Waterford Institute of Technology

Femoroacetabular Impingement: Injury etiology and performance outcomes following arthroscopic surgery

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Author's Declaration:

I hereby declare that this thesis does not contain any material that has been previously submitted to any other third level institution or for any higher degree in this institution. The source of the information contained within this thesis is solely the work of the author except where specified.

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Karen Mullins

Abstract

Introduction: Femoroacetabular impingement syndrome (FAI) is a recently described pathophysiological deformity of the hip joint which has been cited as a possible risk factor for the development of osteoarthritis of the hip in later life. It is highly prevalent in young athletes (Ellis et al., 2011; Philippon et al., 2007; Philippon et al., 2013), and surgical intervention is often recommended to remove impinging bone and repair damaged intra-articular tissue. There are many outcome measuring tools to determine the efficacy of treatment, although the vast majority are subjective in nature and rely heavily on patient opinion. There is a paucity of research which objectively examines the effect of surgical intervention on athletic performance. The aim of phase one of this research was to determine the effect of FAI syndrome on functional performance among athletes and quantify the changes in these measures following arthroscopic surgery.

Whether the movement patterns associated with a field sport are associated with the onset of a hip pathology is unknown. There are many measurement techniques available to quantify movements during training and match play. Previous use of video and optoelectronic analysis together is limited (Bartlett, 2001), furthermore the kinematic patterns of a joint throughout the entirety of a field sport have not been quantified. The aim of the second phase of research was to quantify hip movement patterns throughout an entire competitive hurling game.

Methods: Competitive sportsmen with symptomatic FAI syndrome were compared to age, gender and activity-level matched controls. Patients were tested at baseline (n=59), 12 weeks post-surgery (n=47) and 1-year post surgery (n=35), while controls were tested initially (n=66), 12 weeks (n=32) and one year later (n=23) with no interruption to customary levels of training or competition. Participants carried out functional tests which included a 10-m sprint, a modified agility T-test, a maximal deep squat test, and a single leg drop jump test (reactive strength index). Hip range of motion was also assessed by measuring maximal hip flexion, hip abduction and hip internal rotation (at 90^0 hip flexion). Patients were also asked to report any presence of anterior groin pain throughout the testing. At the 1-year follow-up, data was recorded regarding the return to play status of the patients.

For the second phase of research, 10 intercounty hurlers were video recorded during the National Hurling league and all movements of the game were quantified and categorised using Dartfish software. Three hurlers were recorded using an optoelectronic system while carrying out the movements identified during the video analysis while wearing 43 reflective markers on joint segments. Kinematic data for the hip joint was generated and percentage game time spent in predetermined zones of hip movement were calculated.

Results: At baseline, the FAI syndrome group was significantly slower during the 10-m sprint (3%, p=0.002) and agility T-test (8%, p<0.001); and had lower hip ROM levels (p<0.001). Twelve weeks post-surgery; the patient group had significantly improved on the agility T-test (p<0.001), and in all three measures of ROM (p<0.001). At the 1-year analysis, further improvements were recorded among the patients for squatting depth and RSI (p<0.05). No significant changes were noted among the control group scores after 12 weeks or 1 year compared to baseline and significant time x group interaction effects for acceleration, agility, squat depth and ROM were recorded. Additionally, at 1-year there were no significant differences between the groups for the athletic variables measured. The percentage of patients reporting pain reduced from baseline to 1-year for the 10m-sprint (47% to 8%), agility (60% to 8%) and during the squatting depth measure (52% to 8%). At one year, 83% of patients had returned to full training/competition at an average time of 17 weeks (range 8 – 52 weeks).

Hurlers spend the majority of a hurling game carrying out low intensity movements such as walking interspersed with high speed running. Based on the analysis of the discrete movements of hurling, the side-line cut displays high levels internal rotation with increased flexion (approximately 25^o and 45^o respectively) in the lead leg as well as increased external rotation in abduction in the contralateral leg and places the hip in an “at risk” position.

Conclusion: The results of this prospective study demonstrate the negative impact of symptomatic FAI syndrome on range of hip motion, speed and agility of competitive athletes, compared with matched controls. Arthroscopic surgical correction of FAI syndrome results in significant improvements in athletic function with reduction in pain as early as 12 weeks post-operation. Continued improvement was evident at one year, with performance now comparable to that of healthy controls for speed, agility, power and squatting depth. Arthroscopic correction of FAI syndrome is recommended for athletes who wish to continue sports participation and improve athletic performance.

This is the first study to quantify hip movements for the entire duration of a field sport. This was necessary to gain a greater understanding of the overall movement patterns the hip joint carries out. This can serve to educate coaches, doctors and physiotherapists so appropriate load management protocols can be ensured.

List of Publications and Conferences Presentations

Publications:

1. Mullins, K., Hanlon M., Carton, P. (2017) Differences in Athletic Performance between Sportsmen with Symptomatic FAI and Healthy Controls. *Clinical Journal of Sports Medicine* (In press)
2. Mullins, K., Hanlon M., Carton, P. (2018) Structured Training in Early Adolescence – A Risk Factor for Femoroacetabular Impingement? *Muscles, Ligaments and Tendons Journal* (In Press)
3. Mullins, K., Hanlon M., Carton, P. (2018) Arthroscopic Correction of Femoroacetabular Impingement Improves Athletic Performance among Male Athletes: A Prospective Case-Control Study. *The American Journal of Sports Medicine* (Under Review)

Conferences:

Oral Presentations

1. Mullins, K., Hanlon M., Carton, P. (2015) Differences in Functional Performance between Pre-Surgical Patients with Femoroacetabular Impingement and Controls In: *All Ireland Postgraduate Conference in Sport Science*, *Physical Activity and Physical Education* January 23rd, University of Limerick
2. Mullins, K., Hanlon M., Carton, P. (2015) The Effect of Femoroacetabular Impingement on Athletic Performance Measures In: The Royal College of Surgeons FSEM Annual Scientific Conference, Sept 17th-19th, Dublin (Award for best presentation)
3. Mullins, K., Hanlon M., Carton, P. (2015) Changes in Athletic Performance Measures Following the Arthroscopic Treatment of Femoroacetabular Impingement; Preliminary 12 Week Data In: The Royal College of Surgeons FSEM Annual Scientific Conference, Sept 17th-19th, Dublin
4. Mullins, K., Hanlon M., Carton, P. (2016) Changes in Athletic Performance Measures Following the Arthroscopic Correction of Femoroacetabular Impingement; 12 Week Data In: *All Ireland Postgraduate Conference in Sport Science*, *Physical Activity and Physical Education*, April 29th, Waterford
5. Mullins, K., Hanlon M., Carton, P. (2016) Changes in Athletic Performance Measures Following the Arthroscopic Correction of Femoroacetabular Impingement; 12 Week Data In: *WIT Research Day*, Waterford (Awarded 2nd place for best presentation)
6. Mullins, K., Hanlon M., Carton, P. (2017) Changes in athletic performance one year post arthroscopic surgery for the treatment of Femoroacetabular Impingement in athletes In: *All Ireland Postgraduate Conference in Sport Science*, *Physical Activity and Physical Education*, April 21st, Carlow
7. Mullins, K., Hanlon M., Carton, P. (2017) Are higher training volumes in adolescence a risk factor for the development of FAI? In: *The Irish Orthopaedics Association Annual Meeting*, June 16th-19th, Kilkenny

Poster Presentations

1. Mullins, K., Hanlon M., Carton, P. (2016) The Effects of Arthroscopic Hip Impingement Surgery on Functional Performance Measures in GAA Players In; *Liberty Insurance GAA Games and Development Conference*, January 23rd, Croke Park.

Glossary of Terms and Definitions.

Arthroscopic Surgery/arthroscopy: Minimally invasive key hole surgery. Involves creating small incisions to the area being treated and treating the damaged tissue with an endoscope. Small cameras are also placed within the body to guide the surgeon.

FAI Syndrome: Femoroacetabular Impingement Syndrome; a mechanical disorder of the hip caused by excessive bone group on femoral head-neck junction and/or acetabular rim. FAI syndrome is diagnosed by, symptoms, clinical findings and radiological signs.

GAA: Gaelic Athletic Association. The governing body of the Gaelic games.

OA: Osteoarthritis; Joint disease characterised by the breakdown of protective cartilage within the joint and subsequent degradation of the underlying bone.

PROs: Patient reported outcomes. Any report on the patient's health/condition status which comes directly from the patient.

ROM: Range of Motion: The full movement available to a joint

RSI: Reactive Strength Index. A representation of the stretch shortening cycle function.

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Chapter 1: Thesis Introduction

1.0 Introduction

Femoroacetabular impingement syndrome (FAI syndrome) arises from the abnormal abutment between the femoral head and the acetabulum of the pelvis due to excessive bone growth on either or both the femoral head/neck region and the rim of the acetabulum (Griffin et al., 2016). Repetitive movements that involve flexion, and internal rotation, cause shearing of the soft tissue within the joint, specifically the labrum and the articular cartilage (Philippon et al., 2007b). Concern has risen among clinical practitioners for the potential risk of development of osteoarthritis of the hip should the condition progress to a state where the bone of the acetabulum is in direct contact with the bone of the femoral head for prolonged periods (Ganz et al., 2003; Ganz, Leunig, Leunig-Ganz, & Harris, 2008; Kassarjian, Brisson, & Palmer, 2007; Laude, Boyer, & Nogier, 2007). Given the dynamic nature of the injury, it is not surprising that this condition is commonly seen in athletic populations (Boykin et al., 2012; Ellis et al., 2011; Philippon et al., 2007a), which can lead to deteriorations in performance and an inability to participate fully in training and competitions. While conservative treatments can have a role in relieving symptoms temporarily, surgery is often required to address the underlying impingement. Surgical outcomes are frequently based on patient feedback, using questionnaires which centre mostly on pain levels and satisfaction rates and then generating scoring tools such as the modified Harris hip score or the WOMAC scoring scale. When dealing with athletic populations a quantitative based approach may be more appropriate, if returning to competitive sport is also a goal of the surgery. While pain reduction is still the major focus of surgical interventions, regaining optimal functional performance has to be a chief priority when dealing with athletic patients. Using such measures to assess surgical out comes may be a more appropriate assessment for athletic patients as well as providing objective measuring tool quantify the success of the surgical treatment.

The research to date assessing the incidence of hip injury rates in Gaelic games has not suggested that the hip is a commonly injured site, however, recent reports have emerged from the Gaelic Athletic Association (GAA) regarding the number of financial claims made for the treatment of hip injuries which has seen an incremental increase in recent years, indicating the issue maybe more substantial than originally reported. Annual congress reports published by the GAA (GAA, 2015) indicated that in 2010 the number of claims made for treatment of hip related injuries was 83 for football players and 23 for hurlers. In 2014, however, that number has risen dramatically to 202 for footballers and 102 for hurlers, representing a 143% and 343% increase in claims made for hip treatments for footballers and hurlers respectively over the course of four years. In comparison, claims made for other common injury sites such as the knee increased by only 11% for footballers and 44% for hurlers, while this demonstrates that injuries as a whole may be on the rise; there is a significantly larger increase in relation to the claims made for the hip injuries alone in four years. While it is important to note that the figures from the GAA state that claims made for hip injuries have increased there is no data available as to the nature of these injuries. There is also no way to determine whether these increases are solely due to incidence increase or whether there are other drivers increasing these figures such as availability of treatment.

Hip injuries, in particular femoroacetabular impingement syndrome can be a chronic issue, with patients suffering from painful symptoms up to 2 years without a proper diagnosis (Philippon et al, 2007). Surgical intervention for treatment can have a rehabilitation time of 12 weeks and over, meaning that players who suffer from this condition may have prolonged absence from participation. There is potential for patients to suffer reductions in functional performance vital to their sports. While both hurling and Gaelic football have seen a substantial increase in the number of claims made for hip related injuries, hurling has seen a greater increase in hip related claims than football. Whether the movement patterns of hurling can influence the rate of intra-articular damage if a predisposing bony abnormality is already present has not been established. Gaining a greater understanding of the movement patterns involved in hurling can inform clinical practitioners whether specific movement patterns required for the game may exacerbate symptoms of femoroacetabular impingement syndrome in particular if a bony abnormality has been identified previously. There is no kinematic or kinetic data research for the game of hurling in circulation even in relation to specific movements, furthermore there is no research which attempts to categorise field sports into specific joint movement patterns. For this, a novel approach must be undertaken which utilises both notational and optoelectronic analysis.

1.1 Research Problem/Question

Considering it is not uncommon for athletes with FAI syndrome to continue with sports participation while symptomatic it is important to determine the potential deficits in performance as a result of the condition. To date, no research has investigated the effect of FAI syndrome on aspects of athletic performance which are required for sport. Arthroscopic intervention has been recommended previously for the treatment of FAI syndrome among athletes with significant improvements in subjective outcome measures, however, whether improvements are achieved in athletic performance required for sports participation needs to be determined. The rise in claims made to the Gaelic Athletic Association for the treatment of hip related injuries among hurlers is a growing cause for concern and understanding the movement patterns associated with the game will educate coaching staff as to the requirements of the hip joint during a hurling match.

1.2 Thesis Aims

The aims of this thesis were to i) report on the previous findings within the area of femoroacetabular impingement syndrome, ii) to determine the level of functional deficits in young male athletes with confirmed FAI syndrome by comparing them to a healthy control group and iii) quantify improvements in performance if any, following corrective arthroscopic surgery, iv) assess the possible link between increased training load during skeletal development and the development of FAI syndrome in later life, v) categorise and quantify movement patterns of an intercounty hurling game and v) generate a profile of hip kinematics for the entirety of a hurling game.

1.3 Thesis Structure

This thesis consists of three sections with eight chapters (Figure 1.1), from introduction through to appendices. Section one includes the introduction and a literature review (chapter two) which addresses research to date regarding FAI syndrome and the current concepts of kinematic profiling of sporting activities. Section 2 is comprised of two distinct phases of research; phase one (Chapter 3, 4 & 5) reports the implications of FAI syndrome for performance, effects of arthroscopic surgery and etiology of FAI syndrome. While Phase 2 examines hip kinematics of hurling match play. Section 3 inlucdes chapters 7 & 8 and conclude the thesis.

