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PRACTICAL SCREENING AND INTERVENTION TO REDUCE  
RISK OF ACL INJURY IN YOUNG WOMEN

Degree Programme in Physiotherapy  
2016



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Degree Programme in Physiotherapy

March 2016

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Number of pages: 48

Appendices: 2

Keywords: anterior cruciate ligament, knee, injury, risk, screening, prevention

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Injury of the anterior cruciate ligament (ACL) is a relatively common knee injury amongst participants of competitive sports such as soccer, basketball, gymnastics, volleyball and handball. Its incidence amongst young females is two to six times higher than males participating in the same sports due to a number of factors including biomechanical and neuromuscular differences. ACL injury has serious consequences for affected individuals including costly rehabilitation, long recovery time and a greater risk of subsequent knee injury. Community-wide prevention programs focusing on education and exercise to improve modifiable risk factors could significantly reduce the incidence of injury. For such programs to be successfully adopted, risk screening and training interventions need to be low-cost and of minimal inconvenience.

A brief literature review was made of the current evidence related to risk screening and prevention programs for ACL injury. The aim was to answer four main questions: (a) How can an ACL risk assessment and injury prevention program be rapidly and inexpensively implemented for a team of young females in a community sports setting?; (b) What field-based test method can identify a few of the most important modifiable risk factors?; (c) What training interventions can reduce these risk factors? and; (d) How can these interventions be provided to ensure best possibility for adoption and compliance by sports teams?

In this thesis we propose a field-based screening tool and training intervention guide to help physiotherapists assess groups of young women, identify individuals at high risk of ACL injury and design an injury prevention program based on therapeutic exercise. The screening process uses a tuck-jump landing test to identify four faulty movement patterns that are known neuromuscular/biomechanical risk factors for ACL injury. The faulty movement patterns exhibited during jump landing are ligament dominance (knee valgus), leg dominance (bias on landing leg), trunk dominance (core instability) and quadriceps dominance (insufficient knee flexion). The intervention guide recommends progressive neuromuscular exercise programs targeted specifically at each high risk movement pattern.

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## 1 INTRODUCTION

Anterior cruciate ligament (ACL) is one of the four ligaments that help stabilize the knee joint. A tear or rupture of the ACL is a serious yet relatively common knee injury amongst participants of competitive sports such as football, soccer, basketball, skiing and gymnastics. (Kiapour & Murray 2014, 21.) Typically ACL injuries are associated with non-contact incidents (i.e. no external forces from direct contact with another person or object) and movements that involve pivoting, side stepping or jump landing maneuvers (Rodriguez-Merchan. 2013, 101).

The consequences of anterior cruciate ligament injury can be devastating to the lives of the affected individuals and may be considered a career-ending injury for a professional athlete. ACL injury is associated with pain, knee instability, costly rehabilitation, a risk of early development of knee osteoarthritis, greater risk of re-injury and long-term reduced activity levels. (LaBella et al. 2014, 1439.)

The United States has an estimated ACL injury incidence rate of 1 in 3000, with approximately 100,000 to 200,000 occurring annually and some 100,000 reconstruction surgeries performed (Acevedo et al. 2014, 186). In Norway, Sweden and Denmark for the 10 to 19-year age range, the estimated incidence of ACL reconstructive surgery is 76 in 100,000 for girls and 47 in 100,000 for boys. These figures underestimate the actual occurrence of ACL injury, however. (LaBella et al. 2014, 1439.)

ACL Injury rates amongst young females are two to six times higher compared to males in the same sports (LaBella et al. 2014, 1439). Research of the past 25 years has revealed a large number of interrelated risk factors for female athletes concerning hormones, anatomy, neuromuscular control, biomechanics and environment. Fortunately, several of the key risk factors can be positively affected through training interventions. These modifiable factors relate to faulty movement patterns or neuromuscular deficits known to excessively load the knee under dynamic conditions, e.g. knee valgus, internal rotation of the hip, limited flexion of hip and knee on landing and poor trunk control. (Acevedo, Rivera-Vega, Miranda, & Micheo. 2014, 187-188.)

While repeated calls have been made for development of sex-specific screening batteries and injury prevention programs targeting these modifiable risk factors, no single test battery has emerged that is valid and reliable across all sports or that is feasible to deploy across a wide population (Smith et.al. 2012, 69-71).

This thesis aims to answer four main questions. How can an ACL risk assessment and injury prevention program be rapidly and inexpensively implemented for a group of young females in a community sports setting? What test method can identify a few of the most important modifiable risk factors? What training interventions can reduce these risk factors? How can these interventions be provided to ensure the best possibility for adoption and compliance by sports teams?

To this end an exploration was made of the recent evidenced-based literature to identify applicable tests, screening method and training interventions. In this thesis we aim to develop a simple, quick to use, low cost field screening tool and intervention guide specifically for assessing young female athletes at risk of ACL injury. The screening test is usable in a clinic or in the field to screen a large number of subjects and should assist a physiotherapist in the preparation of an injury prevention program. The output of this work is a field screening tool (Appendix 1) and intervention guide (Appendix 2) for young females at risk of non-contact ACL injury.

## 2 AIM AND PURPOSE

The purpose of this study is to review the scientific literature for current evidence related to ACL risk screening tools and exercise interventions for prevention of ACL injury. In particular our interest is in ACL risk factors that are modifiable through therapeutic exercise and which relate specifically to young women in community sports settings.

Based on the findings of the literature review our aim is provide a functional test to simply and quickly assess female sports groups using commonly available digital cameras and to provide progressive functional intervention exercises which could be easily incorporated into a warm up for any sports team.

Our intent is that the screening tool and intervention guide will help a physiotherapist in the clinic or field to assess a large number of subjects, identify individuals with specific high risk movement patterns and design a targeted ACL injury prevention program based on therapeutic exercise.

### 3 BACKGROUND TO ACL INJURY

#### 3.1 Anatomy of the knee joint

The knee joint is formed by the tibia, femur and patella (Figure 1). The patella sits within the patella tendon gliding over the groove on the anterior facet of the femur. Two fibrocartilaginous menisci lie between the femur and tibia. The joint is surrounded by a layer of synovium, and the contact surfaces of the three bones are lined with articular cartilage. The joint functions in flexion-extension in the sagittal plane and internal-external rotation in the transverse plane. Four major ligaments help to stabilize the knee joint. (Courtney & Hensley 2016, 468.)

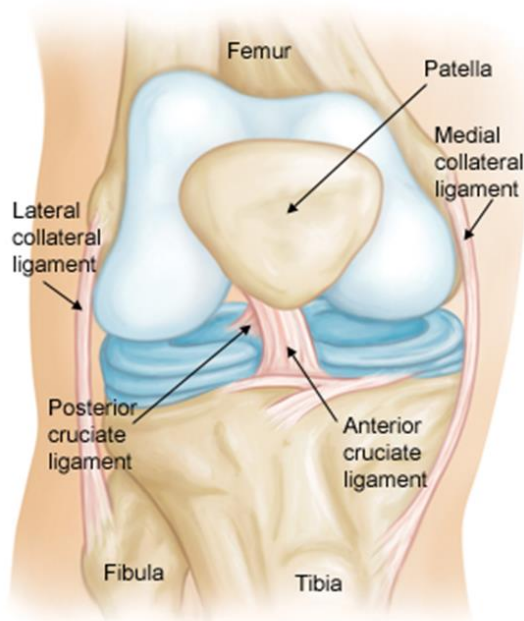


Figure 1 Ligaments of the Knee Joint

(<http://orthoinfo.aaos.org/figures/A00549F01.jpg>)

The anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL) act to limit anterior/posterior translation and medial/lateral rotation of the tibia relative to the femur. The lateral collateral ligament (LCL) and medial collateral ligament (MCL) limit lateral movement of the tibia relative the femur. The ACL and PCL lie within the femoral condyles and form an X-like shape. (Peterson & Renström 2000, 281.) The knee joint is mobilized and stabilized by muscles surrounding it (Figure 2). The

knee stability is maintained by the collateral and cruciate ligaments and the musculotendinous ties across the joint. Effective strength, proprioceptive control and feedback is required for musculature to contribute to stability and prevent injury. (Courtney & Hensley 2015, 467-468.)

