KNEE KINEMATICS DURING A SINGLE-LEG DROP-LANDING IN SPORTS PARTICIPANTS WITH CHRONIC GROIN PAIN.

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Declaration Page

I, the undersigned, hereby declare that the work contained in this thesis is my original work and that I have not previously submitted it, in its entirety or in part, at any university for a degree.

Signature: .... **Date:** .February 2014

Abstract

Introduction

Groin injuries are among the top six injuries in contact sports and may lead to career ending chronic pain. Research on the role of knee kinematics in developing chronic groin pain in sport is scarce.

Objective

The purpose of this study was to determine if there are differences in knee kinematics during a single-leg drop-landing in sports participants with chronic groin pain compared to asymptomatic controls.

Methodology

A descriptive study was conducted. Twenty active sports' participants were recruited from soccer and rugby clubs situated around the Cape Peninsula area, Western Cape, South Africa. The three-dimensional (3D) knee kinematics of ten cases with chronic groin pain and ten asymptomatic controls was analysed. Knee kinematics was analysed in the FNB-3D Vicon Laboratory at Stellenbosch University, using an eight camera Vicon system. A positive adductor squeeze test was used as a diagnostic test to include cases with chronic groin pain. Each participant performed six single-leg drop landings. The main outcome measure was 3D knee kinematics at initial foot contact and at the lowest vertical position of the drop landing. The following sub-groups were analysed: seven unilateral groin pain cases compared to their seven matched controls; three bilateral groin pain cases where their most painful leg and least painful leg were compared to their matched controls, respectively.

Descriptive statistical techniques were used for all outcome measures; means and standard deviations (SD) were calculated, followed by a Student's *t-test* to determine significant differences between the cases and controls. For all outcomes with p-values equal to or below 0.05, the effect size was calculated using the Cohen's D.

Results

The findings of this study indicated a significant difference ($p=0.0001$) between cases with unilateral groin pain having less knee internal rotation compared to the controls at the lowest vertical position of the drop landing in the transverse plane. Significantly less internal rotation ($p<0.0001$), was also noted in the cases with bilateral groin pain (in the most painful leg and the less painful leg), although this was noted at foot contact. Cases with bilateral groin pain also had significantly ($p<0.001$) more knee varus (adduction) during the landing phase.

Conclusion

Differences in knee kinematics between sports participants with chronic groin pain and asymptomatic controls were found. These findings imply that the knee joint should be included during assessment and rehabilitation of individuals suffering with chronic groin pain. Due to the cross-sectional study design of the current study, it cannot be stated for certain whether the knee kinematics noted in the groin pain group are causative or as a result of groin pain. Future prospective studies are thus recommended; these studies should focus on the effect of contralateral knee kinematics on the hip adductors and may include exploration of the muscular components during a single-leg drop landing.

Keywords: *Chronic groin pain*, *motion analysis, knee kinematics, lower extremity biomechanics*

Opsomming

Inleiding

Lies beserings is een van die top ses beserings in kontak sport en kan lei tot chroniese lies pyn en selfs die be-eindigging van ‘n sportloopbaan. Navorsing oor die rol van knie kinematika in die ontwikkeling van chroniese liesbeserings in sport is skaars.

Doelwit

Die doel van hierdie studie was om te bepaal of daar verskille in die knie kinematika is tydens 'n enkel been val landing in sport deelnemers met chroniese lies pyn in vergelyking met gesonde kontroles.

Metode

'n Beskrywende studie was uitgevoer. Twintig aktiewe sport deelnemers is gewerf van rugby en sokker sportklubs geleë rondom die Kaapse Skiereiland, Wes-Kaap, Suid-Afrika. Die 3D knie kinematika van tien gevalle met chroniese lies pyn en tien asimptomatiese bypassende kontroles is ontleed. Knie kinematika was ontleed in die FNB-3D Vicon Laboratorium by die Universiteit van Stellenbosch, met behulp van 'n agt-kamera Vicon stelsel. 'n Positiewe Adduktor druk toets was gebruik as 'n diagnostiese toets om gevalle met chroniese lies pyn in te sluit. Om die knie kinematika te analiseer, het elke deelnemer ses enkel been val landings uitgevoer . Die belangrikste uitkomsmeting was 3D knie kinematika by die aanvanklike voet kontak en by die laagste vertikale posisie van die enkel-been val landing. Die volgende sub-groepe was ontleed: sewe unilaterale lies pyn gevalle in vergelyking met hul sewe bypassende kontroles; drie bilaterale lies pyn gevalle waar hul mees

pynlike been, sowel as minder pynlike been onderskeidelik vergelyk was met hul bypassende kontroles. Beskrywende statistiese tegnieke was gebruik vir alle uitkoms maatreëls; gemiddeldes en standaardafwykings (SA) was bereken, gevolg deur 'n Studente's *t-toets* om beduidende verskille tussen die gevalle en kontroles te bepaal. Vir al die uitkomste met p-waardes gelyk of onder 0.05, is die effekgrootte bereken deur die Cohen's D.

Resultate

Die bevindings van hierdie studie dui op 'n beduidende verskil ($p=0,0001$) tussen gevalle met unilaterale lies pyn met minder interne knie rotasie in vergelyking met die kontroles by die laagste vertikale posisie van die val landing in die dwars vlak. Aansienlik minder interne rotasie ($p<0,0001$), is ook opgemerk in gevalle met bilaterale lies pyn (in die mees pynlike been en die minder pynlik been), alhoewel tydens voet kontak. Gevalle met bilaterale lies pyn het ook betekenisvol ($p <0.001$) meer knie varus (adduksie) tydens die landingsfase gehad.

Gevolgtrekking

Verskille bestaan in die knie kinematika tussen sport deelnemers met chroniese liesbesering pyn en gesonde kontroles. Hierdie bevindinge impliseer dat die knie behoort ingesluit te word tydens die assessering en rehabilitasie van individue met chroniese lies pyn. As gevolg van die deursnee-studie ontwerp van hierdie studie, kan dit nie bevestig word of die knie kinematika die oorsaak van die chroniese pyn is nie. Toekomstige voornemende studies word dus aanbeveel, hierdie studies moet fokus op die effek van die kinematika van die kontralaterale knie op die heup adduktore en kan moontlik die ondersoek van die spier kinetika tydens hierdie aktiwiteit insluit.

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List of abbreviations

PFPS	Patellofemoral pain syndrome
PFJ	Patellofemoral Joint
ACL	Anterior cruciate ligament
OA	Osteoarthritis
PIG	Plug-in-Gait model
ROM	Range of motion
SD	Standard Deviation
3D	Three dimensional
EMG	Electromyography
ICC	Interclass correlation coefficient
FC	Foot contact
LVP	Lowest vertical point

List of definitions

Biomechanics	The science concerned with the internal and external forces acting on the human body and the effects produced by these forces (Pietro, 2006).
Kinetics	Examines the forces causing a movement (Pietro, 2006).
Kinematics	Spatial and temporal components of motion (position, velocity, acceleration) with no consideration of the forces causing the motion (Pietro, 2006).
Knee varus/adduction	The tibia is angled inward in relation to the femur, resulting in adduction of the knee (Kamath et al, 2010).
Knee valgus/abduction	The tibia is angled outward in relation to the femur, resulting in abduction of the knee (Kamath et al, 2010).
Ipsilateral	Situated on or affecting the same side, as pain (www.medterms.com).
Contralateral	Taking place or originating in a corresponding part on the opposite side as pain(www.medterms.com).

Chapter 1: Introduction

Groin injuries accounts for 10%-18% of injuries in contact sports and are among the top six most cited injuries in the sports of ice hockey and soccer (Maffery & Emery 2007). Groin injuries often become a chronic problem and may lead to the ending of a promising sports career (Morelli & Weaver, 2005). According to Cross (2010), groin pain in the athlete refers to discomfort noted around the area of the lower abdomen anteriorly, the inguinal regions, the area of the adductors and perineum and the upper anterior thigh and hip. Chronic groin pain is usually observed unilaterally, but can be bilateral; it usually has a atraumatic aetiology and develops progressively over time (McSweeney & Nagarhi, 2012; Morelli & Weaver, 2005). This usually occur through repetitive strain of the hip adductor muscle due to repetitive fast change in direction which increase demands on the hip adductors (Zuzana et al, 2009; Morelli & Weaver, 2005). Chronic groin pain can be as result of a wide variety of pathologies, with different conditions having overlapping symptoms (Hackney, 2012). Often individuals have coexisting groin pathologies which result in the diagnosis of groin pain being very challenging (Hackney, 2012; Cross, 2010; Morelli & Weaver, 2005; Maffey & Emery, 2007; Holmich, 2007). According to Morelli and Weaver (2005) 62% of groin injuries are as result of adductor strains.

Musculoskeletal groin pain could result from acute traumatic mechanisms or by repetitive strain type injuries which often lead to chronic conditions aggravated by sporting activity (Zuzana, Kumar & Perraton, 2009). Fast changes in direction and landing strategies increase biomechanical demands, which has been identified as major risk factors for injuries to the lower limb (Lawrence et al, 2008; Morelli & Weaver, 2005). This is probably why groin pain may be more prevalent in sports such as soccer, hockey and rugby as these sports often require quick changes in direction (Morelli & Weaver, 2005) and frequent jumping and landing (Delahunt & Prendiville, 2012).

The adductor muscle group plays an important role in stabilization of the pelvis and hip joint in closed chain motions (Tyler, Nicholas & Campbell, 2001; Quinn, 2010). These muscles are exposed to injury through muscle imbalance, fatigue or overload. Maffey and Emery, in their 2007 systematic review, suggest that a large percentage of groin pain may actually be due to inadequate absorption of ground reaction forces through eccentric attenuation of the knee muscles during the landing phase. This may lead to strain on the adductor muscles, and subsequently a groin injury due to the inability to maintain the centre of gravity within a small base of support during single-leg landing.

Morelli and Weaver (2005) and Maffey and Emery (2007) proposed that the biomechanics of the lower limb may be causative factors of chronic groin pain. Abnormalities such as knee pathologies, leg length discrepancy, over pronation of the feet and muscular imbalances at the hip joint were identified as important factors to be considered (Morelli & Weaver, 2005). Unfortunately these biomechanical factors have not been studied in individuals with chronic groin injuries. Gottschall and Kram, (2005) in their analysis of running, found the knee absorbed increased ground reaction forces through knee adduction (varus), resulting in large loads on the hip adductors, which could lead to injury of the adductors. The above biomechanical factors indicate that knee biomechanics should be considered in groin pain management to provide holistic and effective therapeutic interventions.

Several studies have focussed on the biomechanics of the knee and hip in knee pathologies and have confirmed the link between knee and hip mechanics. For example hip abductor weakness in patellofemoral pain syndrome (PFPS) and knee osteoarthritis (OA) (Ferber, Kendall & Farr, 2011; Dierks, Manal, Hamill & Davis, 2008; Wilson & Davis, 2008; Cichanowski, Schmitt, Johnson & Niemuth, 2007; Robinson & Nee, 2007; Ireland, Wilson, Ballantyne & Davis, 2003; Mascal, Landel & Powers, 2003). Abductor weakness is associated with altered mechanics; increased hip adduction, hip internal rotation or contralateral pelvic drop during running activities (Noehren, Pohl, Sanchez, Cunningham & Latterman, 2012; Crossley et al, 2011; Souza & Powers 2009; Willson & Davis, 2008). Hip joint imbalances noted in PFPS may be similar in people with groin injuries (Moreli & Weaver, 2005). Poor knee biomechanics which is not addressed may also contribute towards the persistent nature of groin pain. It is thus important to evaluate the entire lower kinematic chain when assessing an individual with groin pain.

During drop-landing, participants with weak hip external rotators revealed 146% increase in ground reaction force, knee valgus/abduction and knee flexor moments (Lawrence, Kernozek, Miller, Torry & Reutemanl, 2008). According to Kipp, McLean and Palmieri-Smith (2011) the hip flexion moment and hip flexion control during a single-leg drop landing and side-step cut manoeuvre, influences knee rotations and valgus/varus moments. The authors concluded that gradual hip flexion and greater overall hip flexion range of motion (ROM) during the landing process; will decrease knee valgus/abduction and internal rotation moments during landing and thereby possibly reduce injury to the groin muscles (Kipp et al, 2011).

