

PELVIC KINEMATICS DURING SINGLE-LEG DROP-LANDING IN SPORTS PARTICIPANTS WITH CHRONIC GROIN PAIN

This thesis is presented in partial fulfilment of the requirements for the degree of Master of Science in Physiotherapy (Structured) OMT at Stellenbosch University

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April 2014

Declaration

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Abstract

Introduction

Chronic groin injuries are common among athletes and have the potential to lead to chronic and career-ending pain. There is no evidence available whether pelvic kinematics can be perceived as a risk factor in developing chronic groin pain in sport or be the cause of further injuries of the lower quadrant or lumbar spine.

Objective

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

Methodology

A descriptive study was conducted. The three-dimensional (3D) pelvic kinematics of ten cases with chronic groin pain and ten asymptomatic controls was analyzed. Pelvic kinematics was analyzed at the FNB 3D Vicon Laboratory at Stellenbosch University using an eight camera Vicon system. A physical examination, including functional movements, posture analysis, hip, knee and ankle passive range of motion measurements, sacro-iliac tests and anthropometric measurements was done by two physiotherapists prior to the 3D analysis. To analyze the pelvic kinematics, each participant performed six single-leg drop-landings. The main outcome measure was 3D pelvic kinematics at initial foot contact (IFC) and foot contact at lowest vertical position (LVP). The following sub-groups were analyzed: seven with unilateral groin pain and

three with bilateral groin pain; the latter was further divided into those with the most painful leg and the least painful leg. Mean and standard deviations (SD) for pelvic kinematics were calculated and significant differences between sub-groups were determined using two-tailed Student's *t*-tests. The Cohen's D effect size calculator was used to calculate the effect size of significant differences in pelvic kinematics between case and control groups.

Results

The findings indicated a significant difference ($p=0.03$) in frontal plane pelvic kinematics at IFC for the unilateral group. The most painful groin group showed significant differences at IFC ($p=0.004$) and at LVP ($p=0.04$) in the frontal plane pelvic kinematics. The least painful groin group showed a significant difference at LVP ($p=0.01$). All cases landed with pelvic downward lateral tilt during the landing phase compared to matched controls. The groin pain group with bilateral pain showed significant differences at IFC ($p < 0.001$) and LVP ($p=0.005$) for the most painful groin; and the least painful groin at IFC ($p=0.01$) and LVP ($p=0.01$) in the sagittal plane pelvic kinematics. The bilateral groin pain group showed an increase of anterior pelvic tilt in the sagittal plane during the landing phase when compared to matched controls. Increased internal pelvic rotation in the transverse plane was significant for the unilateral group at IFC ($p=0.04$) and for the most painful groin group at IFC ($p < 0.001$) and LVP ($p < 0.001$) compared to matched controls.

Conclusion

Results from this study shows that pelvic kinematic changes in the frontal, sagittal and transverse planes do occur in patients with chronic groin pain when compared to controls. This may imply that muscle weakness around the hip and pelvis may contribute to the development of chronic groin pain in active sports participants. Rehabilitation of these muscles should be taken into consideration when treating patients with chronic groin injuries. Further research should be focused on muscular recruitment patterns in sports participants with groin pain to critically define the muscular causal factors in more depth.

Opsomming

Inleiding

Kroniese lies beserings is 'n algemene verskynsel onder die aktiewe sport populasie. Dit mag tot kroniese pyn lei en het die potensiaal om 'n sport loopbaan te be-eindig. Tans, is daar geen verdere navorsing beskikbaar oor die invloed van bekken kinematika op onderste ledemaat beserings asook die moontlike oorsaak tot kroniese lies pyn in atleten.

Oogmerk

Die doel van hierdie studie was om vas te stel watter verskille in die bekken kinematika ontstaan tussen aktiewe sport deelnemers met kroniese lies pyn teenoor aktiewe sport deelnemers sonder enige pyn of beserings tydens 'n enkel been aftrap beweging.

Metodologie

Tien deelnemers met kroniese lies pyn en tien asimptomatiese deelnemers is gebruik om die verskille tussen die 3D bekken kinematika te bepaal. Die FNB 3D Vicon Lab by die Stellenbosch Universiteit is gebruik vir die data analise en insameling. Deelnemers het 'n fisiese ondersoek ondergaan wat die volgende ingesluit het: funksionele bewegings, postuur analise, omvang van beweging van die heup, knie en enkel, toets ter uitsluiting van die ilio-sakrale gewrig asook antropometriese aftmetings. Elke deelnemer is versoek om ses enkel-been aftrap sessies te doen. Die hoof uitkomsmeting was die bekken hoeke in the frontale vlak by inisiële voet kontak (IVK) asook die voet kontak teen die laagste vertikale posisie (LVP).

Resultate

Die resultate wys 'n beduidende verskil ($p=0.03$) in die frontale vlak vir bekken kinematika by IVK vir die unilaterale groep. Die mees geaffekteerde been wys 'n beduidende verskil by IVK ($p=0.004$) en by LVK ($p=0.04$) in die frontale vlak vir bekken kinematika. Die groep met die minste geaffekteerde been toon 'n beduidende verskil by LVP ($p=0.01$). Alle simptomatiesse deelnemers het met die bekken in afwaartse bekken kanteling geland tydens die landings fase. Die groep met bilaterale pyn toon 'n beduidende verskil by IVK ($p < 0.001$) en by LVP ($p=0.005$) vir die mees geaffekteerde been en vir die minste geaffekteerde been by IVK ($p=0.01$) en LVP ($p=0.01$) in die sagittale vlak vir bekken kinematika. Die bilaterale groep met kroniese lies pyn land met meer anterior bekken kanteling in die sagittale vlak gedurende die landings fase teenoor die asimptomatiesse groep. Interne bekken rotasie was beduidend meer vir die unilaterale groep by IVK ($p=0.04$) en vir die mees geaffekteerde been by IVK ($p < 0.001$) en LVP ($p < 0.001$) teenoor asimptomatiesse deelnemers.

Gevolgtrekking

Die resultate van hierdie studie bewys dat daar wel 'n verskil is in die bekken kinematika van deelnemers met kroniese lies pyn teenoor asimptomatiesse deelnemers. Hierdie verskille is waarneembaar in die frontale, sagittale en transverse vlakke. Dit impliseer dat spier swakheid van die bekken en heup spiere 'n bydrae mag he tot die ontwikkeling van kroniese lies beserings in atlete. Rehabilitasie van bogenoemde spiere is belangrik in die behandeling van kroniese lies beserings. Verdere navorsing oor spier aktiverings patrone in aktiewe, sports deelnemers met kroniese lies pyn word benodig, om die oorsprongs faktore te ondersoek.

Acknowledgements

I would like to sincerely thank the following:

- The National Research Foundation for funding this study.
- My fellow group members, Karien Maritz, Lauren Harwin, Michael Dare and Tracy Morris for their contribution of the research protocol and the data collection.
- Professor Quinette Louw and Mr. John Cockroft for their supervision of this study.
- The staff at the 3D Vicon Lab at the Stellenbosch University for their assistance with the data collection.
- Mrs. Wilhelmine Pool at the Medicine and Health Sciences Library of the Stellenbosch University for her assistance in the sourcing of journal articles.

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List of abbreviations

AL	Adductor longus (muscle)
EMG	Electro-myographic
GM	Gluteus medius (muscle)
IFC	Initial foot contact
LBP	Lower back pain
LVP	Lowest vertical position
PIG	Plug-In-Gait
RCT	Randomized control study
ROM	Range of motion
SD	Standard deviation
SIJ	Sacro-iliac joint
TrA	Transversus abdominus (muscle)
3D	Three-dimensional

List of definitions

Biomechanics	The study of the mechanics of a living body, especially of the forces exerted by muscles and gravity on the skeletal structure (The American Heritage Dictionary of the English Language, 2009).
Kinematics	The branch of mechanics that studies the motion of a body or a system of bodies without consideration given to its mass or the forces acting on it (The American Heritage Dictionary of the English Language, 2009).
Enthesopathy	An inflammation or disease of an enthesis (the point at which a tendon joins to a bone) and similar to tendinitis (Avrahami & Choudur 2010).

Chapter 1: Introduction

Chronic groin injuries are common among the sporting population and account for about 20% of all sporting injuries (Koulouris, 2008). Groin injuries are often persistent and can be career-ending (Koulouris, 2008; Davies, Clarke, Gilmore, Wotherspoon, Connell, 2010). Although about 62% of groin injuries involve adductor muscle strains, the aetiology of groin pain is complex (Morelli & Weaver 2005). Associated problems include osteitis pubis and sports hernia. This complex interplay of impairments may explain the persistent nature of the problem (Morelli & Weaver, 2005). Groin pain in athletes is thus a common and disabling impairment (Davies et al., 2010; Jansen, Mens, Backx & Stam, 2010; Koulouris, 2008).

Diagnosing the underlying cause of chronic groin pain is of utmost importance for optimal management of the patient (Morelli & Smith 2001). Groin pain can also be referred from the lumbar spine or results from pelvic nerve entrapment (Davies et al., 2010). Commonly, patients with chronic groin pain will present with local tenderness at the origin of the adductor longus muscle, pain on passive stretching and resisted contraction of the adductor group, in addition to pain with exercise or kicking (Holmich, 2007). Frequent strain at the musculo-tendinous junction of the adductor muscles is known as an enthesopathy and involves muscle spasm, atrophy and weakness (Davies et al., 2010). Accurate diagnosis to determine the involved structures will assist the patient and therapist in optimal management.

The biomechanical factors that may be associated with groin pain has not been investigated in great detail. It is postulated that a large percentage of groin pain may be due to the inability to properly transfer load from the legs and torso to the pelvis (Maffey & Emery, 2007). Load transfer during mid-stance of the walking gait cycle is important (Maffey & Emery 2007). In this moment, a co-contraction of the hip abductors and adductors muscles are critical for pelvis stabilization in the frontal plane, preventing a pelvic lateral tilt as seen in a mild-Trendelenburg drop (Quinn 2010, Nicola & Jewison 2012; Tyler, Nicholas, Campbell, 2001; Morrissey et al., 2012). Co-contractions between the abductor and the adductor muscle groups, especially the gluteus medius (GM) and adductor longus (AL) muscles are important in maintaining the pelvis in the frontal plane (Seniam, 2011). Strength imbalances between the abductor and adductor muscles may be risk factors for groin strain in sport (Maffey & Emery 2007). Although the influence of altered motor control on lumbo-pelvic pain has been researched (Hungerford et al., 2003; Cowan et al., 2004), evidence about hip muscle function and its influence on the pelvic kinematics during functional tasks is scarce (Morrissey et al., 2012). However, based on the limited information, there is an indication that pelvic kinematics and hip muscle strength may be associated with chronic groin pain.

To our knowledge there is currently no published research on pelvic kinematics in sports participants with chronic groin pain. Altered pelvic kinematics may be associated with the development of chronic groin pain (Niemuth, Johnson, Meyers, Thieman, 2005). The aim of this study is thus to determine if there are differences in 3D-pelvic kinematics of active

sports participants with chronic groin pain compared to healthy controls during a single-leg drop-landing task.

The format of the thesis is according to the faculty guidelines for publication format.

The general outline of the thesis is illustrated in Figure 1.

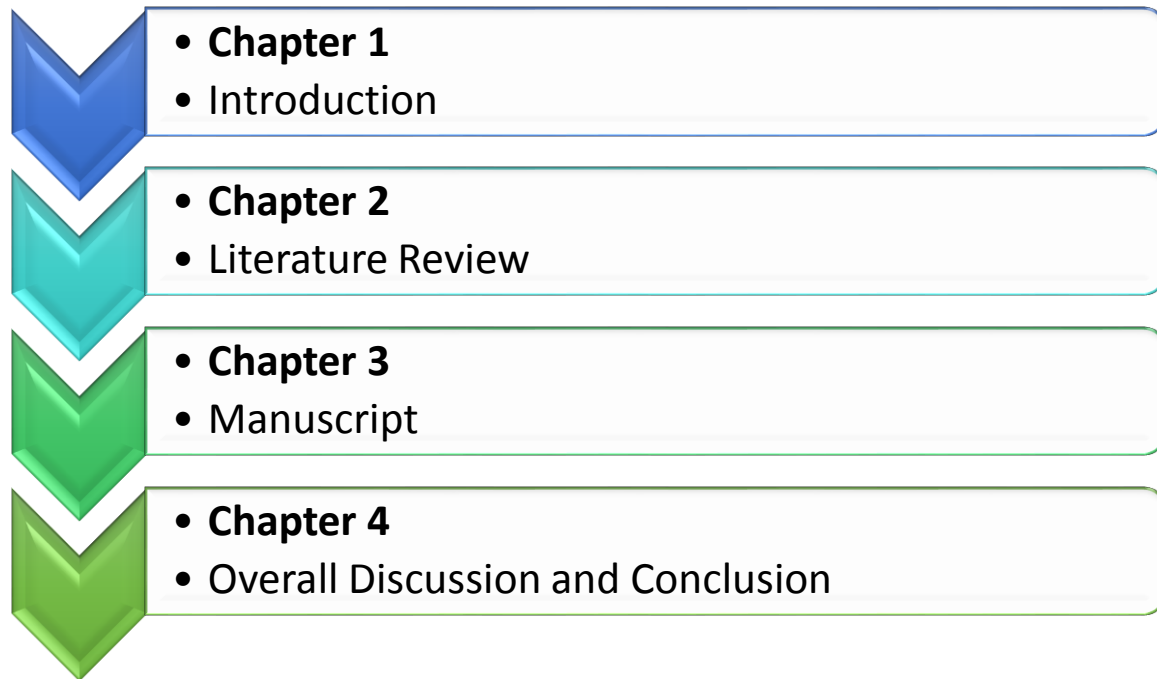


Figure 1. Outline of thesis.

Chapter 2: Literature Review

The aim of this literature review is to provide an overview of the scope of chronic groin pain in sports participants. Risk factors of groin pain, with particular reference to the pelvis will also be reviewed.