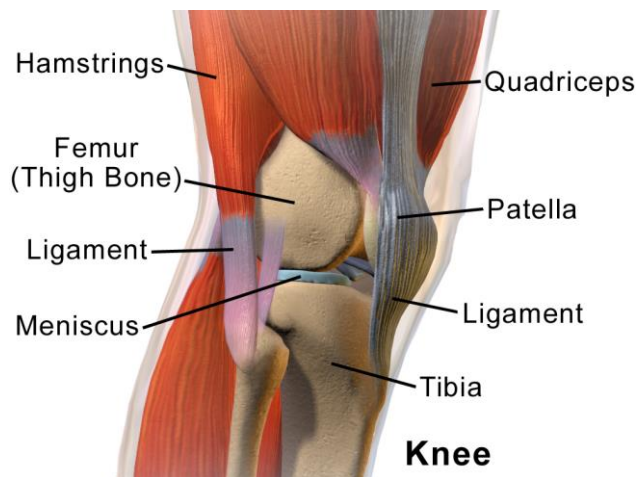


Figure 2 Musculature around knee joint

([https://upload.wikimedia.org/wikipedia/commons/b/bc/Blausen\\_0597\\_KneeAnatomy\\_Side.png](https://upload.wikimedia.org/wikipedia/commons/b/bc/Blausen_0597_KneeAnatomy_Side.png))

### 3.2 Anterior Cruciate Ligament

The ACL is a flat, band-like structure made up of two functional units, the anteromedial and posterolateral bundles. The ACL bundles function together throughout the range of motion of the knee. The ACL has a tibial attachment anterolateral to the anterior tibial spine. It runs below the transverse ligament, blends with the anterior horn of the meniscus, then passes proximally, laterally and posteriorly attaching to the lateral femoral condyle at the posterior part of its medial surface. From tibia to femur the ACL runs in an approximate  $110^{\circ}$  spiral. (Palastanga & Soames, 2012, 312-313.)

The ACL has a typical range of length of 31mm to 38mm along the anterior border and widths ranging 7 to 17mm. While as a whole the ACL is considered to be taut throughout the range of knee motions, the tightness of the individual bundles and thus the force transmitted through them vary according to joint position and geometry of loading. At extension the posterolateral bundle is under maximum lengthening and tightness. At 60 to 90 degree knee flexion the anteriomedial bundle is at maximal ten-



sion, while the posteriolateral band is tightest at full knee extension. The bundles work together to control and limit anterior posterior translation and rotation of the tibia as the knee flexes. (Rodriguez-Merchan. 2013, 99.) During extension the ACL also guides the “screw-home mechanism” of the knee through internal rotation of the femur and preventing tibial internal rotation (Courtney & Hensley 2015, 468).

The ACL is made up of collagen fibres with 10% being elastic fibres giving it a high tensile strength. At the fibre level there are two phases of loading. The first phase involves elastic deformation while allowing full recovery after unloading. The second involves permanent deformation due to damage or microfailure of the crosslinks in the collagen fibres. Such microfailures can occur well before actual ligament tear and represent progressive wear and weakening of the ligament. (Palastanga & Soames, 2012, 312-313.) The strength of the ACL is significantly less than the forces occurring in athletic performance; therefore, stability of the knee under dynamic loading requires cooperation between passive and dynamic stabilizers, ligaments and musculature. (Courtney & Hensley 2015, 467-468.)

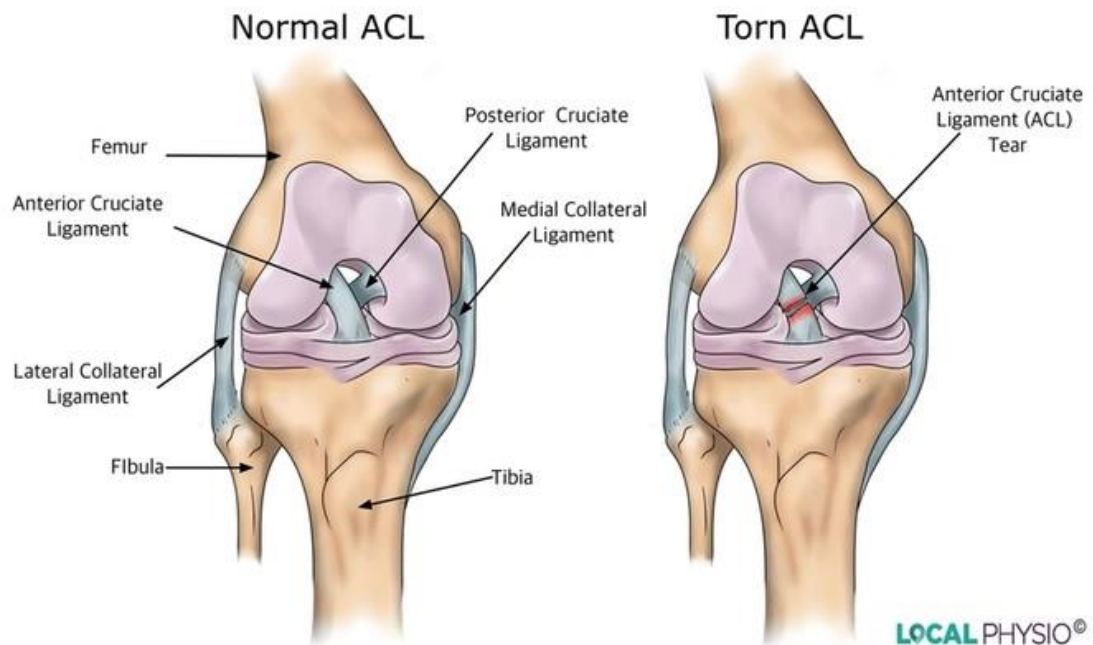


Figure 3 Healthy ACL and torn ACL

(<http://strengthtrainingforyou.blogspot.fi/2015/07/acl-reconstruction-and-rehab.html>)

### 3.3 Mechanism of ACL injury

ACL tear or rupture is a common knee injury amongst participants of competitive sports involving pivoting, side stepping or jump landing (Rodriguez-Merchan. 2013, 101) such as football, soccer, basketball, skiing, gymnastics (LaBella et al. 2014, 1438). Some 70% of ACL injuries are associated with non-contact incidents. That means there is no external forces from direct contact with another person or object (Kiapour & Murray 2014, 21). Injury rates are 2 to 6 times higher amongst females compared to males in the same sports (LaBella et al. 2014, 1439.)

Researchers described that the injury mechanism of ACL in female athletes (Figure 4) involves the combination of an increase of tibia rotation, hip adduction, hip internal rotation, knee abduction moment with decreased knee flexion, and higher ground reaction force (GRF). It has been observed that the involved foot appears in pronated position and the body outside of center of mass (COM). This vulnerable position it is called “the position of no return”. (Avecedo et al. 2014, 187-188.) Boden et al. reported a delayed activation of calf muscle to absorb GRF at full contact, which ends up to be shifted to the knee, causing an excessive compression force to the knee. Hence, all these factors contribute to an increase of load and stress on the ACL during athletic tasks. (Boden et al. 2010, 4.)

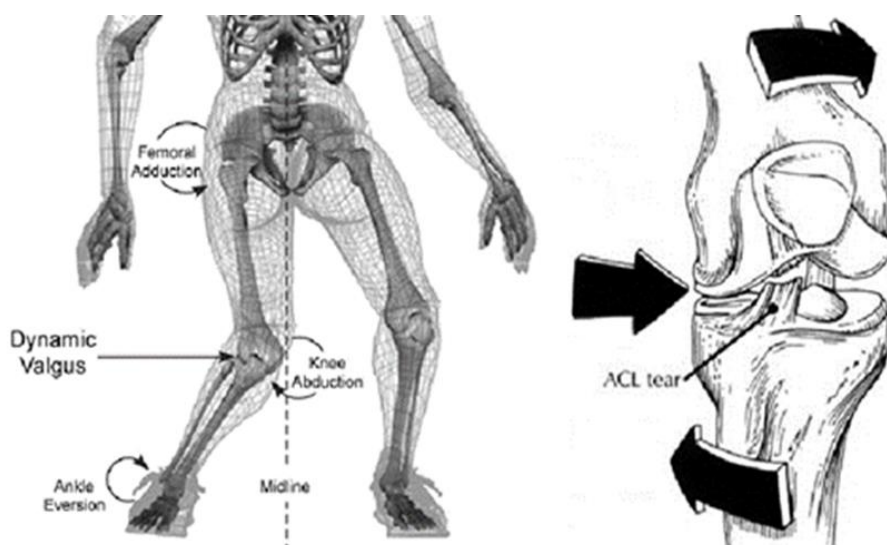


Figure 4 Mechanism of ACL injury from dynamic valgus (Left) and tibial rotation (Right) (<http://strengthtrainingforyou.blogspot.fi/2015/07/acl-reconstruction-and-rehab.html>)

Strain on the ACL varies according to type of loading, knee flexion, limb position and muscular control. When loaded in the transverse and coronal planes, the strain on the ACL has been found to be highest at a knee flexion angle of less than 40 degrees. At these lower flexion angles the quadriceps exerts a greater anterior force on the tibia and there is a significantly less strong restraining force from the ACL and hamstring muscles. Greater anterior shear forces on the ACL and tibia are known to occur when large differences occur in force production of the quadriceps over that of the hamstrings from differences in strength or activation of these muscles. (Courtney & Hensley 2015, 470.)