There is poor understanding of the association between groin pain and lower limb biomechanical risk factors. The knee biomechanics could potentially be associated with groin pain, since the lower limb acts as a single kinematic chain. To date, no biomechanical studies have been conducted exploring the biomechanics of the lower limb in individuals with chronic groin pain. Therefore, the purpose of this study was to explore and describe the three-dimensional kinetics/kinematics of the knee in active rugby, hockey and/or soccer players with chronic groin pain compared with asymptomatic controls.

Chapter 2: Literature Review

2.1 Introduction

The aim of this literature review was to provide an overview of the biomechanical factors associated with knee dysfunction, with a specific focus on how these relate to the hip and groin. To our knowledge, there are no published studies into the biomechanics of the lower limb in individuals with chronic groin pain to inform clinical practice.

The following Stellenbosch University electronic databases were searched: *Pubmed, Science Direct, Cinahl, PEDro and Cochrane. Keywords used in different combinations included 'groin pain', 'chronic groin pain', 'anatomy', 'sports injuries', 'gait cycle', 'diagnosis', 'single leg drop landing', 'knee mechanics', 'knee biomechanics', 'muscle imbalances', 'adductor strains', 'lower extremity kinematics', 'three-dimensional motion analysis', 'lower limb biomechanics', 'functional activities' and 'sport participants'.* The literature search was conducted between May 2012 and September 2013. Studies deemed relevant to the topics covered in this literature review were retrieved and included.

2.2 Groin injury prevalence and definition

Groin injuries accounts for 10%-18% of injuries in contact sports and are among the top six most cited injuries in the sports of ice hockey and soccer (Maffery & Emery, 2007; Morelli & Weaver, 2005). Chronic groin pain may lead to functional limitations and has the potential to lead to the ending of a promising sports career (Morelli & Weaver, 2005). According to Cross (2010), groin pain refers to discomfort in the area of the lower abdomen anteriorly, the inguinal regions, the adductors origin area, perineum and the upper anterior thigh and hip. The pathologies responsible for groin pain is varied and may include: Osteitis Pubis, Sports Hernia, Snapping Hip Syndrome, Osteoarthritis (OA) of the Hip joint, Acetabular Labral tears, Femoral-Acetabular impingement, muscular injuries, stress fractures (of the pubis, sacroiliac and femoral) and avulsion injuries (Cross, 2010). Groin pain may also be referred from the disc, lumbar facet joints or lumbar nerve roots (Hackney, 2012; Cross, 2010).

2.3 Differential Diagnosis of Groin Pain

Much controversy exists in defining groin pain due to the difficulty of diagnosis. This is mainly due to the fact that 27% to 90% of patients presenting with groin pain have more than one coexisting groin pathology (Morelli & Weaver, 2005; Maffey & Emery, 2007; Holmich, 2007). The coexistence of multiple pathologies can complicate the subjective and objective assessment of patients with groin pain. Groin pain may also be difficult to assess due to the pain being widely spread with unclear referral patterns (Hackney, 2012). Due to the above mentioned complexities, it has been advised that groin disorders should be managed holistically by a team of different health care providers, which may include the general surgeon; urologist; gynaecologist; obstetrics' surgeon; orthopaedic surgeon, physiotherapist, coaches and biokinetikist (Hackney, 2012). Holistic management will assist in confirming differential diagnosis and appropriate management.

Morelli and Weaver's (2005) found that 62% of groin injuries were identified as adductor strains, but they also highlighted the importance of excluding other pathologies, such as those listed above.

2.3.1 Musculoskeletal groin pain: the hip adductor muscles

There are 22 muscles acting on the hip joint that provide stability and movement (Byrne et al, 2010). Of these, six are adductors of the hip, namely the adductor longus, adductor magnus and adductor brevis, gracillis, obturator externus and pectinius muscles. According to Tyler et al (2001) and Quinn (2010) the primary function of the adductor muscle group is adduction of the hip in open chain motions, such as the swing phase during walking and running, as well as stabilization of the pelvis and hip joint in closed chain motion such the stance phase. During closed chain activities such as the stance phase in walking and the landing phase during jumping; knee varus/adduction assist in absorption of ground reaction forces. This leads to an increase in the load placed on the hip adductors (Lawrence et al, 2008). The adductors are vital in stabilization of the lower limb during activity and any impairment may predispose an individual to pain or injury (Maffrey & Emery 2007).

The hip adductors are vulnerable to injury through muscle imbalances, fatigue or overload (Zuzana et al, 2009). Adductor strains could result from acute traumatic mechanisms or repetitive strain type injury which leads to a more chronic condition (Zuzana et al, 2009). Hackney (2012) stated that forced abduction of the hip was the most common cause of adductor strain, occurring most frequently at the musculo-tendinous junction. However according to Morelli and Weaver (2005) the majority of chronic groin pain cases have an atraumatic aetiology which develops progressively over time. For instance during repetitive fast changing in direction, large biomechanical demands are placed on the adductors (Morelli & Weaver, 2005). This places sports participants such as soccer and rugby players where quick direction changes are required, at larger risk for such injuries. Maffey and Emery, in their 2007 systematic review, suggest that a large percentage of groin pain may actually be due to the inability to properly load transfer from the legs and torso to the pelvis. The adductor muscle group may thus play a crucial role in this load transfer from the lower limb to the pelvis.

Since adductor muscles strains accounts for the majority of groin injuries, the assessment and management of these muscles is thus very important in the diagnosis and rehabilitation of groin pain (Lovell et al, 2012; Fulcher et al, 2010; Wollin & Lovell, 2006). The adductor squeeze test (Appendix B) is a valid and reliable test procedure that is used to assess the hip adductor muscles as a source of groin pain and adductor endurance. The test is most reliable when performed in 45 degrees of hip flexion, where the muscles are at their biggest mechanical advantage and the most force can be produced in this position (Lovell et al, 2012). The 45 degrees hip angle is also the ideal position for initiating strengthening and rehabilitation of the adductors, (Lovell et al, 2012; Delahunt et al, 2011). The adductor squeeze test has an excellent intra-class coefficient (ICC) of 0.92 for intra-rater reliability measured with a sphygmomanometer (Delahunt et al, 2011)

2.4 Lower extremity mechanics related to Groin Pain

The biomechanics of the lower limb is an important factor to consider when dealing with individuals suffering from chronic groin pain (Morelli & Weaver, 2005; Maffey & Emery, 2007). More specifically, biomechanical abnormalities such as over pronation of the feet, increased ground reaction forces and knee adduction, altered load transfer and muscular imbalances at the hip joint are important biomechanical factors to consider during groin pain evaluation (Morelli & Weaver, 2005).

Altered foot biomechanics result in adapted knee and hip biomechanics (Nicola & Jewison, 2012). For example, during running, hyper-pronation of the fixated foot on the ground leads to increased tibial internal rotation at the knee joint and corresponding femoral internal rotation at the hip joint (Crossley et al, 2012; Gottschall & Kram, 2005). Increased femoral internal rotation is accompanied by hip adduction; which places increased loads on the hip adductors and may lead to overuse injuries (Noehren et al, 2012; Crossley et al, 2012; Gottschall & Kram, 2005). The relationship between foot, knee and hip biomechanics is thus highlighted.

Higher functional demands, such as during professional sport participation demands increased ground reaction forces. Confirming this notion, Gottschall and Kram (2005) found that as the ground reaction force increased during running, increased adduction (varus) occurred at the knee, placing larger loads on the hip adductors. This mechanism probably occurs to absorb the increased ground reaction forces. However, if the hip adductors are not able to handle these large loads from the knee, injury might ensue (Gottschall & Kram, 2005).

Similarly, appropriate load transfer is also important during the gait cycle. Load transfer in mid-stance is vital and is usually the moment in the gait cycle where the risk for injury is greatest (Quinn 2010; Nicola & Jewison, 2012). Mid-stance demands a co-contraction of the abductors and adductors for pelvis stabilisation to transfer weight from the one leg to the other (Nicola & Jewison, 2012; Tyler et al, 2001). Muscle imbalances between the hip abductors and adductors can thus hamper efficient load transfer during gait and may lead to injuries (Quinn 2010; Nicola & Jewison, 2012; Tyler et al, 2001; Maffey & Emery 2007). Weakness of the abductors is associated with increased knee adduction, increased hip adduction and internal rotation during gait; which increases loads on the hip adductors (Noehren et al, 2012; Crossley et al, 2012; Souza & Powers, 2009; Willson & Davis, 2008). This repetitive strain on the adductors can result in chronic groin pain.

From the above discussion, it becomes clear that the relationship between the hip and the knee, through the adductor muscles, is an important consideration for groin pain. These biomechanical risk factors mentioned above have not yet been studied thoroughly in individuals with chronic groin pain injuries. It is thus important to investigate these biomechanical factors through appropriate movement analysis methods to understand their role in groin injuries, to be able to enhance the effectiveness of therapeutic interventions.

2.5 Knee Kinematics and Kinetics

2.5.1 Method for 3D analysis of Knee kinetics and kinematics

In recent years three-dimensional (3D) motion analysis has become a popular method of investigation and resulted in the availability of high quality biomechanical studies. Camera-based motion analysis systems are viewed as the gold standard for biomechanical analysis of the lower limb. Five previous studies during the past five years, has been conducted to ascertain the test-re-test, repeatability, between days, inter and intra-observer reliability and validity of 3D knee kinematics in all three planes during multiple functional activities (Nakagawa et al, 2013; Whatman, Hume & Hing, 2013; Desloovere et al, 2010; Webster et al, 2010; Labbe et al, 2008). These studies focused on the reliability of knee adduction/abduction (valgus/varus) and internal/external rotation; since the measurement in these planes are thought to be unreliable due to the small ranges available in these planes and measurement errors due to skin movement as a result of the placement of the retro-reflective markers on the skin (Nakagawa et al, 2013; Desloovere et al, 2010). All of these studies supported the fact that the ICC was high for all three planes of knee kinematics and had good test-re-test, inter- and intra-observer reliability and validity (Nakagawa et al, 2013; Whatman et al, 2013; Desloovere et al, 2010; Webster et al, 2010; Labbe et al, 2008).

Whatman *et al.* (2013) assessed the kinematics in three planes in 23 asymptomatic sport participants during three functional tests. The authors found the within-day reliability was excellent, with the ICC≥0.85 and the between-day reliability was excellent too good with the ICC ranging from 0.60-0.92. Webster *et al.* (2010) assessed the reliability of tibial rotation measurements in 11 asymptomatic subjects (male and female) during stair decent and pivoting tasks, within-day reliability was found to be excellent with an ICC=0.83 and for between-day reliability the ICC was 0.76. Desloovere *et al.* (2010) assessed the repeatability of knee rotations in three planes during 11 different functional tasks (viz. walking, walking with a side step, crossover turns, ascent onto and descent off a step, descent with sidestep and crossover turns, chair rise, mild and deep squats, lunges) in ten young asymptomatic individuals. Moderate to high repeatability was found with lunges and squats having smaller repeatability. This could have been due to the very little instruction that was given on performing the functional tasks; which possibly increased the repeatability (Desloovere et al, 2010). All of the above mentioned studies have relatively small sample sizes. The above mentioned data provides enough evidence to ensure confidence in 3D motion analyses of the knee and that conclusions made in this study are applicable.

2.5.2 3-D biomechanical analysis of the knee during functional tasks

Functional tasks that are often used in biomechanics studies on sports participants includes the following: drop jumps, single- or double-leg squatting, lunges, single-leg drop-landing or running (Whatman et al, 2013; Desloovere et al, 2010; Webster et al, 2010).

Landing strategies has been identified as major contributing factors to risk for lower limb injuries (Lawrence et al, 2008). Single-leg drop-landing is often used in studies to investigate biomechanical risk factors in sports participants. The reasons for this is that asymmetries often occur between legs when bilateral landings are used and often lower limb injuries in landing occur during single-leg landing activities (Lawrence et al, 2008).

