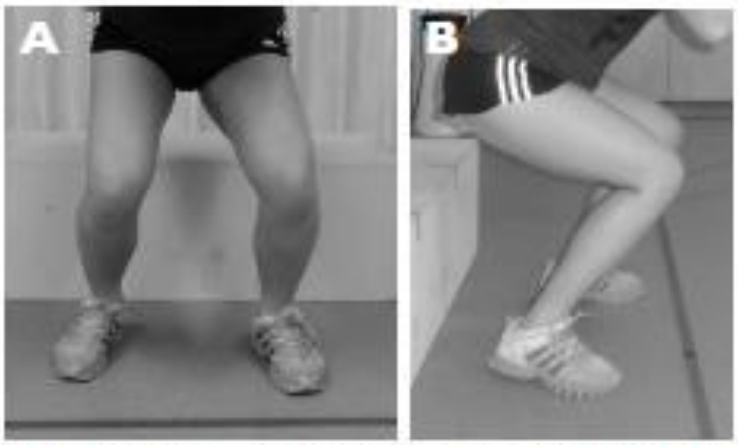

FIGURE 8. Example images of asymmetry demonstrated by staggered foot placement, with the right foot placed posteriorly to the left, suggesting a weaker left limb. (A) Frontal plane and, (B) sagittal plane views. Staggered foot placement is more easily observed from the sagittal view

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Appendix C: Western Research Ethics Approval

Western Research

Western University Health Science Research Ethics Board
HSREB Amendment Approval Notice

Principal Investigator: Dr. Alan Getgood
Department & Institution: Schulich School of Medicine and Dentistry\Surgery,Western University

Review Type: Full Board
HSREB File Number: 104524
Study Title: Multicenter Randomized Clinical Trial comparing Anterior Cruciate Ligament Reconstruction With and Without Lateral Extra-articular Tenodesis in Individuals Who Are At High Risk of Graft Failure.
Sponsor:

HSREB Amendment Approval Date: March 16, 2017
HSREB Expiry Date: February 07, 2018

Documents Approved and/or Received for Information:

Document Name	Comments	Version Date
Instruments	Clinician Rated Drop Vertical Jump Scale	2017/02/23
Revised Western University Protocol	Received Mar 23, 2017	
Letter of Information & Consent		2017/02/23

The Western University Health Science Research Ethics Board (HSREB) has reviewed and approved the amendment to the above named study, as of the HSREB Initial Approval Date noted above.

HSREB approval for this study remains valid until the HSREB Expiry Date noted above, conditional to timely submission and acceptance of HSREB Continuing Ethics Review.

The Western University HSREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the International Conference on Harmonization of Technical Requirements for Registration of Pharmaceuticals for Human Use Guideline for Good Clinical Practice Practices (ICH E6 R1), the Ontario Personal Health Information Protection Act (PHIPA, 2004), Part 4 of the Natural Health Product Regulations, Health Canada Medical Device Regulations and Part C, Division 5, of the Food and Drug Regulations of Health Canada.

Members of the HSREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB.

The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

[redacted]
chalf of Dr. Joseph Gilbert, HSREB Chair

EO: Erika Basile ✓ Nicole Kaniki ___ Grace Kelly ___ Katelyn Harris ___ Nicola Morphet ___ Karen Gopaul ___

[redacted]

Appendix D: Letter of Information and Consent

FOWLER KENNEDY
SPORT MEDICINE CLINIC

LETTER OF INFORMATION

Title of Research:
Multicenter Randomized Clinical Trial comparing Anterior Cruciate Ligament Reconstruction With and Without Lateral Extra-articular Tenodesis in Individuals Who Are At High Risk of Graft Failure.

Lead Researchers:
Dr. Alan Getgood
[redacted]

Dr. Dianne Bryant
[redacted]

Study Sponsors:
International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine (ISAKOS)
Orthopaedic Research and Education Foundation (OREF)

Information:
You are being invited to participate in a research study because your surgeon has determined that you have a torn anterior cruciate ligament (ACL) and you have elected to undergo surgery to reconstruct this ligament. The purpose of this letter is to provide you with information required for you to make an informed decision regarding participation in this research.