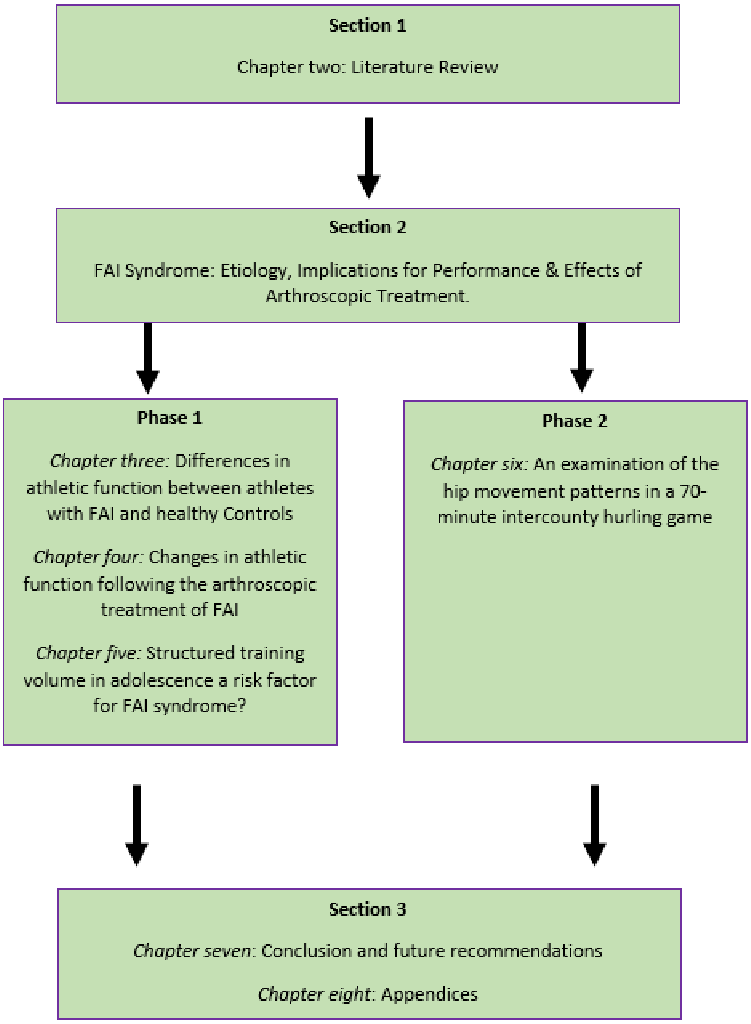

Figure 1.1 Research Design

1.4 Femoroacetabular Impingement Syndrome Definition

The 2016 consensus statement for the diagnosis of FAI (Griffin et al., 2016), now termed FAI syndrome, concluded that patients need to present with; a history in keeping with FAI, clinical findings of FAI and radiological signs of the condition for the diagnosis of FAI syndrome. If a patient does not present with all three aspects they are not thought to be diagnosed with FAI syndrome. However, the majority of the literature included in Chapter 2 was carried out prior to the 2016 consensus statement and there are slight differences in diagnosis parameters. FAI is used in instances throughout the literture review where FAI syndrome is not appropriate (when referring to these individual studies) in all other cases

FAI syndrome is used. The patients included in the current study meet all three criteria and so the term FAI syndrome is used when discussing the results of the current thesis.

> *"FAI syndrome is a motion-related clinical disorder of the hip with a triad of symptoms, clinical signs and imaging findings. It represents symptomatic premature contact between the proximal femur and the acetabulum" (Griffin et al., 2016)*

1.5 Framework of FAI Syndrome

The framework of FAI syndrome (Figure 1.2) has a number of different yet related components. The very definition of FAI syndrome requires pain reporting and subjective assessment of patients. Understanding the patient's perception of the severity of the condition and subsequent treatment protocols are of paramount importance in clinical practice. Until recently, patient reported outcomes were the main variables assessed in the literature regarding diagnosis and treatment of FAI syndrome. Recent literature has focused on more functional assessments of the condition; the focus of this thesis is to examine athletic function both before and following intervention. While patient reported outcomes (PROs) are no doubt an extremely valuable resource when quantifying the effect of surgical intervention, they are beyond the scope of this thesis and are therefore not included.

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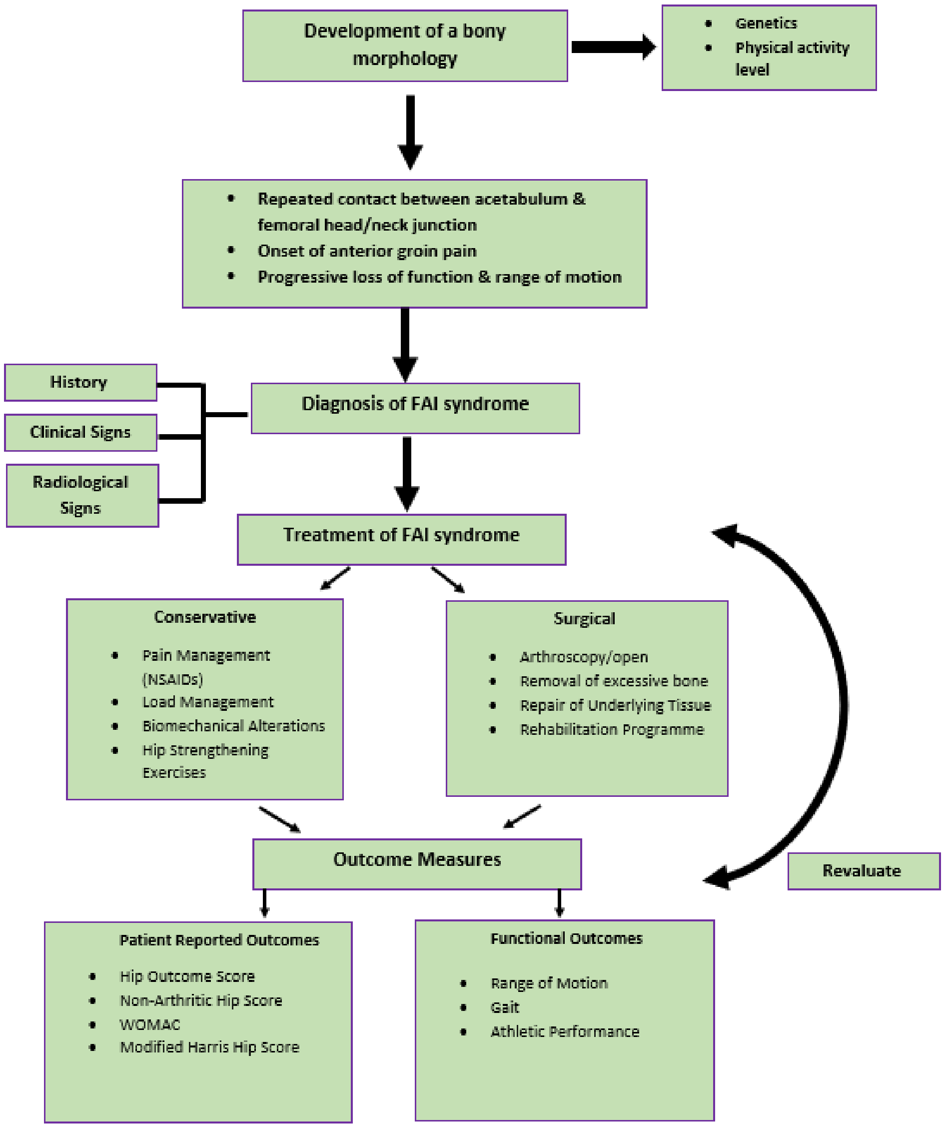


Figure 1.2 Framework of FAI Syndrome

Chapter 2: Literature Review

2.0 Introduction

The idea that bony impingements obstruct normal range of motion around the hip joint was first described by Myers et al. (1999) and further expanded on by the work of Ganz and colleagues (2003) who suggested that femoroacetabular impingement (FAI) has the potential to progress to osteoarthritis of the hip (Ganz et al., 2003). This is a significant worry for orthopaedic surgeons and sports medicine practitioners worldwide, as this phenomenon is routinely seen in young athletic populations (Ayeni et al., 2014; Ellis et al., 2011; Philippon et al., 2007a). Conservative treatment of FAI which utilises behaviour modification can relieve symptoms temporarily (Emara et al., 2011) although this type of approach may not be suited to athletes, in particular professional athletes who may be financially obligated to compete. Open surgery techniques have been shown to yield favourable results (Botser et al., 2011, Ganz et al., 2003; Matsuda et al., 2011) in restoring normal joint anatomy, although the invasive nature of that approach as well as the potential increase in the risk of complications compared to arthroscopy (Matsuda et al., 2011), may be a deterrent to athletes who wish to return to competitive action as soon as possible. In this instance, arthroscopic surgery for the correction of FAI syndrome becomes a more appealing solution.

While pain reduction and restoring optimal function of the joint itself are the foremost priorities of surgical intervention, looking at changes in functional performance must be a concern when dealing with athletes. How functional performance is influenced by surgical treatments for FAI syndrome has yet to be definitively established. To do so, functional discrepancies associated with this patient cohort must be identified and tracked over time to quantify the benefits of addressing the hip problem. The aim of the first section of this literature review is to provide an oversight of the research to date that discusses FAI syndrome as pathological hip condition, including causes, prevalence and treatment options. Functional limitations as a result of the problem are also discussed. Previous literature investigating the outcomes of surgery, as well as return to play research is discussed.

The second part of this literature review will examine the current approaches to generating kinematic data from athletic movements. The reasons for this include the fact that there is little information regarding the movement patterns of specific joints for the entirety of a field sport. In the case of this thesis the area of focus is the hip, and while kinematic data is available for specific movements with a fixed start and endpoint e.g. a golf swing, there is no research which determines hip positioning for an entire game. This is particularly relevant considering the game of Hurling (one of the most popular sports in this country) has seen a dramatic rise in the increase of financial claims made for the treatment of hip related conditions (GAA, 2015). Whether this is in part due to the stresses placed on the joint during the games itself due to positions employed to strike the ball is unclear.

2.1 Basic anatomy of the hip joint

The hip joint is a ball and socket joint consisting of the acetabulum of the pelvis and the femoral head (Derrickson, 2009) . The nature of the joint allows a great diversity of movement including flexion, extension, circumduction, abduction and adduction. The pelvis is the term given to the entire basin like structure made up of the pelvic girdle, the sacrum and the coccyx, and it provides a strong base of support for the trunk as well as an attachment site for the lower extremities. The pelvis can be divided into two regions, known as the true and false pelvises which are divided by the pelvic brim. Any structure above the pelvic brim is considered to be part of the false pelvis while anything below this is makes up the true pelvis (Derrickson, 2009).The pelvic girdle is made up of two pelvic bones also known as coxal bones, which are joined together anteriorly at the pubic symphysis and each is joined posteriorly to the sacrum. The individual coxal bones are made up of three separate bones fused together which include the Ilium, ischium and the pubis. The ilium is the largest of the three bones with the pubic bone located anteriorly and the ischium situated posteriorly. These three bones fuse together on the lateral region of the pelvis, in a hollow region known as the acetabulum, which forms the socket component of the hip joint. It is in this region that FAI syndrome occurs through the abnormal contact between the acetabulum and the head of the femur. The entire pelvic girdle has many protrusions which provide a greater surface area for muscle attachment. Differences do exist between the male and female pelvis; a female pelvis by nature is smoother, lighter and has a wider girth necessary for childbirth although no correlations have been made between differences in pelvis size and the onset of FAI syndrome (Seeley, Vanputte, Regan & Russo, 2011).

The hip joint is surrounded by over 20 muscles which can be divided into categories based on their function. The hip flexor group is made up of the iliacus, psoas, iliocapsularis, pectineus, rectus femoris and sartorius and decrease the hip joint angle (Derrickson, 2009). Alternatively, the extensor muscle group which increase joint angle space include the gluteus maximus, semimembranosus, semitendinosus, biceps femoris and the adductor magnus. The abductor muscle group which facilitate the movement of the lower limb away from the trunk include the gluteus medius, gluteus minimus, tensor fascia latae and the iliotibial band (Martini, Timmons & Tallitsch, 2006). On the other hand, muscles which draw the lower limb closer to the midline of the skeleton fall into the category of the adductor muscles and include the adductor brevis, adductor longus, gracilis and the anterior segment of the adductor magnus. Finally, the external rotator muscle group include the piriformis, quadratus femoris, inferior and superior gemellus as well as the externus and internus oburator. It is this extensive network of synergistic and antagonistic muscles that allows for the great deal of range of motion available to the hip joint (Seeley, Vanputte, Regan & Russo, 2011).

The head of the femur is surrounded by hyaline cartilage, and located in the centre of the femoral head lies a hollow depression known as the fovea capitis, from which the ligamentum teres extends (Martini, Timmons & Tallitsch, 2006). The ligamentum teres attaches the head of the femur to the acetabulum at the acetabular fossa, which is a non-articular fat-filled section of the acetabulum. The rest of the acetabulum is encased circumferentially by articular cartilage except at the base of the acetabulum, at a point known as the acetabular notch. This notch provides entry of vascular tissue and is crossed by the transverse acetabular ligament which connects either side. The outer boundaries of the acetabulum are surrounded by fibrocartilaginous tissue known as the labrum which helps to deepen the overall socket (Martini, Timmons & Tallitsch, 2006). Figure 2.1 illustrates the acetabulum and the tissues that line the joint. In FAI, tears usually occur in the anterior superior aspect of the acetabulum that is damaged by repeated contact with excessive bone.