A narrative review was conducted, but in order to reduce selection bias, the following electronic databases were searched for relevant published articles through the Stellenbosch University library: *Scopus*, *Pubmed*, *Science Direct*, *Ovid*, *Lippencottt*, *Williams & Williams*, *PEDro* and *Sabinet*. Keywords used in different combinations included: '*longstanding groin pain*', '*chronic groin pain*', '*pelvis*', '*biomechanics*', '*kinematics*', '*sporting activities*', '*drop landing*', '*single leg*', '*diagnosis*', '*prevalence*', '*males*', '*three-dimensional motion analysis*' and '*lower limb biomechanics*'. The literature review was conducted between February 2012 and October 2013. Articles deemed relevant for the topics covered in this review were retrieved and included in this review.

2.1 Scope of sports related chronic groin pain

Groin injuries are common among athletes and can account for about 20% of all sporting injuries (Hawkins et al, 2001; Koulouris, 2008; Davies et al, 2010). Groin pain is difficult to resolve clinically, as it has an ambiguous aetiology (Holmich, Uhrskou, Ulnits, Kanstrup, Nielsen, Bjerg, 1999; Cowan, Schache, Brukner, Bennell, Hodges & Coburn 2004). Groin pain is common in individuals who participate in sports such as soccer, hockey and rugby. These types of sports demand frequent and quick changes in direction,

in addition to large ranges of hip motion (Kavanagh et al., 2006; Morelli & Weaver, 2005). Cutting and twisting movement forces transmit even greater forces through the pubic symphysis (Morelli & Espinoza 2005). Due to the adductor group tendonous insertion into the pubic symphysis, these quick changes in direction place strain on the adductor muscles (Kavanagh et al., 2006). Tyler *et al.* (2001) and Quinn (2010) propose that the primary function of the adductor muscle group is adduction of the hip in open chain motions, such as swing phase during walking and running, as well as stabilization of the pelvis and hip joint in the frontal plane during closed chain motions such as the stance phase of the walking gait cycle. The adductor group is thus active throughout walking and running due to its insertion into the pubic symphysis (Tyler et al., 2001; Quinn, 2010). The adductor muscles are further more susceptible to greater forces during movements that require quick changes in direction or landing movements, which are typically performed in sports (Kavanagh et al., 2006). 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 by eccentric attenuation of the knee muscles during the landing phase. This in turn 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 and consequent downward lateral tilting of the pelvis on the landing side. Lawrence *et al.* (2008) also describes that landing strategies are a contributing risk factor in lower limb injuries. This may explain why groin pain is more prevalent in certain types of sports.

Groin injuries have the potential to lead to chronic and career-ending pain in sports participants (Kavanagh et al., 2006). It is responsible for time away from training since it can be poorly responsive to treatment (Davies et al. 2010). Often patients are unable to return to their sporting activities and this may have great economic repercussions on professional sporting clubs and the individual (Koulouris, 2008; Davies et al., 2010). Of concern is that almost one third of soccer players will develop groin pain during the course of their sporting career (Smolaka, 1980). Groin pain in athletes is thus a common and disabling impairment (Koulouris, 2008; Davies et al., 2010; Jansen, Mens, Backx & Stam, 2010).

2.2 Aetiology and diagnostics of groin pain

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 adductor muscles and perineum, and the upper anterior thigh and hip. Diagnosing the underlying cause of chronic groin pain is difficult, but essential for optimal management of the patient (Morelli & Smith 2001). Typically, patients with chronic groin pain will present with local tenderness at the origin of the adductor longus muscle, pain on passive stretching and resisted contraction of the adductor group and pain with exercise or kicking (Holmich, 2007). Imaging such as ultrasound and MRI can also be used to determine tendon thickening, interstitial tearing, pubic bone marrow oedema and osteophyte formation in the region of the pubic symphysis (Robinson, Barron, Parsons, Schildes, Grainger & O'Connor, 2004). These changes are often due to the repetitive stress to the adductor

longus tendon (Robinson, Barron, Parsons, Schildes, Grainger & O'Connor, 2004; Holmich, 2007). As a result, an enthesopathy (inflammation or disease of the point at which a tendon joins to a bone) develops from this repetitive microtrauma which in turn causes micro-tears and leads to a long-term cycle of tendon injury and repair (Machotcka, Kumar & Perrason, 2009). Osteitis pubis and adductor enthesopathy often co-exist in chronic groin pain which leads to instability at the pubic symphysis due to weakness which affects the biomechanics of the adductor muscles (Machotcka et al., 2009). To date, diagnosis of the underlying cause in adductor-related chronic groin pain is not definitive.

Sixty-two percent of groin injuries are as a result of adductor strains (Morelli & Weaver, 2005). Other associated pathologies which may lead to chronic groin pain include osteitis pubis, sports hernia, bursitis, snapping hip syndrome, osteoarthritis of the hip joint, acetabular labral tears, femoral-acetabular impingement, muscular strains/tears or contusions, stress fractures (pubic, sacroiliac and femoral) and avulsion injuries (Davies et al., 201; OHackney, 2012). Groin pain can also be referred from the lumbar spine or as a result of pelvic nerve entrapment (Davies et al., 2010). Gynaecological pathology has also been linked to a cause of groin pain in female athletes (Cross, 2010). Each condition, however, has overlapping symptoms and objective findings which makes a definite diagnosis difficult (Davies et al., 2010). Currently, there is much controversy in defining groin pain due to the difficulty of diagnosis, but also because 27% to 90% of patients presenting with groin pain have more than one co-existing groin pathology (Morelli & Weaver, 2005; Holmich, 2007; Maffey & Emery, 2007). Groin pain in athletes is thus a

complex impairment which requires further research and attention (Koulouris, 2008; Davies et al., 2010; Jansen et al., 2010).

2.3 Risk factors related to chronic groin pain in sport

Risk factors in chronic groin pain can either be modifiable or non-modifiable (Maffey & Emery 2007). Modifiable factors include muscle endurance and muscle strength imbalances, whereas non-modifiable factors are age, gender, leg length discrepancy and previous injury of the individual. Risk factors for groin pain are related to the body's kinematic chain. The biomechanics of the foot, ankle, knee, hip, thoracic spine and pelvis may be associative factors for chronic groin pain (Morelli & Weaver, 2005; Maffey & Emery, 2007).

In the systematic review of Maffey & Emery 2007, which included 11 articles, the authors found that hip abductor to adductor strength imbalances are risk factors for groin strain in sport. This is also shown in an earlier prospective cohort study and randomized control trial (RCT) which concluded that decreased muscle strength, especially the strength of the hip abductor to adductor muscles are predictive of adductor groin strain (Emery & Meeuwisse, 2001; Holmich et al., 2010). It was proposed that the mechanism of injury in groin injuries of ice hockey players is due to the eccentric load of the adductors attempting to decelerate the leg during a stride (Tyler et al., 2001). These muscular imbalances may also be risk factors to other injuries such as anterior knee pain, iliotibial band syndrome, medial tibial stress syndrome, Achilles tendinosis, plantar fasciitis and stress fractures (Niemuth et al., 2005). A shortcoming of the study by Niemuth *et al.* (2005), was that they

used a hand-held dynamometer which could have affected the reliability of the measurements and the study was not case-controlled matched. Another descriptive study of 211 athletes found the significant differences between the hip abductors and extensor muscle strength was linked to developing low back pain (LBP) (Nadler, Malanga & Bartoli, 2002). Co-contractions between the abductor to the adductor groups, especially the gluteus medius and adductor longus muscles, are important in maintaining the pelvis in the frontal plane (Seniam, 2011). Thus improving the adductor to abductor strength ratio will benefit patients with chronic groin pain and will affect their pelvic kinematics by maintaining the pelvis stable in the frontal plane.

Some evidence for adductor strains due to muscle strength imbalances between propulsive and stabilizing/core muscles of the hip and pelvis exists (Meyers et al., 2000). Maffey and Emery (2007), suggest that a large percentage of groin pain may actually be due to inadequate absorption of ground reaction forces 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 and consequent lateral tilting of the pelvis on the landing side. It was also demonstrated that athletes with adductor-related groin pain showed a delay in the transversus abdominus (TrA) when performing an active straight leg raise (ASLR) (Cowan et al., 2004). Strengthening the stabilizing/core muscles of the pelvis (TrA, obliques, diaphragm, multifidi and pelvic floor muscles) and gluteal muscles led to the possibility that improving pelvic stability may lead to the adductors and abductors in working more explosively and preventing strain of the lower back (Cusi et al., 2001). A

RCT also demonstrated a decrease in pain in the intervention group after strength training of the hip and core muscles as treatment for athletes with chronic adductor-related groin pain (Holmich et al., 1999). Shortcomings of this study, however, were that they aimed to restore muscle strength (only hip abductors and adductors) with balance training. The strengthening program was also insufficient to affect the maximum oxygen intake since muscle endurance with sport-specific exercises were not included. The pelvic stabilizing/core muscles may thus play a role in preventing adductor-related groin pain.

Due to poor validity and reliability of testing methods, there is inconclusive information regarding adductor length as a risk factor for groin pain (Maffey & Emery, 2007). A study using Australian football players suggested a decrease in quadriceps flexibility was an independent predictor for hamstring injuries (Gabbe et al., 2005). This finding may suggest that muscle length of the synergistic and antagonistic muscles (abductors and hip flexors) may be a risk factor for groin pain and not adductor muscle length (Maffey & Emery, 2007). As previously mentioned, the adductor to abductor strength ratio affects the pelvic kinematics in the frontal plane. Thus, it may be hypothesized that the hip adductor to abductor length differences may also have an effect on the stability of the pelvis in the frontal plane.

The literature reviewed in this section illustrated that modifiable risk factors such as hip adductor to abductor strength ratio, pelvis/core strength and adductor length may be linked to groin pain and other lower quadrant injuries. It is important to understand and diagnose the underlying risk factors as chances of sustaining a recurrent groin injury is

almost double (Holmich et al, 2010). However, there are gaps in our understanding of groin pain. The evidence base is very limited and often not of good quality, with small samples and poor definitions of chronic groin pain.

2.4 Anatomy of the pelvic region and pathology of chronic groin injuries

According to a literature review done by Davies *et al.* (2010), the pelvic complex consists of two innominate bones that join anteriorly through a non-synovial, diarthrodial joint called the pubic symphysis and posteriorly by the sacrum. To ensure the mechanical integrity of the joint during weight-bearing of the trunk from the sacrum to the hips, the pubic symphysis is formed via the two innominates by various ligaments namely the anterior and posterior pubic ligaments, arcuate pubic ligament and the inter-pubic-fibro-cartilagenous lamina (Davies et al., 2010). The superior fibres of the anterior and posterior pubic ligaments crosses in an oblique formation to blend into the aponeuroses of the external oblique and rectus abdominus muscles. Most of the pubic symphysis joint stability is formed by the inter-pubic fibro-cartilagenous lamina and the arcuate ligament (Gray, 2000).

There are 22 muscles acting on the hip joint that provide stability and movement (Byrne, Mulhall & Baker, 2010). Of these, six are adductors of the hip, namely the adductor longus, adductor magnus and adductor brevis, gracillis, obturator externus and pectinius. The adductor muscle group together with the abdominal muscles play a vital role in the stabilization of the symphysis pubis (Davies et al., 2010). Through the abdominal

muscles and the aponeurosis, the symphysis pubis is connected to the xyphoid process of the sternum. Laterally to the inguinal ligament, the internal oblique and the TrA muscles arise and flows into the capsular tissues of the anterior symphysis pubis medially to the inguinal ligament (Davies et al., 2010). The adductor longus, more commonly than the adductor brevis, also attaches into these capsular tissues. The symphysis pubis capsular and disk structures are closely related to the rectus abdominis, adductor longus and brevis muscles and the inguinal ligament (Robinson et al., 2007).

Davies *et al.* (2010) stated that the abdominal muscle attachment to the thoracic cage and pubis, function synergistically with the posterior paravertebral muscles to stabilize the symphysis pubis. During a kicking action, the adductors bring the lower extremity closer to the pelvis due to their origin from the pubis and insertion into the medial femur. While the synergistic abdominal muscle - and posterior paravertebral muscle groups allow balance during a single-leg stance and contribute to the power of the kicking leg, the adductor muscle group transfers mechanical traction forces towards the symphysis pubis and acts as the primary mover of the kicking leg (Davies et al., 2010). Imbalances between these muscle groups disturb the equilibrium of the symphysis pubis (Davies et al., 2010).

According to Davies *et al.* (2010), chronic groin pain that develops due to adductor muscle dysfunction can occur from two conditions namely chronic myotendinous strain or tenoperiosteal disease (enthesopathy). It can be speculated that this myotendinous strain results from an alteration in the motor control strategies during load transfer between the pelvis and the lower extremities (Cowan et al., 2004; Morrissey et al., 2012). Cowan *et*

al. (2004) hypothesized that optimal control of the transversely orientated abdominal muscles (core) stabilizes the pelvic ring and plays a role in chronic groin pain. The authors concluded that when performing an active straight leg raise (ASLR), patients with chronic groin pain showed a delayed onset of the TrA muscle when compared to healthy controls. This delayed onset of the TrA compromises the pelvic ring and leaves it unprotected from forces which can lead to strain on the adductors etc. (Cowan et al., 2004). This is supported by other studies which found a delay in the recruitment of the TrA in patients with lower back pain (LBP) and sacro-iliac joint (SIJ) pain (Hogan, 1998; O'Sullivan, Beales, Beetham, Cripps, Graf & Lin, 2002; Hungerford, Gilleard & Hodges, 2003). This deficit in motor control can lead to chronic groin pain (Cowan et al, 2004). Weak pelvis stabilizing/core muscles have been associated with increasing the strain on the adductors (Meyers et al., 2000; Cusi et al., 2001, Cowan et al., 2004). Another mechanism of injury was reported Hackney (2012) who indicated that forced abduction of the hip was the most common cause of adductor strain, occurring most frequently at the musculo-tendinous junction. Enthesopathy or myotendinous strain involves muscle spasm, atrophy and weakness. The adductor longus is most commonly affected whereas the gracilis, adductor brevis and magnus are rarely affected due to their posterolateral position (Davies et al., 2010). Chronic adductor pain results from repetitive strain at the musculo-tendinous junction due to poor motor control of the hip and pelvic muscles or due to a recruitment delay of the abdominal muscles, mostly the TrA (Cowan et al., 2004). Since the pelvic anatomy and structures are complex and interrelated (Davies et al., 2010; Morrissey et al., 2012), further research on the role that the pelvis anatomy plays in pelvic kinematics and biomechanics of patients with chronic groin pain is therefore warranted.