2.5.3 Knee biomechanics during drop landing

The biomechanics of the knee during a drop-landing activity has been studied intensively by multiple researchers. These studies focused on the normal biomechanics in asymptomatic individuals; gender differences and possible biomechanical risk factors during landing strategies contributing to lower limb injuries (i.e. anterior cruciate ligament (ACL) strains and knee joint OA (Ida et al, 2013; Lawrence et al, 2008; Nagano et al, 2007).

The landing phase of the drop-landing activity is divided into: initial contact/foot contact, the lowest vertical position and point of stability (Ida et al, 2013). The normal kinematics observed during a drop-landing are as follows: at foot contact the knee was in slight flexion, external tibial rotation and varus angulation (Lawrence et al, 2008; Nagano et al, 2007). Following foot contact, the knee flexion and internal tibial rotation increased with time towards the peak ground reaction force. Furthermore, following foot contact, the knee varus angle also increased with time until the maximum varus angle was reached and there after the knee valgus progressively increased with time (Ida et al, 2013; Lawrence et al, 2008; Nagano et al, 2007).

The kinetics during a drop-landing activity revealed a greater knee adduction moment when decreased hip external rotator muscle strength was observed (Lawrence et al, 2008). It has been suggested that knee load-bearing capability is decreased with hip abductor and external rotator muscle weakness. This may result in higher ground reaction forces per unit body mass in the sagittal and frontal planes of the knee (Zazulak et al, 2005). This was confirmed by Lawrence *et al.* (2008) where individuals with weak hip abductor and external rotator muscle activation demonstrated 146% more ground reaction force.

2.5.4 The influence of gender during drop landing

Controversy exists regarding gender differences during drop-landing activities. Some researchers concluded that females land in less knee flexion compared to males, some other researchers reported females landing in more flexion, while others found no differences in knee flexion (Nagano et al, 2007; Ford et al, 2005; McLean et al, 2004; Fagenbaum & Darling, 2003; Huston et al, 2001; Malinzak et al, 2001). These differences in research findings may be explained by instructions to perform tasks, differences in functional levels and the age of the participants.

Various gender-related studies demonstrated that females revealed significantly more knee adduction/varus moments, greater knee valgus, hip internal rotation, and hip adduction during landing and other athletic tasks in asymptomatic individuals (Hewett et al., 2005; Kernozek et al., 2005; McLean, 2004; Ferber et al, 2003).

However, kinematic differences observed between males and females were not significant at foot contact ((Ida et al, 2013; Lawrence et al, 2008). Although when observing the entire landing task during drop-landing, internal tibial rotation of the females was significantly larger than that of the males (Ida et al, 2013; Nagano et al, 2007). No differences in gender were observed for knee flexion, varus, valgus and anterior tibial translation (Ida et al, 2013; Lawrence et al, 2008; Nagano et al, 2007).

Kinetic differences observed between males and females during a drop-landing task were also contradicting between studies. Nagano *et al.* (2007) found that following foot contact, males reached the maximum vertical ground reaction force significantly faster than females. Whereas Ida *et al.* (2013) found no significant difference between males and females in regards to the peak value or peak time for maximum ground reaction forces.

Other kinetic differences observed between genders were electromyographic (EMG) activity where females revealed greater quadriceps muscle activation and lower hamstring/quadriceps ratio before foot contact than males (Nagano et al, 2007). The co-contraction of the hamstring and quadriceps muscle groups provide knee joint stability during landing activities, while quadriceps contraction alone can cause anterior tibial translation, a risk factor for anterior ACL injury (Nagano et al, 2007).

2.5.5 The influence of muscle activity on knee kinematics during landing activities.

Fatigue of the hip stabilising muscles affects the knee joint stability as well as the proprioception (Rozzi et al, 1999), which might lead to compensating joint mechanics leading to injuries. Zazulak *et al.* (2005) concluded that decreased hip abductor and external rotator muscle activity can contribute to decreased weight-bearing ability of the knee joint; which in turn can also lead to increased ground reaction forces (Zazulak et al, 2005). Increased ground reaction forces result in increased knee adduction/varus and internal rotation to absorb these forces, which leads to increase loading of the hip adductors (Zuzana et al, 2009; Gottschall & Kram, 2005).

The above findings thus indicate that muscular fatigue, as well as muscle weakness, results in biomechanical changes in the lower limb, which could result in injury. These aspects should be addressed in groin injuries.

2.6 Lower limb biomechanical factors associated with knee pathologies

Altered lower limb biomechanics is observed in multiple lower limb pathologies. During the literature search, no studies were found on groin injuries and the influence of knee biomechanics. However, multiple studies focussed on the biomechanical changes that occur with different knee pathologies. The following pathologies will be discussed: knee OA, PFPS and ACL injuries. Emphasis will be on the relationship between the biomechanics of the hip and the knee; and the influence it has on the muscular systems. This above information will provide a context for the current study regarding biomechanical changes in individuals with chronic groin pain.

2.6.1 Knee kinetics and kinematics in knee OA

Knee OA has been found to be a significant contributor to altered lower limb biomechanics (Wilson et al, 2008; Dieppe, 2004; Andriacchi et al, 2004). Knee OA is most common in the medial joint compartment due to increased loads as a result of the increased knee varus/adduction (Takacs & Hunt, 2012; Miyazaki et al, 2002).

The kinematics observed in knee OA participants during different functional tasks include increased knee varus/adduction which is associated with hip adduction and internal rotation (Noehren et al, 2012; Crossley et al, 2012; Souza & Powers, 2009; Willson & Davis, 2008; Weidenheilm et al, 1992). Increased varus/adduction at the knee increases the risk of knee OA progression by four times (Chang et al, 2004; Sharma et al, 2001). Increased knee varus is associated with weak hip abductors and external rotators. This places higher demands and increased load on the hip adductors (Noehren et al, 2012; Crossley et al, 2012; Doberstein et al, 2011; Souza & Powers, 2009; Willson & Davis, 2008). Which could possibly result in repetitive atraumatic type injury of the adductor muscles (Zuzana et al, 2009; Morelli & Weaver, 2005).

2.6.2 Knee kinetics and kinematics in PFPS

In previous studies on PFPS and knee OA; a clear relationship between altered hip kinetics and PFPS was observed. The main finding was hip abductor muscle weakness (Ferber et al, 2011; Dierks et al, 2008; Wilson & Davis, 2008; Cichanowski et al, 2007; Robinson & Nee, 2007; Ireland et al, 2003; Mascal et al, 2003), and more specifically decreased activation of the Gluteus medius muscle during gait (Crossley et al, 2012). This hip abductor weakness revealed in individuals suffering from OA and PFPS had associated altered kinematics such as, increased hip adduction, hip internal rotation or contralateral pelvic drop during running activities (Noehren et al, 2012; Crossley et al, 2012; Souza & Powers, 2009; Willson & Davis, 2008).

The literature discussed above illustrates the relationship between increased hip adduction; internal rotation, increased knee adduction/varus and contralateral pelvic drop, which is associated with muscle imbalances (Pohl et al, 2013). These kinematics results in increased loads on the hip adductor muscles which can possibly lead to overuse injury of the hip adductors end result in persistent groin pain.

2.6.3 Knee kinetics and kinematics in ACL injuries

As mentioned in section 2.5.4, knee valgus/abduction moments during a drop-landing task may be a predisposing factor to ACL injury (Hewett et al, 2005). Lawrence *et al.* (2008) also concluded that during drop-landing, participants with weak hip external rotators revealed a 146% increase in ground reaction force, knee valgus/abduction and flexor moments. This landing strategy increased loads on the ACL and was identified as an increased risk factor for ACL strains (Lawrence et al, 2008; McLean et al, 2004). Although Koga *et al.* (2010) demonstrated that small flexion moments at initial contact is a risk for ACL injuries, the authors agreed that sudden knee valgus/abduction moments combined with these small flexion angles is a great risk for ACL strain (Koga et al, 2010).

Other kinematic and kinetic risk factors for ACL injuries were identified by Kipp *et al.* (2011). This included decreased hip flexion moment and hip flexion control during a single-leg drop-landing and side-step cut manoeuvre which influences knee rotations and valgus/varus moments. The authors concluded that gradual hip flexion and greater overall hip flexion ROM during the landing process; will decrease knee valgus/abduction and internal rotation moments during landing. This in turn will decrease the risk of ACL injuries (Kipp et al, 2011).

Increased knee abduction/valgus and knee flexion was the main kinematic observation increasing the risk for ACL injuries. Increased knee abduction/valgus results in increased ground reaction forces which can result in a higher demand on muscular structures, such as the hip adductors and lead to groin pain.

2.7 Conclusion

There is poor understanding of the association between groin pain and lower limb biomechanical risk factors. To date, no biomechanical studies have been conducted exploring the biomechanics of the lower limb, and specifically the knee in individuals with chronic groin pain. Therefore, the purpose of this study was to explore the kinetics/kinematics of the knee in active rugby, hockey and/or soccer players with chronic groin pain compared with asymptomatic controls. From the literature discussed above, there is a clear relationship between hip and knee biomechanics and enough evidence motivating the possibility that altered knee mechanics can contribute to chronic groin pain.

Chapter 3: The manuscript

Manuscript to be submitted to Physical Therapy in Sport Journal

**Journal guidelines included in Appendix A.*

KNEE KINEMATICS DURING A SINGLE DROP LANDING IN SPORTS PARTICIPANTS WITH CHRONIC GROIN PAIN

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ABSTRACT

Objectives

To determine if there are knee biomechanical differences in sports participants with groin pain compared with asymptomatic controls.

Study Design

Descriptive study, cross-sectional design.

Setting

FNB-3D Motion Analysis Laboratory at Stellenbosch University, South Africa.

Participants

Twenty subjects participated in the study. Ten asymptomatic controls and ten cases with chronic groin pain were included. Three of the cases had bilateral groin pain and seven had unilateral groin pain.

Main Outcomes Measures

Three-dimensional (3D) knee kinematics were analysed at foot contact and the lowest vertical position during a single-leg drop landing.

Results

Cases with unilateral groin pain had significantly ($p=0.0001$ and $p<0.0001$ respectively) less knee internal rotation compared to the controls at the lowest vertical position. Cases with bilateral groin pain also had significantly ($p<0.0001$) less knee internal rotation at foot contact. Cases with bilateral groin pain had significantly ($p<0.001$) more knee varus (adduction) at foot contact and the lowest vertical position of the drop landing.

Conclusion

The findings of this study indicate that there is a difference in knee kinematics between sports participants with chronic groin pain and asymptomatic controls. These findings imply that the knee joint should not be excluded when examining or

treating an individual suffering from chronic groin pain. Due to the nature of the study design it cannot be stated for certain whether the knee kinematics noted in the groin pain group are causative or as a result of groin pain. Future prospective studies are therefore warranted.

Keywords*: *Chronic groin pain*, *motion analysis, knee kinematics, lower extremity biomechanics

1. INTRODUCTION

Groin injuries account for 10%-18% of injuries in contact sports (Morelli & Weaver, 2005). It often becomes a chronic problem and may lead to career ending chronic pain (Morelli & Weaver, 2005). Morelli and Weaver's (2005) study found that 62% of groin injuries were due to adductor muscle strains. The adductor muscle group are exposed to injury through muscle imbalance, fatigue or overload. Chronic groin pain mostly presents as a unilateral problem, but can be bilateral as well (McSweeney & Naraghi, 2012).

Maffey and Emery, in their 2007 systematic review, suggest that a large percentage of groin pain may actually be due to inadequate absorption of ground reaction by eccentric attenuation of the knee muscles during the landing phase. This may lead to strain on the adductor muscles due to the inability to maintain the centre of gravity within a small base of support during single-leg landing. This in turn may lead to injury to the adductor muscles.

Biomechanics of the lower limb may be causative factors of chronic groin pain, but this has not yet been investigated (Morelli & Weaver, 2005; Maffey & Emery, 2007). Gottschall and Kram, (2005) in their analysis of running, found that as the ground reaction force increased, further adduction (varus) occurred at the knee to absorb these forces, placing larger loads on the hip adductors. Unfortunately, these biomechanical factors have not been studied in individuals with chronic groin injuries. These biomechanical factors should be investigated in individuals with groin pain to improve the effectiveness of therapeutic interventions.