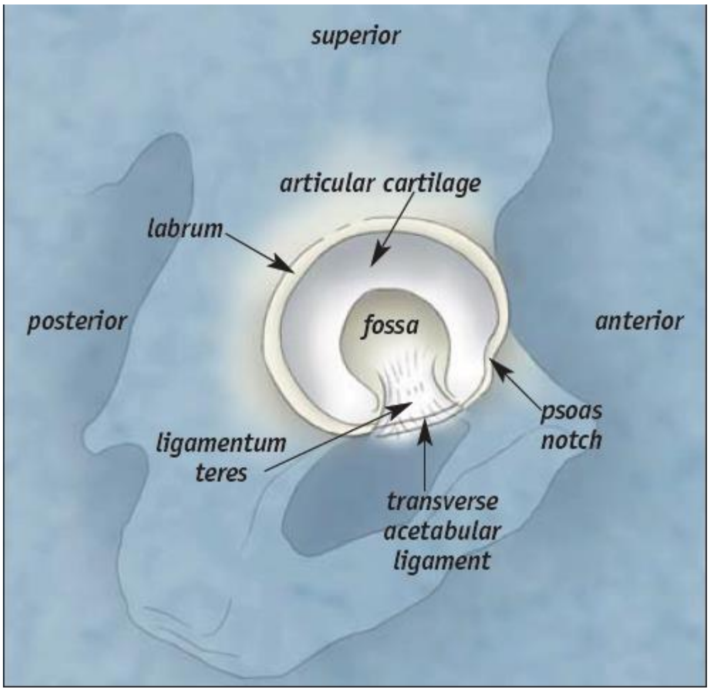


Figure 2.1: The Acetabulum (Shugars and More, 2005)

2.2 Femoroacetabular Impingement Syndrome (FAI)

FAI is a condition of the hip caused by the abnormal contact between the femoral head and the acetabulum during motion due to excessive bone growth on either or both the head of the femur and the acetabulum (Kapron et al., 2012; Clohisy et al., 2009; Ganz et al., 2003). Two distinct types of FAI have been described; cam and pincer, although it is common for patients to present with a mixture of both (Ellis et al., 2011; Philippon et al., 2007b; Rimmasch & Ravert, 2013). Cam impingement is characterised by excessive bone growth on the femoral head and is reported to be more common in young male athletes (Streit et al., 2012), while the second type of impingement, known as pincer impingement can be identified with an unnecessary amount of bone on the acetabulum which restricts movement of the femoral head into the joint during motion. This type of impingement is reported to be more prevalent in middle aged females (Rimmasch & Ravert, 2013) although it is rare for patients to present with an isolated pincer impingement (Kuhns et al., 2015). In a recent consensus statement (Griffin et al., 2016) for the correct diagnosis and management of FAI, it was recommended that the term *FAI syndrome*, rather than the traditional FAI, be used to describe the condition.

2.2.1 Diagnosis

For a patient to be diagnosed with FAI syndrome, they must present with a triad of symptoms including but not limited to hip/groin pain that is exacerbated by motion or a particular hip position e.g. sitting/stair climbing. Pain may also be reported in the lower back, knee, thigh or buttocks. Finally, patients must report either clicking/locking/catching of the hip with stiffness and loss of motion to be considered to have symptoms in keeping with FAI syndrome. Clinical and radiological signs as well as symptoms are necessary for the diagnosis of FAI syndrome. Clinical signs include a multitude of hip impingement tests that replicate the usual pain experienced by the patient and a typical restriction of internal rotation in the flexed position. The most well-known test used is the FADIR test (Flexion, Adduction, Internal Rotation) and is quite sensitive although not specific (Clohisy et al. 2009; Ito et al. 2004; Philippon et al., 2007). While reports regarding the loss of range of motion have been conflicting (Diamond et al., 2014; Freke et al., 2016) the general opinion of the consensus statement was that reduced hip ROM was a clinical sign of FAI syndrome (Griffin et al., 2016), weakness in the surrounding muscles of the hip is also considered a clinical sign of FAI syndrome. Finally, radiographic evidence of cam and/or pincer morphology must be present in order to accurately diagnose FAI syndrome and a number of methods can be utilised for this.

Plain radiographs can be used to assess the quality of bone in the joint and rule out osteoarthritis of the hip, dysplasia and avascular necrosis; plain anteroposterior (AP) views, Dunn lateral views and cross table lateral views are routinely used (Barton et al., 2011; Clohisy et al., 2008; Meyer et al., 2006). Radiographic measurements can then be used to identify structural abnormalities of the hip; such measures include the alpha angle which has been described in detail by Nötzli et al. (2002); the angle is formed by initially drawing a line from the centre of the femoral neck, at its narrowest point to the centre of a best fit circle drawn around the femoral head. The second line which makes up the angle is drawn from the centre of the circle around the femoral head to the point at which the femoral head extends beyond that of the circle (Figure 2.2a). Values of 50.5° or less are considered to be indicative of normal femoral head-neck off-sets; however disagreements among practitioners and surgeons in relation to this value have questioned the validity of using this measurement as a diagnostic tool, and many researchers use altered cut-off values for the diagnosis of cam morphology (Agricola et al., 2014; Gosvig et al., 2008; Joo et al., 2013). In relation to the diagnosis of pincer morphology, a number of radiographic tools can be used which include, assessing acetabular depth, acetabular inclination using the Tönnis angle, and assessing the overcoverage of the femoral head by the acetabulum using the centre-edge angle (Clohisy et al., 2009; Clohisy et al., 2008).

The Tönnis angle can be calculated using AP radiographs using three lines; the first is a horizontal line which connects the base of both acetabular teardrops, the second line is a horizontal line which runs parallel to line 1 and runs through the most inferior segment of the sclerotic acetabular sourcil (known as point I) and finally a third line which extends from point I to another point (known as L) located at the lateral margin of the acetabular sourcil (figure 2.2b). Individuals with a Tönnis angle between 0 and 10^o are thought to have no inclination or considered to be normal hips, while a Tönnis angle greater than 10^o indicates increased inclination, whereas hips with a Tönnis angle less than 10^o are reported to have decreased inclination (Clohisy et al., 2008). Other radiological signs of FAI syndrome include "pistol grip deformity", this is an examination of the femoral head where by there is loss of concavity anterior-superior head/neck junction, which results in a non-spherical femoral head and resembling that of the handle of a pistol (Doherty et al., 2008; Spencer, Millis & Kim, 2006).

Figure 2.2a: The alpha angle (Agricola et al., 2014)

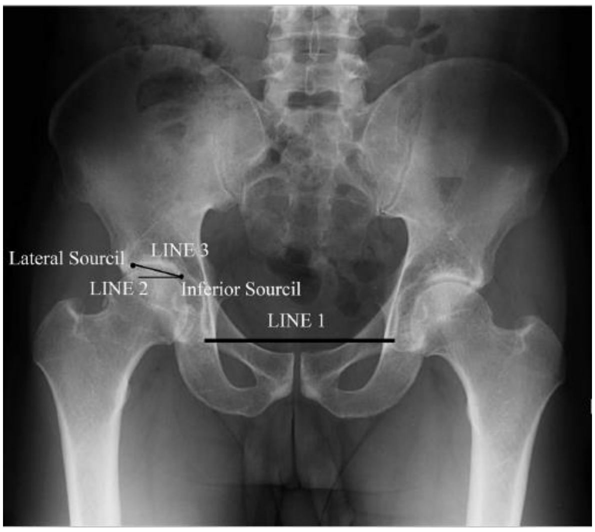


Figure 2.2b: The Tönnis angle (Clohisy et al., 2008)

The anterior centre edge angle can be used to determine the level of coverage of the femoral head by the acetabulum. This angle can be constructed on an AP radiograph by drawing a line through the centre of the femoral head which is perpendicular to the transverse axis of the pelvis and a second line which also originates at the centre of the femoral head and extends to the most anterior point of the acetabular sourcil. Values greater than 40^{o} have been reported to be indicative of pincer deformity with sensitivity of 84.2% and 100% specificity (Kutty et al., 2012). Assessing acetabular depth can also be used to diagnose pincer morphology, the relationship between the acetabular floor and the ilioischial line is assessed to judge acetabular depth. Hips are described as coxa profunda when the ilioischial line touches the fossa acetabuli, while in cases where the medial aspect of the femoral head is found to be medial to the ilioischial line hips are described as protrusio acetabuli. Although some authors have disputed the use of cox profunda as a radiological parameter for the diagnosis of FAI (Nepple et al., 2013). A cross over sign on radiograph is also indicative of pincer deformities and is recognised if the anterior rim of the acetabulum is projecting more laterally than the posterior rim on radiograph (Clohisy et al., 2008). The cross over sign is an indication of pelvic retroversion which is associated with pincer deformity although has been reported to overestimate retroversion (Zaltz, Kelly, Hetsroni & Bedi, 2013). Finally, a posterior wall sign is also often used in the assessment of bony deformities on radiograph, a positive posterior wall sign is identified when the posterior wall of the acetabulum lies medial to the centre of the femoral head (Laborie et al., 2011). Radiographic imaging is important in the diagnosis of FAI syndrome; however, care must be taken to ensure the quality of images. It is important that the hips are in an optimal position for the view being used to ensure accurate images (Tannast et al., 2007).

Assessing the presence/severity of damage to intra-articular structures within the joint can be achieved by MR arthrogram and/or CT scans which are considered the gold standard in diagnosing cam morphology due to their ability to obtain images in different planes (Tibor & Sekiya, 2008) although they are also used to identify bony abnormalities of the acetabulum (Tannast et al., 2007). An MR arthrogram is carried out by aseptically injecting contrasting dye into the joint under the guidance of fluoroscopy and carrying out an MRI scan within thirty minutes of injecting the dye. In a study by Barton et al. (2010) comparisons were made between the alpha angle scores from radiographic findings and those obtained from MR arthrograms, it was found that the Dunn view correlated most closely to the arthrographic findings with a 90% sensitivity rate in comparison to 60% for AP imaging and 74% for cross table radiographs. MR arthrograms can be used also to determine whether damage has occurred to the labrum and articular cartilage within the joint itself which will indicate whether bony abnormalities have the potential to be pathological.

Previously, conflicting definitions of FAI cam and pincer morphologies and differences in methods used to diagnose FAI have led to conflicting reports as to the best methods to accurately diagnose and optimally treat the condition. Recently general consensuses have been proposed which state that a patient must present with a triad of symptoms, clinical and radiological findings in keeping with the condition to diagnose patients. From here appropriate patient centred treatments can be identified.

2.2.2 Causes of FAI Syndrome

Though the causes of FAI syndrome have not yet been definitively stated, a number of probable causes have been proposed; in the case of cam morphology sub-acute slipped femoral epiphysis, in patients with previous history of femoral neck fractures, and decreases in the anteversion of the femoral neck (Eijer et al., 2001; Philippon and Schenker, 2007; Tönnis & Heinecke, 1999) could result in the onset of cam type FAI. Pincer morphology itself may be a causing factor of cam morphology; with constant microtrauma to the femoral neck junction through repetitive contact between the bones can cause ossification on the femoral neck which becomes pathological. In relation to cam type FAI, Siebenrock et al. (2004) suggested that, while the epiphysis of the femur is joining with the rest of the femur during adolescence it extends to the anterior or anterosuperior neck region. The author proposed that this is due to high mechanical load on the joint during development usually as a result of sporting activity, indicating that this may be a critical time frame for the development of FAI in the emerging athlete. This idea has been supported by Agricola and colleagues (2014) who proposed that cam morphologies develop during a period of increased mechanical load as a result of sporting activities while the growth plates are open, but observed a plateau in the development of further deformity once growth plates have closed (Agricola et al., 2014). However, it must be mentioned that due to the ethical issues surrounding research involving underage adolescents, it was not possible to include a control group. Therefore, it would be unwise to automatically assume that high levels of sporting activity cause cam deformities at that age while it does appear to be related. Although there is a growing albeit small body of evidence to support the idea that cam deformities develop as a result of hip loading during skeletal development, it is not definitive and raises more questions as to whether simply modifying athletic activity during this time frame is sufficient to avoid development of a cam deformity (Weinans, 2015).

A number of compensatory injuries may occur in conjunction with FAI ; these include osteitis pubis, sports hernia, posterior hip subluxation, lumbar spine damage and muscle damage (Voos et al., 2010). Knowing the associated injuries is extremely important as clinical practitioners may misdiagnose the primary problem, meaning patients not being treated for the route of their discomfort for prolonged periods of time (Philippon et al., 2007).

2.2.3 Prevalence of cam and pincer morphologies

2.2.3.1 Prevalence among General Populations

Femoroacetabular impingement syndrome is a relatively new concept in sports medicine, and so, extensive epidemiological research is lacking. Researchers have however, made attempts to discover the extent of cam and pincer deformities in the general population using radiographs from asymptomatic people which may shed light on the magnitude of this problem, however differences in the definition of what constitutes a bony deformity rather than simple anatomical variation among people has led to varying reports (Pun et al., 2015). In an investigation of 1184 male and 2018 females, Gosvig et al. (2008) used AP radiographs to determine the prevalence of cam deformity in asymptomatic people. The authors used both the alpha angle (>50.5^{o}) and a specifically designed triangular index to rate the level of cam deformity which was estimated to be 17% in males and 4% in females using the triangular index and 8.5% and 3.5% in males and females respectively using the alpha angle. However, the cohort sample in this study ranged in age from 22-90 years and the authors found no importance of age, exposure to heavy workloads or BMI on the development of cam deformity. It is possible therefore that development of a deformity occurred prior to the age of 22 which cannot be determined without prospective research. Laborie and co-workers (2011) attempted to quantify the prevalence of cam and pincer morphologies in healthy young adults (mean age 18.6 years for male and female) again using AP radiographs, although the assessment of the images was purely subjective. The images were visually inspected for signs of pistol grip deformity, flattening of the lateral region of the femoral head and focal prominence on the femoral neck which were considered indicative of cam deformity. To determine whether there were any signs of pincer deformity the images were assessed using the cross over sign, posterior wall sign and extensive acetabular overcoverage. It was found that one or more cam type deformities were seen in 304 of 868 males (35%) and 121 of 1192 females (10.2%), while one or more pincer symptoms were noted in 298 males (34.3%) and 198 females (16.6%) using the cross over sign. The large differences in prevalence rates reported by Gosvig et al. (2008) and Laborie et al. (2011) highlight the difficulty in assessing population wide prevalence of FAI, while Gosvig et al. (2008) suggested that the prevalence of cam deformity is less than five percent in women, Laborie et al. (2011) proposed that the prevalence of cam deformity is more than double that in females. The subjective nature of the Laborie study may have influenced the rate of cam deformity detection; the examination of the radiographs only included visual signs of pistol grip deformity, focal prominence of the femoral neck and flattening of the lateral aspect of the head of the femur. At which point these signs transgress from normal hip anatomy to positive radiological signs of cam deformity cannot be determined. Secondly, the radiographs for the Gosvig et al. study were obtained from the years 1991 to 1993 while the study itself was published in 2008, therefore the lower quality of these older radiographs (Silva, 2013) may have influenced the alpha angle and triangular index scores.