The purpose of this study is to compare outcomes (function, strength, range of motion and quality of life) between patients who receive the usual anterior cruciate ligament (ACL) reconstructive surgery to patients who receive anterior cruciate ligament reconstructive surgery with a lateral extra-articular tenodesis. A lateral extra-articular tenodesis is the creation of a new ligament-like structure using a piece of the Iliotibial (IT) band on the outside of the knee. The usual standard of care for an ACL tear is ACL reconstruction without this lateral extra-articular tenodesis (new ligament-like structure). Some studies have shown high graft failure rates (ACL re-tear) in young individuals who return to pivoting contact sports following ACL reconstruction. This study is designed to look at whether or not adding this extra structure reduces the risk of graft failure in this population. To determine whether one procedure is better than the other, we must randomize (like flipping a coin) you into one of the surgery groups. Six hundred (600) patients will take part in this study at different centres around the world. This centre will recruit one hundred (200) patients; approximately 100 per group.

Eligibility:
To participate in this study you must be 25 years of age or younger. You cannot have had

previous ACL reconstruction on either knee. You cannot have a multi-ligament injury (two or more ligaments requiring surgery). If you are currently participating in another research study, you must inform your surgeon and the research assistant.

Explanation of the Study Procedures:

The goal of anterior cruciate ligament reconstruction surgery is to replace the torn ACL with a tissue graft to provide stability to the knee. This is done through a surgical procedure that is performed arthroscopically (with a camera). Either spinal or general anesthesia is used. Small screws are placed into the bone to hold the tissue graft in place.

If, during the surgery, your surgeon determines that your knee does not meet the requirements for the study i.e. other ligaments are found to be torn, or it cannot be treated using the surgical procedure defined in the study protocol, he/she will withdraw you from the study and you will be treated according to standard practice of your surgeon.

Description of the Study:

The total time commitment of the study is two years. Visits for this study will coincide with follow-up visits that you would already attend with your surgeon after your surgery. Each visit with the surgeon will take approximately 40 minutes of your time. Before your surgery, you will be asked to complete ten questionnaires along with a strength assessment, hop test and range of motion measurement. Following your surgery you will receive instructions to undergo standardized physical therapy. You will be given a Rehabilitation Guide to give to your physical therapist.

After surgery, you will come in for an appointment with your surgeon at 3 months, 6 months, 1 year and 2 years where you will be asked to complete the same nine questionnaires. At that time, we will also measure your range of motion. Completing these questionnaires will take approximately 15 - 20 minutes of your time and collection of range of motion measurements, strength and hop testing will take approximately 45 minutes.

At 6 months, 1 year and 2 years post - surgery, we will measure your strength and assess your ability to perform a series of simple jumping tasks. Strength tests will be performed by bending and extending your knee 3 times to measure your strength against resistance. This is done using a computerized machine called an isokinetic dynamometer. During each test session, you will be seated with your back against a backrest with a seat belt securing you into place.

We will schedule 100 patients (50 from each group) for Magnetic Resonance Imaging (MRI) at or after your 2 year appointment. MRI is a common medical diagnostic tool that uses a strong magnetic field, a low frequency magnetic field and a radio frequency field. The purpose of the MRI is to evaluate the lateral compartment of your knee following your ACL reconstruction. The MRI will take approximately 2 hours of your time and we will schedule and confirm the time and location with you beforehand.

If you have undergone a posterior meniscal root repair we will schedule you for MRI testing at or after your 1 year appointment. The purpose of the MRI is to evaluate the healing of your meniscus following its repair. The MRI will take approximately 2 hours of your time and we will schedule and confirm the time and location with you beforehand.

The jumping tests are subdivided into functional tests and biomechanical assessment. The functional tests include a single hop for distance, a timed 6 metre hop test, a triple hop for distance and a crossover hop for distance. The biomechanical assessment will use motion analysis equipment and a clinician rated scale to look at the mechanics of your knee as you perform a vertical jumping task.

The single hop for distance test is performed by having you stand on your leg to be tested, and hop forward on the same leg. The timed 6 metre hop test is performed by having you perform large one - legged hops in series over the 6 metres. The triple hops for distance test is performed by having you stand on one leg and perform three hops in a row on the same leg, landing as far away as possible. The crossover hop for distance is performed by having you hop forward three times while making a "Z" pattern.

The biomechanical assessment will take place in the Wolf Orthopaedic Biomechanics Laboratory (WOBL) at the Fowler Kennedy Sports Medicine Clinic. The task will require you to jump onto a force plate while sensors monitor your movements and muscle activity. These sensors will be placed on your skin over your feet, knees, hips, arms and shoulders using double-sided tape. You will be asked to wear dark (black or navy) shorts and a dark (black or navy) T-shirt or tank top to limit identifiable features and assist with the placement of the sensors. Although the sensors are easily removed, the tape may cause some pulling of hair therefore we may ask to shave some areas with a plastic disposable razor in order to limit discomfort.