There is prolific research illustrating the relationship between the hip and knee joint (Noehren, Pohl, Sanchez, Cunningham & Latterman, 2012; Crossley et al, 2011; Souza & Powers 2009; Willson & Davis, 2008). Hip abductor weakness is a well-recognised risk factor in individuals suffering from patellofemoral pain syndrome (PFPS) (Ferber, Kendall & Farr, 2011; Dierks, Manal, Hamill & Davis, 2008; Wilson & Davis, 2008; Cichanowski, Schmitt, Johnson & Niemuth, 2007; Robinson & Nee, 2007; Ireland, Wilson, Ballantyne & Davis, 2003; Mascal, Landel & Powers, 2003). In PFPS, hip abductor weakness is associated with increased hip adduction, hip internal rotation or contralateral pelvic drop during running activities (Noehren et al, 2012; Crossley et al, 2012; Souza & Powers, 2009; Willson & Davis, 2008).

This effect of hip abductor weakness on the knee valgus/varus moment was also illustrated by Doberstein, Kernozek, Patrek, Wilson and Wright (2011), where the peak knee valgus decreased with almost 30% with a single-leg drop-landing after hip abductor fatigue protocol. Hip joint imbalances noted in PFPS, may be similar in people with groin injuries (Moreli & Weaver, 2005). Poor knee biomechanics which is not addressed may also contribute towards the persistent nature of groin pain. It is thus important to evaluate the entire lower kinematic chain when assessing an individual with groin pain.

There is poor understanding of the association between groin pain and knee joint biomechanical risk factors. The knee biomechanics could potentially be associated with groin pain, since the lower limb acts as a single kinematic chain. To date, no biomechanical studies have been conducted to explore the kinematics of the knee in sports participants with chronic groin pain. Therefore, the purpose of this study was to explore the 3D kinematics of the knee in active rugby, hockey and/or soccer players with chronic groin pain compared with asymptomatic controls.

2. METHODOLOGY

A descriptive study design was ideal for this investigation, since no information is currently available on this specific subject.

2.1 Participants

Twenty male (ten cases and ten asymptomatic matched controls) participants ranging between the ages of 18 and 55 years were recruited from soccer and rugby clubs in the Western Cape, South Africa. None of these participants had a history of spinal, lower limb or pelvis pathology other than groin pain in the cases. The cases and controls were matched with regards to age, sport type and sports club. The ten cases as divided and examined by two physiotherapists to ensure that they met the inclusion and exclusion criteria as stated in Table 1. The main inclusion criterion at the first evaluation was a positive adductor squeeze test. This test is a valid and reliable test for hip adductor strains/injuries; see Appendix B (Delahunt, Kennelly, McEntee, Green & Coughlan, 2011a; Delahunt et al, 2011b). The inclusion criteria for the matching controls were the same as for the cases, except that they should not have had a history of lower limb injury in the past year and should have had a negative adductor squeeze test. All participants provided written informed consent to participate. The protocol for the study was approved by the Human Research Ethics Committee (S12/10/265) of the Faculty of Medicine and Health Sciences (FMHS), Stellenbosch University (Appendix C).

Table 1: Inclusion and Exclusion Criteria for Chronic groin pain cases

Inclusion Criteria	Exclusion Criteria
• **Soccer, hockey or rugby players at a club level**	• Any orthopaedic surgical procedure of the lower quadrant and lumbar spine within the last 12months.
• **Ages of 18-55 years**	• Positive findings on previous imaging for bony lesions
• **Chronic groin pain of any intensity for at least the last 3 months.**	• Any disease that has an influence on functional ability/movement, e.g. Ankylosing Spondylsis, Scheuermann's disease, Rheumatoid Arthritis, Muscular Dystrophy, Paget's disease.
• **Positive Adductor squeeze test with a sphygmomanometer (Delahunt et al 2011).**	• No history of spinal, lower limb or pelvis pathology other than groin injury
• **Participating in sport or do a form of physical training despite the limitation of the groin injury.**	
• **Good general health.**	

2.2 Instrumentation

The Vicon motion analysis (Ltd) (Oxford, UK) system is a 3D system which is used in a wide variety of ergonomics and human factor application. It is capable of capturing 250 frames-per second at full frame resolution (1 megapixel). For this study an eight camera T-10 Vicon (Ltd) (Oxford, UK) system with Nexus 1.4 116 software was used to capture trials. The T-10 is a motion capturing system with a unique combination of high speed accuracy and resolution (Windolf et al, 2008).

A 3D Bertec (Bertec Corporation Ltd) force plate was used to determine foot contact during the drop-landing task.

Knee kinematics was calculated according to the Plug-in-Gait (PIG) model (Vicon Motion systems, 2010). In the PIG model the knee angles, force, moment and power is defined between the thigh and the shank (Vicon Motion systems, 2010).

2.3 Testing Protocol

All twenty participants attended the FNB-3D Motion Analysis Laboratory once on separate appointments scheduled for approximately 90 minutes, during a period of one month. Prior to the motion analysis assessment a physical examination (Appendix E) was conducted, this included leg dominance; postural observation (feet, knees, pelvis, lumber and thoracic spine); functional movement tests (*viz.* lunges, squats); range of movement of the hip (*viz.* extension, abduction, internal and external rotation); leg length (as measured from the anterior superior iliac spine to the medial malleolus); special tests to clear the sacro-iliac and hip joints and coughing to increase the intra-abdominal pressure (Morelli & Weaver, 2005) thereby ruling out an inguinal hernia. This study was a sub-study of a larger study; this resulted in an extensive physical examination although all of the information was not necessarily used during this specific sub-study.

Anthropometrics (*viz.* weight, height, leg length, knee and ankle width) were taken with participants standing barefoot. Thirty three retro-reflective markers were placed on bony landmarks according to the lower limb PIG (Appendix D). This was done by the laboratory physiotherapist who has training in marker placement, understands the PIG model and has good reliability between test occasions (r=0.8-0.97 for all three planes).

Each participant performed six single-leg drop-landings on each leg from a 20 cm height platform. The start leg was randomized (using the coin-tossing method) by one of the researchers (Figures 1 and 2).

The distance of the subject from the force was 60% of the participant's leg length from the border of the force plate. Prior to each test participants were given standard verbal instructions from the researcher (Table 2). The researcher demonstrated each test. One practice round of the single-leg drop-landings on any leg was allowed prior to the testing.

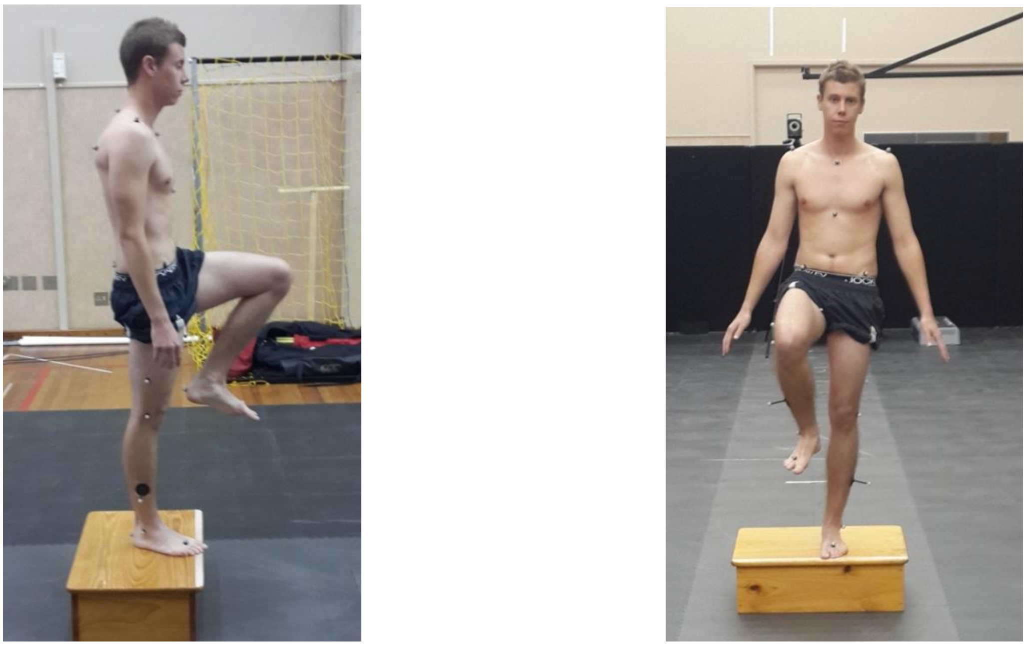

Figure 1: Starting position for the single-leg drop-landing.

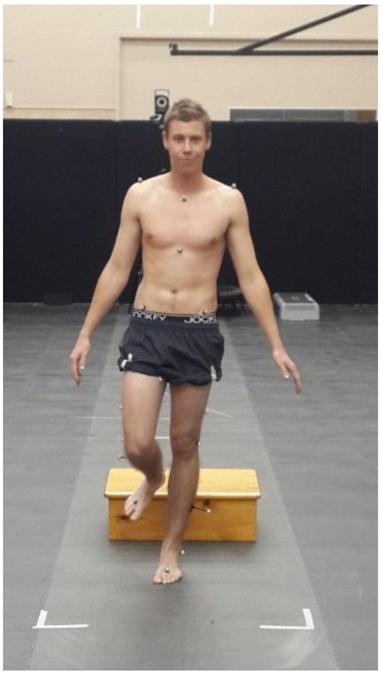

***Figure 2: End position of the single-leg drop-landing*.**

Table 2: Instructions for the single-leg drop-landing

DROP-LANDING
• Stand on box, arms next to your sides.
• Lift one leg until the hip and knee is bent to 90 degrees.
• Your foot must touch the line on the 20cm cm box.
• Jump down onto the ground with your landing foot touching the white line.
• Hold your landing positioned for 5 seconds.

2.4 Data Processing

Gap filling was performed using the standard Wolt ring filter supplied by Vicon. The events for foot contact and lowest vertical position of the pelvis were calculated automatically using Matlab Version R2012b. Segment and joint kinematics were calculated using the PIG-model and filtered with a 4^{th}-order Butterworth filter at a 10Hz cut-off frequency. Data was exported to Matlab to extract the parameters of interest

2.5 Kinematic Outcomes

The following parameters were used to determine if there were differences in the biomechanical performance of sports participants with groin pain compared with asymptomatic controls:

- Knee angles in three planes at foot contact during the landing phase of the drop-landing task. Foot contact was defined as the moment in time where any part of the foot came in contact with the force plate. Foot contact was also defined as the time when vertical force on the plate exceeded a threshold of 30N.
- Knee angles in three planes at the lowest vertical point. The lowest vertical point was defined as the moment in time where the centre point of the pelvis reaches its lowest vertical point during the landing phase of the single-leg

drop-landing task. The centre point was calculated with the four markers that were placed on the pelvis.

- Knee range of motion (ROM) in three planes from foot contact to the lowest vertical point of the pelvis during the single-leg drop-landing task.

2.6 Sample Size Calculation

A post hoc sample size calculation was calculated using G.-Power Version 3.1 statistical power analysis program. Considering a large effect of at least 1 (alpha 0.05) and sample size of 14 (which included the seven unilateral groin pain subjects and their controls) in the unilateral subgroup, the power was calculated to be 93%. For a medium effect size of at least 0.75 (alpha 0.05) and sample size of 14, the post hoc power calculation was 73%

Considering a very large effect of at least 1 (alpha 0.05) and six subjects (three bilateral groin pain subjects and their controls) in the bilateral subgroup, the post hoc power was calculated to be 50%. For a huge effect size of at least 1.45 (alpha 0.05) and sample size of six, the post hoc power calculation is 80%.

2.7 Data Analysis

The group data was divided into the subgroups with matched control groups (Figure 3) for the comparisons.