One study examined 20 years of knee injury assessments involving 1700 subjects (800 female) with ACL injury. It examined activity, mechanism and dynamic alignment at the time of injury. It found that female ACL injuries occurred more often during competitions (49.2% compared to 34% during practice), that most (69.7%) were non-contact incidents and that more than 50% of the injuries involved knee valgus (knee in, toe out) alignment regardless of type of incident (collision, accident, non-contact, contact). (Kobayashi et al. 2010, 671-672.)

### 3.4 Incidence and Consequences of Injury

Recent studies have demonstrated that young female athletes are significantly more likely than young males to suffer a severe non-contact ACL injury, with estimates ranging from two to six times greater risk depending on the sport and setting (Hewett, Ford, Hoogenboom & Myer 2010, 235). It is estimated that in the United States ACL injury has an incidence rate of 350,000 people annually seeking repair or rehabilitation. Data obtained from an International Olympic Committee and from European and Scandinavian countries reported an incidence of 38-40 ACL injuries per 100,000 people in the community over eighteen months. (Serpell, Scarvell, Ball & Smith. 2012, 3161.) ACL injuries reports are higher in high school than at the collegiate level. It is estimated that 1 in 60 to 100 high school female athletes in the US suffer from ACL injury every year. (Ladenhauf, Graziano & Marx 2013, 64.)

LaBella et al. (2014) noted that ACL injuries can result in many adverse consequences such as surgery and rehabilitation. Recovery may take long periods, typically seven to nine months, and may have overall long-term effects on the health of a person. The injury is associated with chronic knee pain, knee instability, long breaks from sports participation, loss or decreasing chance of a college sport scholarship and costly rehabilitation. As the rate of ACL injuries continues unabated, the health care costs associated with these injuries are also increasing. In the long term, individuals who have suffered an ACL injury may be at higher risk of early development of knee osteoarthritis (OA) 10-15 years after injury, they are more likely to suffer further injury due to knee instability and they generally have significantly limited levels of functional activity. (La-Bella et al. 2014, 1439.) Studies report that 50% of ACL patients will develop osteoarthritis regardless of the treatment received, either surgery or conservative treatment (Acevedo et al. 2014, 186).

## 4 RISK FACTORS

### 4.1 Anatomical & Biological

Most occurrences of knee ligament injuries in sportswomen are caused by noncontact mechanisms that include lateral pivoting, deceleration, or jump landing. Optimal stabilization of the knee joint requires proper muscular recruitment and activation timing coupled with sufficiently strong ligaments and tendons that traverse and surround the lower extremity. In addition, muscle activity helps to absorb ground reaction forces and their absence results in increased risk of ACL injury. Risk factors for anterior cruciate ligament injury are likely to be multifactorial. Factors associated with ACL injuries can be grouped as non-modifiable and modifiable factors. Non-modifiable factors include anatomical differences, gender, hormonal influences, and previous ACL injury. Modifiable factors- those that can be modified through training-include neuromuscular and biomechanical imbalances. (Acevedo et al. 2014, 187.)

The anatomical factors identified by researchers to influence the risk of women suffering ACL injury are the size of the ACL, the size and shape of the intercondylar notch and the geometry of the pelvis. Women tend to have a smaller anterior cruciate ligament and narrower intercondylar notch. Several case studies discussed by Smith et al. (2012) found that the width of the intercondylar notch in female athletes is smaller than in male athletes. (Smith et al. 2012a, 73.) Similarly, females have a wider pelvis than males, making a greater Q-Angle (Figure 5), where the femur angles inward (medially) more sharply from hip joint to knee joint. This orientation puts more pressure on the medial aspect of the knee making the ACL more likely to tear. Women's knees tend to align inwards when they land, and it is this vulnerable position that also predisposes them to ACL injuries. (Acevedo et al, 2014, 187; Smith et al. 2012a, 74-76.)

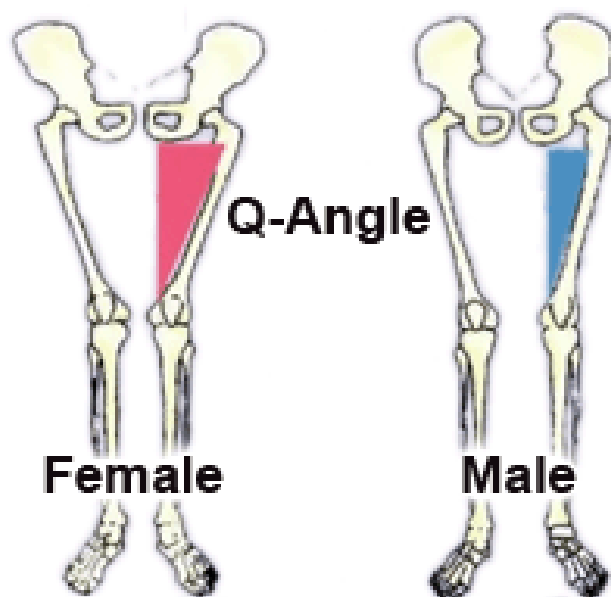


Figure 5 Differences between male and female Q-Angle.

(<http://www.proformsportschiropractic.com/piriformis-syndrome-part-ii-evaluation/>)

Investigations have hinted at the prevalence of higher generalized joint laxity and greater knee laxity in female adolescents than in their male counterparts. The generalized joint laxity patterns are the same for both males and females before puberty, and divergence occurs only during and after puberty. As males mature with time, joint flexibility and ligament laxity decrease. Conversely, these features increase in females. The changes also occur in the anterior-posterior (AP) knee laxity in addition to gender differences in post-puberty generalized joint laxity. Researchers have also reported increased joint laxity during menstrual cycle. (Hewett, Myer, Ford, Paterno & Quatman. 2012, 2932.) A number of studies show that movement stability of the knee is influenced by joint constraints that can either be passive or active. The passive restraints are due to ligaments while active restraints involve the neuromuscular control. It is evident that increased knee abduction motion and torque during dynamic landing tasks increase the risk of ACL injury if there is insufficient dynamic knee stability and neuromuscular control. (Serpell et al. 2012, 3162.)

Hormonal influences have been identified as a contributing factor in ACL injury, and there exists strong evidence that in post-pubertal athletes, the rates of ACL injury are gender-dependent. However, there is little evidence suggesting a similar case in pre-pubescent athletes. The risk of ACL injury after puberty is attributed to the changes

that occur in boys and girls after the onset of puberty. (Hewett, Myer, Ford, Paterno & Quatman. 2012, 2932.)

During this period, there is a surge in levels of hormonal concentrations accompanied by a rapid increase in height and mass. Girls develop smaller muscle mass compared to boys, which may contribute to poor body control during sport activities. Similarly, these hormonal changes accompanying puberty are responsible for the joint laxity differences in adolescent male and female athletes. The differences that occur during development might also be responsible for the gender gap in decreased dynamic knee stability and increased ACL injury rate that occurs after puberty. However, some changes like the laxity of the knee ligament are specific to a particular gender. (Shultz et al. 2015, 1081.)

It has been noted that the risk of ACL injuries in females increases during the pre-ovulatory phase of the menstrual cycle (Smith et al. 2012b, 156). It is thought that this increased risk is due to the fluctuation of female estrogen hormone levels that occur during menstruation and affects the strength and elasticity of the ACL (Shultz et al. 2010, 502). Some researchers suggest that it is the daily fluctuations in the hormone levels during the cycle that have an influence on the AP knee laxity. However, no conclusive evidence has been established to directly link an increase in ACL injury to a predictable time in the menstrual cycle. Thus, the alterations in joint laxity and increased ACL injury risk in female athletes might be attributed to growth and development as well as hormonal fluctuations after puberty. (Hewett et al. 2012, 2932-33; LaBella et al. 2014, 1441.)

#### 4.2 Previous Injury

History of a previous ACL injury has been found to be a risk factor in ACL injury in the same or contralateral leg. One case study shows that athletes who have suffered from an ACL injury in the past 12 months are 11.3 times more likely to re-tear an ACL graft or injure the other knee compared to previously uninjured athletes. (Smith et al. 2012, 158.) Young female athletes are four times more likely to suffer a second ACL injury, and six times more likely to tear ACL on the unaffected knee than men of the same age (LaBella et al. 2014, 1441).