After becoming familiarized with the instrumentation we will ask you to perform a double leg drop vertical jump. This task will require you to drop/hop off a box (at an elevated height of 31cm) and land with both legs on a force plate outlined on the ground, following which you will immediately jump vertically as high as you can, as if rebounding a basketball. As you are performing this task, a clinician and a researcher will use a Clinician Rated Drop Vertical Jump Scale to evaluate your landing. Additionally, we will videotape your jump so that the same clinician and researcher can later review the video and re-rate your jump, which will help us determine whether the evaluation of your landing is similar whether it is done in-person or using a video. Only your torso and lower body will be visible in the video.

Alternatives to Participation:

If you do not choose to participate in this study, you will receive the usual ACL reconstructive surgery provided by your surgeon.

Risks:

You could fall, injure or re - injure yourself while performing tests, however, the risks are no greater than those encountered with typical postoperative rehab protocols.

Your participation in this study may involve an MRI. No X-rays are used. As with any technology there is a risk of death or injury. For MRI the risk of death is less than 1 in 10 million and the risk of injury is less than 1 in 100,000. These risks do not arise from the MRI process itself but from a failure to disclose or detect MRI incompatible objects in or around the body of the subject or scanner room. It is therefore very important that you answer all questions honestly and fully on the MRI screening questionnaire.

Almost all the deaths and injuries related to MRI scans have occurred because the MRI operator did not know that surgically implanted metal hardware (such as a cardiac pacemaker) was present inside the subject during the MRI scan. Other Remote risks involve temporary hearing loss from the loud noise inside the magnet. This can be avoided with ear headphone protection that also allows continuous communication between the subject and staff during the scan. For comparison, the risk of death in an MRI is similar to travelling 10 miles by car, while the risk of injury during an MRI is much less than the risks associated with normal daily activities for 1 hour.

If you have any history of head or eye injury involving metal fragments, if you have ever worked in a metal shop or been a soldier, if you have some type of implanted electrical device (such as a cardiac pacemaker), if you have severe heart disease (including susceptibility to arrhythmias), if you are wearing metal braces on your teeth, or [for women] if you could be pregnant, or have an intrauterine device, you should not have an MRI scan.

If you undergo a posterior meniscus root repair and are unable to have an MRI scan you will still be allowed to continue participating in the rest of this study.

There are no other known health risks associated with this study.

Benefits:

There are no direct benefits to you for participating in this study; however your participation will help inform surgeons and physiotherapists as to which surgical procedure offers patients who undergo ACL reconstruction the best outcome.

Cost/Compensation:

You will not be compensated for your participation in this study. You will be responsible for the cost of parking.

Voluntary Participation:

Your participation in this study is voluntary. You may refuse to participate, refuse to answer any questions or withdraw from the study at any time with no effect on your future care. Should you choose to withdraw from this study, we will keep all data obtained up to the point that you chose to withdraw.

Participation in this study does not prevent you from participating in any other research studies at the present time or future. If you are participating in another research study, we ask that you please inform of us of your participation. You do not waive any legal rights by signing the consent form.

Request for Study Results:

Should you decide to participate and want to receive a copy of the study results, please provide your contact information on a separate piece of paper. Once the study has been published, a copy will be mailed to you. Please note that the results of this study are not expected for at least 5 years. Should your mailing information change, please let us know.

Confidentiality:

All information will be kept confidential to the best of our ability. The company that takes care of the research database is EmPower Health Research. Your identifying information (name, mailing address, phone number, email address, date of birth) is being collected as part of your participation in this study. Your data is protected by a username and password. It travels in a scrambled format to a server (storage computer) that is located in Montreal, Quebec, Canada. The company that houses the server is a professional company (Netelligent) with extremely high standards of physical and virtual security. We want to let you know however, that even with this high level of security, there is always a remote chance that your information could be accessed or "hacked" by someone who is not supposed to have your information. The chance that this information will be accidentally released is small. In any publication, presentation or report, your name will not be used and any information that discloses your identity will not be released or published. We wish to make you aware that Dr. Bryant, who is one of this study's investigators, is the Director of EmPower Health Research. However, Dr. Bryant is not paid a salary by EmPower.

Study data will be kept for seven years. Representatives of The University of Western Ontario Health Sciences Research Ethics Board may contact you or require access to your study-related records to monitor the conduct of the research.