2.5 Pelvic stability

Maffey and Emery (2007), suggested that a large percentage of groin pain may actually be due to inadequate absorption of ground reaction forces by eccentric attenuation by the knee muscles during the landing phase. This may lead to strain on the adductor muscles due to inability to maintain the centre of gravity within a small base of support during single leg landing and consequent lateral tilting of the pelvis on the landing side. The hip adductors are vital in stabilization of the lower limb during an activity and any impairment to the adductors may predispose an individual to pain or injury (Niemuth et al, 2005; Seniam, 2011). During mid-stance of the gait cycle, co-contraction of the abductors and adductors are critical for pelvis stabilization in the frontal plane, preventing a pelvic lateral tilt similar to a mild Trendelenburg drop (Tyler et al., 2001; Quinn 2010; Nicola & Jewison 2012; Seniam, 2011; Morrissey et al, 2012). Gabbe *et al.* (2010) suggests that poor pelvis stabilization muscles such as weak core muscle strength can account for 32% of sports-related groin pain.

Pelvic stability can be defined as *“the effective accommodation of the (pelvic) joints to each specific load demand through an adequately tailored joint compression, as a function of gravity, coordinated muscle and ligament forces, to produce effective joint reaction forces under changing conditions”* (Vleeming, Albert, Ostgaard, Stuesson & Stuge, 2008, p. 798). For effective load transfer and stability of the pelvis, optimal functioning of the passive, active and neuromotor joint control systems are required (Vleeming, Stoeckaart, Volkers & Snijders, 1990a; Panjabi, 1992; Snijders, Vleeming &

Stoekart, 1993). Evidence regarding the pelvic core muscle strength as well as the hip musculature and their function or influence on the pelvic kinematics (lumbo-pelvic and femoro-pelvic) remains elusive (Morrissey et al., 2012). The adductor and abductor muscles therefore play an important role in the stabilization of the pelvis during functional activities.

2.6 Pelvis kinematics during a single leg drop landing

Single-leg landing is a common sporting action and is performed from varying vertical heights and horizontal distances during sports such as soccer and basketball (Dufek & Bates, 1991). Vertical height and horizontal distance landings pose different landing effects on joint kinematics that can cause different injuries due to the total ground reaction forces (Ali, Robertson & Rouhi, 2012). For example, patients landing with increased knee abduction may result in a valgus collapse of the knee which is a risk factor for ACL injuries (Olsen, Myklebust, Engelbretsen, Holme & Bahr, 2005; Krosshaug, Nakamae & Boden, 2007). During a jump landing, the landing phase is shown to be more stressful than the take-off phase (Chappell et al., 2002). Thus, lower limb injuries are common during the landing phase.

The pelvis undergoes kinematic changes in the frontal and transverse plane during a single-leg drop-landing (Takacs & Hunt, 2012). Vialle *et al.* (2005) suggests that the mean pelvic tilt angle for asymptomatic subjects in the normal standing position is $13^{\circ} \pm 6^{\circ}$, with the pelvis slightly anteriorly inclined. To our knowledge the literature failed to demonstrate existing evidence on pelvic kinematics in the sagittal, frontal and transverse planes for

patients with chronic groin pain or asymptomatic subjects during the gait pattern or when performing a single-leg jump or drop landing.

2.7 Summary

This literature review provided an overview on the prevalence, anatomy and pathology of chronic groin pain. Although the evidence is limited to a small number of studies, biased designs and relatively small sample sizes, the normal pelvic kinematics during the landing phase of walking, a single-leg drop-landing and the effect of muscle strength imbalance, fatigue or overload of the pelvic stabilizers were described. There is no evidence around the association between chronic groin pain and lower limb biomechanical risk factors. To date, no biomechanical studies have been conducted exploring the biomechanics of the pelvis in individuals with chronic groin pain. Such information will be useful since the prevalence of groin injuries in specific sporting activities is high.

Chapter 3: The manuscript

Manuscript to be submitted to Physical Therapy in Sport Journal

Author guidelines included as Appendix 1

PELVIC KINEMATICS DURING SINGLE-LEG DROP-LANDING IN SPORTS PARTICIPANTS WITH CHRONIC GROIN PAIN

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Abstract

Objectives: To determine if there are differences in the pelvic kinematics of active sports participants with chronic groin pain compared to healthy control during a single-leg drop-landing task.

Design: Descriptive study incorporating a cross-sectional design

Setting: FNB-3D motion analysis laboratory, Stellenbosch University, South Africa,

Participants: Ten cases with chronic groin pain and ten asymptomatic matched controls participated.

Main Outcome Measures: Three-dimensional (3D) pelvic kinematics at initial foot contact (IFC) and lowest vertical position (LVP).

Methods: A physical examination, including functional movements, posture analysis, hip, knee and ankle passive range of motion measurements, sacro-iliac tests and anthropometric measurements was done by two physiotherapists prior to the 3D analysis. To analyze the pelvic kinematics, each participant performed six single-leg drop-landings. The following sub-groups were analyzed: seven with unilateral groin pain and three with bilateral groin pain; the latter was further divided into those with the most painful leg and the least painful leg. Mean and standard deviations (SD) for pelvic kinematics were calculated and significant differences between sub-groups were determined using two-tailed Student's t-tests. The Cohen's D effect size calculator was used to calculate the effect size of significant differences in pelvic kinematics between case and control groups.

Results: The findings indicated a significant difference ($p=0.03$) in frontal plane pelvic kinematics at IFC for the unilateral groin pain group. The most painful groin group showed significant differences at IFC ($p=0.004$) and at LVP ($p=0.04$) in the frontal plane pelvic kinematics. The least painful groin group showed a significant difference at LVP ($p=0.01$). All cases landed with pelvic downward lateral tilt during the landing phase compared to matched controls. The groin pain group with bilateral pain showed significant differences

at IFC ($p < 0.001$) and LVP ($p=0.005$) for the most painful groin; and the least painful groin at IFC ($p=0.01$) and LVP ($p=0.01$) in the sagittal plane pelvic kinematics. The bilateral groin pain group showed an increase of anterior pelvic tilt in the sagittal plane during the landing phase when compared to matched controls. Increased internal pelvic rotation in the transverse plane was significant for the unilateral group at IFC ($p=0.04$) and for the most painful groin group at IFC ($p < 0.001$) and LVP ($p < 0.001$) compared to matched controls.

Conclusion: The study findings show that sports participants with groin pain have altered pelvic kinematics in all three planes during drop landing compared to controls. This implies that muscle weakness around the hip and pelvis may contribute to the development of chronic groin pain.

Keywords: chronic groin pain; pelvis; kinematics

1. Introduction

Chronic groin injuries account for up to 18% of all sporting injuries, it is persistent and can be career-ending (Hawkins, Hulse, Wilkinson, Hodson & Gibson, 2001; Koulouris, 2008; Kavanagh et al., 2006; Davies, Clarke, Gilmore, Wotherspoon & Connell, 2010). About 62% of groin injuries involve adductor strains, although other associated pathologies such as osteitis pubis and sports hernia should be excluded (Morelli & Weaver, 2005).

Athletes with groin pain have discomfort in the anterior region of the lower abdomen, adductor and inguinal regions as well as the upper anterior thigh and hip (Cross 2010; Davies et al., 2010; Hackney, 2012). Groin pain can also be referred from the lumbar spine or as a result of pelvic nerve entrapment (Davies et al., 2010). Groin pain in athletes is thus a common, disabling and complex impairment (Davies et al., 2010; Jansen, Mens, Backx & Stam 2010; Koulouris, 2008).

Diagnosing the underlying cause of chronic groin pain is important for optimal management of the patient (Morelli & Smith 2001). Typically, patients with chronic groin pain will present with local tenderness at the origin of the adductor longus muscle, pain on passive stretching, resisted contraction of the adductor muscle group and pain with exercise or kicking (Holmich, 2007). Hackney (2012) indicated that forced abduction of the hip was the most common cause of adductor strain, occurring most frequently at the musculo-tendinous junction. This is known as an enthesopathy or myotendinous strain and involves muscle spasm, atrophy and weakness (Davies et al., 2010). The adductor longus muscle is most commonly affected whereas the gracilis, adductor brevis and magnus muscles are rarely affected due to their posterolateral position (Davies et al.,

2010). Accurate diagnosis to determine the exact involved structures will therefore assist the patient and therapist in optimizing management.

The biomechanical factors that may be associated with groin pain is under-investigated. A large percentage of groin pain may be due to the inability to properly transfer load from the legs and torso to the pelvis (Maffey & Emery, 2007). Load transfer during the mid-stance phase of the gait cycle is important (Maffey & Emery 2007). In this moment, co-contraction of the hip abductors and adductors are critical for pelvic stabilization in the frontal plane, preventing a pelvic lateral tilt similar to a mild Trendelenburg drop (Tyler, Nicholas & Campbell 2001; Quinn 2010; Nicola & Jewison 2012; Morrissey, Graham, Screen, Sinha, Small, Twycross-Lewis & Woledge, 2012). Poor pelvic stabilization due to e.g. weak core muscle strength arguably account for 32% of sports-related groin pain (Gabbe et al., 2010). Furthermore, strength imbalances between the abductor and adductor muscle strength may be risk factors for groin strains in sport (Maffey & Emery 2007). It is proposed that the mechanism of injury in groin injuries of ice hockey players is the eccentric load place on the adductors attempting to decelerate the leg during a stride (Tyler et al., 2001). Co-contractions between the abductor to the adductor groups, especially the gluteus medius and adductor longus are important in maintaining the pelvis in the frontal plane (Seniam, 2011). Hip abductor and adductor strength plays a role in the stabilization of the pelvis and imbalances between these muscles may pose as a risk factor for developing chronic groin injuries. Abnormal pelvic kinematics and poor muscle strength are therefore likely to be associated with chronic groin pain.

To our knowledge there is currently no research on pelvic kinematics in sports participants with chronic groin pain. Altered pelvic kinematics may lead to the development of chronic groin pain as well as other lower extremity overuse injuries (Niemuth, Johnson, Myers & Thieman, 2005). The aim of this study was thus to determine if there are differences in 3D- pelvic kinematics of active sports participants with chronic groin pain compared to healthy matched controls.

2. Methodology

2.1 Ethical considerations

Ethical approval was obtained from the Human Research Ethics Committee of the University of Stellenbosch (reference number S12/10/265) (Appendix 2). The project was conducted according to the internationally accepted ethical standards and guidelines of the Declaration of Helsinki, the South African Guidelines of the South African National Health Act No. 61 2003 as well as the South African Medical Research Council Ethical Guidelines for Research. Informed consent was obtained from all participants (Appendix 3).

2.2 Study design

A cross-sectional, descriptive study was conducted at the FNB 3D motion analysis laboratory, Stellenbosch University, Tygerberg Campus, Cape Town, South Africa.

2.3 Sample recruitment and eligibility criteria

Twenty male participants, ranging from 18 to 54 years of age without any history of spinal, lower limb or pelvic pathology were conveniently selected to participate in the study. The

participants were recruited from soccer, hockey, rugby, running and cycling clubs in the Western Cape, South Africa. Ten cases with chronic groin pain (> three months in duration) of any intensity and ten asymptomatic matched controls were recruited. The cases and controls were matched according to age and type of sport. The participants were screened and recruited by two experienced musculoskeletal physiotherapists. According to the inclusion and exclusion criteria (Table 1). The screening protocol was based on previous studies. (Delahunt et al., 2011).

Table 1. Inclusion and exclusion criteria for participants

Inclusion criteria for cases	Exclusion criteria for all participants
Soccer, hockey, rugby, hockey runners or cyclists at club level	Any orthopaedic surgical procedure of the lower quadrant and lumbar spine within the last twelve months
Complaining of chronic groin pain of any intensity for at least 3 months	Positive findings on previous imaging for bony lesions
Positive adductor squeeze test at 45° of hip flexion with a sphygmomanometer (Delahunt et al, 2011).	Any disease that has an influence on functional ability/movement, e.g. Ankylosing Spondylitis, Scheuermann's disease, Rheumatoid Arthritis, Muscular Dystrophy or Paget's disease
Still participating in sport or other physical training	
Good general health	
Inclusion criteria for controls	
Pain free in the lower quadrant and no groin pain	
Soccer, hockey, rugby, hockey runners or cyclists at club level	
Still participating in sport or other physical training	
Good general health	

2.4 Instrumentation

An eight camera T-10 Vicon (Ltd) (Oxford, UK) system with Nexus 1.8 software was used to analyze a single-leg drop-landing task. The Vicon motion analysis system is a three-dimensional (3D) system which is used in a wide variety of ergonomics and human factor

applications. 3D motion analysis technology has been widely used in gait studies and is regarded as the gold standard for 3D analysis of movement due to good reliability and validity (Windolf, Gotzen & Morlock, 2008; McGinley et al., 2009; Chung & Ng, 2012).

2.5 Procedures

Each participant was scheduled for a 90-minute session in the Stellenbosch University's FNB 3D motion analysis laboratory. During this session a physical examination was done for each participant by two experienced musculoskeletal physiotherapists. The examination included the following: leg dominance testing, postural observation (feet, knees, pelvis, lumbar and thoracic spine) and functional assessment including lunges and squats. Coughing which increases the intra-abdominal pressure and other special tests to exclude nociception from the sacro-iliac joint (SIJ) and hip joints were also conducted. Following the physical examination, anthropometric measurements were taken by an experienced laboratory technician. This consisted of measuring the participant's body height, weight, leg length and width of both knees and ankles. Leg length was measured from the anterior superior iliac spine (ASIS) to the medial malleolus.