### 4.3 Extrinsic

The extrinsic risk factors refer to environmental conditions associated with the sport activity including weather, playing surface, type of shoes, among other factors. These factors typically relate to the friction and mechanical connection between foot, shoe and playing surface. A high level of mechanical connection or friction with the ground causes greater torsional load transfer to the ankle and knee. Several studies have shown a greater incidence of ACL injury when playing on some surfaces (e.g. artificial grass, or on grass in dry weather) as well as when different types of sports shoe are worn. (Smith et al. 2012b, 159.)

The type of sport activity and genetics have been found to play a role in ACL injury. Studies have shown that competitive sports involving jumping, pivoting and cutting maneuvers are reported to have a higher incidence of ACL injuries amongst female athletes. Examples of such sports are basketball, soccer, volleyball, lacrosse and gymnastics. Furthermore, sports like soccer, basket-ball, and volleyball involve cutting, planting and changing direction and require a lot of engagement from the ACL, thus increasing the risk of ACL injury. (Acevedo et al. 2014, 188.) It is has also been shown that genetic factors may contribute to risks for ACL injuries. Hewett et al. showed an example of twin sisters who were screened, both presenting with similar anatomic, neuromuscular and biomechanics risk factors. This indicated a potential familial predisposition related to ACL injuries. (Hewett et al. 2012, 2933.)

### 4.4 Neuromuscular and Biomechanical

Neuromuscular and biomechanics risk factors are related to the mechanism of the non-contact ACL injury. These factors are related to neuromuscular deficits and can be identified in four dominances according to riskier movement patterns: ligament dominance, quadriceps dominance, leg dominance and trunk dominance. (Hewett et al. 2010, 235-236.)

Ligament dominance is one of the neuromuscular/biomechanical risk factors for ACL injuries in female athletes. Researchers have revealed that females demonstrate higher



valgus forces at the knee, caused by poor activation of gluteus muscles during dynamic movements. This pattern of movement primarily depends on ligaments to control joint motion and absorb the ground reaction forces. Because of poor muscles action, the knee tends to turn inward in a valgus position, which is one of the components in the mechanism of ACL injury in female athletes. (Hewett et al. 2010, 235-236.)

A common neuromuscular imbalance amongst female athletes is Quadriceps Dominance which involves the tendency to over-activate or over-use quadriceps muscles rather than hamstring muscles, typically demonstrated by limited knee flexion during jumping and landing activities. This is one of the faulty movement patterns in the ACL injury mechanism. In cases of quadriceps dominance there is an increase of quadriceps muscle activity which pulls the knee in near extension position, increasing the forward directed shear on the tibia and consequent stress on the ACL. (Hewett et al. 2010, 236.) Additionally, the female athletes have poor hamstring strength shown in greater quadriceps/hamstring strength ratio. This results in the hamstring not being able to balance the power of the quadriceps which can cause significant stress to the ACL, leading to injury. (LaBella et al. 2014, 1441.)

Studies also have shown that young female athletes tend to have a greater differences in muscular strength between right and left legs, compared to young male athletes. This asymmetry, known as Leg Dominance, can result in unequal weight distribution on the lower extremities during landing and may cause the body's center of mass to be shifted off its base of support putting additional loading vectors on the dominant knee and placing an athlete at greater risk of ACL injury. (Hewett et al. 2010, 236.)

Research has revealed that poor core and trunk stability, known as Trunk Dominance, can predict ACL injuries in female athletes but not in male athletes. It has been shown that women more often demonstrate excessive trunk displacement during sport activities. This deficit in trunk control can be related to difference in growth and maturation. After maturation, boys develop body mass and muscular strength in the "neuromuscular growth spurt". However, in their growth spurt, girls develop greater proportions of body mass as body fat and less proportion of muscular strength. Consequently, girls' neuromuscular control of their center of mass is disturbed, which shows as greater

shifts from the center of gravity during sports maneuvers, leading to poorer body control and balance. (Smith et al. 2012a, 69-72.)

Moreover, because the trunk positions laterally, it is predicted that it has a high potential for creating high valgus torques at the knee by both biomechanical and neuromuscular processes. As a result, authors identified several components of injury including increased lateral trunk motion when the body weight shifts over one leg, high knee abduction, low knee flexion, and the flatly fixed plantar surface of the foot on the playing surface and displaced away from the trunk. Another common component of ACL injury is unanticipated disturbance in trunk motion. (Hewett et al. 2010, 238.)

#### 4.5 What factors are modifiable?

There are two areas of ACL injury risk for young female athletes that can be considered modifiable. Firstly, some risk factors are modifiable through education and awareness of individuals, coaches, teachers or parents. These can include the factors of fatigue, BMI, footwear, playing surface, play technique (risky movements) and type of sport. (Hewett et al. 2010, 235-241.)

The second area of modifiable risk factors includes those that can be modified through a training intervention. These include high-risk movement patterns associated with neuromuscular deficits such as ligament dominance, quadriceps dominance, leg dominance and trunk dominance. These modifiable factors can be identified in screening and improved through neuromuscular (NM) training. (Hewett et al. 2010, 235-241.)

It is these training modifiable risk factors we will consider in our screening and intervention program. The next part of this thesis is an exploratory literature search examining evidence on how screening of these factors can be done in a community setting and what training interventions can be used for an ACL injury prevention program.

## 5 LITERATURE REVIEW

### 5.1 Methods and Aims

A two-stage exploratory literature search was made for current evidence related to testing, screening and interventions for modifiable risk factors of ACL injury in young female athletes. The purpose of this study is to find evidence related to screening tools and the prevention of ACL injury amongst young women in community sports settings.

Our aim is to produce an effective, low-cost, evidence-based field screening tool and intervention guide targeting young female athletes at risk of ACL injury. Such a tool would help a physiotherapist in a community setting to identify individuals with faulty movement patterns and design effective exercise intervention programs.

An online search was made using PubMed and Pedro databases and the Google Scholar search engine. The search parameters were for research articles published January 2011 through March 2016 in peer reviewed journals. The inclusion criteria were articles related to ACL injury risk, available free in full text electronic format in English. We excluded articles related to ACL reconstruction or rehabilitation, those dealing with contact injuries and studies of male-only subjects.

The first round of the search was made for high-level studies (systematic literature reviews and meta-analyses) examining field screening of ACL risk factors and training interventions for injury prevention. The following search terms were used; ACL, anterior cruciate ligament, injury, risk, screening and prevention. Based on these findings, a second stage search of research studies (reviews, clinical trials) was then made for more specific information on implementation of screening and interventions for ACL injury prevention.

## 5.2 Testing and Screening

Swart et al. (2014) carried out an economic analysis comparing three strategies for dealing with the risk of ACL injury for a hypothetical sports team. Long-term cost comparisons and cost sensitivities were made for: (a) no training or intervention (accepting injury and rehabilitation costs); (b) a universal training intervention (whole team gets generic neuromuscular training); and (c) screening and a targeted neuromuscular training intervention for high-risk individuals. Their findings were that a universal neuromuscular training program for all athletes in a group is more cost effective than screening unless the intervention costs are very high. They did note in their limitations of study that some of the costs were assumptions due to the lack of primary cost data for training and screening. (Swart et al. 2014, 710.)

Dallinga, Benjaminse & Lemmink (2012) carried out a systematic literature review from 1966 to 2011 of screening tools and clinical markers for predicting various lower limb injuries in sports. It was suggested that variation of anterior/posterior knee laxity, hyperextension of the knee and differences in knee abduction between legs may be useful markers for prediction of ACL injury. These clinical markers for risk are not specific to young female athletes but are generalizable for both male and female. (Dallinga, Benjaminse & Lemmink. 2012, 791-792.)

Another systematic review of publications 1990 to 2015 examined field based screening of ACL risk comparing the methods, effectiveness and applicability to community settings. Some 20 studies were found that identified five ACL specific screening methods with potential application to the field. These studies were not gender specific and covered a variety of sports. The review identified two screening tests as appropriate for field testing as they were low cost and easy to execute in a community setting. These were the Landing Error Scoring System (LESS) and the Tuck Jump Assessment (TJA). Both tests were able to identify multiple biomechanical risks during dynamic movements. (Fox, Bonacci, McLean, Spittle & Saunders 2015, 11-14.)

While the review recommended the LESS as the best across most criteria, it was noted that the LESS has been found to be a poor predictor of ACL injury for female athletes in high school and collegiate competition (Fox, Bonacci, McLean, Spittle & Saunders

2015, 14). This has been further confirmed by a more recent cohort study that concluded that the vertical drop jump (VDJ) test used in the LESS cannot predict ACL injury for young female soccer and handball athletes. For this reason the LESS and VDJ can be considered unsuitable for screening young female athletes. (Krosshaug, et.al. 2016.)

Closer examination of the 2015 systematic review revealed that their primary criticism of the Tuck Jump Assessment (TJA) was that some of the assessment criteria are not validated as specific risk factors. Specifically these are landing noise, legs in tuck not parallel, changing of landing position, unequal foot timing, and pause between jumps. (Fox, Bonacci, McLean, Spittle & Saunders 2015, 11-12.)