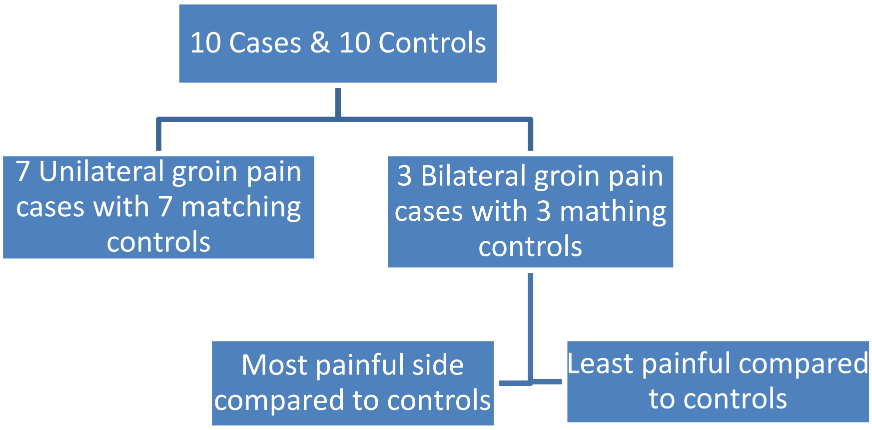

Figure 3: Subgroups divisions

Descriptive statistical calculations (means and ranges to indicate variability) were used to describe the participants' demographic information. Descriptive statistical techniques were used for all outcome measures (means and standard deviations (SD)) was calculated, followed by a Student's two-tailed *t-test* to determine significant differences between the cases and controls. For all outcomes with a significant p-value equal to or less than 0.05, the effect size was calculated using the Cohen's D (Thalheimer & Cook, 2002) to indicate the size of the effect. Interpretation of the effect size is demonstrated in Table 3.

Table 3: Cohen's D Values

Relative Size of Cohen's D	
Small effect	>=.15 and <.40
medium effect	>=.40 and <.75
large effect	>=.75 and <1.10
very large effect	>=1.10 and <1.45
huge effect	>1.45

3. RESULTS

3.1 Sample Description

Twenty male participants (ten cases and ten controls) participated in this study; consisting of matched pairs - ten rugby players, four runners, two cyclists and four soccer players. All cases had a positive adductor squeeze test at 45 degrees of hip flexion, whilst the test was negative in the controls. The sample demographics are presented in Table 4. Within both the unilateral and bilateral cases there were no significant differences in regards to age, weight and height. The VAS score immediately after a match or a game in their specific sport (VAS post game) and duration of the injury is illustrated in Table 4.

Table 4: Participant demographics' information

	Age (yrs.) Mean Range	Weight (kg) Mean Range	Height (m) Mean Range	10 point VAS post game Mean Range	Duration of injury (yrs.) Mean Range
Unilateral Groin Pain Group (n=14)					
CASES (n=7)	29.0 22 - 48	86.8 61.6 - 129.1	1.79 1.71-1.91	6.28 5-8	2.64 0.5-6
CONTROLS (n=7)	28.71 19 - 54	85.71 62.4 - 107	1.77 1.66-1.89	N/A	N/A
p VALUE	0.96	0.87	0.19	N/A	N/A
Bilateral Groin Pain Group (n=6)					
CASES (n=3)	28.67 27 - 39	91.83 74.4 - 102.8	1.81 1.76 - 1.91	6.0 3-9	3.33 1-6
CONTROLS (n=3)	26.33 20 - 31	81.57 74.7 - 87.3	1.77 1.68 - 1.84	N/A	N/A
p VALUE	0.70	0.49	0.44	N/A	N/A

3.2 Kinematic Differences

3.2.1 Unilateral Groin pain cases compared to the matching side of their controls

In the sagittal plane there were no significant differences when comparing knee flexion of the cases' injured leg with the matching controls during a drop-landing task (Table 5).

The cases had a significantly greater ROM in the frontal plane during the drop-landing task, with a medium effect size (p=0.02). There were no significant differences in the joint angle at foot contact and at the lowest vertical point when comparing the cases and controls when looking at the frontal plane.

Significant differences in the transverse plane was revealed, with the cases having significantly (p=0.001) less internal rotation angles of the knee (closer to neutral) at the lowest vertical point during landing.

Table 5: Unilateral Groin pain cases (n=7) compared to the matching side of their controls (n=7)

	Knee angle at foot contact (degrees) MEAN (SD)	Range of Motion (degrees) MEAN (SD)	Angle at lowest vertical point (degrees) MEAN (SD)
SAGITAL PLANE			
CASES (n=7)	13.57 (± 6.72)	55.47 (± 20.09)	41.76 (± 14.51)
CONTROLS (n=7)	12.53 (± 5.51)	28.32 (± 9.64)	42.46 (± 13.54)
p VALUE	p= 0.38	p=0.43	p=0.82
FRONTAL PLANE			
CASES (n=7)	1.43 (± 4.20)	14.54 (± 8.77)	15.53 (± 10.53)
CONTROLS (n=7)	3.56 (± 4.78)	10.84 (± 7.22)	13.89 (± 9.60)
p VALUE	p=0.05	*p=0.02	p=0.52
EFFECT SIZE		0.5 Medium	
TRANSVERSE PLANE			
CASES (n=7)	0.39 (± 7.08)	10.52 (± 9.31)	5.08 (± 16.03)
CONTROLS (n=7)	2.87 (± 6.83)	18.56 (± 17.61)	20.70 (± 22.13)
p VALUE	p=0.08	*p =0.02	*p=0.001
EFFECT SIZE		0.62 Medium	0.87 Large

±Sagittal Plane: Flexion: + Extension: -
±Frontal Plane: Adduction/Varus: + Abduction/Valgus: -
±Transverse Plane: Internal Rotation: + External Rotation: -
* Indicated significant difference (p<0.05)

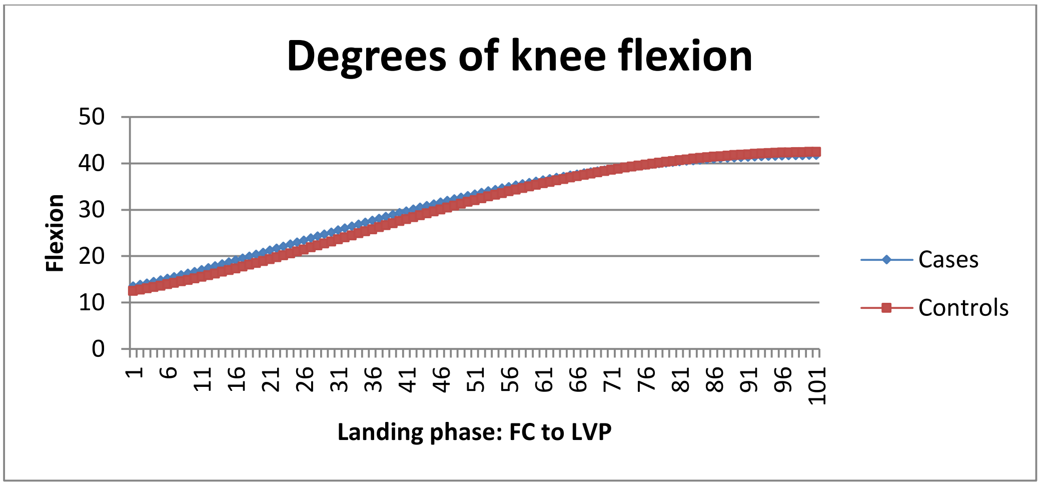

***Figure 4.1:** Movement diagram of the knee joint flexion/extension angle between the femur and the tibia in the sagittal plane, representing single-leg drop-landing from foot contact to the lowest vertical point of unilateral groin pain cases (n=7) and their matching controls (n=7).*

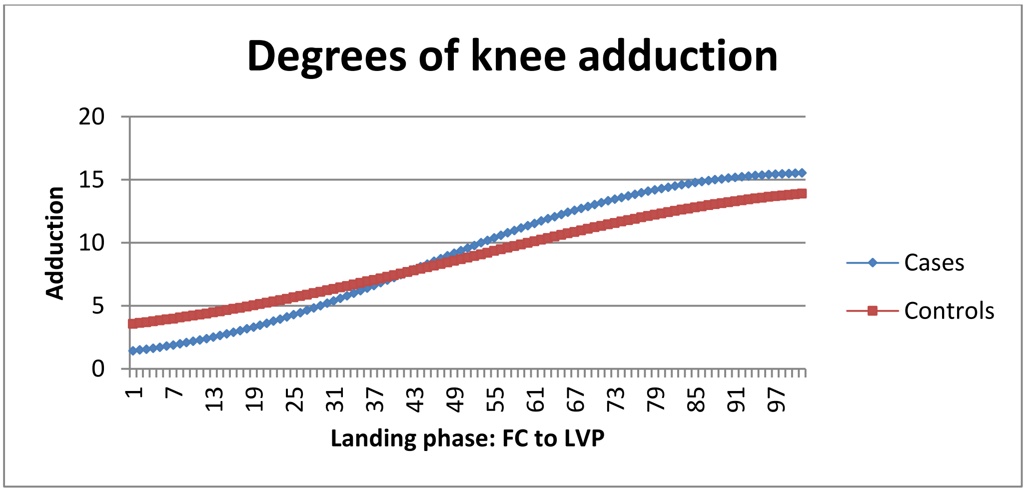

***Figure 4.2:** Movement diagram of the knee joint adduction/abduction angle between the femur and the tibia in the frontal plane, representing single-leg drop-landing from foot contact to the lowest vertical point of unilateral groin pain cases (n=7) and their matching controls (n=7).*

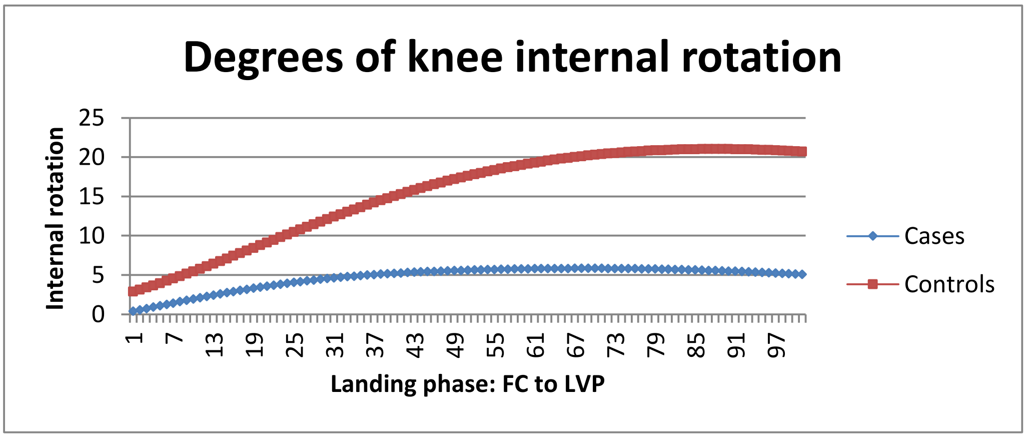

***Figure 4.3:** Movement diagram of the knee joint internal/external rotation angle between the femur and the tibia in the transverse plane, representing single-leg drop-landing from initial contact to the lowest vertical point of the unilateral groin pain cases (n=7) and their matching controls (n=7).*

3.2.2 Bilateral groin pain cases: Most painful side compared to matching side of their controls.

Significant differences were found in the sagittal plane at foot contact between the two groups, where the cases revealed significantly (p<0.001) less knee flexion (Table 6).

Significant differences were also found in the frontal plane: The cases revealed a huge clinical effect (when looking at the effect size (4.17 and 2.17)) with more knee adduction/varus at foot contact (p<0.001) and at the lowest vertical point (p=0.002) (Table 6).

There were statistical differences and huge clinical effect (2.22) revealed in the transverse plane: At foot contact the cases were in significantly (p<0.001) more external knee rotation compared to the controls that were in internal knee rotation. The cases also revealed significantly (p<0.001) greater ROM in the transverse plane (Table 6).