Retro-reflective markers were placed on bony landmarks of the thoracic and lumbar spine, the posterior superior iliac spine (PSIS) and the anterior superior iliac spine (ASIS), the hip, knee and ankle by a physiotherapist with experience and training in marker placement according to the conventions for the Plug-in-Gait (PIG) model (Appendix 4). All reflecting clothing or objects were either removed or covered to prevent interference with the camera system. System calibration was done according to standard Vicon procedures and model calibration of each participant was captured with the subject

assuming a standard T-position (standing with feet hip distance apart and arms abducted to 90 degrees).

To determine the distance from the drop-landing-box to the landing surface on the force plate, 60% of the participant's leg length was calculated. After the physiotherapist demonstrated the drop-landing task, each participant performed single-leg drop-landings on each leg from a 20 cm high step. The subject was allowed one practice drop-landing on one leg. The landing leg (either landing on the right or left leg) was randomly chosen using coin tossing. The following instructions: "Ready, Jump!" was given by the laboratory technician capturing the data. The participants were instructed to maintain the landing position for five seconds. If a participant lost his balance or there was a data capturing failure, the drop-landing task was repeated. Twelve trials, six landings on the left leg and six landings on the right leg, were captured for each participant for analysis.

2.5.1 Data processing

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

2.6 Kinematic Outcomes

To determine if there were differences in pelvic kinematics of sports participants with chronic groin pain compared with healthy controls, the following outcome variables were calculated:

- 3D pelvic kinematics at initial foot contact (IFC). IFC was defined by the moment in time when any part of the foot came into contact with the force plate and the vertical force on the plate exceeded the threshold of 30N.
- Total range of pelvic kinematics in any of the three planes was the range from IFC to the lowest vertical position (LVP).
- 3D pelvic kinematics at LVP. LVP was defined by the moment in time where the centre point of the pelvis reached its lowest vertical position. The centre point was calculated using the four pelvic markers.

2.7 Sample size

A post-hoc sample size calculation was performed using GPower (Version 3.1) statistical power analysis program. Considering a medium size effect of at least 0.15 (alpha 0.05) and 14 participants (seven cases with unilateral groin pain and seven controls), the power was calculated to be 73%. In order to detect a large effect size of at least 1 (alpha 0.05) and a huge effect size of at least 1.45 (alpha 0.05) the post-hoc power had to be 50% and 80%, respectively for the subgroup of six participants with bilateral groin pain (three cases and three controls).

2.8 Data analysis

The case group data was divided into three different subgroups with matched control groups (Figure 2).

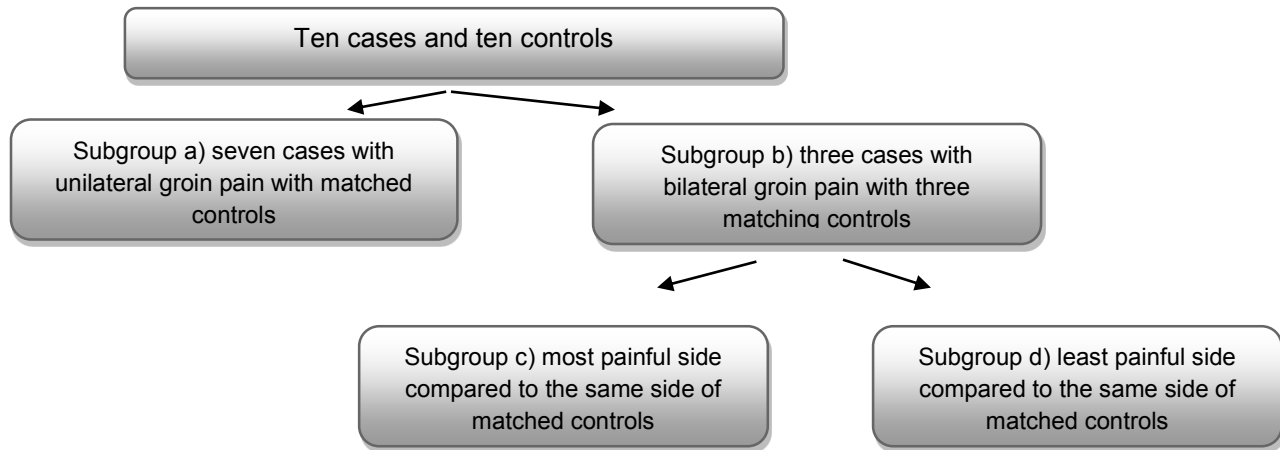


Figure 2. Divided into two main subgroups and group b) further divided into 2 subgroups

Descriptive statistics (means and SD's to indicate variability) were used to describe the participants' demographics. The mean and standard deviations (SD) for pelvic kinematics were calculated. Significant differences in pelvic kinematics between subgroups (Figure 1) ($p < 0.05$) were determined using two-tailed Student's *t*-tests. The Cohen's D effect size calculator was used to calculate the effect size of significant differences in pelvic kinematics between the case and control groups. The relative size of the Cohen's D is illustrated in Table 2.

Table 2. Cohen's D relative size

Size of effect	Criterion values
Small effect	= 0.15 and < 0.40
Medium effect	>0.40 and < 0.75
Large effect	>= 0.75 and < 1.10
Very large effect	>= 1.10 and < 1.45
Huge effect	>1.45

3. Results

3.1 Sample description

Twenty participants (10 cases and 10 controls) participated in this study. Ten participants played rugby, four were runners, two were cyclists and there were four soccer players. The basic sample demographics are presented in Table 3. There were no significant differences in the age, weight and height among the participants. The worst VAS score immediately after the game and duration of the injury for the cases is documented in Table 3.

Table 3: Demographics of the sample (n=20)

	Age (yrs) Mean(Range)	Weight (kg) Mean (range)	Height (m) Mean (range)	VAS Mean (range)	Duration (yrs) Mean (range)
UNILATERAL PAIN GROUP AND CONTROLS (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 PAIN GROUP AND CONTROLS (n=6)					
CASES (n=3)	28.67 27 – 39	91.83 74.4 – 102.8	1.81 1.76 – 1.91	6.00 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 between cases and controls

3.2.1 Differences between cases with unilateral groin pain and matched controls

3.2.1.1 Sagittal plane

No significant differences ($p=0.86$ of IFC; $p=0.65$ at LVP) were found in the sagittal plane. (Refer to Figure 3).

3.2.1.2 Frontal plane

The cases had a significant increase in pelvic downward lateral tilt ($p=0.03$) at IFC compared to the controls (Table 4.1). There were no significant differences in the total range of motion (ROM) ($p=0.23$) and at the angle of LVP ($p=0.17$). (Refer to Figure 4).

3.2.1.3 Transverse plane

All participants landed at IFC with pelvic internal rotation. The control group had significantly more internal rotation ($p=0.04$) than the cases at IFC. No significant differences were found for average ROM ($p=0.32$) and LVP ($p=0.66$). (Refer to Figure 5).

Table 4.1 Comparison between cases with unilateral pain (n=7) and matched controls (n=7)

	Angle at initial foot contact (°) Mean (SD)	ROM (°) Mean (SD)	Angle at lowest vertical position (°) Mean (SD)
Sagittal plane			
Cases	3.80 (7.22)	4.73 (2.02)	2.64 (7.32)
Controls	4.21 (10.98)	5.30 (3.33)	3.56 (7.93)
p-value	0.86	0.38	0.65
Effect Size	N/A	N/A	N/A
Frontal plane			
Cases	-12.16 (5.94)	7.21 (2.43)	-5.10 (4.94)
Controls	-8.42 (8.70)	6.24 (4.18)	-3.54 (5.85)
p-value	0.03*	0.23	0.17
Effect Size	0.54	N/A	N/A
Transverse plane			
Cases	5.38 (3.59)	3.26 (2.54)	7.57 (3.80)
Controls	7.18 (3.67)	2.85 (1.91)	7.18 (3.88)
p-value	0.04*	0.32	0.66
Effect Size	0.54	N/A	N/A

Sagittal plane: positive scores = anterior tilt; negative = posterior tilt

Frontal plane: positive scores = upward lateral tilt; negative scores = downward lateral tilt

Transverse plane: positive scores = internal rotation; negative scores = external rotation

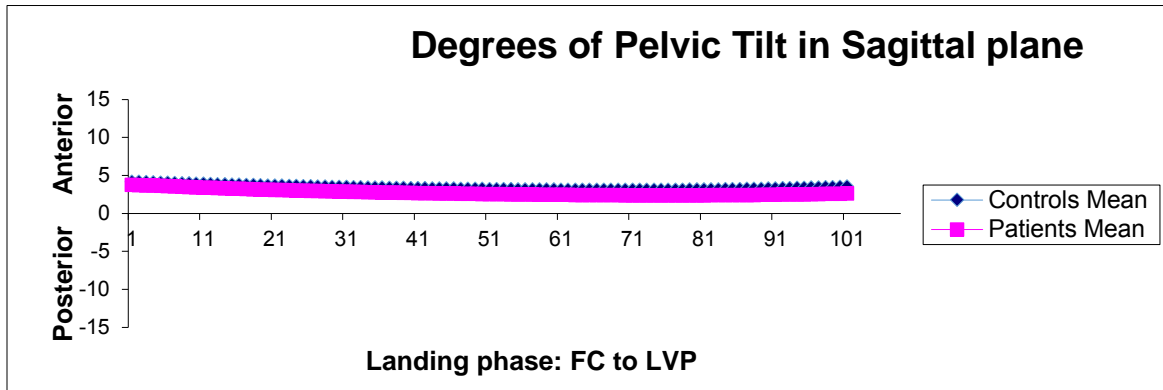


Figure 3. Degrees of pelvic tilt in the sagittal plane

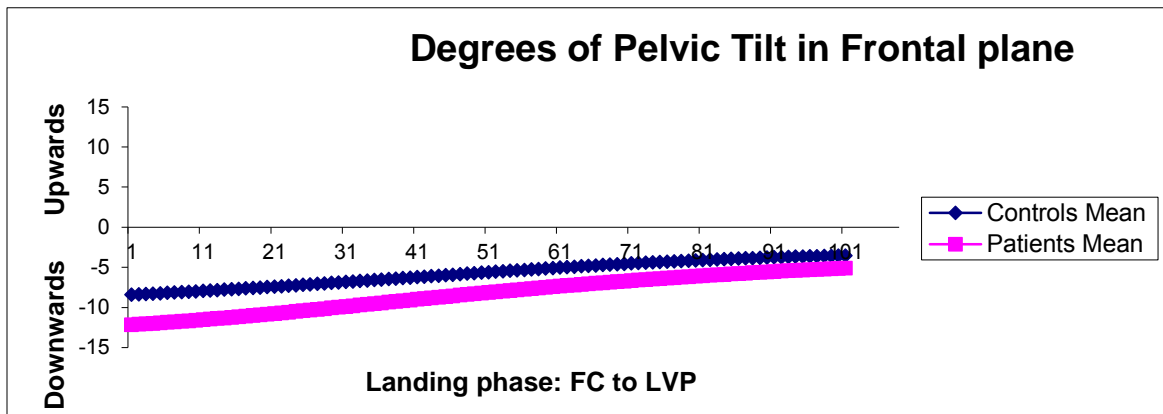


Figure 4. Degrees of pelvic tilt in the frontal plane

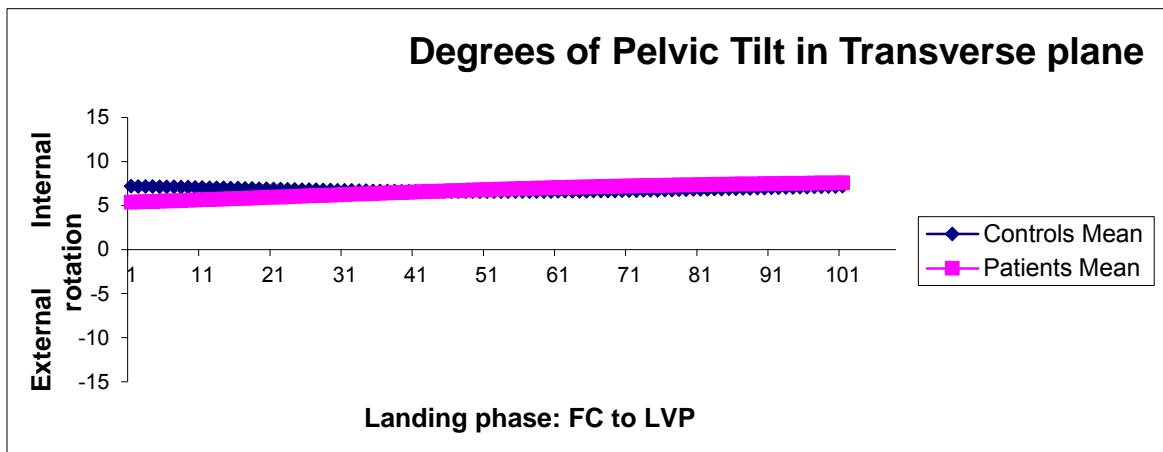


Figure 5. Degrees of pelvic tilt in the transverse plane

Figure 3-5: Indicates the 3D- pelvic kinematics for the group with unilateral groin pain

3.2.2 Bilateral cases: Most painful groin of case compared to same side of control

3.2.2.1 Sagittal plane

The cases had a significant increase in anterior pelvic tilt ($p < 0.001$) at IFC and at LVP ($p = 0.005$) compared to the controls (Table 4.2). No significant differences were found for average ROM ($p = 0.17$). (Refer to figure 6).

3.2.2.2 Frontal plane

The cases had a significant increase in pelvic downward lateral tilt at IFC ($p = 0.004$) and at LVP ($p = 0.04$) compared to controls. No significant differences were found for average ROM when compared to controls ($p = 0.10$). (Refer to figure 7).

3.2.2.3 Transverse plane

Significant differences were found for cases with increased pelvic internal rotation at IFC ($p < 0.001$) and at LVP ($p < 0.001$) compared to controls. The average ROM for cases was significantly less ($p = 0.01$) than the controls. (Refer to figure 8).