While this is correct, if we examine the assumptions of the TJA test, we see that these particular criteria are observations of secondary effects related to known risk factors. Landing noise can be an indicator of high ground reaction force and limited knee flexion on landing. Legs not parallel in tuck and unequal foot timing on landing can indicate extra high knee loading. Changing of landing position can indicate poor trunk stability (core control), extra high knee loading and high knee abduction moment (KAM). The pause between jumps can indicate poor trunk stability or deficits in hamstring muscle strength and control weakness. These factors, if observed as repeated events, give a clue to neuromuscular deficits that may not be seen in gross movements. (Myer, Ford & Hewett 2004, 360-362.)

The Tuck Jump Assessment has been used successfully to assess the effectiveness of training interventions on female athlete in a number of settings. One trial used the TJA in a comparison of a neuromuscular training (NMT) intervention to standard in-season training in two female soccer teams. (Klugman et.al. 2011, 839-831.) The TJA was used in a double-blind randomized control trial by Stroube et al. (2013) examining the use of augmented feedback (AF) to improve neuromuscular control in young female athletes. The test was used for assessment movement pattern defects of the control and intervention groups and as training tool providing video feedback on movement deficits for the intervention group during training. The TJA appears to be the most promising of the tests for field screening of young women for ACL injury risk. (Stroube et al. 2013, 7-18.)

An investigation of the interrater and intrarater reliability of the TJA was made in 2013. Five raters of different educational level in health science, assessed video footage of 40 test participants undertaking the TJA. The raters were given identical educational information and a brief training. The finding was poor reliability of score across the five raters. However, with repeated assessment sessions the interrater reliability improved, suggesting a learning effect. It appears that rater reliability is low without supervised experience rating the TJA, suggesting that untrained and inexperienced individuals are unsuitable to act as raters in the TJA test. (Dudley et al. 2013, 1-5.)

In their article Myer, Brent, Ford & Hewett (2011) describe the rationale of using the tuck jump assessment (TJA) to assess modifiable risk factors for non-contact ACL injury in young females. The focus of the TJA protocol is to observe jumping and landing movements patterns of test subjects and to identify evidence of four high-risk factors related to neuromuscular deficits. Ligament dominance refers to knee valgus in landing, which creates a high knee abduction moment (KAM). Leg dominance refers to a leg preference in landing, which causes a greater loading on the preferred leg, making injury more likely. Quadriceps dominance refers to a significantly higher quadriceps strength or activation than hamstring muscles, resulting in less flexion of the knee under dynamic loading. This causes poorer stability of the knee against anterior tibial translation. Trunk dominance refers to a deficit in core/trunk stability resulting in unpredictable loading bias from the trunk through the kinetic chain of the leg, making landing stability more difficult. Identifying high-risk individuals allows for neuromuscular training for these specific risk factors. The article has recommendations on the assessment criteria for each dominance dysfunction and a developed assessment tool. (Myer et al. 2011, 27-33.)

### 5.3 Interventions

In a meta-analysis of 11 studies, the researchers found that the neuromuscular training programs are effective in reducing ACL injury. They were found to be particularly valuable for female athletes aged between 14 and 18 years old, and they resulted in a reduction of 72% in ACL injury among the female adolescents. Therefore, it is recommended that the athletes should undertake neuro-muscular training programs that

would orient them to safer movement patterns that can reduce injury risk during athletic activities. (LaBella et al. 2014, 1445-1446.)

The TJA was used in a double-blind randomized control trial by Stroube et al. (2013) examining the use of augmented feedback (AF) to improve neuromuscular control in young female athletes. The subjects were 37 female high school soccer players. The TJA was used to assess the intervention and control groups before and after the 8-week trial period. Both groups were given identical strength, plyometrics and conditioning training. The intervention group received additional augmented feedback training using the TJA as a task specific exercise. Observed movement faults were video recorded and used as visual feedback on technique and for the basis of controlled feedback training to address the specific flaws of individuals. The feedback training involved executing the tuck jumps with verbal instructions and internal focus cues (“get your thighs parallel with the ground on landing”). The intervention group reduced movement deficits by 23% compared to the control group of 10.6% improvement. Task specific augmented feedback training plus generalize training (strength, plyometric and conditioning training) shows better improvement in faulty movement patterns from TJA than generalized training alone. (Stroube et al. 2013, 7-18.)

In 2012 Sugimoto and colleagues investigated the relationship between dosage, effectiveness of neuromuscular training compliance and ACL injury incidence rates. They reported that the higher the program compliance the lower the ACL injury incidence rates. Similarly, six neuromuscular prevention studies showed higher compliance rates and low ACL injury incidence rates in female athletes. They also reported that lack of proper supervision leads to poor motivation and low compliance rate. (Sugimoto et al. 2012, 718-722.)

A meta-analysis examined three main areas in dosage for the neuromuscular training (NMT). These are duration, frequency and volume of the training. Sugimoto et al. (2014) revealed that longer training duration is more effective than shorter duration. Shorter duration programs tend to have only a few number of exercises, which means less neuromuscular exercises included in the program; and they lead to unsuccessful results. Two clinical trials found that pre-season and in-season training are more effective in reduction of ACL injury risks. (Sugimoto et al. 2014, 558-559.)

It is recommend that a good program takes at least 6 to 12 weeks because it requires time for adaption of neuromuscular patterns to take place. In addition, it suggested that NMT sessions be at least 2 to 3 times a week times of 20 minutes each session and that high volume programs tend to work better than the low volume training. Researchers found that high volume NMT reduce ACL injuries by 68% compared to moderate volume by 44-54% and low volume by 24%. Generally, ACL injury prevention programs showed greater effectiveness with longer duration, higher frequency and high volume of training. (Sugimoto et al. 2014, 558-559.)

### 5.3.1 Prevention of ACL injuries

In a literature review Voskanian (2013) examined implementation of ACL injury prevention programs. Some of the studies have shown that ACL prevention programs need to incorporate a multifactorial approach to decrease the risk of ACL injuries in young women athletes. The repetition of faulty landing movements and poor neuromuscular adaptation increases stress in ACL. Appropriate muscular strength, recruitment and proper timing are crucial in knee stability. Programs should be started before the onset puberty to develop neuromuscular and biomechanics adaptation required to meet the demand of the specific sport activity. Effective programs have included proper education, neuromuscular training, muscle strengthening, and plyometric training. (Voskanian 2013, 161-163.)

### 5.3.2 Program information

Researchers reveal that prevention programs should start as early as late childhood and during onset of puberty. Programs should begin before season and continue during the season and the training sessions should be as short as 20 minutes to 30 minutes or longer for at least three times a week for six weeks prior to the season. Moreover, studies show that programs that continue throughout the seasons are more effective because athletes continue to perform with proper techniques. It is suggested that the



prevention programs should replace the traditional warm-up routine. (Acevedo et al. 2014, 188.)

In their systematic literature review, Benjaminse, Welling, Otten & Gokeler (2015) examined nine successful ACL injury prevention programs, comparing the training methods using internal focus (IF) to external focus (EF) on improving jump landing technique. IF refers to focusing on cues of subject's own body (e.g. bend your knees on landing), EF refers to focusing on cues outside the person (e.g. a cone marking distance, a landing noise or someone else demonstrating technique). (Benjaminse, Welling, Otten & Gokeler, 2015. 176-186.)

Their findings were that verbal instructions with an EF as visual feedback cue (e.g. subjects being told to focus on a cone marking distance) provided superior results compared to using IF (e.g. bend your knees) in the improvement of jump technique and other variables related ACL injury risk (e.g. ground reaction force). Also, the more distant the EF cue the better the motor learning and performance. It should be noted that one study successfully used combined EF and IF in their training. Subjects were told to minimize jump-landing noise (EF auditory cues) as feedback and were told to bend the knee when landing (IF cue). EF auditory cue (landing noise) also showed an improvement in landing technique. Recommendations were that ACL injury prevention programs aimed at improving technique should use simple verbal instructions to the trainee and to focus on external auditory or visual cues as feedback for correctly applied technique. (Benjaminse, Welling, Otten & Gokeler, 2014, 176-177.)

In a 2011 non-systematic review D.P. Bien examined ACL injury prevention programs that used a warm-up format. His finding was that the warm-up had advantages of improved compliance and completion as they were easier to integrate and maintain as part of existing sports training programs. The drawbacks included lack of equipment and resources for monitoring progress and improvement. (Bien 2011, 280-282.)