Table 6: Bilateral cases and matching controls (n=6)

	Knee angle at foot contact (degrees) MEAN (SD)	Range of Motion (degrees) MEAN (SD)	Angle at lowest vertical point (degrees) MEAN (SD)
COMPARING MOST PAINFUL SIDE OF CASES WITH MATCHING CONTROLS (n=6)			
SAGITAL PLANE			
CASES (n=3)	12.18 (± 5.31)	34.87 (± 16.30)	46.90 (± 21.55)
CONTROLS (n=3)	20.55 (± 5.95)	37.73 (± 9.18)	58.23 (± 7.47)
p VALUE	*p<0.001	p=0.49	p=0.07
EFFECT SIZE	1.82 Huge		
FRONTAL PLANE			
CASES (n=3)	7.42 (± 2.85)	5.78 (± 3.09)	12.46 (± 5.71)
CONTROLS (n=3)	-1.07 (± 2.07)	6.88 (± 3.06)	4.72 (± 2.38)
p VALUE	*p<0.001	p=0.349	*p=0.002
EFFECT SIZE	4.17 Huge		2.17 Huge

TRANSVERSE PLANE			
CASES (n=3)	-3.37 (± 2.27)	16.07 (± 5.01)	11.49 (± 6.18)
CONTROLS (n=3)	8.29 (± 8.82)	8.17 (± 2.37)	14.44 (± 8.66)
p VALUE	*p<0.001	*p<0.001	p=0.376
EFFECT SIZE	2.22 Huge	2.47 Huge	

±Sagittal Plane: Flexion: + Extension: -
±Frontal Plane: Adduction/Varus: + Abduction/Valgus: -
±Transverse Plane: Internal Rotation: + External Rotation: -
* Indicated significant difference (p<0.05)

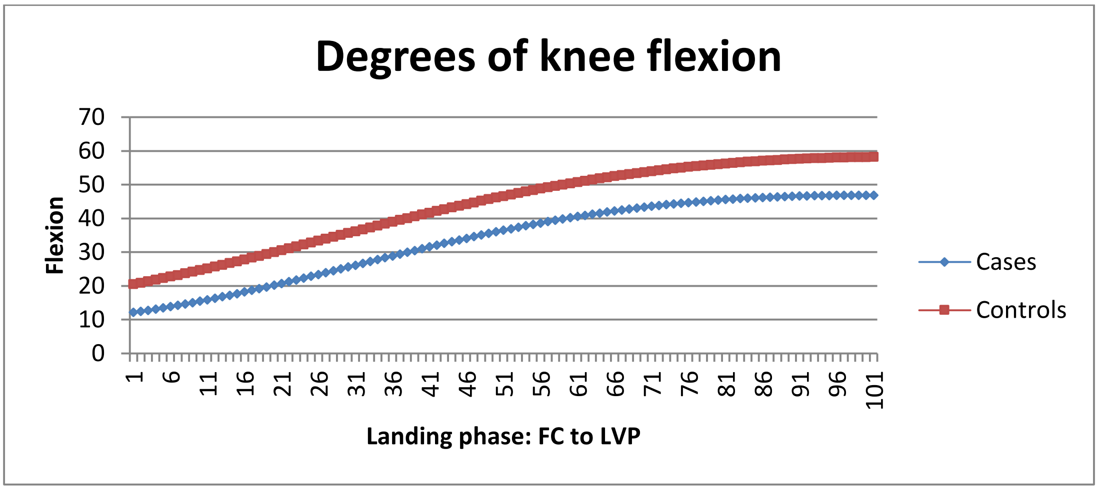

***Figure 5.1:** Movement diagram of the knee joint flexion/extension angle between the femur and the tibia in the sagittal plane, representing single-leg drop-landing from initial contact to the lowest vertical point of the MOST painful leg of bilateral groin pain cases (n=3) and their matching controls (n=3).*

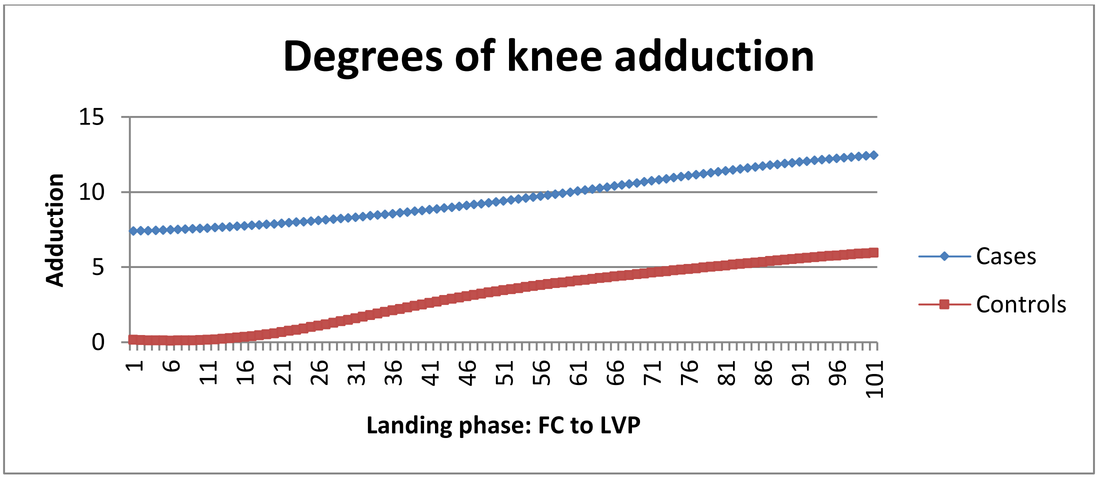

***Figure 5.2:** Movement diagram of the knee joint adduction/abduction angle between the femur and the tibia in the frontal plane, representing single-leg drop-landing from initial contact to the lowest vertical point of the MOST painful leg of bilateral groin pain cases (n=3) and their matching controls (n=3).*

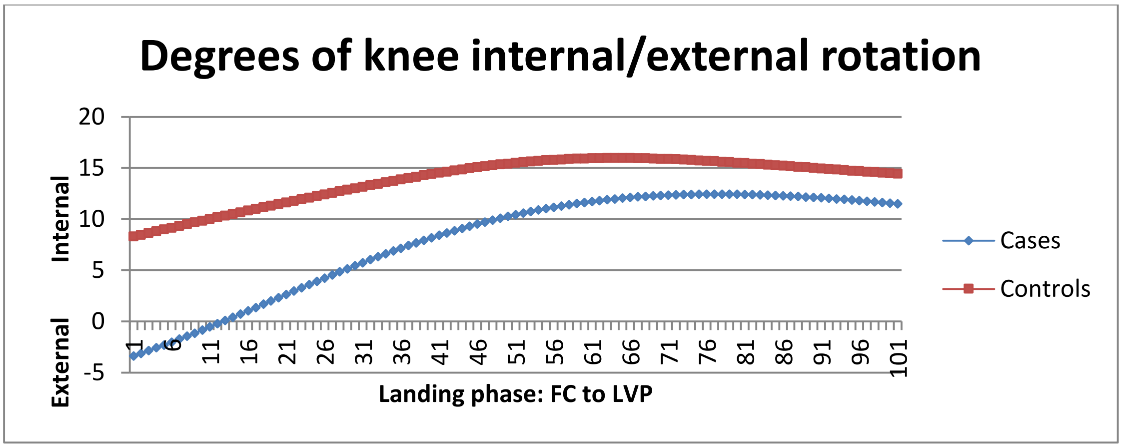

Figure 5.3: Movement diagram of the knee joint internal/external rotation angle between the femur and the tibia in the transverse plane, representing single-leg drop-landing from initial contact to the lowest vertical point of the MOST painful leg of bilateral groin pain cases (n=3) and their matching controls (n=3).

3.2.3 Bilateral groin pain cases: Least painful side compared to matching side of their controls

Statistical differences in the sagittal plane within this group were found; the cases were significantly (p<0.001) in greater knee flexion range at foot contact (Table 7).

Significantly (p<0.001) more knee varus/adduction in the frontal plane at foot contact was found for the cases. The ROM occurring in the frontal plane from foot contact to the lowest vertical point, was significantly (p<0.001) less in the cases (Table 7).

Significant differences were revealed in the transverse plane: Cases had significantly (p<0.001) less internal rotation (closer to neutral) at foot contact and greater knee ROM within the transverse plane (Table 7).

Table 7: Bilateral cases and matching controls (n=6)

	Knee angle at foot contact (degrees) MEAN (SD)	Range of Motion (degrees) MEAN (SD)	Angle at lowest vertical point (degrees) MEAN (SD)
COMPARING LEAST PAINFUL SIDE OF CASES WITH MATCHING CONTROLS (n=6)			
SAGITAL PLANE			
CASES (n=3)	19.56 (± 3.29)	36.72 (± 8.710	56.26 (± 6.51)
CONTROLS (n=3)	16.35 (± 3.87)	34.11 (± 5.62)	50.37 (± 7.32)
p VALUE	*p<0.001	p=0.34	p=0.06
EFFECT SIZE	1.09 Large		
FRONTAL PLANE			
CASES (n=3)	6.97 (± 3.82)	8.91 (± 8.28)	14.61 (± 13.16)
CONTROLS (n=3)	1.22 (± 1.30)	14.51 (± 7.48)	15.48 (± 7.54)
p VALUE	*p<0.001	*p<0.001	p=0.59
EFFECT SIZE	2.47 Huge	0.87 Large	
TRANSVERSE PLANE			
CASES (n=3)	2.95 (± 12.41)	13.45 (± 3.77)	15.40 (± 8.63)
CONTROLS (n=3)	12.06 (± 5.40)	7.12 (± 2.91)	17.82 (± 3.28)
p VALUE	*p<0.001	*p<0.001	p=0.249
EFFECT SIZE	1.17 Very Large	2.3 Huge	

±Sagittal Plane: Flexion: + Extension: -
±Frontal Plane: Adduction/Varus: + Abduction/Valgus: -
±Transverse Plane: Internal Rotation: + External Rotation: -
* Indicated significant difference (p<0.05)

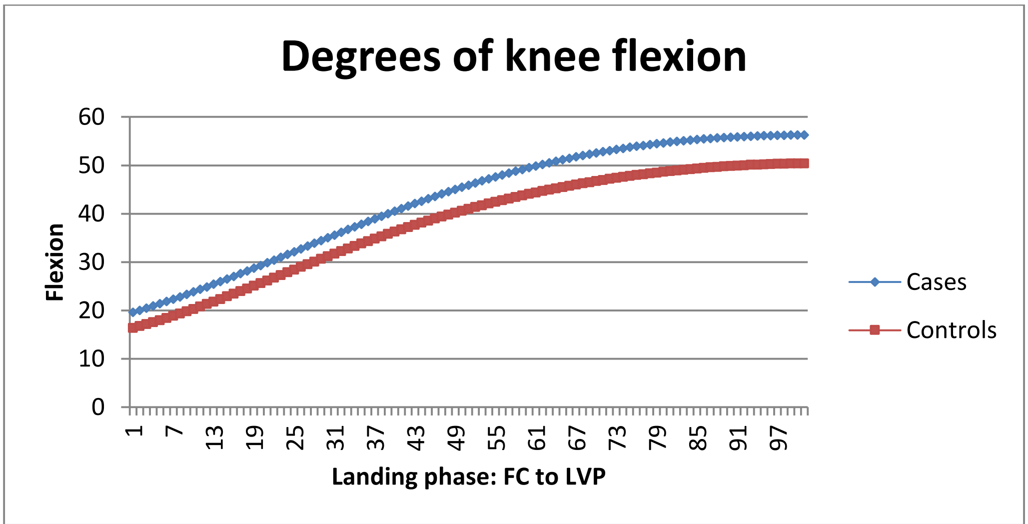

***Figure 6.1:** Movement diagram of the knee joint flexion/extension angle between the femur and the tibia in the sagittal plane, representing single-leg drop-landing from initial contact to the lowest vertical point of the LESS painful leg of bilateral groin pain cases (n=3) and their matching controls (n=3).*

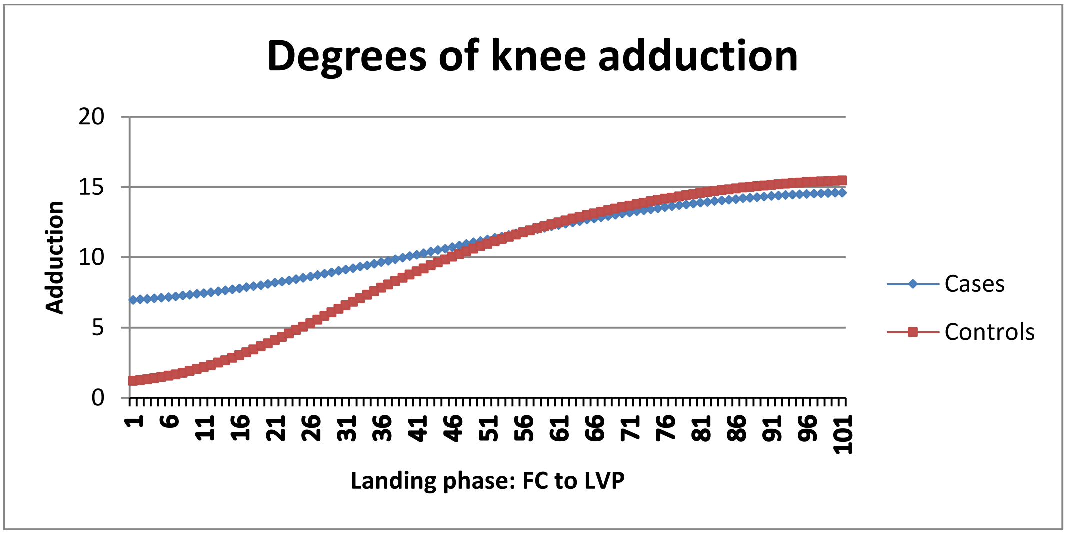

Figure 6.2: Movement diagram of the knee joint adduction/abduction angle between the femur and the tibia in the frontal plane, representing single-leg drop-landing from initial contact to the lowest vertical point of the LESS painful leg of bilateral groin pain cases (n=3) and their matching controls (n=3).