Table 4.2 Comparison between bilateral cases (n=3), most painful leg to matched side of controls (n=3)

	Angle at initial foot contact (°) Mean (SD)	ROM (°) Mean (SD)	Angle at lowest vertical position (°) Mean (SD)
Sagittal plane			
Cases	12.61 (5.99)	3.63 (1.29)	9.18 (6.07)
Controls	4.09 (4.33)	4.68 (2.54)	1.96 (7.59)
p-value	$p < 0.001^*$	0.17	0.005*
Effect Size	2	N/A	1.29
Frontal plane			
Cases	-10.86 (2.01)	6.10 (1.65)	-4.77 (2.46)
Controls	-8.88 (2.77)	7.40 (2.03)	-2.89 (2.23)
p-value	0.004*	0.10	0.04*
Effect Size	1	N/A	0.98
Transverse plane			
Cases	6.14 (2.85)	1.85 (1.18)	5.13 (2.49)
Controls	-0.48 (5.21)	3.73 (2.11)	0.93 (3.22)
p-value	$p < 0.001^*$	0.01*	$p < 0.001^*$
Effect Size	1.93	1.35	1.79

Sagittal plane: positive scores = anterior tilt; negative = posterior tilt
 Frontal plane: positive scores = upward lateral tilt; negative scores = downward lateral tilt
 Transverse plane: positive scores = internal rotation; negative scores = external rotation

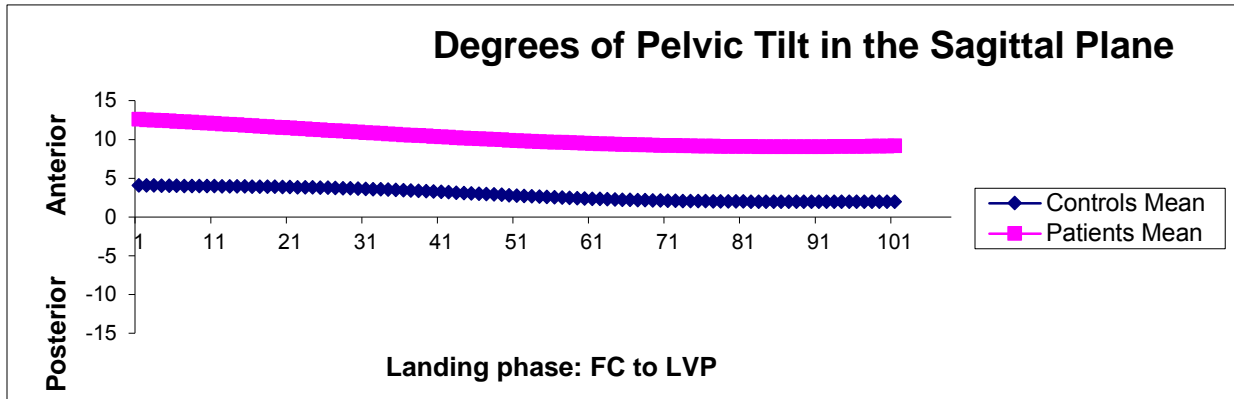


Figure 6. Degrees of pelvic tilt in the sagittal plane

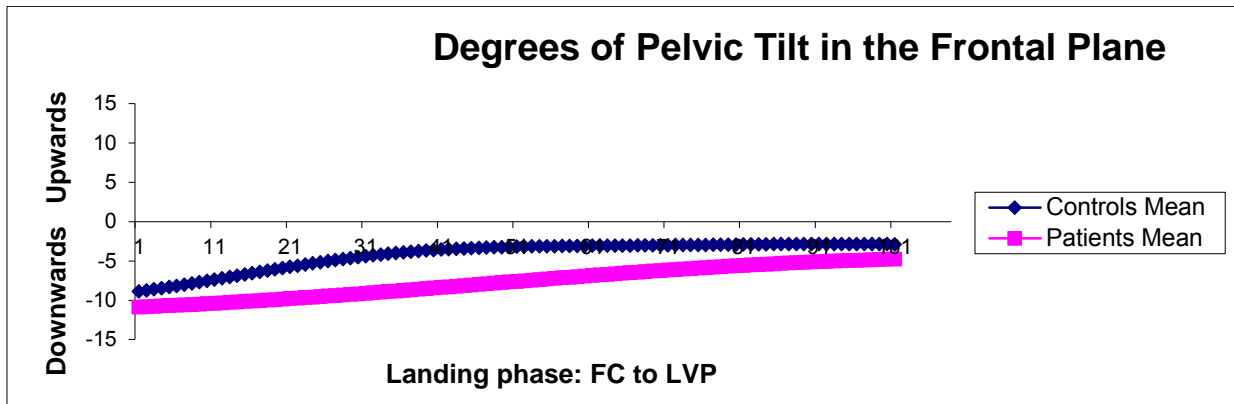


Figure 7. Degrees of pelvic tilt in the frontal plane

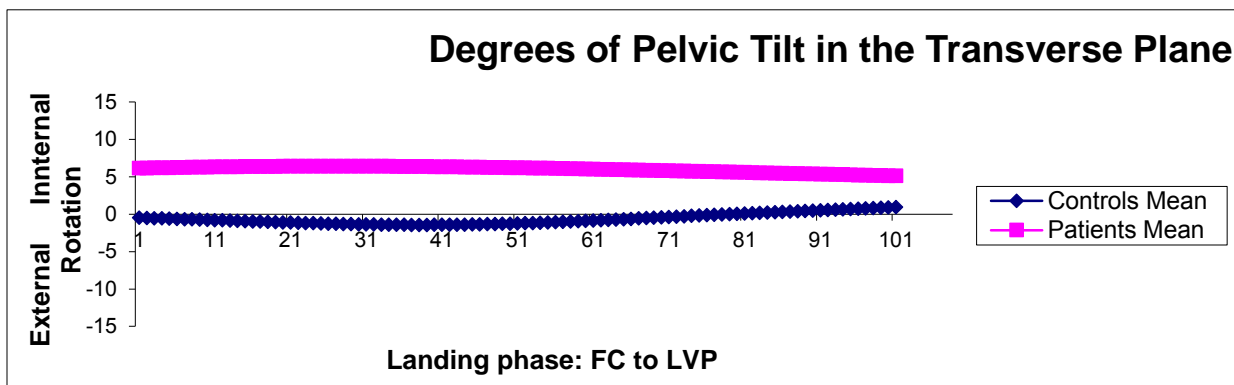


Figure 8. Degrees of pelvic tilt in the transverse plane

Figure 6-8: Indicates the 3D- pelvic kinematics for the bilateral sub-group with most painful groin

3.2.3 Bilateral cases: Least painful groin of case compared to same side of control

3.2.3.1 Sagittal plane

Significant differences were found for cases with increased anterior pelvic tilt at IFC ($p=0.01$) and at LVP ($p=0.01$) compared to controls (Table 4.3). Average ROM was significantly less for cases ($p=0.03$). (Refer to figure 9).

3.2.3.2 Frontal plane

The cases showed significant increased downward lateral pelvic tilt at LVP ($p=0.01$) and less average ROM ($p=0.04$) compared to controls. No significant differences were found at IFC ($p=0.07$). (Refer to figure 10).

3.2.3.3 Transverse plane

The cases had significantly less average ROM ($p=0.003$) compared to the controls. No significant differences were found at IFC ($p=0.65$) or LVP ($p=0.26$). (Refer to figure 11).

Table 4.3 Comparison between bilateral cases (n=3), least painful side to matched side of controls (n=3)

	Angle at foot contact (°) Mean (SD)	ROM (°) Mean (SD)	Angle at lowest vertical point (°) Mean (SD)
Sagittal plane			
Cases	10.77 (2.76)	3.43 (1.35)	7.49 (3.10)
Controls	6.08 (4.71)	5.44 (3.09)	2.33 (6.34)
p-value	0.01*	0.03*	0.01*
Effect Size	1.49	1.03	1.27
Frontal plane			
Cases	-12.40 (2.36)	7.28 (1.81)	-5.13 (3.07)
Controls	-11.00 (2.29)	8.71 (1.84)	-2.60 (2.25)
p-value	0.07	0.04*	0.01*
Effect Size	N/A	0.96	1.15
Transverse plane			
Cases	5.31 (3.22)	2.31 (1.51)	4.14 (4.21)
Controls	4.88 (2.54)	4.78 (2.96)	5.78 (5.15)
p-value	0.65	0.003*	0.26
Effect Size	N/A	1.29	N/A

Sagittal plane: positive scores = anterior tilt; negative = posterior tilt

Frontal plane: positive scores = upward lateral tilt; negative scores = downward lateral tilt
 Transverse plane: positive scores = internal rotation; negative scores = external rotation

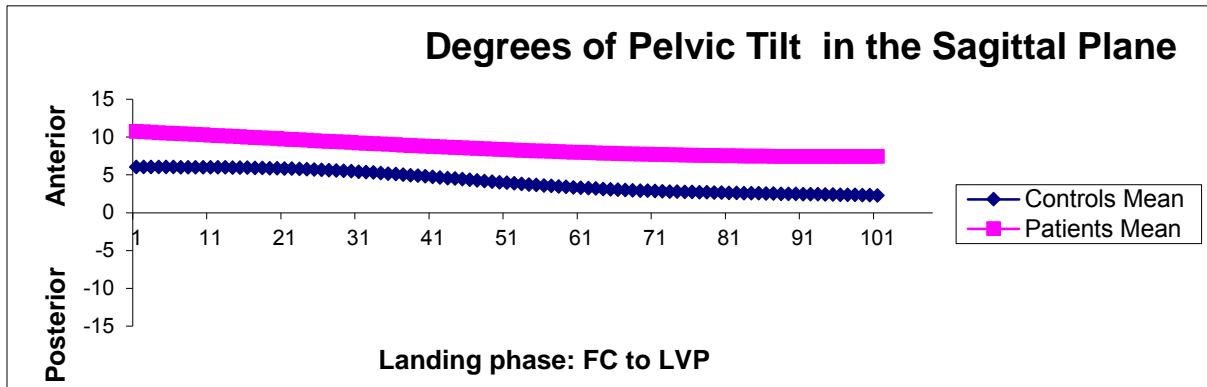


Figure 9. Degrees of pelvic tilt in the sagittal plane

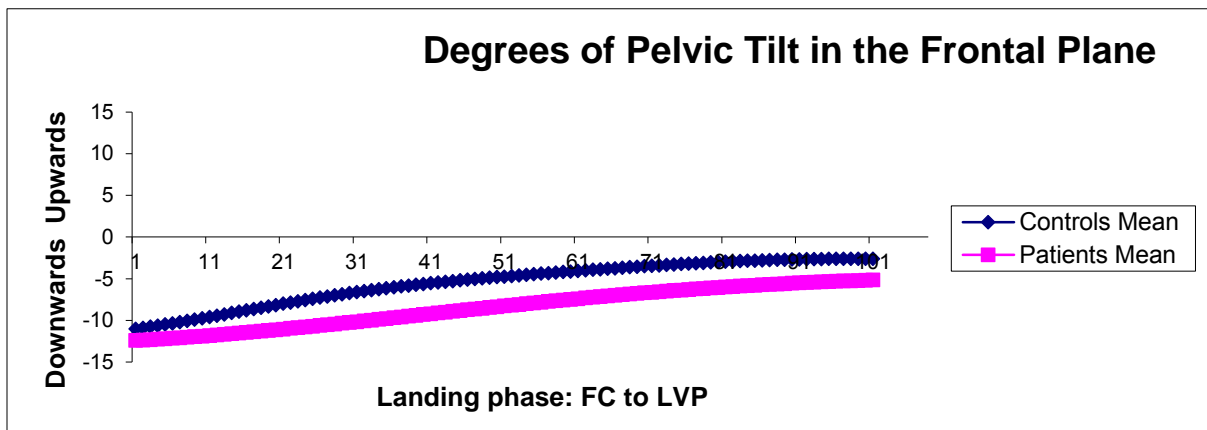


Figure 10. Degrees of pelvic tilt in the frontal plane

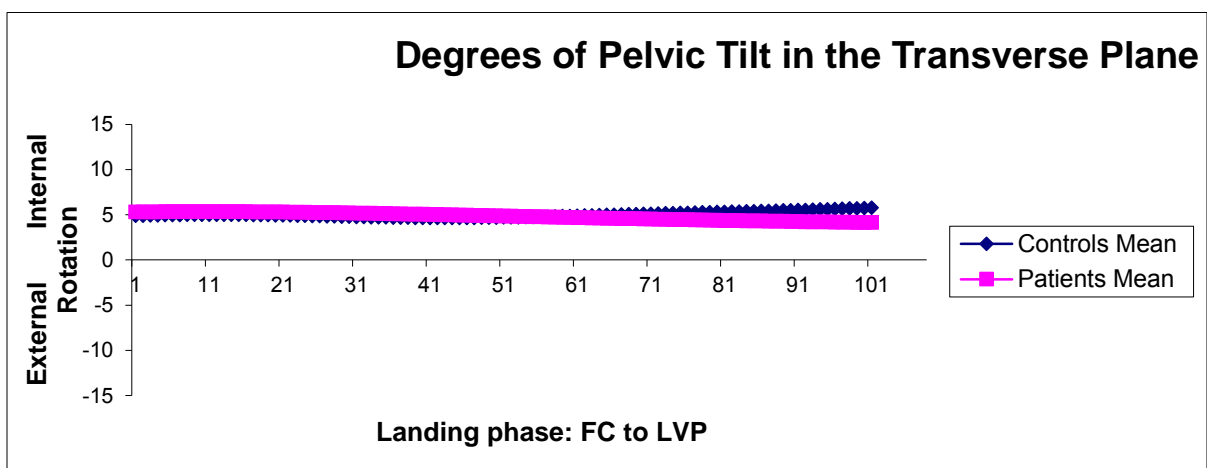


Figure 11. Degrees of pelvic tilt in the transverse plane

Figures 9-11. Indicates the 3D- pelvic kinematics for the bilateral sub-group with most painful groin

4. Discussion

This is the first study to report on 3D pelvic kinematics of sports participants with chronic groin pain while performing a single-leg drop-landing activity. Pelvic kinematics and muscle strength are likely to be associated with chronic groin pain. Our study used 20 male participants, ten cases and ten controls. Similar to other groin studies the participants were actively participating in sports such as rugby, soccer, running and cycling (Kavanagh et al, 2006; Morelli & Weaver, 2005). Evidence about pelvic and hip muscle function and its influence on the pelvic kinematics during functional tasks is scarce (Morrissey et al, 2012).