### 5.3.3 Strengthening training

ACL prevention program should incorporate strengthening training. Program design should focus on strengthening and recruitment of hamstrings, hip abductors, there-

fore, and gluteus strengthening to prevent knee valgus. In addition, studies emphasize core and trunk stability training. Addressing hamstring strengthening in ACL prevention programs is very important because hamstrings are the main prime mover of knee flexion and thus play a big part preventing the anterior tibial displacement at landing. Researchers have shown that women athletes tend to have an activation delay in recruiting and generating maximum hamstring torque. They activate more quadriceps than hamstrings as compared to male athlete counterparts playing the same sport. Moreover, a strengthening program should follow age-appropriate guidelines. (Acevedo et al. 2014, 189.)

#### 5.3.4 Plyometric training and sports agility

Plyometrics and sports agility training are very important in a prevention program. Exercises should be functional and should incorporate high intensity drills, emphasizing strength, power, speed and proper landing techniques and recruitment. The nature of plyometric and sport agility exercises is that they are fun yet challenging to athletes. They train the athlete for various demands needed during sport event, thus, increasing motivation and compliance with the program. (Ladenhauf et al. 2014, 68.)

Ladenhauf et al. (2013) reported that plyometric and agility training programs that included unanticipated movement changes, proper postural techniques and feedback showed significant improvement in medial hamstring activation and knee valgus during cutting activities. (Ladenhauf et al. 2014, 68.)

Several randomized controlled trials and cohort studies investigated the effectiveness of neuromuscular training programs on knee injuries in sports such as basketball, handball, soccer and volleyball. Athletes were divided into several groups: comprehensive type of program, plyometrics and balance together and either plyometrics or balance alone. In general the results were promising; however they have shown that single-component types of programs have not shown much success in prevention of ACL injuries in the female population. In particular balance training alone may not be enough for prevention of ACL injury. (LaBella 2014, 1445.)

In 2013, Ladenhauf et al. (2013) reviewed a number of established warm-up ACL prevention programs to determine the effectiveness in reducing knee injuries. Results revealed that the Prevent Injury, Enhance Performance (PEP) program was the best in preventing first time ACL injury and in preventing recurrence of previous ACL injury. Moreover, the “Harmoknee” program showed a noticeable knee injury risk reduction, and the Knee Injury Prevention Program (KLIPP) had some potential of reducing lower extremity injuries; however, the program failed to demonstrate any significant prevention against risks of ACL and other knee injuries. PEP is designed as a warm-up program, incorporating different types of exercises, such as stretching, strengthening, plyometrics and sport specific agilities. Athletes performed in every normal practice session and during competitive games. (Ladenhauf et al. 2013, 69-70.)

### 5.3.5 Education and feedback

Education information that includes injury awareness, mechanism, body awareness and feedback are the important aspects when it comes to effectiveness of any intervention programs or treatment. Education focusing on healthy and active lifestyle is recommended. Researchers have shown us that an ACL prevention program should include ongoing feedback about proper landing techniques and biomechanics. Feedback should be provided at the start, middle and the end of the training or practice. The use of visual aids during practicing (such as mirrors and video-taping) and verbal feedback are highly recommended to facilitate motor learning and improve proper performance during sport activities. (Sugimoto et al. 2014, 282.)

Athletes should receive proper basic training from the beginning regarding proper sport functional position or the athletic ready position, with flexed knees, hips and trunk in correct form. Emphasis should be on jumping and landing techniques and on verbal cues like “land softly and quietly like a feather,” and “land with your weight on the fore-foot”. Studies prove that if verbal feedback is repeated over and over during training, athletes will translate this knowledge to the competition field. (Acevedo et al. 2014, 188.) Studies have also shown that from a motor-learning point of view, if correct techniques are performed from an early age, the movement will become automatic and more natural (Benjaminse et al. 2010, 623).

### 5.3.6 Considerations for implementation

Program compliance enhancement is very important for the effectiveness of the program. In order for the program to be successful, athletes should perform the exercises efficiently and in a timely manner. Clinicians should design easy but challenging programs that require a minimum of equipment to decrease set-up time. The program itself should not take too much time to complete. (Voskanian 2013, 162-163.) Researchers suggest that the prevention program should be included in the warm-up routine during normal practice sessions. In addition, athletes should be supervised by qualified clinicians or personnel to assure that proper techniques are taught and implemented effectively. To increase motivation and compliance, the program should be designed not only to improve strength and neuromuscular adaptation but also provide enhancement to sports performance such as strength, power and speed applicable to the sport's activities in the field. (Shultz et al. 2012, 596-597.) Studies show that by doing this coaches and athletes are more motivated and will enhance compliance to the program (Voskanian 2013, 162-163; Noyes & Barber-Westin, 2012, 40-42).

Acevedo et al. (2014) reported in one meta-analysis that incorporation of neuromuscular training and education reduced ACL injury rates by approximately 50%. Intervention programs such as the Prevent Injury and Enhance Performance Program (PEP) and the Sportmetrics program of Cincinnati, Ohio, reported to be the best programs in preventing and reducing ACL injury in young female athletes. (Acevedo 2014, 188-189.) Furthermore, LaBella et al. (2014) recommended adoption of a program that combines exercises that strengthen the active muscles during an activity such as the gluteus and hamstring muscles during balancing. They also acknowledged that the balance training and repetitive jumping exercises should be able to build power and strength (plyometrics). Information about proper landing techniques focusing on hip and knee positions should be provided to allow girls to learn the safe and unsafe positions. (LaBella et al. 2014, 1445.)

## 6 RESULTS

### 6.1 Analysis of Results

From the literature review a risk screening tool (the tuck jump test) was identified as suitable for the rapid assessment of female sports groups. Information was gained on functional neuromuscular training methods that have been used successfully in ACL prevention programs. The neuromuscular training information was relevant to injury prevention for young sportswomen and much of it was suitable for use in a warm up session of sports training. The information obtained from the literature review was used to design a field-based screening tool and intervention guide for modifiable ACL risk factors.

As this was an exploratory search our analysis included only studies that provided relevant information for our project aims. Where a number of papers covered similar ground we examined the most recent and most extensive. Articles relevant to our topic area were divided into two subject groups: risk screening and interventions. The articles were initially examined for relevance and specificity to our study aims and then examined critically. Articles with no direct relevance to our aims were removed. In addition, where multiple articles had effectively the same information, only the more recent and more extensive article was kept.

In two areas our analysis led us to different conclusions from those of the studies in our review. Firstly, one study (Fox et al. 2015, 11-14) identified both the LESS and TJA as appropriate for testing in a community setting but recommended the LESS because the TJA used a number of criteria that are only indirectly related to ACL risk. Another study (Krosshaug et al. 2016) examining the VDJ (used in the LESS) found it to be a poor predictor of ACL injury for female athletes in high school and collegiate competition due to low sensitivity and specificity. Further the TJA has been used successfully in a number of screening and training interventions involving young female athletes (Myer et al. 2011, 21-23; Stroube et al. 2013, 7-13). For our purposes we will use a modified version of the TJA adapted from Myer et al. (2011) and Stroube et al. (2013) as our screening testing and assessment protocol.

The second study we disagreed with was Swart et al. (2014) in their economic comparison of ACL screening and targeted intervention versus universal training intervention for injury prevention. Their conclusion was that greater economic benefit was gained from implementing universal injury prevention training for elite female sport teams. Our criticism of this conclusion is that the fundamental assumption was that a training intervention would be accepted by the team and coaches without direct evidence of risk. This may be reasonable to assume for professional elite sports where risks are known and prevention programs have a cost rationale. However, for community sports groups, the primary function of screening may be to educate coaches, sports-persons and families to the individual risks of injury and provide the impetus for adoption of training interventions. Our assesment gives weight to our stated aim of providing a low-cost ACL risk screening assessment for identification of at-risk individuals followed by targeted NM training interventions.

## 6.2 Risk Screening

Low-cost screening programs for non-elite athletes in a community setting have the potential for better outcomes than universal injury prevention programs. Identification of at-risk individuals can be a vital first step in injury prevention and may provide the athlete, coaches and parents motivation for adopting a training intervention. Periodic re-screening can be used to monitor progression and motivate teams in compliance and continuation.

No single field screening method has emerged as being a universally accepted standard for assessing ACL risk amongst young female athletes. The Tuck Jump Assessment (TJA) is a promising screening method that has been used in a number of studies to identify neuromuscular risk factors young female athletes. The TJA test can clearly identify the significant high risk movement patterns of knee valgus, limited knee flexion, poor core control (trunk instability), and one-leg landing preference. The TJA is suitable for use by a physiotherapist as an assessor; however, sufficient practice with the assessment is need to develop better rater reliability.

The Tuck Jump Assessment would seem to be the most suitable for low-cost ACL risk screening of young females in a community setting. For our risk screening tool we

propose to design a simplified TJA adapted from the assessment protocols detailed in Myer et.al. (2011) and Stroube et al. (2013).