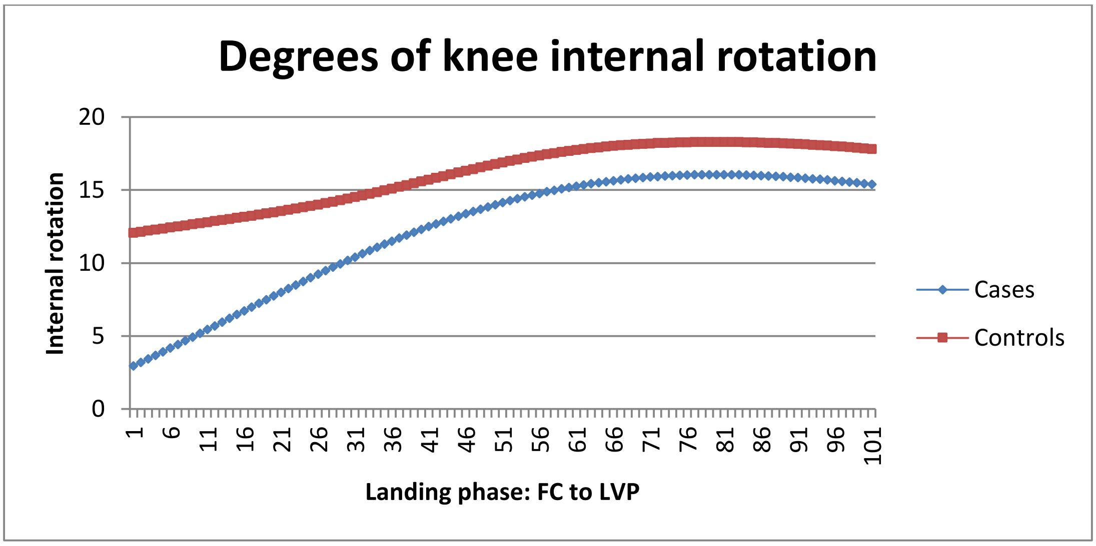

Figure 6.3: Movement diagram of the knee joint internal/external rotation angle between the femur and the tibia in the transverse plane, representing single-leg drop-landing from initial contact to the lowest vertical point of the LESS painful leg of bilateral groin pain cases (n=3) and their matching controls (n=3).

4. DISCUSSION

The aim of this study was to evaluate knee kinematics in three planes during a single-leg drop-landing, in sports participants with chronic groin pain compared to asymptomatic controls.

Cases were matched to asymptomatic controls by age, gender, and sport type. No significant difference was seen between the cases regarding the demographics such as age, weight, height, ten point VAS and duration of injury. This would then not have been able to influence the comparison between kinematic data. Cases and controls were also matched for specific sport they participated in, if sport possibly had an influence how a single drop-landing was performed. This could not have influenced the comparison of kinematic data between cases and controls.

The results of this study indicated an increased knee varus/adduction angle at foot contact during a single-leg drop-landing task in subjects with bilateral groin pain, but not those with unilateral groin pain. It has been speculated that decreased hip abductor strength leads to increased knee varus/adduction during ambulation (Takacs & Hunt, 2012; Chang et al, 2004; Mϋndermann, King, Dyrby & Andriacchi et al, 2005b). Since muscular imbalances between the abductors and adductors at the hip joint was identified as a risk factor for the development of hip adductor strains (Morelli & Weaver, 2005), this implies that there might be a relationship between altered knee kinematics, specifically increased knee varus/adduction, and adductor strains in chronic groin pain. However, it is not known whether this finding is as a result of groin pain or a causative factor since a cross-sectional study was conducted.

According to Takacs and Hunt (2012) knee varus/adduction moment was increased in single-leg standing where increased pelvic drop was observed. This increased knee varus/adduction was only observed in the contralateral knee to the side of the pelvis drop. This could be a possible reason why increased knee varus/adduction was only illustrated in the bilateral group and not in the unilateral groin pain group, since the contralateral knee joint was automatically analysed with groin pain being on both sides whereas only the ipsilateral knee was compared in the unilateral groin pain group. It could be possible that increased knee varus/adduction would have been found in the pain-free leg of the unilateral groin pain group. Since a pelvic drop was identified as one of the risk factors for the development of chronic groin pain, we can conclude that the increased knee varus/adduction in the contralateral knee might contribute to persistent groin pain (Takacs & Hunt, 2012; Maffey & Emery, 2007; Morelli & Weaver, 2005). One might debate that this could imply that in the case of chronic groin pain, the contralateral knee should also be investigated. This might lead to the conclusion that groin pain could be due to altered biomechanics in the contralateral knee and not just the ipsilateral knee joint. In a clinical setting it is thus indicated that one needs to evaluate bilaterally, even if the patients suffers from unilateral groin, since groin pain often becomes bilateral.

The second finding in the current study is significantly less knee internal rotation (closer to neutral) at the lowest vertical position, in the unilateral and in the least painful leg of the bilateral groin pain group compared to the controls. Although the available degrees of ROM for internal/external knee rotation in the transverse plane is small, 3D motion analysis has been proved to have high inter-observer reliability as well as a good between day and within day reliability (Nakagawa et al, 2013; Webster et al, 2010; Labbe et al, 2008). According to Aria and Miaki (2013), the normal kinematics of the knee during a single-leg-landing task is that the knee has to internally rotate and shift medially when the knee flexes to absorb ground reaction force. If less knee internal rotation occurs, like we observed in the current study, it could possibly decrease the ability of the knee to absorb ground reaction forces. Since the hip adductors play an important role in stabilization and proper load transfer during weight-bearing activities, fatigue and overload caused by increased ground reaction forces can contribute to adductor strains in groin pain (Quinn, 2010; Tyler, Nicholas & Campbell, 2001; Maffey & Emery, 2007). This supports the fact that in this study the asymptomatic controls reveal more knee internal rotation versus a more neutral knee rotation observed in the unilateral and bilateral groin pain groups. Once again a cause effect relationship for groin pain remains to be investigated.

A number of limitations need to be considered for the current study; one limitation is the small sample size, especially in the bilateral groin pain subgroup. A sample group of three subjects limits the confidence with which conclusions can be made. Another limitation to the current study was that leg dominance was not matched due to practical limitations. An overall limitation is the difficulty in diagnosis of groin pain and the pain being widely spread (Hackney, 2012). Future studies should include investigations such as MRI to define the aetiology of groin pain.

Future research could focus on the relationship between chronic groin pain and knee biomechanics of the contralateral knee in other functional activities and in prospective designs. Future researchers should also consider electromyography (EMG) measurements of hip abductors and adductors muscles in individuals with groin pain during a single-leg drop-landing to aid in the understanding of interplay of muscle activity during a single-leg landing.

5. CONCLUSION

Groin pain accounts for 10-18% of injuries in contact sports and tends to become a chronic problem leading to the termination of promising sport careers. The aim of this study was to determine whether there are differences in knee kinematics in active sports participants with chronic groin pain compared to asymptomatic controls during a single-leg drop-landing task. The knee varus/adduction angle was increased at foot contact and the lowest vertical point in the bilateral groin pain group but not in the unilateral groin pain group when compared to controls. The unilateral groin pain had significantly less internal rotation compared to the controls at the lowest vertical position and the bilateral groin pain group at foot contact. This could indicate impaired force attenuation of the knee muscles, which consequently places the hip adductors at risk of injury.

A reason why increased knee varus/adduction was only seen in the bilateral groin pain group could be due to previous research suggesting that a contralateral pelvic drop during single-leg activities relates to altered frontal plane knee kinematics (Takacs & Hunt, 2012). Clinically, it indicated that sport people with groin pain should be assessed bilaterally, albeit groin pain may be unilateral. Future research should focus on exploring contralateral knee kinematics in groin pain subjects and can possibly include exploration of muscular components during a drop-landing, possibly making use of EMG.

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CHAPTER 4: Conclusions, Limitations and Recommendations

The aim of this study was to determine whether differences exist in knee kinematics in the three different planes when performing a single-leg drop-landing task, when comparing sports participants with chronic groin pain and asymptomatic matched controls. The main findings of the current study indicate less knee internal rotation in cases with unilateral groin pain at the lowest vertical position and in cases with bilateral groin pain at foot contact during the drop-landing task in the transverse plane. The second finding was more knee varus (adduction) in cases with bilateral groin pain during the landing phase. These findings indicate that knee kinematics and chronic groin pain in sport participants, is associated. However, it is still unclear whether altered knee kinematics is a cause or result from chronic groin pain. The information gained from this study, suggest that knee kinematics should be considered in the assessment of groin injuries.

Prior to conducting this study, ethics approval was obtained from the Committee for Human Research of Stellenbosch University (Appendix C). Different sport clubs were contacted to recruit participants. Prospective subjects were interviewed to ensure that they met the inclusion and exclusion criteria. Ten male soccer and rugby players with chronic groin pain and ten male asymptomatic players were recruited to participate in the study and provided written consent to participate. The clinical presentation of the cases included the subjective reporting of pain in the groin area for more than three months. The main objective finding during the physical examination for the cases included a positive adductor squeeze test performed with the hips placed in 45 degrees (Appendix B). Incidentally three cases complained of bilateral groin pain whereas the rest experienced unilateral groin pain. This resulted in subgrouping of cases into a bilateral and unilateral groin pain groups. The knee kinematics of both, cases and controls, was analysed at the FNB-3D Motion Analysis Laboratory at Stellenbosch University.

The literature proposed that the biomechanics of the lower limb were particularly important and may be causative factors of chronic groin pain. However, this has not been studied in individuals with chronic groin injuries before (Morelli & Weaver, 2005; Maffey & Emery, 2007). It was previously mentioned by Gottschall & Kram, (2005) that the knee absorbs increased ground reaction forces through knee adduction (varus), resulting in larger loads being placed on the hip adductors. The above factors indicate that knee biomechanics should be considered in groin pain to provide holistic and effective therapeutic interventions.

Co-contraction of the hip abductors and adductors during mid-stance is required for pelvis stabilisation to transfer weight from the one leg to the other. Muscle imbalances between the hip abductors and adductors can thus hamper efficient load transfer during gait and may lead to injuries (Quinn 2010; Nicola & Jewison, 2012; Tyler et al, 2001; Maffey & Emery 2007). Weakness of the abductors is associated with increased knee adduction, increased hip adduction and internal rotation during gait, which increases loads on the hip adductors (Chang et al, 2005; Mundermann, Dyrby, Andriacchi, 2005). If the increased knee varus/adduction observed during landing in individuals with groin pain during the current study is due to weak hip abductors; then the weakness of hip abductors could be a predisposing factor for developing chronic groin.