The findings of this study indicated that at IFC of a single-leg drop-landing task, the cases with chronic groin pain showed significantly increased pelvic downward lateral tilt (frontal plane) compared to controls. The 3D kinematic differences noted, could lead to inefficient load transfer, force changes around the pubic symphysis and development of groin pain and in other areas such as the lumbar spine and SIJ (Hodges & Richardson 1996; Nadler, Malanga & Bartoli, 2002; O'Sullivan, Beales, Beetham, Cripps, Graff & Lin, 2002; Hungerford, Gilleard & Hodges, 2003). Lumbo-pelvic and femoro-pelvic movement alterations occur in the presence of injury-associated muscle activation patterns (Morrissey et al., 2012). For example, during single-leg stance, the co-contraction of the abductor to adductor muscle groups, especially the gluteus medius (GM) and adductor longus (AL) are vital in maintaining the position of the pelvis in the frontal plane (Seniam, 2011). Muscle imbalances between these aforementioned muscle groups cause the

pelvis to excessively tilt laterally or even lead to a Trendelenburg movement abnormality in the frontal plane (Watelain, Dujardin, Babier, Dubois & Allard, 2001). An electromyography (EMG) study showed weaker abductor to adductor strength ratio (GM:AL) in participants with chronic groin pain performing a single-leg stance (Morrissey et al., 2012). The GM activation was especially lower on the injured leg compared to healthy controls (Morrissey et al., 2012). The ratio difference in GM strength and activation may cause an over-activity or strain on the adductor group during movement which could be aetiologically linked to chronic groin pain. No studies were found on muscle size measuring in participants with chronic adductor pain, although some have shown GM atrophy associated with hip osteoarthritis (Amaro, Amado, Duarte & Appell, 2007; Grimaldi, Richardson, Stanton, Dunbridge, Donnelly & Hides, 2009). It is evident that pelvic muscle imbalances exist in patients presenting with chronic groin pain. Pelvic lateral tilt in the cases can be caused by weak abductors that results in strain of the adductors which may lead to chronic groin pain.

Our study findings showed cases with bilateral groin pain had increased anterior pelvic tilt compared to controls at IFC and LVP during the single leg drop-landing. It is suggested that an increase in anterior pelvic tilt is associated with overuse running injuries (Geraci, 1996) but recent research supporting this is limited. EMG studies found the position of the pelvis during sporting activities very dependent on abdominal muscle activity, due to the insertion of the rectus abdominus into the anterior iliac spine (Shirado, Toshikazu, Kaneda & Strax, 1995). Higher abdominal activity was noted in participants performing a bent-knee sit-up with the pelvis in posterior tilt. The reverse was noted with the pelvis in anterior tilt (Workman, Docherty, Parfrey & Behm, 2008). In our study, this

theory could be explained by the “common-adductor-rectus-abdominus”, the origin of the adductor longus and rectus abdominus tendons into a single continuous structure (Gibbon, 1999). This common origin forms a critical biomechanical axis as both these muscles acts as dynamic stabilizers of the pubic symphysis (Gibbon, 1999). Patients with chronic groin pain will have failure of the adductor longus first which will overload the smaller rectus abdominus tendon (Koulouris, 2008). As a result, the pelvis will pull anteriorly (Workman et al., 2009). Youdas, Garrett, Egan & Therneau, (2000) suggests that anterior pelvic tilt may lead to other injuries such as lower back pain (LBP) (Workman et al., 2009). The findings of this current study correlates with other studies that patients with increased anterior pelvic tilt may be at risk of developing bilateral chronic groin pain (Shirazi-Adl, Sadouk, Parnianpour, Pop & El-Rich, 2002; Drysdale, Kennelly & Hertel, 2004).

Our study findings revealed that all cases with groin pain landed with increased pelvic internal rotation. This was noted at IFC for the unilateral group and significantly IFC ($p < 0.001$) and LVP ($p = 0.01$) for most painful leg group. However, the control group compared to the unilateral groin pain group landed in more internal rotation. Hip joint musculature plays an extremely important role in the lumbo-pelvic stabilization during ambulation (Lyons et al., 1983). Poor hip abduction and external rotation strength is often linked to poor GM strength and decrease in postural control (Cichanowski, Schmitt, Johnson & Niemuth, 2007). The GM therefore plays an important role in maintaining the pelvis in the frontal plane, as well as maintaining the pelvis in the transverse plane, preventing the femur to rotate excessively internally (Nguyen, Shultz, Schmitz, Luecht & Perrin, 2011). These findings correlate to a study by Seay, van Emmerik & Hammell

(2011), who suggested that a group of runners with LBP presented with a greater mechanical challenge to motion and coordination of the lumbo-pelvic system which resulted in increased internal rotation of the pelvis. A possible explanation for the increased internal rotation is the result from neuromuscular damage (soft tissue weakness or injury) or a pain inhibitory effect from the LBP (Seay et al., 2011). This causes coordination problems in the lumbo-pelvic system in the transverse plane and could lead to LBP and other lower extremity injuries. Weak GM strength can cause increased pelvic internal rotation during a single leg drop-landing task and can pose as a risk factor in developing chronic groin pain.

The limitations of this study are:

- Non-random samples may not be a clear representation of the groin pain population.
- This study was laboratory-based, and may not accurately reflect what happens in real life.
- Participants were only matched for age and sporting activity.
- Our study focused on pelvic kinematics during a single-leg drop-landing whereas information regarding lumbo-pelvic muscle control and activity would be valuable in future for understanding chronic groin pain.

- In this cross-sectional, descriptive study it remains uncertain whether these findings are as a result of the chronic groin pain or a causative factor.
- The small sample size, especially the group with bilateral injuries does not adequately reflect the population of patients with chronic groin pain.
- The diagnosis of groin pain remains complicated due to the many possible causes.

5. Recommendations for further research

Future research should investigate lumbo-pelvic muscle control and activation, especially GM to AL ratio by using EMG in patients performing a single leg drop-landing task. Comparison between patients with unilateral groin pain and patients with bilateral groin pain might provide better insight of pelvic control and the effect thereof on pelvic kinematics. Additional studies in which investigators evaluate the effect of increased pelvic stability by means of a pelvic belt might help us understand the importance of core stability in decreasing chronic groin pain.

6. Conclusion

Groin pain commonly occurs in various sporting activities and can result in chronic and career ending pain. The aim of this study was to determine if there are differences in 3D-pelvic kinematics of active sports participants with chronic groin pain compared to healthy matched controls. The main finding was that pelvic lateral tilt in the frontal plane was significantly more during the landing phase for cases compared to matched controls. This

may imply weakness of the abductors as stabilizers of the pelvis during the landing phase, which will impose a lengthened position of the adductors. This pattern may contribute towards the persistent nature of groin pain. Further research should be focused on muscular recruitment patterns in sports participants with chronic groin pain to critically define the muscular causal factors more in depth.

7. Acknowledgements

Funder: National Research Foundation

Other contributors to this study: M Dare, L Harwin, K Maritz, T Morris

FNB-3D Motion Analysis Laboratory and their staff.

Conflict of interests

The authors declare that they have no conflicts of interest.

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Chapter 4: Overall Summary and Conclusion

Evidence about pelvic and hip muscle function and its influence on the pelvic kinematics during functional tasks is scarce (Morrissey et al, 2012). Pelvic kinematics and muscle strength are likely to be associated with chronic groin pain. Our study used 20 male participants, ten cases and ten controls. Similar to other groin pain studies the participants were actively participating in sports such as rugby, soccer, running and cycling (Kavanagh et al, 2006; Morelli & Weaver, 2005). This is the first study to report on 3D pelvic kinematics in sports participants with chronic groin pain while performing a single-leg drop-landing task.

The findings of this study indicated that at initial foot contact of a single-leg drop-landing task, the sports participants with chronic groin pain showed a significant increase in pelvic downward lateral tilt on the landing leg when compared to their controls. This increase in pelvic downward lateral tilt may result in inefficient load transfer, changes in the forces around the pubic symphysis and the development of pain or injury to other areas such as the lumbar spine and sacro-iliac joint (SIJ) (Hodges & Richardson, 1996; Nadler et al., 2002; Hungerford et al., 2003; O'Sullivan et al., 2002). Lumbo-pelvic and femoro-pelvic movement alterations occur in the presence of injury-associated muscle activation patterns (Morrissey et al., 2012). As an example, during single-leg stance, the co-contraction of the abductor to adductor muscle groups, especially the gluteus medius (GM) and adductor longus (AL) are vital in maintaining the neutral position of the pelvis in the frontal plane (Seniam, 2011). Muscle imbalances between these aforementioned muscle groups cause the pelvis to excessively tilt downwards or can cause a

Trendelenburg type of movement abnormality (Watelain, Dujardin, Babier, Dubois & Allard, 2001). An EMG study found that during a single-leg stance, participants with chronic groin pain showed weaker activity of the abductor to adductor ratio (GM:AL) and especially lower activation of the GM on the injured leg (Morrissey et al., 2012). This ratio difference in GM strength and activation may cause an over-activity or strain on the adductor group during movement which could be aetiologically linked to chronic groin pain. Although no studies were found on muscle size measurements in participants with chronic adductor pain, some imaging studies have shown GM atrophy associated with hip osteoarthritis (Amaro, Amado, Duarte & Appell, 2007; Grimaldi, Richardson, Stanton, Durbridge, Donnelly & Hides, 2009). Contradictory, a cross-sectional study consisting of a 100 soccer players found the adductors marginally weaker on isometric contraction than the abductors in the dominant and non-dominant legs, but no difference was found between the isometric adductor/abductor ratio for both the dominant and non-dominant legs (Thorborg, Serner, Petersen, Madsen, Magnussen & Holmich, 2011). However, a post hoc analysis showed a significant decrease in isometric adductor/abductor ratio for patients with groin pain when compared to controls (Thorborg et al., 2011). Altered abductor to adductor strength ratio could change pelvic kinematics and lead to chronic groin pain or possibly other lower extremity overuse injuries (Niemuth et al., 2005). It is evident that pelvic muscle imbalances exists in patients presenting with chronic groin pain. Pelvic downward tilt in the cases included in this study could have been caused by weak abductors that results in strain on the adductors and leading to chronic groin pain.

Our study findings showed that cases with bilateral groin pain had increased anterior pelvic tilt compared to controls at IFC and LVP during the drop-landing. It is suggested

that an increase in anterior pelvic tilt is associated with overuse running injuries (Geraci, 1996) but recent research supporting this is limited. In the literature, an increase of lumbar lordosis posture in standing is linked to shortened erector spinae and hip flexor muscles (Kendall, McCreary & Provance, 1993; Jull & Janda, 1987). Short hip flexors may pull the pelvis into an anterior tilt due to the attachment of the hip flexors onto the anterior iliac spine and the erector spinae into the posterior iliac spine (Jull & Janda, 1987; Kendall et al., 1993; Cailliet, 1995; Shirado, Toshikazu, Kaneda & Strax, 1995; Kisner & Colby, 1996). For example, Workman *et al.* (2009) found in an EMG study that the hip flexors (rectus femoris and iliopsoas muscles) were more active than the rectus abdominus muscle when the pelvis is anteriorly tilted during a bent-knee sit-up. The reverse was found with the pelvis posteriorly tilted during a bent-knee sit-up (Workman, Docherty, Parfrey & Behm, 2008). This can be explained by the anterior pelvic tilt providing an optimal length position for the rectus femoris and iliopsoas muscle groups (hip flexors) providing higher contractile forces from these muscles (Workman et al., 2008). Simultaneously, the rectus abdominus may be placed in a disadvantageous position as they are lengthened, which leads to a reduction in contractile forces (Workman et al., 2008). Cases with bilateral groin pain showed increased anterior pelvic tilt compared to controls at IFC and LVP during the drop-landing. This may be due to shortened hip flexors that pulls the pelvis anteriorly. However, further evidence to confirm this finding needs to be researched.

Higher abdominal activity was noted in participants performing a bent-knee sit-up with the pelvis in a posterior tilt. The reverse happened with the pelvis in anterior tilt (Workman et al., 2008). EMG studies have found abdominal muscle activity very dependent on the

position of the pelvis during sporting activities, due to the insertion of the rectus abdominus into the anterior superior iliac spine (Shirado et al., 1995). In our study the increase anterior tilt can be explained by the “common-adductor-rectus abdominus”, the origin of the adductor longus and rectus abdominus tendons into a single continuous structure (Gibbon, 1999). This common origin forms a critical biomechanical axis as both these muscles act as dynamic stabilizers of the pubic symphysis (Gibbon, 1999). In patients with chronic groin pain the adductor longus fails first which overloads the smaller rectus abdominus tendon (Koulouris, 2008). This overloading of the rectus abdominus causes the pelvis to pull anteriorly (Workman et al., 2009). However, in contrast Walker *et al.* (1987) and Youdas *et al.* (2000) found no relation between lumbar lordosis, pelvic inclination and abdominal muscle force in the standing posture. Cases that landed with an increase anterior pelvic tilt compared to the controls in the current study may have had weakness of the rectus abdominus muscle which could lead to chronic groin pain. An increase of anterior pelvic tilt can therefore pose as a risk factor for developing bilateral chronic groin pain (Shirazi-Adl, Sadouk, Parnianpour, Pop & El-Rich, 2002; Drysdale, Earl & Hertel, 2004). It can also predispose these patients to other injuries such as lower back pain (LBP) (Youdas et al., 2000; Workman et al., 2008). Our study showed that cases with bilateral groin pain had increased anterior pelvic tilt than the matched controls which can be attributed to shortened hip flexors and/or weak abdominal muscles.