### 6.3 Interventions and Prevention

Recent reviews on evidence based ACL injury prevention programs reveal that programs must have multiple components as is the nature of ACL mechanism itself. Therefore, programs should target multiple areas and incorporate different types of therapeutic exercises, such as strengthening (especially hamstring and gluteus muscles), plyometrics, balance and agility training. In addition the program should be a part of a warm-up practice session to improve the likelihood of compliance.

A prevention program should be adapted to be age appropriate, and be started just before the onset of puberty to develop the neuromuscular and biomechanics adaptations required for the specific demands of the sport.

A good prevention program should provide education about ACL injury risk, body awareness, injury-mechanism, and healthy lifestyle. Phase one of the program should focus on motor learning by emphasizing proper jumping and landing techniques to facilitate safe movement patterns. Phase two should emphasize development of strength, conditioning and endurance. The third phase should focus on speed agility, power and sport specific skill transfer.

It is highly recommended that verbal feedback, visual aids and external focus as visual feedback cues be used to facilitate motor learning and improve proper performance during sport activities. Athletes should receive ongoing feedback during and after the training session.

Effectiveness of a neuromuscular program is determined by the training compliance rates: the higher the compliance, the lower the ACL injury incidence. Motivation of coaches and athletes directly affects rate of compliance. To increase motivation and compliance, the program should be designed not only to improve strength and neuromuscular adaptation but also to enhance sports performance.

The duration of the NMT program plays a role in the effectiveness of the program. Longer training programs (e.g., 6 to 12 weeks) showed greater reduction of ACL risk factors than shorter NM training programs (e.g., less than six weeks). Higher frequency and higher volume of training is suggested by the research. Our findings were that prevention programs should ideally start six weeks pre-season and continue throughout the competitive season. The programs should be at least six weeks in duration with training sessions of 20-30 minutes, two to three times a week.



## 7 ACL RISK SCREENING TOOL

### 7.1 Field Screening Tool

The proposed field-screening tool (FST) is an adaptation of the tuck jump assessment (TJA) detailed in Myer et al. (2011) and Stroube et al. (2013). The complete FST booklet (Appendix 1) contains a test procedure with assessment tools and a guide for the assessor. The results from the FST can be used with the Intervention Guide (Appendix 2) to assist in the design of an ACL injury prevention program.

The aim of the FST is to identify individuals at risk of ACL injury and detail what specific neuromuscular deficits can be improved with training. The FST is designed to screen female athletes 12 to 25 years old and is intended for use in a community or school sports setting.

The FST involves a tuck jump test and assessment to identify individuals with high risk movement patterns in jumping and landing. The tuck jump is a relatively demanding maneuver and through repeated jumps is likely to reveal any movement or control flaws. These risky movement patterns are known to contribute to ACL injury and are modifiable through exercise.

The FST results may be used as diagnostic information for designing an exercise program for injury prevention. Monitoring progression of individuals in an exercise program can be done by periodic retesting using the FST. The FST can also be used as a training aid to provide real-time video feedback on tuck jump and landing technique.

The individuals that should be excluded from the test include those with injury or severe pain (especially in ankle, knee or hip), illness, fatigue or those under the influence of drugs or alcohol. These conditions may result in injury during the test or will not produce useful results.

## 7.2 Test Administration

The test and assessment can be administered by a physiotherapist in a clinic or field setting. The tuck jump test is quick to administer and suitable for testing whole teams or groups in a short time. The jump zone is a 40cm x 40cm square is marked on the floor with tape. Two digital cameras are set up to record from frontal and sagittal plane. Floor surface should be even, firm and not slippery. Test subject should wear comfortable sports shoes, shorts and tee shirt. Test subjects should briefly warm up before the test.

An initial brief interview of the subject is conducted to obtain personal information, health status and contraindications for testing. The test subject is instructed in basic tuck jump technique (Figure 6) and given verbal cues for the jump: athletic starting position, jump high, bringing knees up, soft landing softly the on balls of the feet, bending knees, no pause between jumps, try to land in the marked jump zone. The subject then does 10 rapid tuck jumps while being video recorded.

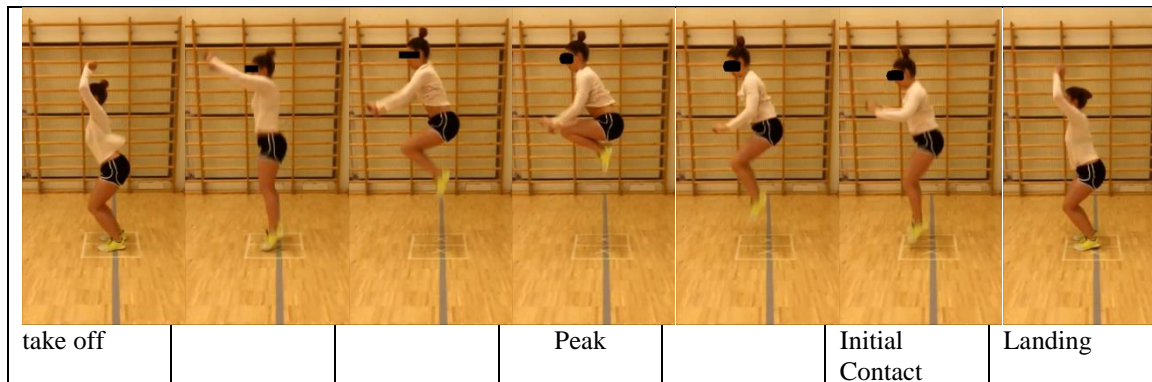


Figure 6 Example of the Tuck Jump

## 7.3 Assessment & Results

The test is assessed by examining video record and identifying instances of the 12 technique flaws at peak, initial contact and landing phases of all 10 jumps. Examples of specific flaws can be seen in Figure 7 below: (A) knee extension on landing; (B) foot contact not simultaneous in landing; (C) knee valgus, one leg; (D) knee valgus, two legs; (E) lateral trunk movement at peak; (F) knees not up high enough at peak; (G) too narrow foot placement; (H) not landing in target square; (I) limited change in

flexion; (J) Too wide foot placement; (K) Flat footed landing; (L) Feet not parallel front-to-back.



Figure 7. Examples of Specific Flaws

In the Screening Assessment Tool (Figure 8) a note is made of each instance of the 12 specific flaws. As can be seen in Figure 8 each flaw is related one of the four movement dysfunctions. A positive dysfunction is indicated when a specific flaw occurs three times or has one extreme occurrence. Individual still pictures taken from the video record can be attached to the assessment tool to illustrate specific flaws.

The results of the assessment are indications of the four potential dysfunctions: ligament dominance, trunk dominance, leg, dominance and quadriceps dominance. These represent component of neuromuscular control, proprioception and strength that con-

tribute to ACL injury. Where more than one dysfunction is indicated, their priority should be based on severity.

<b>Tuck-Jump-Test---Field-Screening-Assessment-Tool</b>			
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
A:Dysfunction is positively indicated when: a:Specific-Flaw occurs 3 or more times OR has 1 Extreme Occurrence within the 10-jump sequence.			
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
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<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>Assessment-Notes</b>			
<input type="checkbox"/>			
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>→</b>	<b>Ligament-Dominance-Dysfunction</b>	<b>Quadriceps-Dominance-Dysfunction</b>	
Knee-valgus-of-one-leg-at-landing	<input type="checkbox"/>	Knee-flexion<40°-at-initial-contact	<input type="checkbox"/>
Knee-valgus-both-legs-at-landing	<input type="checkbox"/>	Little-change-in-knee-flexion-at-landing	<input type="checkbox"/>
Foot-placement-too-narrow/wide-at-landing	<input type="checkbox"/>	Flat-footed/-excess-noise-on-landing	<input type="checkbox"/>
	<input type="checkbox"/>		<input type="checkbox"/>
<b>Leg-Dominance-Dysfunction</b>		<b>Trunk-Dominance-Dysfunction</b>	
Foot-contact-not-simultaneous	<input type="checkbox"/>	Excess-lateral-trunk-movement	<input type="checkbox"/>
Feet-not-landing-parallel-(front-to-back)	<input type="checkbox"/>	Pause-between-jumps	<input type="checkbox"/>
Thighs-not-equal-height-or-not-parallel-at-peak	<input type="checkbox"/>	Not-landing-in-same-footprint	<input type="checkbox"/>
	<input type="checkbox"/>		<input type="checkbox"/>

Figure 8. Screening assessment tool with the four dominance dysfunctions and their specific flaws. Adapted from Myer et al. (2011.)

Each dysfunction identified by the FST can be treated with a therapeutic exercise program. The Intervention Guide in Appendix 2 outlines a program of progressive neuromuscular exercises specifically designed to improve these movement dysfunctions and reduce the risk of ACL injury.