Using the standard alpha angle of 50.5°, Hack and colleagues (2010) investigated the prevalence of cam morphologies in 200 asymptomatic volunteers and found a rate of 14% over all with the majority of those being male. The authors also proposed that the prevalence of cam morphologies were more commonly seen in individuals with less internal rotation at the hip (Hack et al., 2010). While Kang (2010) investigated the prevalence of bony morphologies among patients undergoing MRI scans for abdominal pain/trauma and reported that 39% of the hip joints assessed showed at least one radiological sign of bony deformity which is almost three times that of the Hack paper. Again in patients ranging in ages from 15-40 males had a higher predisposition to a bony deformity than females, and the majority of patients had bilateral deformities at the hip joint (Kang et al., 2010).

While these studies do reflect the prevalence of both cam and pincer deformity in the general population they are not without some limitations; the major one being the use of AP radiographs. Reichenbach and colleagues (2010) disputed the use of AP radiographs suggesting that they are not sufficient to detect the level of deformity in the anterosuperior region where they found the majority of deformity to be located, in young healthy males using MRI. This study also classified the level of deformity into separate semi quantitative categories; images were graded on the head-neck junction offset and categorised accordingly. “0” was considered a normal image where there was no evidence of a non-spherical femoral shape, “1” indicated a possible deformity with a mild decrease of the anterior head-neck offset, “2” represented a definite deformity with a distinct decrease in the head-neck offset while “3” was considered a severe deformity with a large decrease in the head-neck offset. Grades “2” and “3” were further categorised by the location of the deformity using a clockwise system (Figure 2.3).

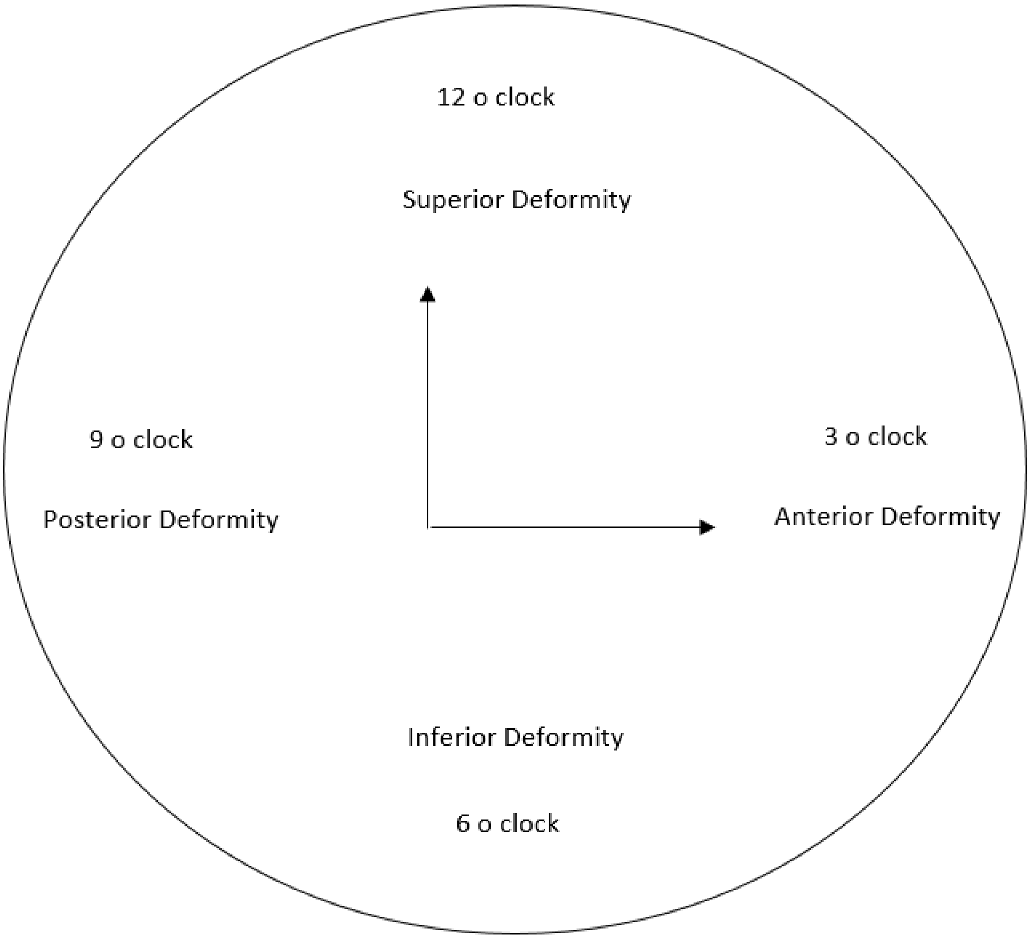


Figure 2.3 Locations of the cam deformity (Reichenbach et al., 2010)

Bony deformity at the 12.00 o clock position indicated a superior deformity, 3.00 indicated an anterior deformity, 6.00 represented an inferior deformity and 9.00 indicated a posterior deformity. The mean alpha angle for each group was also determined. The results of this study are presented in Table 2.1.

Table 2.1 Results from Reichenbach Study (Reichenbach et al., 2010)

Grade (Mean alpha angle ± SD)	Numbers of people (% of Group)
0 (44.8 ± 8°)	65 (26.6)
1 (48.4± 10.1°)	112 (45.9)
2 (57.7 ± 12.7°)	54 (22.1%)
3 (76.4 ± 9.7°)	13 (5.3)

The 67 grade 2 and 3 subjects had deformities that were predominately located in the anterosuperior position, one was located at 1.00, thirty were located at 2.00, and thirty located at 3.00. Three deformities were located anteroinferiorly and two were located posteroinferiorly while one was located posterosuperiorly. The use of a developmental scale in this study adds strength to the research in comparison to both the Gosvig et al. (2008) and Laborie et al. (2011) papers which simply report cam deformities as present/not present. Reichenbach et al. (2010) highlight the fact that the locations of some cam deformities would not be detected using AP radiographs and suggest that AP radiographs alone are not sufficient to detect cam deformities. The authors also propose that level one cam deformity is of little clinical consequence, had the researcher been able to assess the labrum also for any early signs of fraying or degeneration it would have exposed the effect of cam deformity even in the early stages where pain is not yet a factor. Subsequently in a follow up report involving the same subject data Reichenbach et al. (2011) described how the cam deformities detected in the population of men previously described were in fact associated with hip structural damage including labral lesions, impingement pits, and changes in cartilage thickness. In the same year, although using a computed tomography scanning approach, Jung et al. (2011) retrospectively examined the prevalence of cam deformity (alpha angle >83° for males and >57° for females) in 108 men and 272 women with a mean age of 62 years (range 26.6-92.6). The authors found a prevalence of pathological cam deformity in 13% of men and 5% of women, however these values altered when men and women were grouped chronologically, with 7% of men and 7% of women under 50 with pathological cam deformity. The main limitations of the study were the retrospective nature of the research, secondly, if the radiologists were not specifically looking at hip related issues at the time of scanning, optimum hip positioning for scanning may not have been a major concern.

The studies discussed in the previous paragraph were carried out in western countries where the prevalence of osteoarthritis is considerably higher than in Asian populations (Nevitt et al., 2002). Joo and colleagues (2013) sought to assess the prevalence of FAI in healthy adults using the alpha angle in a study involving 994 healthy Korean hips (497 people) using spine MRI images for the detection of cam deformity. This study utilised the same cut-off values as the Jung research discussed above, (≥83° for men and ≥57° for women), borderline cam deformities were identified using alpha angles of 69°-82° for men and 51°-56° for women, images with alpha angles ≤68° for men and ≤50° for women were considered normal. The mean age of the male participants was 50.02 (range 19-96) years while the mean age for women was 58.19 years (18-86). The mean alpha angle for men was 50.61 ± 7.61 degrees and 49.82 ± 4.14 for women. While the incidence of pathological alpha angle in both men and women was substantially lower than previous reports (0.5% and 3.1% respectively); women showed a substantially higher incidence of pathological and borderline (32.2%) alpha angles than men (4.0%) compared to western data previously reported. Again, the use of alpha angles is debatable as a diagnostic tool for cam impingement; here it would seem that the average alpha angle for Korean men is lower than western males, although the incidence of pathological cam deformity among women is higher than their western counterparts. For future research it would seem, not only does the alpha angle cut-off limit need to be validated in western countries, it also needs to be population specific. Table 2.2 summarises the prevalence of cam deformities in general populations.

Table 2.2 Summary of the prevalence of Cam deformity in general populations

Authors	Year	Population Studied	Cut-off Alpha Angle used (Deg)	Prevalence of Cam Deformity
Gosvig et al.	2008	Asymptomatic men (n=1184) and women (n=2018)	50.5	17% (men) 4% (women)
Hack et al.	2010	Asymptomatic men (n=89) and women (n=111)	50.5	25% (men) 5% (women)
Kang et al.	2010	Men and women (n=50) with unspecified abdominal pain	55	10% (men) 10% (women)
Reichenbach et al.	2010	Asymptomatic young males (n=244)	N/A	24%
Laborie et al.	2011	Asymptomatic men (n=868) and women (n=1192)	N/A	35% (men) 10% (women)
Jung et al.	2011	Asymptomatic men (n=108) and women (n=272)	Pathological: >83 (men) >57 (women) Borderline:69-82 (Men) 51-56 (women)	13% (men) 5% (women)
Joo et al.	2013	Asymptomatic Asian men and women (n=496)	Pathological: >83 (men) >57 (women) Borderline:69-82 (Men) 51-56 (women)	0.5% (men) 3.1% (women)

Whether the presence of hip deformities will ultimately lead to hip pain and discomfort remains to be confirmed (Allen et al., 2009; Bardakos & Villar, 2009), however, a recent case control study by Khanna et. al (2014) has provided some useful information in this area. In this study, 170 volunteers (77 males, 93 females; mean age 29.5 yrs) underwent an MRI scan of both hips, and were followed for a mean time of 4.4 years, using an alpha angle of 50.5° as a cut off point for cam deformity. Eleven patients reported at least one episode of hip pain lasting longer that six weeks at the four-year follow up. Three of these patients had bilateral pain, yielding 14 painful hips, 7 of which (50%) had evidence of a cam deformity at the original MRI, the other seven hips with pain had no previous evidence of a cam deformity on MRI. Of the 318 non-painful hips, 37 (11%) had previous evidence of a cam deformity. The authors concluded that people who had cam deformity on MRI were 4.3 times as likely to develop hip pain especially those with cam morphology at the 1.30 clock position. The authors also report that participants with limited internal rotation were significantly more likely to develop hip pain. While the prospective nature of the study is an advantage the source of pain was not fully determined, participants were merely asked to report the presence of pain and the location. The pain may well have been as a result of the cam deformity but there could have been other factors associated with the onset of pain which were not explored. For example, no information relating to physical or sporting activity was recorded, nor any incidents of a traumatic event which could have led to hip pain yet were not recorded. Screening asymptomatic people for bony abnormalities of the hip using MRI can be time consuming and cost-ineffective but may have a role in screening of professional athletes who are more at risk of developing pain as a result of impingement, due to the high mechanical load and repetitive microtrauma to the joint through constant training and competition (Gerhardt et al., 2012; Silvis et al., 2011).

Throughout the literature available, the prevalence of cam and pincer deformities lies anywhere between 3.5 and 45%, with substantial differences in the criteria for defining bony deformities leading to notable inconsistencies in the research. More recent studies have accommodated for potential differences in alpha angle between males and females due to anatomical differences, with increased the cut-off values for pathological cam deformity for women. Therefore, previous reports which used the same cut-off angles for both men and women could have led to an overestimation of the issue among female populations. However, indications from the research to date is that the rate of bony morphology and cam deformity in particular, are higher in males than females. A general consensus of radiological cut-off points is also needed to be determined in order to accurately identify bony abnormalities. Finally, it is still unclear whether having a bony morphology will ultimately lead to a pathological hip condition although only one paper has sought to address this, highlighting the need for more prospective research.

2.2.3.2 Prevalence among Athletic Populations

The studies reviewed in the previous section have all attempted to assess the prevalence of FAI symptoms in asymptomatic general populations, while Ochoa and colleagues (2010) sought to determine the prevalence of FAI characteristics in a young active population with hip complaints. This study found a high incidence of FAI in the young active patient (age 18-50) with hip pain using military men (n=78) and women (n=79); 94% of patients with adequate AP films had at least one radiographic finding consistent with FAI while 81% had at least two findings, with 65% presenting with both cam and pincer impingement. However, it should be noted that no criteria regarding pain upon flexion or internal rotation were included in the assessments nor did the authors separate those patients with confirmed aseptic necrosis of the hip or developmental dysplasia. So, while this study does attempt to assess the prevalence of FAI in symptomatic active people there are several limitations which should be addressed for future research in this area, which will give a clearer indication of the true prevalence of FAI in this population.