Our study findings revealed all cases with primary painful legs landed with increased pelvic internal rotation. This was noted at IFC for the unilateral group and at IFC and LVP for the most painful leg group. However, the control group compared to the unilateral groin pain group landed in more internal rotation. The hip joint musculature

plays an extremely important role in the lumbo-pelvic stabilization during ambulation (Lyons et al., 1983). Poor hip abduction and external rotation strength is often linked to poor GM strength and a decrease in postural control (Cichanowski, Schmitt, Johnsonn & Niemuth, 2007). The GM plays an important role in maintaining the pelvis in the frontal plane, as well as maintaining the pelvis in the transverse plane, preventing the femur to rotate excessively internally (Nguyen, Schultz, Schmidt, Luecht & Perrin, 2011). This correlates to another study by Seay *et al.* (2011) who suggested that a group of runners with LBP represented with a greater mechanical challenge to the motion and coordination of the lumbo-pelvic system which resulted in an increase of internal rotation of the pelvis. A possible explanation for the increased internal rotation is the result from neuromuscular damage (soft tissue weakness or injury) or a pain inhibitory effect from the LBP (Seay et al, 2011). This causes coordination problems in the lumbo-pelvic system in the transverse plane and could lead to LBP and other lower extremity injuries. Weak GM strength can cause increased pelvic internal rotation during a single leg drop- landing and can pose as a risk factor in developing chronic groin pain.

Study limitations

The limitations of this study are:

- Non-random samples 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.
- Participants were only matched for age and sporting activity.
- Our study focused on pelvic kinematics during a single-leg drop-landing whereas information regarding lumbo-pelvic muscle control and activity would be valuable in future for understanding chronic groin pain.
- In this cross-sectional, descriptive study it remains uncertain whether these findings are as a result of the chronic groin pain or a causative factor.
- The small sample size, especially the group with bilateral injuries, does not adequately reflect the population of patients with chronic groin pain.
- The diagnosis of groin pain remains complicated due to the many possible causes.

Recommendations for future research

Future research should determine the lumbo-pelvic muscle control and activation, especially the GM and AL with the use of EMG in patients performing a single leg drop-landing. Comparison between patients with unilateral groin pain and patients with bilateral groin pain might provide better insight of pelvic control and the effect thereof on pelvic kinematics. Additional studies in which investigators evaluate the effect of increased pelvic stability by means of e.g. a pelvic belt might help us understand the importance of core stability.

Conclusion

Groin pain is common in various sporting activities and can result in chronic and career-ending pain. The main finding was that pelvic downward lateral tilt in the frontal plane was significantly more during the landing phase for the cases compared to the matched controls. It is suspected that weakness of the abductors as stabilizers of the pelvis during the landing phase contributed to the pelvic downward tilt, since the adductors are in a lengthened position during this activity. This finding may be a contributing factor towards the persistent nature of groin pain. Rehabilitation should focus on abductor, especially GM, AL and abdominal muscle strengthening. Further research should be focused on muscular recruitment patterns in sports participants with groin pain to critically define the muscular causal factors in more depth.

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Appendix 1: Journal guidelines

Journal type

Physiotherapy in Sport Journal

Journal requirements

The following instructions are available for authors are supplied online:

[1466-853X/guide-for-authors](#)

Presentation of manuscripts

Provide a full length account of original research that will not exceed 4000 words. These word counts include Keywords, Acknowledgements and the references contained within the article. The reference list at the end of the article, the Abstract, figures/tables, title and author information and Appendices are not included in the word count.

The article should be typed on A4 paper, double-spaced with margins of at least 3cm. Number all pages consecutively beginning with the title page. Papers should be set out as follows, with each section beginning on a separate sheet.

Title page

Provide the following data on the title page (in the order given).

Title: Concise and informative. Titles are often used in information-retrieval systems. Avoid abbreviations and formulae where possible.

Author names and affiliations: Present the authors' affiliation addresses (where the actual work was done) below the names. Indicate all affiliations with a lower-case superscript letter immediately after the author's name and in front of the appropriate address. Provide the full postal address of each affiliation, including the country name, and, if available, the e-mail address of each author.

Corresponding author: Clearly indicate who is willing to handle correspondence at all stages of refereeing and publication, also post-publication. Ensure that telephone and fax numbers (with country

and area code) are provided in addition to the e-mail address and the complete postal address.

Present/permanent address: If an author has moved since the work described in the article was done, or was visiting at the time, a 'Present address' (or 'Permanent address') may be indicated as a footnote to that author's name. The address at which the author actually did the work must be retained as the main, affiliation address. Superscript Arabic numerals are used for such footnotes.

Abstract: An abstract of the manuscript, summarizing the content in no more than 200 words, should be provided. Abstracts should follow a structured format. For empirical studies, this will usually involve these headings: Objectives, Design, Setting, Participants, Main Outcome Measures, Results, Conclusions. For other types of study, contributors may adapt this format, but should retain the idea of structure and headings.

Keywords: Include three or four keywords. The purpose of these is to increase the likely accessibility of your paper to potential readers searching the literature. Therefore, ensure keywords are descriptive of the study. Refer to a recognised thesaurus of keywords (e.g. CINAHL, MEDLINE) wherever possible.

Text: Headings should be appropriate to the nature of the paper. The use of headings enhances readability. Three categories of headings should be used:

- major headings should be typed in capital letters in the centre of the page and underlined;
- secondary headings should be typed in lower case (with an initial capital letter) at the left-hand margin and underlined; and
- minor headings should be typed in lower case and italicized.

Do not use 'he', 'his' etc. where the sex of the person is unknown; say 'the participant', etc. Avoid inelegant alternatives such as 'he/she'. Avoid sexist language.

- Any acknowledgements should be included at the end of the text.

References: Please ensure that every reference cited in the text is also present in the reference list (and vice versa). Avoid using references in the abstract. Avoid citation of personal communications or unpublished material. Citations to material "in press" is acceptable and implies that the item has been accepted for publication. Citation of material currently under consideration elsewhere (e.g. "under review" or "submitted") is not.

Text: Single author (Graham, 2001)

Two authors (Geyer & Braff, 1999)

Three to six authors (Lehman, Stohr, & Feldon, 2000)

for the first citation and (Lehman et al., 2000) for subsequent citations.

More than six authors (Karper et al., 1996)

Separate references in the text in parentheses by using a semi-colon.

List: References should be arranged first alphabetically and then further sorted chronologically if necessary. More than one reference from the same author(s) in the same year must be identified by the letters "a", "b", "c" etc., placed after the year of publication.

Reference to a journal publication:

Herrington, L., and Munro, A. (2010). Drop jump landing knee valgus angle; normative data in a physically active population. *Physical Therapy in Sport*, 11, 56-59.

Reference to a book:

Magee, D.J. (1997). *Orthopaedic physical assessment*. (3rd ed.). Philadelphia: Saunders.

Reference to a chapter in an edited book:

Hudson, Z., & Brown, A. (2003). Athletes with disability. In: G. S. Kolt, & L. Snyder-Mackler (Eds.), *Physical therapies in sport and exercise* (pp. 521-304). Edinburgh: Churchill Livingstone.

Citing and listing of Web references:

As a minimum, the full URL should be given. Any further information, if known (Author names, dates, reference to a source publication, etc.), should also be given. Web references can be listed separately (e.g., after the reference list) under a different heading if desired, or can be included in the reference list; in square brackets in line with the text.

Tables, Illustrations and Figures:

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 18th 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.

Patient anonymity

Studies on patients or volunteers require ethics committee approval and informed consent which should be documented in your paper. Patients have a right to privacy. Therefore identifying information, including patients images, names, initials, or hospital numbers, should not be included in videos, recordings, written descriptions, photographs, and pedigrees unless the information is essential for scientific purposes. Written consents must be provided to Elsevier on request. Even where consent has been given, identifying details should be omitted if they are not essential. If identifying characteristics are altered to protect anonymity, such as in genetic pedigrees, authors should provide assurance that alterations do not distort scientific meaning and editors should so note. If such consent has not been obtained, personal details of patients included in any part of the paper and in any supplementary materials (including all illustrations and videos) must be removed before submission.

At the end of the paper, but before the references, please provide three statements

- 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.

Contributors and acknowledgements

All authors should have made substantial contributions to all of the following: (1) the conception and design of the study, or acquisition of data, or analysis and interpretation of data, (2) drafting the article or revising it critically for important intellectual content, (3) final approval of the version to be submitted. In the covering letter to the editorial office, we ask you make a true statement that all authors meet the criteria for authorship, have approved the final article and that all those entitled to authorship are listed as authors.

Those who meet some but not all of the criteria for authors can be identified as "contributors" at the end of the manuscript with their contribution specified under the subheading "Acknowledgements". All those individuals who provided help during the research (e.g., collecting data, providing language help, writing assistance or proofreading the article, etc.) that do not meet criteria for authorship should be acknowledged in the paper.

Appendix 2: Ethics approval letter

Approval Notice

New Application

03-Dec-2012

DARE, Michael

JANSE VAN RENSBURG, Lienke

HARWIN, Lauren

MARITZ, Karien

MORRIS, Tracy Louise

Ethics Reference #: S12/10/265

Title: Exploration of Biomechanics during functional Activities in Adults Sports participants with Chronic Groin Pain

Dear Mr Michael DARE, Mrs Lienke JANSE VAN RENSBURG, Ms Lauren HARWIN, Mrs Karien MARITZ and Mrs 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
Nel, Etienne EDLR
Sprenkels, Marie-Louise MHE
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 3: Consent form (English & Afrikaans)

Participant information leaflet and consent form

Title of the research project: Exploration of biomechanics during functional activities in adult sport participants with chronic groin pain

You are being invited to take part in a research project. Please take some time to read the information presented here, which will explain the details of this project. Please ask the study staff any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails and how you could be involved. Also, your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

This study has been approved by the **Health Research Ethics Committee at Stellenbosch University** and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research.

What is this research study all about?

We are conducting this research to ascertain if movement differences exist between players who experience groin problems compared to those who do not. Data of this kind has not been collected before with regards to groin pain, thus it will increase our understanding of how the body moves when someone experiences groin pain. Collecting this data will provide a framework for future research to investigate possible causative factors of groin pain and possibly in the future aid in putting in place preventative measures.

The researchers will conduct a standardized assessment on each participant once informed consent is given. This will include an interview and basic hip examination at your club. A physical examination will be conducted during the second contact at Stellenbosch University's FNB- 3D Movement Analysis Laboratory. Once the examination is completed we will analyze your movements using the Vicon system.

The Vicon motion analysis (Ltd) (Oxford, UK) system is a camera based, three-dimensional (3D) system which is used in a wide variety of ergonomics and human factor applications. The Vicon motion analysis system will be used to analyze specific parameters identified in the objectives of the study.

A total of 33 markers will be required and placed on various points on the participant's body. The participant will then be required to walk down a straight path while the markers record data of your movement. The participant will also be required to jump onto one leg from a set height while the markers once again record data of how you move.

Why have you been invited to participate?

You have been invited to participate in this research because you are an active sports participant who either suffers from groin pain currently or does not suffer from groin pain at all.

What will your responsibilities be?

Your responsibilities during this research will be to attend and allow the researchers to question you and conduct an examination on you which will involve measuring movement at various joints at the University of Stellenbosch motion analysis laboratory.

Once this is complete you will be required to perform self selected walking in the Vicon lab as well as a single-leg drop-landing where various measurements will be taken and recorded with regards to the way you move.

Will you benefit from taking part in this research?

You will not immediately benefit from taking part in the research. But by partaking in this research you will allow the researchers to objectively analyze movements in sports

participants who suffer from groin pain and compare it to those who don't. By doing this we will be able to better understand groin pain and allow future research to investigate possible causative factors of the problem and put prevention measures in place.

Are there any risks involved in your taking part in this research?

There is minimal risk that you may experience your groin pain during the movement tasks, but this will be temporary. The university's indemnity insurance will apply if you should fall or injure yourself while visiting the movement laboratory.

If you do not agree to take part, what alternatives do you have?

You can consult your usual physiotherapist or medical practitioner.

Who will have access to your medical records?

The information gathered during the research will only be available to the researchers and the research supervisor.

What will happen in the unlikely event of some form of injury occurring as a direct result of your taking part in this research study?

The university's indemnity insurance will apply if you should fall or injure yourself while visiting the movement laboratory.

Will you be paid to take part in this study and are there any costs involved?

No, you will not be paid to take part in the study, but your transport and meal costs will be covered for each study visit. There will be no costs involved for you, if you do take part.

Is there anything else that you should know or do?

- You can contact Lienke Janse van Rensburg at 072 795 6991 if you have any further queries or encounter any problems.
- You can contact the Health Research Ethics Committee at 021-938 9207 if you have any concerns or complaints that have not been adequately addressed by your study representative.

- You will receive a copy of this information and consent form for your own records.

Declaration by participant

By signing below, I agree to take part in a research study entitled: *Exploration of biomechanics during functional activities in adult sport participants with chronic groin pain.*

I declare that:

- I have read or had read to me this information and consent form and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurized to take part.
- I may choose to leave the study at any time and will not be penalized or prejudiced in any way.
- I may be asked to leave the study before it has finished, if the study doctor or researcher feels it is in my best interests, or if I do not follow the study plan, as agreed to.

Signed at (*place*) on (*date*)

.....
Signature of participant

.....
Signature of witness

Declaration by investigator

I (*name*) declare that:

- I explained the information in this document to
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did/did not use a interpreter. (*If a interpreter is used then the interpreter must sign the declaration below.*)

Signed at (*place*) on (*date*)

.....
Signature of investigator

.....
Signature of witness

Declaration by interpreter

I (*name*) declare that:

- I assisted the investigator (*name*) to explain the information in this document to (*name of participant*)

..... using the language medium of Afrikaans/Xhosa.

- We encouraged him/her to ask questions and took adequate time to answer them.
- I conveyed a factually correct version of what was related to me.
- I am satisfied that the participant fully understands the content of this informed consent document and has had all his/her question satisfactorily answered.

Signed at (*place*).....on (*date*).....

.....
Signature of interpreter

.....
Signature of witness

Deelnemer inligtingsblad en-toestemmingsvorm

Titel van die navorsings projek: Ondersoek van die Biomeganika in volwasse sports persone met kroniese lies pyn tydens funksionele aktiwiteite.