Knee varus/adduction moment was increased in single-leg standing where increased pelvic drop was observed (Takacs & Hunt, 2012). This increased knee varus/adduction was only observed in the knee contralateral to side of the pelvis drop. This could be a possible reason why increased knee varus/adduction was only illustrated in the bilateral group and not in the unilateral groin pain group, since the contralateral knee joint was automatically analysed with groin pain being on both sides whereas only the ipsilateral knee was compared in the unilateral groin pain group. It could be possible that increased knee varus/adduction would have been found in the pain-free leg of the unilateral groin pain group. Since a pelvic drop was identified as one of the risk factors for the development of chronic groin pain, we can conclude that the increased knee varus/adduction in the contralateral knee might contribute to persistent groin pain (Takacs & Hunt, 2012; Maffey & Emery, 2007; Morelli & Weaver, 2005). One might debate that this could imply that in the case of chronic groin pain, the contralateral knee should also be investigated.

According to Aria and Miaki (2013) the normal kinematics of the knee during a single-limb-landing task is that the knee has to internally rotate and shift medially when the knee flexes to absorb ground reaction force. This supports the fact that in this study the asymptomatic controls reveal more knee internal rotation versus a more neutral knee rotation moment in the unilateral and bilateral groin pain groups at the lowest vertical point. Once again a cause effect relationship for groin pain could not be established due to the study design of the current study.

Limitations

A number of limitations need to be considered for the current study;

- One limitation is the small sample size, especially in the bilateral groin pain subgroup. A sample group of three subjects limits the confidence level with which conclusions can be made.
- Another limitation to the current study was that leg dominance was not matched due to practical limitations. During a landing activity, like the single-leg drop-landing used in the current study, the biomechanics and landing strategy might be different between the dominant and non-dominant leg.
- In this cross-sectional, descriptive study it remains uncertain whether these findings are as a result of the chronic groin pain or a perpetuating/causative factor.
- Non-random samples were used, which may not be a clear representative of the groin pain population.
- This study was laboratory-based, and may not accurately reflect what happens in real life.
- Our study only looked at knee kinematic changes during the contact phase of drop-landing, whereas information regarding other phases of the drop-landing activity or other movements such as running may be useful.
- For the purpose of this study we focussed on the knee joint, but the other regional analysis were done and will be represented in separate articles by co-workers. However, in this study the biomechanics of other regions (pelvis, trunk, hip and ankle) was not taken into account.

Possible methods to prevent groin pain becoming a chronic problem and preventing bilateral spread

- Strengthening of hip abductors and lateral rotators.

- Correcting Quadriceps and Hamstring strength ratio.
- Assessing landing strategies and correcting biomechanical faults.

Recommendations for future research

- Future research should focus on exploring contralateral knee kinematics in groin pain subjects.
- Studies can include exploration of muscular components during a drop-landing task, possibly making use of EMG.
- In the future bigger sample sizes should be used.
- Future studies should include investigations such as MRI to define the aetiology of groin pain.
- Prospective studies are warranted to determine the cause and effect relationship for groin pain. Studies that include the 3D motion analyses of all the joints in the lower limb should also be considered.

Conclusion

The aim of this study was to determine whether there are differences in knee kinematics in active sports participants with chronic groin pain compared to controls during a drop-landing task. There was significantly more knee varus/adduction range at foot contact in the bilateral groin pain group than in the unilateral groin pain group and controls. A possible reason the increased knee varus/adduction was only seen in the bilateral groin pain group could be due the knee affecting the contralateral pelvis and groin. Future research should focus on exploring contralateral knee kinematics in groin pain subjects and can possibly include exploration of muscular components of during a drop-landing, perhaps making use of EMG.

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At the end of the paper (before the references) three statements must be provided:

- Ethical Approval: The organisation providing ethical approval and ethics protocol reference number where appropriate.
- Funding: any sources of funding should be stated.
- Conflict of Interest: Disclosed conflicts will be published if they are believed to be important to readers in judging the manuscript. If there are no conflicts of interest, authors should state that there are none.

Format/Preparation Guidelines

The article should be typed on A4 paper, double-spaced with margins of at least 3cm. All pages must be numbered consecutively beginning with the title page. Papers should be set out as follows, with each section beginning on a separate sheet: **Title page; abstract; keywords, text, and references.**

Parts of manuscript:

- Title page must consist of the following:
  - *Title.* Concise and informative. Titles are often used in information-retrieval systems. Avoid abbreviations and formulae where possible.
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Ethics

Work on human beings that is submitted to Physical Therapy in Sport should comply with the principles laid down in the declaration of Helsinki; Recommendations guiding physicians in biomedical research involving human subjects. Adopted by the 8th World Medical Assembly, Helsinki, Finland, June 1964, amended by the 29th World Medical Assembly, Tokyo, Japan, October 1975, the 35th World Medical Assembly, Venice, Italy, October 1983, and the 41st World Medical Assembly, Hong Kong, September 1989. The manuscript should contain a statement that has been approved by the appropriate ethical committees related to the institution(s) in which it was performed and that subjects gave informed consent to the work. Patients' and volunteers' names, initials, and hospital numbers should not be used. In a case report, the subject's written consent should be provided. It is the author's responsibility to ensure all appropriate consents have been obtained.

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Appendix B: Adductor squeeze test

A sphygmomanometer was used to screen cases for pain with contraction on the adductor squeeze test during the screening session.

The test was performed with the hips flexed to 45 degrees, where the adductor muscles are at their most mechanical advantaged position. A goniometer was used to measure the hip position. The sphygmomanometer cuff, placed between the knees with the cuff's middle third section located between the most prominent part of the medial condyles of the femurs, and then inflated to 10 mm Hg. (Delahunt et al 2011) The Adductor squeeze test was measured once over a period of 20 seconds. During the first 5 seconds the subject had to hold the neutral position of the spine. Between the period of 5s-10s the subject was asked to squeeze the cuff at maximal effort, then release the contraction but hold the test position. From 15s-20s the participant was asked to relax completely. (Lin et al, 2008; Delahunt et al, 2011) A positive test was pain over the adductor muscle belly or at the insertion. Before each squeeze test, the sphygmomanometer was allowed 30 seconds to settle. One standard Sphygmomanometer was used. The readings were taken with the inflatable cuff positioned between the knees. An individual pressure value was recorded for each case and control in mmHg. A positive test was reproduction of pain in the adductor muscle belly or at the insertion.

Appendix C: Ethics Approval

Approval Notice

New Application

03-Dec-2012
MORRIS, Tracy Louise

Ethics Refernce #: S12/10/265
Title: Exploration of Biomechanics during functional Activities in Adults Sports participants with Chronic Groin Pain

Dear Ms Tracy MORRIS,

The New Application received on 22-Oct-2012, was reviewed by Health Research Ethics Committee 1 via Committee Review procedures on 28-Nov-2012 and
has been approved.
Please note the following information about your approved research protocol:

Protocol Approval Period: 28-Nov-2012 -28-Nov-2013

Present Committee Members:

Kinnear, Craig CJ
Seedat, Soraya S
Mukosi, M
Theunissen, Marie ME
Kearns, E
Meintjes, WAJ Jack
Mohammed, Nazli
Weber, Franklin CFS
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Rohland, Elvira EL
Theron, Gerhardus GB
Els, Petrus PJJS
Hendricks, Melany ML
Welzel, Tyson B
Barsdorf, Nicola

Please remember to use your protocol number (S12/10/265) on any documents or correspondence with the HREC concerning your research protocol.

Please note that the HREC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

After Ethical Review:

Please note a template of the progress report is obtainable on www.sun.ac.za/rds and should be submitted to the Committee before the year has expired.
The Committee will then consider the continuation of the project for a further year (if necessary).
Annually a number of projects may be selected randomly for an external audit.
Translation of the consent document to the language applicable to the study participants should be submitted.

Federal Wide Assurance Number: 00001372
Institutional Review Board (IRB) Number: IRB0005239

The Health Research Ethics Committee complies with the SA National Health Act No.61 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 Part 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes 2004 (Department of Health).

Provincial and City of Cape Town Approval

Please note that for research at a primary or secondary healthcare facility permission must still be obtained from the relevant authorities (Western Cape Department of Health and/or City Health) to conduct the research as stated in the protocol. Contact persons are Ms Claudette Abrahams at Western Cape Department of Health (healthres@pgwc.gov.za Tel: +27 21 483 9907) and Dr Helene Visser at City Health (Helene.Visser@capetown.gov.za Tel: +27 21 400 3981). Research that will be conducted at any tertiary academic institution requires approval from the relevant hospital manager. Ethics approval is required BEFORE approval can be obtained from these health authorities.

We wish you the best as you conduct your research.

For standard HREC forms and documents please visit: www.sun.ac.za/rds

If you have any questions or need further assistance, please contact the HREC office at 0219389657.

Included Documents:

Checklist
Application Form
Investigators declaration
Protocol

Sincerely,

Franklin Weber
HREC Coordinator
Health Research Ethics Committee 1

Appendix D: Placement of retro-reflective markers

Placement of the head markers:

- LFHD/RFHD - front approximately over temples
- LBHD/RBHD - in horizontal plane of front head markers

The markers over the temples define the origin, and the scale of the head. The rear markers define the head's orientation.

Placement of the torso markers:

- Clavicle – supero-sternal notch
- Sternum – xiphoid process of sternum
- RBACK - place in the of the right scapula
- C7 – spinous process
- T10 – spinous process
- Placements of the arm markers:
- Left shoulder/Right shoulder – acromioclavicular joint
- Left elbow/R elbow– lateral epicondyle approximating elbow joint axis
- LWRA/RWRA – wrist bar, thumb side
- LWRB/RWRB – wrist bar, pinkie side
- Left finger/Right finger – dorsum of the hand just below the head of the second metacarpal

Placement of the pelvis markers:

- Left ASIS/Right ASIS – directly over the anterior superior iliac spines
- Left PSIS/Right PSIS – directly over the posterior superior iliac spines

Placement of knee markers:

- Left knee/Right knee– lateral epicondyle of the femur
- Left thigh/Right thigh - lower lateral 1/3 surface of the thigh, just below the swing of the hand
- Place the marker in a line from the greater trochanter and knee marker

Placements of the tibia markers:

- Left tibia/Right tibia – lower lateral 1/3 of the tibia to determine the alignment of the ankle flexion axis. The marker is placed in a line joining the knee and the ankle markers
- A wand mounted marker may be used

Placement of the ankle markers:

- Left ankle/Right ankle - lateral malleolus along an imaginary line that passes through the transmalleolar axis

- LMMAL/RMMAL – medial malleolus of the ankle (only used during the Oxford correction static subject calibration)

- The tibial marker should lie in the plane that contains the knee and ankle joint centres and the ankle flexion/extension axis.

Placement of the foot markers:

- LTOE/RTOE - second metatarsal head, on the mid-foot side of the equinus break between fore-foot and mid-foot
- LHEE/RHEE - Place on the calcaneus at the same height above the plantar surface of the foot as the toe marker

Appendix E: Physical Examination

Observation:

Functional demonstration/activity:

Squats

Lunges

Active physiological movements:

Passive physiological movements:

Hip	Left1	Left2	Left3	Mean	Right1	Right2	Right3	Mean
Extension								
Flexion								
Abduction								
Adduction								
Internal Rotation								
External Rotation								

Knee	Left 1	Left 2	Left 3	Mean	Right 1	Right 2	Right 3	Mean
Flexion								
Extension								
Ankle	Left 1	Left 2	Left 3	Mean	Right 1	Right 2	Right 3	Mean

Plantar flexion								
Dorsi flexion								
Eversion								
Inversion								

Special tests:

Leg Length

Lumbar (Active physiological movements, Combined movements, if indicated)

Knee (Active physiological movements, Combined movements, if indicated)

Ankle (Active physiological movements, Combined movements, if indicated)

SIJ (4 battery of tests):
Fabers Test
Gaelen's Test
P4 Test
Posterior gapping

Hip Quadrant (if indicated)

Pain on coughing