Questions:

If you have questions about the conduct of the study or your rights as a research participant, you may contact Dr. David Hill, Scientific Director, Lawson Health Research Institute (519) 667-6649.

If you have questions or concerns about your surgery or physiotherapy, please contact your orthopaedic surgeon or physiotherapist. If you have any questions about this research, please contact [redacted] or your orthopaedic surgeon.

This letter is yours to keep.

Sincerely,

Dr. Alan Getgood, MD
Dr. Dianne Bryant, PhD
Stacey Wanlin
Andrew Firth, MSc
Ryan Pinto, MSc

CONSENT FORM

Title of Research:

Multicenter Randomized Clinical Trial comparing Anterior Cruciate Ligament Reconstruction With and Without Lateral Extra-articular Tenodesis in Individuals Who Are At High Risk of Graft Failure.

I have read the letter of information, have had the nature of the study explained to me, and I agree to participate in the study. All questions have been answered to my satisfaction. I will receive a copy of the Letter of Information and this signed consent form.

Printed Name of the Participant	Signature of the Participant	Date
Printed Name of the Parent or Legally Authorized Representative (if required)	Signature of the Parent or Legally Authorized Representative (if required)	Date
Printed Name of the Person Responsible for Obtaining Informed Consent	Signature of the Person Person Responsible for Obtaining Informed Consent	Date

☐ I would like to receive a copy of the results of this study.
Please mail to:

_____

_____

_____

Curriculum Vitae

NAME **Morgan Jennings**

EDUCATION

Master of Science: Health and Rehabilitation Sciences, Physical Therapy
Collaborative Musculoskeletal Health Research
Western University, London, Ontario, Canada
2016-2018

Bachelor of Arts: Honors Specialization in Kinesiology
Western University, London, Ontario, Canada
2011-2015

HONORS AND AWARDS

2017-2018 Province of Ontario Graduate Scholarship

2017-2018 Collaborative Musculoskeletal Health Research Stipend

2016-2017 Western Graduate Research Scholarship

2016 Certificate in recognition of dedicated volunteer service within Sci Rehab Physiotherapy - Sci/FES/Fitness Center at Parkwood Hospital - St. Joseph's Health Care London

2015 National Student Leadership Award
Canadian Association of Health Sciences Deans

2011-2015 Western University Dean’s Honor List

2015 Certificate of Appreciation for student leadership and significant contribution to the Faculty of Health Sciences, Western University

2011 Western Scholarship of Excellence

RELATED WORK EXPERIENCE

2016 Teaching Assistant
Physical Therapy in Physical Therapy Clinics-PT9537
Western University

2016 Research clinic volunteer
Fowler Kennedy Sport Medicine Clinic

2016-2017	Organizing Committee and Abstract Reviewer: Health and Rehabilitation Sciences Graduate Research Conference Committee, Western University
2017	Organizing Committee/Abstract Reviewer: Exercise is Medicine Canada National Student Conference, Western University
2017-2018	VP External Communications, Health and Rehabilitation Sciences Graduate Student Society, Western University
2017-2018	Trainee Representative, Communications Committee, Bone and Joint Institute, Western University
2017-2018	Health Sciences Representative, Trainee Leadership Committee, Bone and Joint Institute, Western University

PUBLICATIONS

Chircorelli, J., Dennie, A., Heinrich, C., Hinchey, B., Honarparvar, F., Jennings, M., Keefe, C., Metro, T.L., Peel, C., Snowdon, C., Tempelman, J., Wong, M.E., Forbes, S.L., & Livingston, L.A. (in press). Canadian student leaders' perspective on interprofessional education: A consensus statement. Journal of Interprofessional Care.

PRESENTATIONS

Accepted Oral Presentation: Presenter, Health and Rehabilitation Sciences Graduate Research Conference, Western University, February 1, 2018.

Invited Oral Presentation: Presenter, Retiring with Strong Minds, Windemere on the Mount, November 3, 2017.

Accepted Oral Presentation: Presenter, 2017 Orthopaedic National Symposium: Stronger Together, October 22, 2017.

Accepted Oral Presentation: Presenter, Exercise is Medicine Canada National Student Conference, Western University, June 24, 2017.

Invited Oral Presentation: Presenter, Fowler Kennedy Sport Medicine Clinic Research Rounds, Western University, May 4, 2017.

Poster Presentation: Presenter, Bone and Joint Musculoskeletal Research Retreat, Western University, May 2, 2017.

Accepted Poster Presentation: Presenter, Health and Rehabilitation Sciences Graduate Research Conference, Western University, February 1, 2017.