U word genooi om deel te neem aan 'n navorsingsprojek. Lees asseblief hierdie inligtingsblad op u tyd deur aangesien die detail van die navorsingsprojek daarin verduidelik word. Indien daar enige deel van die navorsingsprojek is wat u nie ten volle verstaan nie, is u welkom om die navorsingspersoneel daarvoor uit te vra. Dit is baie belangrik dat u ten volle moet verstaan wat die navorsingsprojek behels en hoe u daarby betrokke kan wees. U deelname is ook **volkome vrywillig** en dit staan u vry om deelname te weier. U sal op geen wyse hoegenaamd negatief beïnvloed word indien u sou weier om deel te neem nie. U mag ook te enige tyd aan die navorsingsprojek onttrek, selfs al het u ingestem om deel te neem.

Hierdie navorsingsprojek is deur die **Gesondheidsnavorsingsetiëkkomitee (GNEK) van die Universiteit Stellenbosch** goedgekeur en sal uitgevoer word volgens die etiese riglyne en beginsels van die Internasionale Verklaring van Helsinki en die Etiese Riglyne vir Navorsing van die Mediese Navorsingsraad (MNR).

Wat behels hierdie navorsingsprojek?

Hierdie studie word uitgevoer om in diepte ondersoek in te stel of daar wel biomeganiese verskille bestaan tussen sportspersone met lies pyn teenoor individuele met geen lies pyn. Data van dië aard, spesifiek tot lies pyn was nog nie voorheen versamel nie, dus sal ons ons kennis verbreed in terme van liggaamlike beweging in reaksie tot lies pyn. Versameling van hierdie data sal 'n raamwerk bied vir toekomstige navorsing in moontlike faktore watkan bydrae tot lies pyn, met die hoop dat dit ook in die toekoms moontlike voorkomende faktore sal identifiseer

Die navorsers sal 'n gestandaardiseerde evaluering uitvoer sodra toestemming vanaf die deelnemers bekom word. Dit sluit in 'n subjektiewe onderhoud asook 'n algemene ondersoek van die heup gewrig, wat by die verskeie klubs uitgevoer sal word. 'n Fisiese ondersoek sal by 'n tweede ontmoeting, by die FNB 3D-Bewegings Analiserings laboratorium van Stellenbosch Universiteit, uitgevoer word. Sodra die fisiese ondersoek voltooi is sal u bewegings analise gedoen word, deur gebruik te maak van die Vicon sisteem.

Die *Vicon motion analysis (Ltd) (Oxford, UK) system* is 'n kamera georiënteerd, drie-dimensionele (3D) sisteem wat toegepas word in 'n groot verskeidenheid ergonomika en menslike bewegingspatrone. The Vicon bewegings analise sisteem sal gebruik word om spesifieke parameters, wat in hierdie studie geïdentifiseer is, te meet.

Drie-en-dertig merkers sal gebruik word om op die verskeie punte op die individu se liggaam te plaas. Elke individu wat in die studie deelneem sal dan vereis word om op 'n reguit lyn te loop terwyl die merkers die data van u beweging vaslê. U sal ook vereis word om met een been van 'n vooraf bepaalde hoogte af te spring, terwyl die merkers weereens u beweging analiseer.

Waarom is u genooi om deel te neem?

U word uitgenooi om deel te neem in hierdie studie, aangesien u 'n aktiewe sportspersoon is wat huidiglik lies pyn ervaar of glad nie lies pyn ervaar nie; en in die studie se insluitings en uitsluitings voldoen.

Wat sal u verantwoordelikhede wees?

U verantwoordelikhede tydens hierdie studie vereis bywoning van kontak sessies, asook toelating van evaluasie deur die navorser. Dit sluit die subjektiewe onderhoud in en ook fisiese meting van verskeie gewrigsbewegings, wat by die Bewegings analise laboratorium van Stellenbosch Universiteit sal plaasvind.

Sodra dit voltooi is sal daar van u vereis word om te loop teen 'n self geselekteerde spoed in die Vicon laboratorium, asook een been val/spring aksie uit te voer terwyl die Vicon sisteem sodoende u bewegings analiseer en dit op rekord te stel.

Sal u voordeel trek deur deel te neem aan hierdie navorsingsprojek?

U sal nie noodwendig onmiddelik self van hierdie studie baat nie, maar deur aan hierdie studie deel te neem laat u die navorsers toe om objektief die funksionele bewegings te aniliseer. En sodoende 'n vergelyking te tref tussen die bewegingspatrone van sportspersone met lies pyn en die sonder lies pyn. Deur hierdie vergelyking laat dit toe vir toekomstige navorsing in faktore wat bydrae tot lies pyn en moontlike voorkomende riglyne in plek te stel.

Is daar enige risiko's verbonde aan u deelname aan hierdie navorsingsprojek?

Daar is wel 'n risiko dat u u lies pyn simptome tydens deelname aan hierdie aktiwiteite sal ervaar, maar dit is slegs tydelik. Die universiteit se vrywarings versekering sal wel in tree in die geval waar u sou val of u self beseer.

Watter alternatiewe is daar indien u nie instem om deel te neem nie?

U kan u huidige fisioterapeut of medies dokter raadpleeg.

Wie sal toegang hê tot u mediese rekords?

Die inligting bekom tydens die studie sal slegs tot die beskiking van die navorsers en hul toesighouer wees.

Wat sal gebeur in die onwaarskynlike geval van 'n besering wat mag voorkom as gevolg van u deelname aan hierdie navorsingsprojek?

Die universiteit se vrywarings versekering sal in tree in die geval waar u sou val of u self beseer met 'n besoek aan die bewegings laboratorium.

Sal u betaal word vir deelname aan die navorsingsprojek en is daar enige koste verbonde aan deelname?

U sal nie betaal word vir deelname aan die navorsingsprojek nie, maar u vervoer en etes ten opsigte van elke besoek vir die navorsingsprojek sal betaal word. Deelname aan die navorsingsprojek sal u niks kos nie.

Is daar enigiets anders wat u moet weet of doen?

- Vir verdere navrae of enige probleme kan u vir Lienke Janse van Rensburg kontak by 072 765 6991
- U kan die **Gesondheidsnavorsingsetiek administrasie** kontak by 021-938 9207 indien u enige bekommernis of klagte het wat nie bevredigend deur u studiedokter hanteer is nie.
- U sal 'n afskrif van hierdie inligtings- en toestemmingsvorm ontvang vir u eie rekords.

Verklaring deur deelnemer

Met die ondertekening van hierdie dokument onderneem ek,, om deel te neem aan 'n navorsingsprojek getiteld: *Ondersoek van die Biomeganika in volwasse sports persone met kroniese lies pyn tydens funksionele aktiwiteite.*

Ek verklaar dat:

- Ek hierdie inligtings- en toestemmingsvorm gelees het of aan my laat voorlees het en dat dit in 'n taal geskryf is waarin ek vaardig en gemaklik mee is.
- Ek geleentheid gehad het om vrae te stel en dat al my vrae bevredigend beantwoord is.
- Ek verstaan dat deelname aan hierdie navorsingsprojek **vrywillig** is en dat daar geen druk op my geplaas is om deel te neem nie.

- Ek te eniger tyd aan die navorsingsprojek mag onttrek en dat ek nie op enige wyse daardeur benadeel sal word nie.
- Ek gevra mag word om van die navorsingsprojek te onttrek voordat dit afgehandel is indien die studiedokter of navorser van oordeel is dat dit in my beste belang is, of indien ek nie die ooreengekome navorsingsplan volg nie.

Geteken te (*plek*) op (*datum*)

.....
Handtekening van deelnemer

.....
Handtekening van getuie

Verklaring deur navorser

Ek (*naam*) verklaar dat:

- Ek die inligting in hierdie dokument verduidelik het aan
- Ek hom/haar aangemoedig het om vrae te vra en voldoende tyd gebruik het om dit te beantwoord.
- Ek tevrede is dat hy/sy al die aspekte van die navorsingsprojek soos hierbo bespreek, voldoende verstaan.
- Ek 'n tolk gebruik het/nie 'n tolk gebruik het nie. (*Indien 'n tolk gebruik is, moet die tolk die onderstaande verklaring teken.*)

Geteken te (*plek*) op (*datum*)

.....
Handtekening van navorder

.....
Handtekening van getuie

Verklaring deur tolk

Ek (*naam*) verklaar dat:

- Ek die navorser (*naam*) bygestaan het om die inligting in hierdie dokument in Afrikaans/Xhosa aan (*naam van deelnemer*) te verduidelik.
- Ons hom/haar aangemoedig het om vrae te vra en voldoende tyd gebruik het om dit te beantwoord.
- Ek 'n feitelik korrekte weergawe oorgedra het van wat aan my vertel is.
- Ek tevrede is dat die deelnemer die inhoud van hierdie dokument ten volle verstaan en dat al sy/haar vrae bevredigend beantwoord is.

Geteken te (*plek*) op (*datum*)

.....
Handtekening van tolk

.....
Handtekening van getuie

Appendix 4: 3D Vicon marker placements

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

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 5: Club screening booklet

- **Contact the respective sports clubs**
- **Arrange a meeting or telephonic consultation date with the coach or manager**
- **At meeting\telephonic consultation:**
 - Gain an indication of the amount of subjects meeting the inclusion criteria (cases and controls)
 - Determine recruitment and screening date and time (30 minutes required before or after practice)
- **At recruitment session:**
 - Brief possible subjects on aim and requirements of the study
 - Hand out consent form and have subjects complete it
 - Hand out form with personal details and eligibility criteria. Subjects to complete patient information and screening form.
 - Complete Subjective Evaluation and Screening
- **Subjective evaluation and screening**
 - Complete screening form.
 - Adductor squeeze test:
 - Supine lying with hips in 45° flexion (measured with a goniometer)
 - 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.
 - Test will be measured once over a period of 20 seconds.
 - During the first 5 seconds the subject must hold the neutral position of the spine.

- Between the period of 5s-10s the subject will be asked to squeeze the cuff at maximal effort, then release the contraction but hold the test position.
 - From 15s-20s the participant will be asked to relax completely.
 - A positive test is pain over the Adductor muscle belly or at the insertion.
 - Each squeeze test, the sphygmomanometer will be allowed 30 seconds to settle.
 - A positive finding will be reproduction of pain in the adductor muscle belly or at the insertion.
- **Arrange second contact date and time for physical examination and data collection.**

Appendix 6: Patient information and screening form

Patient information

Date:

Name and Surname:

Age:

Gender:

Date of birth:

Cell phone number:

Landline:

Email address:

Physical address:

Please complete the following by crossing the appropriate block (*please only cross one block per question*):

- Do you currently play one of the following:

Soccer	Hockey	Rugby	Cycling
--------	--------	-------	---------

- Are you between the ages of 18 – 55 years?

Yes	No
-----	----

- Are you suffering from chronic (longer than 3 months) groin/inner thigh pain?

Yes	No
-----	----

- How would you see your general health?

Excellent	Good	Poor
-----------	------	------

- Have you had any surgical procedures in the last 12 months?

Yes	No
-----	----

If “Yes”, please specify:

- Have you had any X-rays, MRI’s or other scans done with abnormal findings?

Yes	No
-----	----

If “Yes”, please specify:

- Do you or have you had any of the following?

	Yes	No
Ankolysing Spondilytis		
Scheuermann’s Disease		
Rheumatiod Arthritis		
Muscular Dystrophy		
Paget’s Disease		

Appendix 7: Patient interview

Subjective assessment:

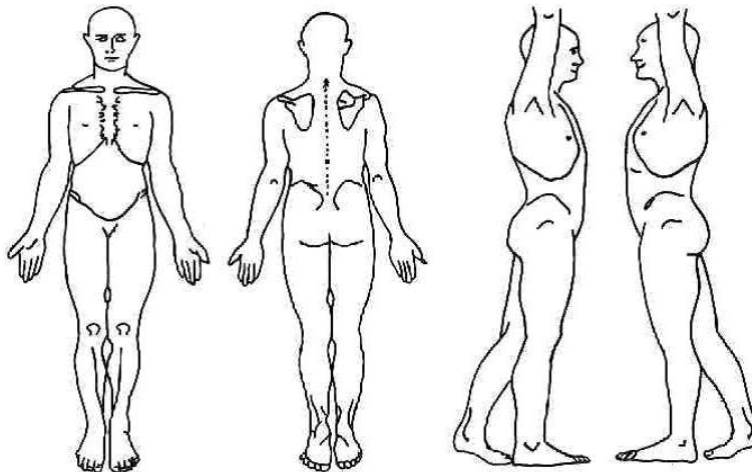
Name:

Age:

Dominance:

Main problem:

Area of symptoms: Quality, intensity, depth, associated symptoms



Behaviour of symptoms: Aggravating/Easing/ 24 hours

History: present/past

Special questions

Appendix 8: Laboratory physical examination

Name:

Age: Case/Control Number:

Affected Adductor:

Any other physical complaints/conditions:

Shoe Size:

Observation:

Alignment, swellings,

Feet-

Knees-

Pelvis/Lx-

Tx-

Functional demonstration/activity: Alignment and control

Squats (holding on with both hands on plinth- flat foot squat)

Lunges (fwd stepping lunge, back to start position X 3 each leg)

Passive physiological movements:

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

Knee	Left 1	Left 2	Left 3	Mean	Right1	Right2	Right3	Mean
Flexion(PRN)								
Extension								

Special Tests:

Leg Length: (ASIS to MM)

SIJ (4 battery of tests):

Fabers Test

Gaelen's Test

P4 Test

Anterior gapping

Hip Quadrant (if indicated)

Pain on coughing

Navicular Drop Test: Left-

Right-

Scoligauge: T2

T8

T12

PSIS

Appendix 9: Laboratory Testing Protocol

Single to single drop landing

- Randomise starting leg – the weight bearing leg is the starting leg (measure 60% of the leg length and position box at the 60% mark).

Instructions:

- Stand on the box with your arms next to your sides.
- The weight bearing foot must touch the line on the jumping box.
- Lift one leg until the hip and knee is bent to about 90 degrees.
- Jump down onto the ground with your landing foot touching the white line.
- Hold your landing position for 5 seconds.
- Alternate legs.
- Physiotherapist then demonstrates to the participant.