The recent research investigating the prevalence of FAI includes a broad spectrum of different sporting codes and there has been no conclusive evidence to suggest that a particular type of sport has more influence on the rate of FAI development than another, although it has been proposed that sports involving greater levels of twisting and turning may be at a greater risk (Philippon et al., 2013). American football is a high intensity field sport with increased levels of twisting and turning interspersed with heavy contact tackling. Athletes are typically heavier and more muscular compared to other sports (Vitale et al., 2016) and may be predisposed to bony morphological adaptations due to the demands of the game. Kapron et al. (2011) sought to determine the prevalence of FAI among male collegiate football players using radiographs with an alpha angle of >50° and/or a head/neck off-set <8mm as indicative of cam impingement. A lateral centre edge angle >40°, presence of a crossover sign or an acetabular index of <0° determined the presence of pincer impingement. Among 67 athletes (134 hips) 95% of the cohort had at least one sign indicative of cam or pincer impingement wit 77% having more than one sign. Data was also collected from the hip outcome score questionnaire with results generated for activities of daily living and sports sub scores from this. Sixty-two athletes had a sports score and activities of daily living score greater than 90%, four athletes reported a sports score between 80-90%, with one athlete reporting an activity of daily living score <90%. This indicates that while radiographical evidence may point toward FAI, the majority of athletes were asymptomatic, which according to the updated consensus on FAI diagnosis is not sufficient alone to determine FAI syndrome (Griffin et al., 2016). Had a clinical exam been carried out the prevalence rates would have been definitively determined as all three diagnostic measures for the condition would have been carried out. The major limitation of this study is the lack of control group and while the levels of bony morphologies appear high it cannot be assumed that American football is a causing factor in the development of FAI. Furthermore, the radiographs were not corrected for pelvic tilt which can influence the determination of a crossover sign and so could have led to an overestimation or underestimation the true prevalence of crossover signs (Tannast et al., 2006; Tannast et al., 2007) and therefore pincer deformity. While athletes included in the previous study were asymptomatic, Nepple et al. (2012) retrospectively examined radiographs of American football athletes with a history of hip or groin pain that was not attributed to FAI at the time of injury. Radiographs were collected for 107 male football players (123 hips), with an alpha angle >50^{o} or a femoral head/neck off-set ratio >0.17 indicated a femoral deformity, while a lateral centre edge angle >39^{o} or a crossover sign arising more than 10mm from the acetabular rim was recorded as a pincer deformity. It was found that 94.3% of the hips had evidence of FAI with combined FAI being the most commonly observed phenomenon. Again, the lack of control group in the study protocol is a limitation, in conjunction with the fact athletes recruited all had a history of hip pain leading to potential selection bias among the population sample. However, the fact that American football is a sport that subjects athletes to high levels of loading, this group may be particularly at risk for the development of hip related issues and so examination of the population is warranted although more prospective research is required.

Due to the fact that FAI syndrome is observed mostly in young athletes it could be suggested that the damage begins much earlier than when symptoms arise, in early adolescence for instance. There have been attempts made to explore the link between engaging in high levels of sporting activity during adolescence and the onset of FAI syndrome in later years although the retrospective nature of the research makes it difficult to draw direct links between the volume of training undertaken at a young age and the presence of impingement. Johnston et al. (2012) reported on the incidences of FAI in former high-level youth soccer players and a control group, using AP radiographs and an alpha angle of >55^{o} for both males and females as indicative of cam deformity. High level soccer was defined as engaging in three or more games or training session per week for at least thirty-six weeks of the year between the ages of 8-12 for girls and 10-14 for boys. It was found during this study that of 25 male participants who had participated in high level soccer as an adolescent, 15 presented with cam deformity, while 14 out of 25 male control participants had evidence of cam deformity in one or both hips. The female rates were identical across both groups, with eight out of twenty five classed with cam deformity in both groups. This study did not show any evidence of greater incidence of cam deformity in those who had previously engaged in high levels of soccer during adolescence than those who did not. However, the fact that only asymptomatic people were used may not have given a true reflection of the extent of the problem. If symptomatic participants had been used it might have given a clearer insight as to how many people with painful FAI engaged in high level soccer as a youth. In a more prospective orientated study Siebenrock et al. (2011) looked at high level basketball players, aged 9-25 years and an age- and gender-matched control group. Both athletes and the non-athletic control group were subcategorised into four distinct age groups; 9-12, 13-15, 16-21 and 22-25 years. MRI images were taken of both hips of each participant, with impingement tests also being carried out to assess the level of internal rotation at the hip joint. The alpha angle, with a cut-off value of 55° considered pathological, was determined throughout the entire cranial hemisphere using a clockwise system. The results indicated that overall athletes had significantly higher mean alpha angles along the anterosuperior quadrant of the femoral head compared to controls, with the highest alpha angle for the athletes located at the 1 o clock position (60.5° for athletes compared to 47.4° for controls). Interestingly the control group had significantly higher alpha angles at the 10 o clock position (superior-posterior region), the researchers did not expand on this finding and no information relating to the control group other than the fact that they did not engage in high level basketball was given. Radiographs were not taken due to ethical considerations given the age profile of some of the participants, and while hip dysplasia and developmental disorders were presumed to be non-existent, this could have been confirmed using AP radiograph. In relation to the impingement test, 48% of the athletes without hip pain in the previous six months reported anterior groin pain during the impingement test compared to 1.3% of controls. Internal rotation angles were calculated for each participant with the hip flexed to ninety degrees, and it was noted that the athlete group had reduced internal rotation values at each age group compared to controls, furthermore the decrease in internal rotation values with increases in age category were more severe in the athletic group than the control. On average the athletes decreased 22.5° in internal rotation values with increasing age compared to 10.2° for controls. Although plain radiographs were not used which could have alluded to other developmental disorders such as hip dysplasia, the authors concluded that cam deformity is a developmental deformity which may be exacerbated by high intensity loading of the proximal femur as a result of frequent exercise. This study highlights the possible relationship between the frequencies of high intensity exercise during skeletal development that may result in the onset of more pronounced cam deformities.

Tak et al. (2015) sought to assess whether the frequency of football activity during adolescence could influence the prevalence of cam deformity in later life in a cohort of professional soccer players. Players were asked to recall the age at which they started playing football with a club and at what age they started playing with a professional club. The results of the study indicated that of all participants included, 64% had radiological signs of a cam deformity (α angle $>60^{o}$) and 29% had evidence of a pathological cam deformity (α angle $> 78^{o}$) on either an AP radiograph or a Frog-leg lateral view. The prevalence of pathological cam deformity was significantly higher in those that had engaged in training four or more times per week prior to the age of 12 years compared to those training less than four times per week before that age. No significant differences in cam deformity were reported when a threshold of 11 years was used, however, overall the results of this study indicate that greater training frequency in the early stages of adolescence could be a risk factor for the development of a cam deformity.

Ice hockey has been cited as a sport particularly associated with FAI (Stull et al., 2011; Philippon et al., 2007) with goalies at an increased risk due to the butterfly manoeuvre employed to defend the goals. In a study involving underage ice hockey players and skiers (control) Philippon et al. (2013) examined the incidence of cam morphology among both groups through the use of MRI and clinical examination. The authors reported a significantly higher rate of cam morphology among the ice hockey group (75%) in comparison to the skiers (42%) and in particular the 16-19 age players when grouped by chronological age (Philippon et al., 2013).

In a recent study involving elite male golfers, Dickenson and colleagues (2016) investigated the hip morphologies in both lead and trail hips in elite golfers (mean age 28 ± 5.5yrs) using two definitions of cam morphology (>55^{o} alpha angle at the 3 o clock position and >83^{o} alpha angle at any position around the femoral head/neck) while pincer morphology was defined by a negative acetabular depth measurement. Out of 55 elite golfers (52 golfers with left hip as lead hip) it was reported that there were 9 cases of cam morphology when defined as an alpha angle >55^{o} at the 3 o clock position and 11 players displayed cam morphology when it was defined by an alpha angle >83^{o} in any position. There were no incidences of isolated cam morphology in the lead hip; all cases were identified in either hips or the trail hip alone. Pincer morphology was not detected in any golfer (Dickenson et al., 2016). Labral tears were also more common in the trail hip compared to the leading hip 37% versus 16%. Despite the relatively large subject numbers for a field based assessment of hip morphology the use of a portable non-contrast MRI scanner does lead to questions regarding the accuracy of the system. Had the imaging been conducted in a clinical setting it might have been easier to control the level of hip rotation which needs to be rigorously restricted to ensure accurate scanning. In this instance the trail hip of golfers was at a greater risk of developing cam morphology than the leading hip. The game of Hurling is indigenous to the country of Ireland and involves high levels of rotation due to the swinging action required to hit the ball, and in some respects, could be compared to golf with the level of hip rotation, although hurlers rarely swing while in a static posture and are generally encouraged to hit the ball from both the left and right sides of the body. However, hip morphologies in hurlers may not be equal and further investigation among this population is warranted.

In contrast to previous investigations regarding types of sport and the prevalence of hip impingement with associated chondral damage, research exploring the role of dance, namely ballet, and the onset of hip injury have produced some interesting findings. It has been found that although hip injury rates are significantly high in this cohort, often a bony abnormality is not the primary cause of labral damage. These types of injury are more often than not due to the extreme range of motion necessary and the large volume of training hours required to perfect movements (Kocher et al., 2006). Ballet movements in particular can cause impingement like movement within the hip joint, often with secondary subluxations. In a motion capture study involving professional ballet dancers (Charbonnier et al., 2011) it was found that of six routine movements, four produced impingements all of which were associated with subluxations. Indeed, the frequency of these movements, particularly in ballet, can lead to lesions within the joint without the presence of a bony abnormality. Kolo et al. (2013) reported that of thirty dancers 55% had hip pain and lesions present while 35% had no pain, yet lesions visible on MRI while only one dancer presented with cam impingement (α angle > 55°). These results echo previous research involving dancers; in a study by Kocher et al. (2006) it was reported that over a three year period 50% of the dancers referred to the clinic were treated for hip pain and of those, 40% were diagnosed with labral tears. None of the dancers involved in this study had any sign of dysplasia, cam or pincer impingement although no detailed radiographic information was given, the authors concluded that the labral tears were likely due to overuse, and that the extensive practice hours accelerated the natural deterioration of the labrum. This is an interesting finding considering that in previous research involving other sports, there are strong suggestions that cam and pincer deformities establish themselves during high intensity loading of the joint during skeletal growth and dancers presumably would undergo the same level of high intensity training hours during skeletal immaturity, the results from the Kocher study do not seem to support this theory. Kocher's results were further supported by Duthon et al. (2009) who reported that of the 18 out of 20 professional dancers diagnosed with labral tears on MRI, only one dancer had evidence of cam morphology. Ballet dancers, as with many athletes, will tend to avoid addressing hip problems until such time as they are unable to perform, and will often be reluctant to undergo labral repair due to the extended rehabilitation time. Poor dancing technique may also initiate hip related problems (Kocher et al., 2006) and therefore biomechanical alterations in association with surgical intervention may have a greater chance of preventing reoccurrence of injury and prevent further surgery being required.

Much of the research examining prevalence of bony morphologies or FAI has included athletes that compete in sports associated with a professional organisation. The professional nature of sports such as these may provide more opportunity for research investigation in comparison to sports which don't have the same funding resources and therefore a level of bias may exist within the research towards these types of sports. In addition, the use of MRI, MR Arthrogram and x-ray to accurately diagnose cam and pincer deformities are necessary, which has an added cost that may prevent non-professional athletes from being included. The use of such diagnostic tools on healthy sports people needs to be closely monitored due to radiation exposure which is not medically required. In a professional environment doctors and medical staff are readily available and so any type of research investigation involving the athletes can be strictly supervised, this may not always be the case with non-professional organisations which could direct research to prioritise professional athletes

While bony morphologies appear to be common among athletes, whether these morphological variations will develop to FAI syndrome is less clear due to a lack of longitudinal research. The increased financial cost of carrying out longitudinal studies involving radiographic screening may be a deterrent for researchers to undertake such investigations.

2.2.4 Implications of FAI Syndrome

FAI is believed to be a substantial risk factor for the early development of osteoarthritis (OA) of the hip (Ganz et al., 2003; Wagner et al. 2003; Tanzer & Noiseux 2004) which is a significant worry due to extensive decreases in quality of life for those affected and the high costs of treatment for the condition. While there has been a growing body of evidence to determine accurate diagnosis of the condition, the progression of FAI syndrome to OA has not been examined extensively, and therefore a direct link between the natural progression of FAI syndrome to OA while logical is unclear. In a recent review by Wright et al. (2015) it was reported that there was moderate evidence to support the idea that an increased alpha angle at baseline is associated with the progression of FAI to labral tear and subsequently the onset of further hip complications. The authors also suggest only moderate evidence to support the theory that there is an association between other radiological variables besides alpha angle and the progression of FAI (Wright et al., 2015). However, a new research study is currently underway to assess the progression of FAI syndrome to OA (Crossley et al., 2018). This study will assess changes in joint structure over a two year period, whether two years is sufficient to see dramatic changes in joint structure remains to be seen.

In the area of hip impingement research, many studies have investigated the diagnosis and treatment of FAI, while only recently has research begun to emerge with regard to the functional consequences of the condition. Much of the earlier research available relates to hip flexibility measurements which are frequently used in the diagnosis of FAI and to evaluate the effectiveness of surgery. Patients with FAI will usually have reduced levels of internal rotation, flexion and abduction (Audenaert et al., 2012; Kubiak-Langer et al., 2007), internal rotation ranges will typically decrease when the hip is placed in greater degrees of flexion and adduction (Kubiak-Langer et al., 2007). Audenaert et al. (2012) conducted a cross-sectional study that investigated hip flexibility measures in three independent groups. The three groups consisted of a patient group with symptomatic FAI undergoing surgery who had both radiographic evidence of FAI and a positive impingement test, an asymptomatic patient group who had radiographic evidence of FAI and an α angle $\geq 55°$ but a negative impingement test and a healthy control group with no radiological signs of cam deformity and an α angle ≤ 50° and a negative impingement test. It was found that the average range of internal rotation was 12.3° for patients, 21.1° for asymptomatic controls and 27.9° for healthy controls which was found to be a significant difference between groups. There were ten participants per group and while a G power analysis proposed that eight participants per group would be enough to detect a clinically significant difference, perhaps the use of a median value or interquartile range would have given a more accurate indication of the magnitude of the differences of these small sample sizes. While research such as this is important, to gain a greater understanding of the true consequences of the condition, tasks involving whole body movements must also be examined as they can give a more accurate account of overall functional deficits in persons with FAI syndrome which may be more reflective of decreases in quality of life for such patients.