## 8 INTERVENTION GUIDE

The Intervention Guide is an evidence based neuromuscular (NM) training program designed to reduce the risk of ACL injury by targeting specific neuromuscular deficits identified by the Risk Screening Tool. These deficits shown in Table 1 are movement patterns related to ligament dominance, trunk dominance, leg dominance and quadriceps dominance.

Table 1 Training Intervention Goals

Neuromuscular Imbalance	Faulty movement	Intervention/Goals
Ligament dominance	Knee valgus (knee inward movement) during landing	Proper Jumping and landing techniques and improve dynamic knee control
Quadriceps dominance	Decreased knee flexion angle	Improvement of hamstring activation and increase knee flexion angle during landing
Leg dominance	Leg asymmetrical in landing	Improvement of side to side leg symmetry, strength and stability
Trunk dominance	Uncontrolled trunk motion	Strengthening: core, trunk stability and balance

The NM training program is designed to help young female athletes (age 12+) in a community sport setting. It is intended that the program is implemented and supervised by a physiotherapist.

The layout of the guide is designed to be user friendly, easy to follow for coaches, player or parents and providing sufficient information and instructions to be given as a home exercise program. A feature of this guide is that of itself it provides guidance on exercise dosing, progression and re-assessment/testing. The exercises themselves have three levels of difficulty for ongoing progression. Each stage can be modified to include a sports-specific action.

For optimal effectiveness, the program assumes exercises will take 20-30 minutes as part of a pre-sports practice warm up, carried out two to three times a week over 6-12 weeks. Ideally the program should begin in the pre-season and continue through competitive season. The program itself can be incorporated into a sports warm up and given as home exercises.

Functional training is important so that exercises are challenging, can mimic sports movement, meet the demands of the sports, and can provide enhancements to sports performance in addition to reducing injury risk. These factors are essential to maximize motivation for players, coaches and parents and to promote compliance with the program.

The program provides comprehensive information in booklet form for coaches, trainers and athletes. Details are given on precise exercise instructions and photos of the exercises are included, as is guidance on feedback and technique correction and monitoring progression.

The exercises in the Intervention Guide were selected for a number of reasons. They conformed to the NM training principles for therapeutic exercise and they are functional as they apply to the whole kinetic chain with natural movements. In addition, the exercises require little equipment set up and can be done indoors and outdoors. They have been adapted for progression and are easy to assess for correct techniques as they relate to ACL risk factors. The exercises are adjustable for training level and safety and can be altered to include sports-specific features. The exercises combine features of NMT plyometrics, balance, strength and agility and so act to increase athletic performance in addition to reducing risk of injury.

The functional exercises chosen for the guide not only target their specific movement dysfunction, but by acting on multi-joint stability they also positively affect other dysfunctions. For example the intervention exercises for Ligament Dominance aim to prevent knee valgus in dynamic movement by improving strength and control of the lateral-medial stability and internal rotation of the knee. Some of the exercises for this involve controlled movement and balance on a bosu-ball with knee in different ranges of flexion. This can also improve deficits in trunk control and quadriceps-hamstrings co-activation.

Some considerations should be made for integration into sports team training. The NMT in the intervention guide has been designed to be used as a 30-minute warm up in a sports session, 2-3 times a week for 6-12 weeks. This necessarily limits the inter-

vention target for each individual player to only one of the four dysfunction per season. From the screening assessment each individual has had their top priority movement dysfunction identified.

For the warm up, the sports team would need to be divided into four groups (Ligament Dominance, Quadriceps Dominance, Leg Dominance, and Trunk Dominance), based on individual player's top priority dysfunction. These four groups would train in parallel during the warm up.



## 9 CONCLUSION

The literature review provided information on the current evidence related to screening and intervention for ACL risk reduction in young women. The modified screening tool we have adopted uses video assessment of a tuck jump test to identify four high risk movement patterns. This can be used to as a diagnostic tool as well as a re-assessment tool to check effectiveness of a training intervention.

The intervention guide we developed details training interventions which target the four neuromuscular movement dysfunctions (ligament dominance, quadriceps dominance, leg dominance and trunk dominance) that are known to be high risk factors for non-contact ACL injury in young women. The interventions involve progressive functional neuromuscular training that is highly functional and suitable for use as a warm up session in sports training.

The outcome of this study is a practical, low cost and simple screening method and intervention guide developed for young female athletes in a community sports setting. The screening tool and intervention guide are designed to help physiotherapists identify individuals at risk of ACL injury and to assist in the development of an injury prevention program for a sports team.

## 10 DISCUSSION

Originally our aim was to review risk factors of ACL injury amongst female athletes; however, this changed when we discovered that this area was well researched by recent systematic literature reviews. Our focus changed to the design of a screening tool and intervention guide for modifiable ACL risk factors. This refocusing was more satisfying because we think we have provided a complete up-to-date evidence-based package for ACL injury prevention for female sports teams.

We feel that our aims in this study have been met. Our intent was to find a risk screening tool to simply and quickly assess community sports groups using commonly available digital cameras and to provide progressive functional intervention exercises which could be easily incorporated into the warm up for any female sports team. For this reason this tool and guide has the potential for widespread adoption and use in a wider community, not just in the clinical setting but also in schools and sports teams in Finland and abroad. This product could easily be marketed as an educational product for use by physical education teachers in schools and in healthcare organizations or other community groups to facilitate health promotion. If adopted for groups of females around 12 years of age, this has the potential to have a positive long-term impact on injury rates and quality of life.

We adopted the tuck jump test because it was the most challenging functional test that would identify movement deficits. It had a number of clinical trials where it had been used successfully and, while some of its components do not yet have strong validity due to limited number of trials, it appears to be the most promising test due to its simplicity, speed of administration and low equipment requirement.

As a paired project, our experience of working together was very positive despite time limitations preventing us from meeting up often due to class schedules and living in different cities. The process of doing this thesis improved our knowledge of ACL injury and the risks related to it. A surprising outcome of the process occurred when we were making photos for this thesis involving a number of our female classmates doing the tuck jump test. From the video we were able to identify a number of individuals at high risk of ACL injury. As a result, they have since undertaken their own training intervention based on our intervention guide.

Our study by necessity meant acceptance of a number of limitations. The male risk profile for knee injury is different from the female one and has not been considered. The screening test is specifically for young women who are relatively active and able bodied. The test requires subjects to perform multiple tuck jumps. This necessarily excludes individuals unable to tuck jump due to poor condition, high risk of injury, musculoskeletal pain or cognitive limitation.

A large number of known risk factors are not addressed by the test (e.g. narrow or stenotic lateral femoral notch). Factors that require special laboratory equipment are not considered because they are difficult to test in the field. Risks factors not treatable by exercise intervention have been excluded (e.g. hormone levels, fatigue, footwear and playing surface). Such factors are more appropriately addressed in an education package on minimizing and preventing knee injury.

The screening process is not entirely sports specific and addresses only the risk of non-contact ACL injury. Some sports have specific high-risk movements (e.g. basketball lay-up, or push off after kicking in soccer), while for others the most significant risk is from contact knee injury (e.g. rugby, American football, martial arts). Such sport-specific risk screening would require assessment of hours of video recording for each individual and so is outside the scope of this work.

There are a number of implications of this study. The simplicity and low-cost nature of the assessment and interventions should permit physiotherapists to more readily assess women's sports teams or school sports groups for ACL risk. This availability may lower the threshold for adoption of screening and intervention programs for ACL injury prevention by schools and community sports teams. If adopted and complied with such programs would not only reduce ACL injury but also the long term devastating effects of premature OA.

The functional progressive exercises selected for the intervention guide not only address ACL injury risk, they also improve aspects of athletic performance such as jump height, speed, power and agility. This should provide an additional incentive for adoption and compliance for both athletes and coaches.

This study opens up a number of opportunities for follow-up project work. Extensive field validation of the screening tool and inter-assessor validation would be needed to improve its reliability as a screening tool. Another interesting project could involve using the tuck jump test with real-time video feedback to rapidly improve skill development and motor learning. A larger scale assessment of a wider population using the FST could be done either as a longitudinal study into the incidence ACL injury amongst individuals with different NM deficits or as an assessment of the incidence of high risk movement patterns in the general population.

The intervention guide at present is designed as a general program with the possibility for some modification of exercises to be more sports specific. A future challenge would be development of whole programs specific to individual sports with exercises to improve NM control in specific tasks and maneuvers unique to that sport. For example separate intervention guides for gymnastics, soccer, basketball or volleyball would provide a better transfer of the improved movement skills to the athletes' particular sporting environment.

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FIELD SCREENING TOOL

INTERVENTION GUIDE