A small but increasing number of studies have sought to address the level of gait dysfunction among patients with FAI and some conflicting reports have emerged. According to Kennedy et al. (2009) there are a number of differences in gait between those with FAI and those without, such differences include a lower peak hip abduction angle, significantly less total frontal hip ROM and lower total sagittal hip ROM in patients than controls. No significant differences between walking speed or step length were detected between groups. Rylander et al. (2011) supported these findings when they reported lower sagittal hip ROM in walking, and again both lower sagittal hip ROM and internal rotation during both walking and stair climbing in a follow up study (Rylander et al., 2013). However, in a similar study involving greater subject numbers and a higher statistical power, Hunt et al. (2013) found patients (n=30) with all three types of FAI exhibited significantly slower walking speeds, significantly reduced cadences, as well as significantly reduced peak hip extension, adduction and internal rotation compared to healthy controls (n=30) (Hunt et al., 2013). However, Diamond et al. (2016) found the only significant variance between FAI patients and controls was a small difference in total hip ROM in the sagittal plane while walking and the author concluded that the differences in walking were small and unlikely to affect patients to any great extent. The differences in walking speeds noted in the Hunt study compared to the others may be related to symptom duration. The patients included in Hunt's research had an average symptom duration of 4.3 years compared to an average of 2.5 years (Diamond et al., 2016), with no other study reporting symptom duration. It is possible that gait alterations are increased with prolonged symptom and pain durations and hence the greater subject numbers and longer symptoms could have led to differences in results.

While the main concern associated with FAI syndrome is the structural deformities of the bones, the potential damage to the surrounding muscles as a result of the dysfunction is also a concern. Casartelli et al. (2011) reported that patients with symptomatic FAI will also suffer from weaknesses in major hip muscle groups including, hip flexors, adductors, external rotators and hip abductors. Recently Diamond and colleagues (2016) examined the differences in isometric and isokinetic hip strength between patients with cam/combined FAI and healthy controls. They reported 30% less isometric hip abduction strength in patients compared to the control group (p=0.04) but no differences in any other muscle group (Diamond et al., 2016). This may have relevance in so far as patients with reduced abductor hip strength may be less likely to control optimal hip positioning which prevents impingement. These findings support previous reports of reductions in hip abductor strength in patients with FAI and labral tears. In this instance, Nepple et al. (2015) also reported reductions were also observed in the muscles employed for hip flexion. Using the same cohort as previously mentioned, Diamond et al. (2016) subsequently reported on the differences between deep muscle synergies between patients and controls during gait and found that there are a number of differences associated with muscle synergies between groups especially in the deep rotator muscles that are involved in hip control during the early swing phase of gait. Although, when gait was simultaneously assessed with muscle activity there were no differences detected between groups with regard to cadence, step length, stride length or walking speed indicating that differences in deep muscle synergies may not affect overall mobility to any great extent.

In relation to more athletic functional movements, Lamontagne et al. (2009) discovered that patients with cam FAI could not squat as low as healthy controls using 3D analysis. A height adjustable bench was made specifically for the research which was set to 1/3 of the tibial height of each participant and acted as a target for participants to reach while squatting. Although controls squatted lower than patients, no information was given on the level of activity these participants routinely carried out which would have highlighted the ability of the either group to carry out squatting manoeuvres appropriately. Nevertheless, this study was among the first to assess functional deficiencies among FAI populations and formed the basis for many subsequent research papers attempting to expand the knowledge base. While assessing the deep squat with controlled squat depth, Kumar and colleagues (2014) found that patients with FAI exhibited greater hip adduction, and a higher internal rotation moment to achieve the required squat depth of 25% of total body height compared to the control group. Furthermore, within group comparisons, indicated that patients with cartilage lesions revealed greater hip adduction and internal rotation moments than patients without cartilage lesions. As with the Lamontagne study (2009) no information regarding the activity levels of the patients or the control group were described in the report by Kumar and co (2014), when comparing groups with regard to functional measures it is important to ensure the groups are related as much as possible in so far as their sporting endeavours. The idea that squat depth is affected by FAI is further supported Bagwell and colleagues (2016) who not only identified reductions in squat depth but also found patients displayed increased anterior pelvic tilt and decreased peak hip internal rotation while squatting. In contrary to these findings, Diamond et al. (2017) examined differences between FAI patients and controls with regard to squatting depth and found no differences in squat depth during a constrained or unconstrained squat. Although the author did report patients with FAI displayed significantly increased levels of hip adduction, ipsilateral rise during the constrained squat as well as increased external rotation during the descent (Diamond et al., 2017). The differences between Diamond's study at that of the previous reports could be attributed to the fact that all participants involved in the Diamond study were required to place their heels on a wedge that placed the feet in 30° of planter flexion to facilitate maximum squat depth. These findings are important in so far as, while patients can achieve the same depth as controls, the mechanisms used to achieve this may have long term negative consequences for hip/pelvis and surrounding structures especially if a load is applied. The findings regarding squatting technique are important as squatting is an integral component in the assessment of overall functional mobility but is also a fundamental training exercise used very frequently with athletes in physical preparation for competition regardless of sporting type (Bagwell et al., 2016). In a recent systematic review, the biomechanical implications of FAI syndrome were discussed (King et al., 2018); the implications for walking and squatting were noted yet the lack of literature on other tasks was highlighted.

Speed, agility and jumping power are vital components of most field sports and may be negatively affected by FAI syndrome which can lead to deteriorations in overall performance. Evaluating how much they can be affected by the condition and may serve to inform coaching personnel that deterioration in these measures are not necessarily an indication of physical fitness, but rather an associated symptom of an underlying hip pathology. In a recent and novel study, Brunner et al. (2016) examined differences in functional measures of speed, agility and acceleration as well as muscular strength in young adolescent elite ice hockey players (n=74). The cohort were divided into three distinct groups; those with no radiological or clinical evidence of hip impingement (control), those with radiological but no clinical signs of FAI (asymptomatic) and those with symptoms and radiological findings in keeping with FAI (symptomatic). It was found that there was no significant difference between groups for any of the functional measures. The athletes young age (average age 16 years) may mean that the injury had not progressed sufficiently to affect functional performance. Had the athletes been tracked for a number of years, more distinct performance deficits could have become more apparent with the progression of the injury. Brunner's study is highly important in the progression of research in this area; considering FAI syndrome is highly common in young athletes whose ultimate goal is to remain playing competitively for as long as possible, it is imperative that research begin to focus more on the functional consequences of this injury.

While dancers do exhibit a large number of labral tears, less is known about the functional deficits in that particular cohort. Kivlan et al. (2016) sought to examine the differences in ROM and performance on a hop test between dancers with FAI and those without. It was found that dancers with clinical signs of FAI displayed lower levels of hip extension strength and performed poorly compared to controls on the functional hop test with no differences between groups when ROM was assessed, which is contrary to previous findings regarding hip ROM. However, a major limitation of the study was that dancers were not examined radiographically for FAI and were grouped on the basis of subjective reports of hip pain and a positive FABER and anterior impingement tests. Clinical examinations for the condition have been cited previously as not being overly specific (Clohisy et al., 2009) and therefore clinical examination alone is not sufficient to accurately diagnose FAI. Therefore, it could not be ruled out that the dancers in question may have been suffering from a hip/groin injury other than FAI. Hip morphologies such as cam and pincer have not been reported previously as a common problem among the dancing community, although labral tears have. Whether labral tears alone are sufficient to cause negative functional performance affects remains unclear.

While not definitive, there are a number of functional consequences associated with FAI syndrome, the most common being a loss of range of motion. This could have potential negative consequences for physical performance. If an athlete cannot employ a suitable position due to loss of ROM at the hip, they may exhibit decrements in attributes such as speed and agility by not being able to produce maximum force due to their sub-optimal body positions. There is a significant paucity among the research available which examines the functional limitations among a group of athletes with diagnosed FAI syndrome.

2.2.5 Treatment of FAI syndrome

2.2.5.1 Conservative management

Conservative treatments may have a benefit in short term pain relief and can be used in the absence of surgical intervention or indeed in the weeks leading up to surgery (Clohisy et al., 2010). These can include treatment with non-steroidal anti-inflammatory medication, behaviour modification and the activation of certain muscle groups in and around the hip joint during walking or strenuous physical activity. Emara and colleagues (2011) examined the influence of a conservative protocol for the treatment of mild FAI in young male and female patients. The authors describe the patients as "athletic patients", however, no indication of the level of participation either before or following intervention was given. The protocol included treatments such as behaviour modification, physiotherapy and the use of anti-inflammatory medication. Patients underwent a four-stage model of treatment; firstly, they were treated with anti-inflammatory drugs for 2-4 weeks during an acute attack. They then underwent physical therapy for 2-3 weeks which involved stretching for 20-30 minutes per day, which aimed to improve extension, abduction, external rotation and flexion. The safe ROM was between maximum internal and external rotation, which patients were advised to keep within these ranges when performing daily tasks although how far inside these ranges was not disclosed. Running on treadmills was avoided as well as running in narrow lines to avoid internal rotation. Cycling was avoided where possible although if patients continued to engage in cycling, they were instructed to raise the seat to avoid deep hip flexion, although no reference was made to the impact that could have on the knee or to the optimal saddle height for their patients. Sitting continuously with the spine fully straight was discouraged, patients were instructed to lean backwards every 5-7 minutes, although how long they were to sit back for was not identified. The patients were followed for 2-3 weeks until the pain subsided and then every three months for twelve months and every six months after that for up to 25-28 months. The Harris hip score (HHS) was used to determine changes in quality of life, as was the non-arthritic hip score while ROM values of symptomatic versus asymptomatic sides were recorded. Of the 37 patients, 4 underwent surgery after the conservative treatment failed to improve their pain levels. The HHS improved from 72 to 91 at the 6-month follow up and remained at 91 at the 24-month follow up. The mean non-arthritic hip scores improved from 72 to 90-91 at the same time frames. At the 24-month follow up six patients had recurrent hip pain although not serious enough to require surgery. These are comparable to both open and arthroscopic techniques which have been reported previously (Byrd and Jones, 2009; Laude et al., 2009; Philippon & Schenker, 2006; Rebello et al., 2009) although longer term follow-up is necessary to assess the sustainability of the program compared to surgical interventions. Conservative treatment did not improve ROM scores at all. This study does attempt to ascertain whether conservative treatment could be a viable option for patients with FAI although a number of issues with this protocol did arise: 1) a major emphasis was placed on behaviour modification and activity reduction which may not be a preferable option for most athletes; 2) no recommendations regarding saddle height were given. Astorino et al. (2005) compared different methods for calculating saddle height in cyclists and reported that if a saddle was too high it would lead to posterior knee pain due to the over extension of the knee at the base of the cycling stroke. 3) Compliance to the protocol was not recorded, while the patients were assessed every 2-3 weeks, whether they fully committed to the intervention was not determined. 4) If the treatment had been compared to a group that underwent surgery as their primary treatment it would allow for the comparison between the two main treatment options for this condition, although the same can be said for surgical outcomes.

In a recent pilot study involving 15 patients with diagnosed FAI who were treated using a home-based exercise programme or a supervised manual therapy and exercise treatment, Wright et al. (2016) found significant improvements in both groups with regard all primary and secondary outcomes including the hip outcome score HOS, pain score, and range of motion. Although, neither treatment was found to be more beneficial than the other and; when patients reported on satisfaction rates only 4/15 patients reported they were satisfied with their current status following intervention. The fact that competitive athletes were included in the patient group, who reported that following the treatment they were improved, yet were unable to perform at their preferred level of competition, may account for this. Besides the low subject numbers, the short duration of the intervention may have been insufficient to observe increases in satisfaction rates among patients. In a larger cohort over an expanded time period these results may change, alternatively objective measures that specifically assess areas of performance may be more useful tools especially when dealing with athletes to evaluate intervention protocols.

While many surgical papers advocate surgical intervention if conservative measures fail, there is very little research regarding conservative treatment options for patients. Further research should focus on biomechanical alterations and physiotherapy protocols that could be employed to manage athletes with FAI syndrome who are either unwilling to undergo surgery or who have some other contraindication to prevent them from doing so. There has been a lack of research which compares non-surgical and surgical treatments for FAI syndrome (Palmer et al., 2014). This research however is currently being undertaken following the report by Griffin et al. (2016) which concluded that such a study would be feasible. Two strands of the Fashion research group have undertaken this research based in the UK and Australia where the aim of both RCTs is to compare a targeted rehabilitation program to arthroscopic treatment. While the UK strand of the research group will be focusing on the self-reported measures the Australian strand will be assessing more functional aspects (Griffin et al., 2016; Heerey et al., 2018; Kemp, Coburn, Jones & Crossley, 2018; Mansell, Rhon, Meyer, Slevin & Marchant, 2018; Murphy et al., 2018). Eight different surgeons will be involved with no standardised rehabilitation program following the procedure which could lead to some variability within the results of the arthroscopy group.

2.2.5.2 Arthroscopic surgery of FAI syndrome

The advancement in modern medicine, including the availability of radiographic equipment and better surgical equipment has led to the improvement in arthroscopic treatment of hip conditions including FAI syndrome (Yaffe & Terry, 2010). Patient positions for arthroscopic surgery to treat FAI syndrome and labral tears include the supine position, modified supine position or lateral decubitus position depending on the preference of the surgeon (Byrd, 2006; Chow et al., 2013; Philippon et al., 2013). To begin the procedure the hip joint is first placed in traction; approximately 50 pounds of force is required to adequately distract the joint, and it is recommended that the amount of time with the joint in traction should be kept as brief as possible, preferably less than 2 hours (Byrd, 2006), the joint may also be distended with 40cc of fluid to enhance distraction. Portal placement for entry of the arthroscopic instrumentation into the joint is critical; Byrd recommends the use of three portals including the, anterior, anterolateral and posterolateral portals (Byrd, 2002; 2006) although there have also been reports of hip arthroscopy procedures using two portals, the anterolateral and midlateral or mid- anterior portals (Chow et al., 2013; Philippon et al., 2013).Typically a 70^{o} scope will give the greatest visualisation for the procedures and is commonly reported throughout the literature (Kelly et al., 2005). In cases of cam impingement, a motorised burr is used to remove excessive bone which is causing the impingement. Dynamic examination of the hip joint can be used to determine the amount of bone to be removed and indeed to assess whether the impingement has been removed completely; the goal of the debridement should be to recreate a spherical femoral head (Weiland & Philippon, 2005). The labrum can appear bruised, partially torn or completely torn in cases of cam impingement and it is imperative to remove enough bone as not to allow reoccurrence of the impingement and the damage that inflicts. In relation to the amount of bone to be removed, a study involving cadavers conducted by Mardones et al. (2005) indicated that no more than 30% of the head neck junction be removed in the case of anterolateral lesions, to avoid the risk of subsequent fracture at the site due to the inability of the joint to bear weight should more than 30% be removed. For pincer lesions the underlying labrum can appear bruised, detached or ossified from severe chronic impingement (Mardones et al., 2005) and a cam lesion may also be present in the opposite region of the head-neck junction of the femur. As with the cam impingement a motorised burr is used to remove the excessive bone on both the acetabulum and femoral head-neck junction if necessary (Poh et al., 2015).

In earlier treatments for a torn labrum, the damaged labral tissue was typically removed as part of the surgical procedure. A study by Byrd & Jones (2009a) found that patients who underwent such labral debridement who had no evidence of arthritis at the time of surgery showed no significant deterioration over the course of ten years. However, in patients who had evidence of arthritis at the time of surgery who underwent labral debridement, almost 90% of those subsequently underwent total hip arthroplasty. More recently, with the greater understanding of the role of the labrum as a stabiliser of the hip joint, as well as acting as a lubricant and a distributor of force, surgeons now advocate repairing damaged labrum where possible (Mlynarek et al., 2015). In cases of repair, absorbable suture anchors are used to reattach torn labral tissue, to the capsule. Anchors are placed approximately 2mm below articular cartilage 1.0-1.5 cm apart (Pennock et al., 2010) and care is needed to avoid penetrating any of the articular cartilage tissue, the sutures are then looped around the labrum or passed through it. The sutures are then tied, with the knots located on the capsular side of the labral-bone junction as to avoid injury to the adjacent cartilage during motion of the hip (Pennock et al., 2010).

A capsular repair can be performed following the removal of impingement bone and repair of the labral tissue (Figures 2.4a and 2.4b). The operated limb is brought back to a neutral position on the operating table that includes no flexion or rotation of any kind, traction is also removed. The capsule is then sutured together which aims to restore proper capsular integrity and prevent instability of the hip joint (Domb et al., 2013)

Figure 2.4a Capsultomy before repair (Domb et al., 2013)

Figure 2.4b Capsular repair (Domb et al., 2013)

The literature has now moved toward more randomised control type research designs and protocols for study research have been published. One such study aims to compare arthroscopic surgery to sham surgery, whereby the "sham" group will undergo diagnostic arthroscopy only. Outcome measures will include a number of self-reported measures assessed at 3 months, 6 months, 1,2,5 and 10 years post treatment (Risberg et al., 2018).

2.2.6 Rehabilitation following surgical intervention for FAI syndrome

The overall goal of rehabilitation is to restore the athlete to pre-injury levels of activity and function within the shortest time possible, with minimal risk of re-injury. This is achieved by giving appropriate consideration to the healing properties of the tissues affected, avoidance of muscle atrophy, improving range of motion, appropriate progression of strength and proprioceptive training, maintenance of cardiovascular fitness and finally sport specific training before return to competition (Enseki & Draovitch, 2010; Stalzer et al., 2005). Before surgery, the physiotherapist will generally aim to meet with the patient to discuss the importance and the general outline of the rehabilitation program, any issues or concerns the patient may have can be addressed here.

Following most hip arthroscopies for procedures that include labral repair, chondroplasty, microfracture or capsular repair, initial pain and swelling are managed through the prescription of non-steroidal anti-inflammatory medication by the surgeon. Passive ROM is carried out immediately using a passive motion machine which will manually provide motion in a single plane which in some cases can be utilised for up to six weeks (Cheatham & Kolber, 2012). Weight bearing is limited for up to two weeks and ambulation is carried out using crutches. Stalzer et al. (2005) recommended no more than 20 lbs (9.1 kg) of weight during stance or walking, however in a more recent study published by Enseki & Draovitch (2010) an increased weight of 30 lbs (13.6 kg) was recommended. In a comprehensive report published by Spencer-Gardner et al. (2014) detailing the rehabilitation protocol prescribed at their institution; the authors stress the fact that during the first phase of rehabilitation the patients be instructed to walk with heel-to-toe contact. This is encouraged to help regain normal gait but will also reduce the stress placed on the iliopsoas muscles and aid in reducing inflammation. Following surgery, flexion is usually limited to less than 90^{o} for the initial ten days, while ROM in different planes may be restricted but this will depend on the site of injury and the procedure used to correct the damage. A brace may be used to limit movement in certain directions, although stationary cycling is introduced as quickly as possible usually the day of or one day following the procedure. It is important to note that the seat must be adjusted accordingly to avoid any excessive hip flexion.

Aquatic ambulation is advised as soon as possible, if waterproof dressing is available, the athletes can begin walking in the pool one day following the procedure, although in the five phase model utilised by Spencer-Gardner and colleagues (2014) aquatic exercises are only introduced once the stiches have been removed and the wounds have healed. Aquatic ambulation provides the athlete with an opportunity to correct gait asymmetries as well as improve ROM in a non-weight bearing environment. Not all initial phases of rehabilitation include aquatic therapy, with a case report by Cheatham and Kolber (2012) involving an 18 year old high school athlete including no aquatic exercise during this initial phase. No specific reason was provided for the omission of aquatic therapy in the report.

Initial strengthening exercises that focus on engaging the gluteal and core stabilising muscles may be introduced the day after surgery, and the advancement of these strength exercises with the inclusion of proprioceptive training may begin once the patient is fully weight bearing. The patient should focus on low intensity exercises but with high repetitions during this phase of rehabilitation (Spencer-

Gardner et al., 2014). Stretching exercises should be avoided until approx. six weeks post-surgery as early stretching of the muscles in and around the hip joint can lead to inflammation and improper healing of the ligaments and tendons surrounding the joint. Cardiovascular fitness can be maintained through resisted stationary cycling which may be introduced as early as three weeks following a labral repair although for microfracture procedures can be limited until seven weeks (Stalzer et al., 2005).

Sport specific training can be resumed at approximately 7 to 10 weeks for labral repair procedures but can be extended to 17 to 20 weeks for procedures including microfracture, chondroplasty and capsular repair. In the model reported by Spencer-Gardner et al. (2014) a number of functional tests were carried out following the fifth stage of rehabilitation and just before the athletes are allowed to return to competition; these include a single leg hop for distance, a single leg triple jump for distance and a single leg vertical jump . The authors recommend that values of the affected limb must be 90% or more of the results of the contralateral side, assuming bilateral impingement is not observed. The progression through the phases of rehabilitation should be approached on a case by case basis and there needs to be frequent communication between the surgeon and the physiotherapy personnel who oversee the rehabilitation process to ensure the correct course of action is being applied.

Regarding the outcomes following rehabilitation Spencer-Gardner et al. (2014) reported that of the 52 patients who undertook the five-phase model of rehabilitation, at the one year follow up 38% reported excellent results, as demonstrated with a modified Harris Hip score (mHHS) of 90 or more. 23% reported good outcomes (mHHS of 80-90) 15% reported fair outcomes (mHHS of 70-79) while 23% reported poor outcomes (mHHS of <70). It is important to note that the actual compliance rate of the patients with the protocol was not measured which makes it difficult to ascertain whether the protocol was to blame for some of the poorer results. The average age of the patients was 42 years and no medical history was provided as to the progression of the injury to osteoarthritis or what level of chondral damage was present at the time of corrective surgery, therefore this five-phase rehabilitation protocol could be more affective in younger athletes provided levels of compliance are recorded. No control group was included in this study and therefore it is impossible to separate the effects of surgery from the effects of the rehabilitation protocol, secondly, no functional tests measures were recorded in the study which would have given a more objective indication of how patients had improved rather than the subjective questionnaires used.

While reports indicate that rehabilitation following arthroscopic surgery yields favourable results (Bennell et al., 2017), the patients are largely responsible for management of their own rehabilitation with periodic appointments with surgeons to review progress. In a study proposal by Bennell et al. (2014) the effect of a physiotherapist supervised rehabilitation program was to be compared to a control group who do not undergo a formal rehabilitation program. Comparisons could then be made between the intervention group and the control group in regards to a number of predefined outcome measures which include pain scores, sport participation, activity levels, medication use and patient satisfaction. It should be noted that no functional testing was included in the protocol to measure outcomes following the intervention and the results were to be based largely on questionnaires and subjective reports from the patients. TIjessen et al. (2016) published a similar protocol for a randomised control trial whereby the effect of self-management would be compared to the usual care physical therapy following arthroscopy.

2.2.7 Outcomes following surgery

2.2.7.1 Self-Reported Outcome Measures

A number of patient reported outcome tools are available to determine functional deficits in patients collectively known as patient reported outcome measures (PROMs) and include the modified Harris Hip score, Hip Outcome Score-activities of daily living (HOP-ADL), the Non-Arthritic Hip Score and the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) and a number of others. These questionnaires can be used to record improvements, if any, following a treatment intervention (Aprato et al., 2012; Tijssen et al., 2011). Some limitations with these measuring tools have been identified; for instance, the WOMAC was designed for patients with arthritis using an elderly population and therefore may not be suitable for young athletic patients. While the Non-Arthritic Hip score is derived from the WOMAC score and has the potential to be limited by ceiling effects (Aprato et al., 2012). Alternatively, the Hip outcome score was designed without the use of patients and indicates a functional score only, while the modified Harris Hip Score (mHHS) has been reported to both overestimate and underestimate patient satisfaction rates (Aprato et al., 2012). However, most published research quantifying the success of surgical intervention for FAI syndrome has included these measures.

In a systematic review of 26 research papers involving open, arthroscopic and combined approaches to the treatment of FAI, Botser et al. (2011) found that the mean improvement in the modified Harris hip score for arthroscopic surgery was 26.4 points, with 20.5 points for open surgery, and 12.3 for the combined approach. Clohisy et al. (2010) published a systematic review of surgical outcomes that involved 11 studies which met the inclusion criteria of, having clinical outcomes following surgery for FAI with a minimum of two year follow up, and which were original articles that did not include previous findings. The studies included six open techniques, four arthroscopic and one combined approach, and the results indicated an overall improvement with decreased pain and increased functional capacity in the majority of patients (65-96% of patients reported across all studies). Some common themes for poorer outcomes emerged from the studies included; advanced pre-surgical osteoarthritis, older age, greater incidences of severe pain, and advanced articular cartilage disease were linked with poorer results. A total of 21 individual cases of major complications were recorded out of a total of 473 patients (4.4%) across the 11 studies, with 18 of these recorded in the study conducted by Laude et al. (2009) which utilised a combined approach. In this instance there were 8 cases of failed labral refixation, 2 cases of deep infection, 1 head-neck fracture, 1 case of heterotopic ossification (bone formation in soft tissue site) and 6 cases of inadequate osteochondroplasty. Among the 10 other studies there were 2 cases of loss of fixation (failure of bone repair technique) and 1 heterotopic ossification. In a similar report conducted by Ng et al. (2010) including 23 articles for review, 9 of which overlapped with the Clohisy review; 9 papers adopted an arthroscopic approach, 11 utilised an open approach and 3 were combined approaches. It was found that average improvement in pain ranged from 25-100% across the studies. Patient dissatisfaction rates and the numbers of patients who reported no improvement in symptoms ranged from 0-31% across the results and the rates of conversion to total hip arthroplasty ranged from 0-30% across the board.

As with the review published by Clohisy et al. (2010), Ng and colleagues (2010) found that severe chondral lesions and evidence of osteoarthritis are associated with poorer patient outcomes. Ng et al. (2010) also highlighted the research which had been published in relation to the outcomes from labral fixation in comparison to labral debridement. For example, Espinosa et al. (2007) using an open technique, found that a group of 35 patients who underwent labral fixation had significantly better outcome scores at one year and two years post-surgery compared to 25 patients who underwent resection. While Laude et al. (2009) using a combined approach, found no significant difference in a labral repair group compared to a debridement group with regard to clinical outcomes. Although not included in the Ng study; Larson & Giveans (2009) examined the outcomes from patients who underwent arthroscopic labral repair compared to a group who had undergone previous arthroscopic labral debridement when repair techniques were unavailable. The results indicated that outcome measures (mHHS, visual analog scale for pain and Short form 12) at one-year post-surgery were significantly better in the repair group compared to the fixation group. In a study involving females, who were being treated arthroscopically for pincer or combined FAI with either a labral fixation or debridement, Krych et al. (2013) found significantly better outcomes in the repair group for both the hip outcome score in relation to activities of daily living and the sports hip outcome score.

The patient numbers across the research have ranged from 5 to 207 patients and the follow up times have ranged from 6 months to 4.5 years, such different research approaches present a difficulty with directly comparing outcome measures from different studies. Six months post-surgery may be too short a time to determine the full outcome of the surgery depending on the surgical procedure and the expectations of the patients. In such a short time following surgical intervention patients may avoid stressful activity that may exacerbate symptoms so soon in the recovery process and therefore problems may only arise once patients have begun to push the boundaries with regard to activity. The outcome measures to date for FAI syndrome have been designed originally for older arthritic patients and may suffer from ceiling effects to a certain extent when used with a younger, more active cohort (Ramisetty et al., 2015). This highlights the need for more objective outcome measures which cannot be influenced by the patient's own feelings or indeed the opinion of the surgeon who performed the procedure.

Sansone et al. (2015) reported on both clinical and statistically significant improvements in all PROMs measured in a group of 85 top level athletes who underwent arthroscopic treatment of FAI. The aim of the research was to determine the benefits of the surgery to a group who engaged in high level sports using outcome measuring tools that were more relevant to that cohort than previously used tools derived from arthritic patients. All patients completed a number of questionnaires including the International Hip Outcome Tool, the Copenhagen Hip and Groin Outcome Score, the EuroQOL 5 dimensions questionnaire, the Hip Sports Activity Scale and a visual analog scale for hip function. At an average of 12.3 ± 0.6 months significant improvements were reported for all measures (Sansone et al., 2015). This is similar to a subsequent report by the same research group which included 289 patients (not only athletes) which examined the effectiveness of corrective surgery two years post-op. The measuring tools were the same as the prior study and again significant improvements were identified for all measures. In both studies a number of patients required secondary surgery (3.5 and 5.9% respectively). Army personnel could be compared to high level athletes in the volume of physical activity required for duty, but the added weight bearing component must be taken into consideration. In line with the previously established hip pain rehabilitation pathway in the active military population it was found that improvements were detected with regard to VAS, NAHS, and functional activity assessment (FAA) in 101 military patients (Bennett et al., 2016). FAA is a generic subjective measuring tool used to assess the ability of military personnel to carry out work duties. Contrary to previous findings which found significant improvements in outcome measures at 12-18 months post-surgery; the Bennett et al. (2016) research found significant improvements among patients at 6 months post-surgery but no more improvements at 12 months post-intervention indicating a plateau effect. It was mentioned in the paper that a paced 8-mile march carrying a load of 30kg is the minimum fitness requirement for army personnel, however, it was not assessed either before or following surgery which may have been a useful objective measure to use with such patients. While no control group was included in the study which is a limitation, it can be concluded that arthroscopic surgery with a comprehensive monitoring protocol following the procedure can detect functional improvements in a military population as early as six months.

Considering that FAI syndrome is believed to develop throughout the early stages of skeletal maturity as a result of vigorous physical activity, early treatment of the condition may serve to delay the onset of further complications as patients grow older and progress throughout their sporting career. Fabricant et al. (2012) who described improvements of an average of 21 points on the mHHS and 33 points on the HOS among adolescent athletes treated with arthroscopy (Fabricant et al., 2012). While Tran et al. (2013) examined the effects of arthroscopic surgery among 34 (29 males) adolescent patients at an average of 14 months post-surgery. The report found that significant improvements were detected in both the mHHS and NAHS. Of the 34 patients included, 32 were engaged in regular sporting activity; at the follow up 25 were returning to habitual sporting activity while four returned to a lower level and three could not return to sport at any capacity (Tran et al., 2013). With greater subject numbers Bryd et al. (2016) examined the outcomes following arthroscopic treatment of FAI among adolescent athletes, and found a high improvement among a group of 104 patients. An average improvement of 25 points on the mHHS was reported following the intervention (Byrd et al., 2016). Eighty-seven percent of patients returned to competitive sport with 5 patients unable to return to sport and six who chose not to. In the overall cohort female patients accounted for 57% of the group, whether the patients who did not return to sport were female or not were not identified; young adolescent girls are more likely to drop out from competitive sport compared to their male counterparts for various reasons (Spencer et al., 2015). A recent meta analysis and systematic review which included relevant literature assessing the outcomes of surgery using self-reported measures, reported that pain and activities of daily living improved earlier in the rehabilitation process compared to more functional and sporting tasks (Kierkegaard et al., 2017).

Longitudinal research examining surgical intervention for FAI syndrome has been lacking although reports by Steppacher and colleagues described the surgical outcomes of patients at a minimum five years (Steppacher, Huemmer, Schwab, Tannast, & Siebenrock, 2014) and ten years post open dislocation for FAI (Steppacher, Anwander, Zurmühle, Tannast, & Siebenrock, 2015). At the five year follow up, of the 75 patients (97 hips), seven hips had progressed to total hip arthroplasty (THA) with a further seven showing signs of OA progression, although significant improvements were identified in the internal rotation and abduction measures as well as reductions in pain. At the ten year follow up 72 patients (93) hips were available for analysis and the authors found that survival rates for the procedure (those who did not progress to THA) averaged at 80%. At both time points a number of factors that led to the progression of OA were identified and included patients who were older than 40 years of age, who had a BMI greater than 30, as well as patients who had presented with a lateral edge angle of less than 22° or greater than 34°.

2.2.7.2 Functional Outcomes following Surgical Intervention

Functional testing of patients following a surgical intervention is an important consideration considering the goal of surgery is to reduce pain and restore normal function. A small number of studies have sought to quantify changes in functional outcome following surgery. In a follow up report to the original research where Lamontagne et al. (2009) outlined that patients with cam impingement could not squat as low as controls, the same author reported that following arthroscopy there were no significant differences in any of the kinematic variables associated with the squat, although significant improvements were seen in the overall squatting depth (Lamontagne, Brisson, Kennedy, & Beaulé, 2011). This was attributed to the fact that greater knee flexion and ankle dorsiflexion were recorded following the procedure. No control group was included in the follow up testing which would have allowed comparison between groups over time to determine whether changes in knee and ankle mechanics were as a direct result of the surgical procedure or not.

Rylander et al. (2011) collected 3D biomechanical data to assess the gait patterns of 11 patients with diagnosed FAI both before and 1 year following arthroscopy. Prior to surgery both pain and lower sagittal plane ROM were features of gait in the patient group, and were found to have improved significantly at one year post-surgery (Rylander, Shu, Andriacchi, & Safran, 2011). In a report including 17 patients, Rylander et al. (2013) found reduced internal rotation and sagittal plane ROM during walking and stair climbing at baseline compared to healthy matched controls. Following surgery, the patient group had similar gait patterns to the control data but the levels of internal rotation, sagittal ROM and maximal hip extension were still significantly reduced compared to controls during stair climbing. Patients also exhibited greater pelvic tilt and pelvic rotation ROM at both time points compared to controls. Alternatively, Brisson and colleagues (2013) found that following open/combined intervention there were no improvements in gait among patients (n=10) who were treated for unilateral cam FAI compared to healthy controls. At the follow up (21 ± 9 months) patients displayed significantly lower levels of hip frontal and sagittal ROM, smaller peak hip abduction and internal rotation moments, indicating that after a considerable amount of time gait had not returned to normal and while pain had reduced, stiffness had not (Brisson, Lamontagne, Kennedy, & Beaulé, 2013). This highlights again that arthroscopic treatment for FAI may be a more effective treatment option as gait seems to return to normal function in comparison to more invasive treatments.

In an attempt to quantify sporting performance following arthroscopic treatment for FAI which included microfracture for the treatment of a grade IV chondral defect, McDonald et al. (2014) examined match performance indicators among professional ice hockey players. The cohort included 17 ice hockey players that were made up of goalies, centres, defencemen and wings, and outcome measures included wins, losses, ties, save percentages, points scored and shooting percentage;

patients were also compared to a control group with two control participants recruited for every patient. Control participants were recruited to match patients as closely as possible with regard to age, playing level, and number of seasons completed at a certain level. The authors reported that following the procedure, 14 patients of the original 17 returned to professional ice hockey at a pre-intervention level. There were no significant differences detected between groups with regard to decreases in numbers of games played over time, decreases in points scored, saving percentage by goalies, although within the patient group significant decreases were observed in the number of shots taken by non-goalies from pre-surgery to post-surgery (McDonald, Herzog, & Philippon, 2014). However, this report only included data on the control group for one time point only, and while the authors mention that the control group did decrease the number of games over time (to show the decreases among the patient group was non-significant) follow up data with the control group was not included. Therefore, it is impossible to determine whether the number of shots taken by non-goalies reduced over time also without the inclusion of time X group interaction effects. Another significant limitation of the study is the inability to control the testing environment; there are a number of confounding factors that could have influenced on-ice performance of the players including the quality of opposition, the overall team performance rather than individual performance and motivational factors, all of which cannot be quantified. While optimising functional athletic performance is a key consideration of returning to play following treatment for FAI syndrome, overall match performance is difficult to link directly to surgical intervention. In this instance performance measures that are indicators of functional ability that can be more accurately measured may be more beneficial.

From the research investigating the outcomes of surgical intervention for the treatment of FAI syndrome, patients can expect at least short term (<10 years) improvements using any of the three approaches to surgery with few complication risks. The reduced rehabilitation time and the less invasive nature of arthroscopy may make it a more appealing treatment option than open surgery. While more investigation is needed to clarify whether labral repair yields better long-term outcomes than debridement, early reports would suggest that this is the case. Some prerequisites to poorer outcomes from surgery have been noted and include older patients, advanced osteoarthritis, lower pre-operative mHHS/HHS-ADL (Nwachukwu, Fields, Nawabi, Kelly, & Ranawat, 2016) and higher pre-surgery pain levels. Much of the research especially involving functional movements has involved a control group, however the control groups were only tested at one time point with patients being tested pre- and post-operatively. This does not allow comparisons between changes in the patient group and changes in controls over time. Changes in physical function could occur for any number of reasons and to determine whether changes in the patient groups are directly related to surgical intervention control groups should be tracked over time also.

2.2.8 Returning to sporting activity following surgical intervention

Considering that a large portion of FAI syndrome surgery patients are young and physically active, the level of sporting activity following corrective surgery is an important concern. Patients who are extremely active will often have high expectations regarding surgical outcomes and therefore assessing functional capacity as well as pain reduction is important in gaining a clearer understanding of overall patient satisfaction following surgery. Again, the differences in return to play rates in patients following open surgery versus those who underwent arthroscopic surgery could have an influence on both the satisfaction rate following surgery and even the initial decision to undergo treatment in the first place. A number of studies have assessed the return to sporting activity following both arthroscopic and open surgical intervention in either recreational or competitive athletes.

In a report regarding the return to sport following arthroscopic decompression of FAI and labral repair where viable, Philippon et al. (2007a) described how, of all forty five professional athletes (42 male, 3 female) of various sporting codes (primarily hockey, n=24) who were previously unable to participate in their respective fields, forty two (93%) returned to professional sport, eleven of which had undergone previous surgical intervention which had failed. Five of the athletes required further surgery to do so, while three players did not return to play at all. The author notes that at the time of the surgery each of these three patients had evidence of diffuse osteoarthritis. Thirty five of the original forty five athletes (78%) were still competing at a professional level at an average of 1.6 years post-surgery. The reasons for dropout rates among the seven athletes who had returned to play yet had to desist were not accounted for and it was not indicated whether those that had ceased playing sports were the same athletes that underwent previous surgery. This study provides limited information on the ability of the athletes to perform movements necessary for their sport, and so while they may have returned to sport, the functional capacity of these athletes following surgery is unknown. In another examination of return to play data using only unilateral patients that engaged in professional ice hockey (n=28) Philippon et al. (2010) reported that following arthroscopic treatment for bone debridement for FAI and labral repair the average time for return to sports specific on ice drills was 3.4 months. All players returned to competition, with an average improvement of 25 points on the mHHS and median satisfaction rate of 10 (range 5-10); although two players required subsequent surgery for re-injury (Philippon, Weiss, Kuppersmith, Briggs, & Hay, 2010). Furthermore, Byrd and Jones (2011) reported that in a group of 23 professional athletes 95% were able to return to professional sport following arthroscopy; this study also tracked 56 intercollegiate athletes, 85% of whom returned to previous levels of competition (Byrd & Jones, 2011). Nho et al. (2011) investigated the return to play data among athletes (n=33) including professionals (19%), collegiate (53%) and high school (28%) following arthroscopic surgery for FAI. At an average of 9 months, 79% percent of athletes had returned to play of which 93% were competing at a level equal to that prior to symptom onset (Nho, Magennis, Singh, & Kelly, 2011). Whilst Amenabar et al. (2013) examined the return to play following arthroscopic treatment of FAI among 26 professional AFL players and found that 25 players returned to professional AFL following surgery while one patient was forced to retire as a result of further hip complications (Amenabar & O'Donnell, 2013). In the same year, Boykin et al. (2013) reported rates of 85.7% return to play among professional athletes that included soccer players, football players, hockey players, skiers, as well as a baseball player, basketball player and skier. Arthroscopic labral reconstruction was carried out using iliotibial band tissue material, with 81% of those returning to a playing level similar to previously carried out (Boykin, Patterson, Briggs, Dee, & Philippon, 2013). Alternatively, the same author found that of 18 competitive rowers (15 female), ten (56%) were able to return to competitive rowing at a mean time of eight months post-arthroscopy. Six (33%) rowers did not return to rowing although no reasons for this were given and so it is unclear whether persistent hip pain was the reason for this, while follow up data was not possible for two patients (Boykin et al., 2013).

When reporting on return to play data with athletes it is important to distinguish between professional and recreational or sub-elite. Professional athletes may be financially or contractually obligated to return to play and so may have a bearing on the return to play rates. Recreational athletes have the option of reducing levels of activity in response to unfavourable surgical outcomes. When dealing with recreational sports people, Brunner et al. (2009) sought not only to assess the level of sporting activity both before and following arthroscopy, but to also correlate those findings with the clinical outcome measures already used in the hospital to determine pain and functional levels. To achieve this, a sports frequency scale previously described by Valderrabano et al. (2006), was used in conjunction with a non-arthritic hip score questionnaire (Christensen et al., 2003). Only unilateral patients (N=53) were used in this study, 45 of which were previously regularly active before the onset of hip pain; at the time of the clinical exam, only four of these 45 patients had been able to maintain their usual level of physical activity. The remaining 41 patients had to reduce their levels of participation (n=13) or were unable to continue with any kind of physical activity due to severe pain levels (N=28) prior to surgery. At the final postoperative check-up (mean post-operative follow up 2.4 years), 31 patients (of the 45 previously active group) had returned to their habitual activity level, six (13%) could participate at a reduced level and eight (18%) could not return to any level of physical activity. Conducting research which included 47 recreational patients (20 male and 27 female, mean age 36 years) who routinely performed squats in a gym setting, Polesello et al. (2012) found that 30 patients returned to activity with 25 (53%) of those at a previous level following arthroscopy. Five (16%) of those thirty returned but had to modify their gym activity, which may have been to prevent the onset of painful symptoms again and would include avoidance of hyperflexion beyond 90° at the hip joint. Six (13%) patients did not return to any sporting activity of any kind and there was no information given regarding the remaining 11 patients who made up the original cohort.

Alternatively, in a group of professional, collegiate and club baseball players (n=70) who underwent arthroscopic treatment for FAI, Degen et al. (2016) reported that 88% had returned to play at approx. 8.6 ± 4.2 months following intervention. Ninety seven percent of those players had returned to a level of play either equal to or above the standard of play they were accustomed to prior to the onset of hip pain. Significant improvements were noted in all outcome measuring tools including mHHS, HOS-ADL, and Sports Scale (Degen et al., 2016). This is an interesting and important find considering the levels of hip rotational forces involved in the game of baseball. To further examine the differences in return to play data among athletes, Malviya et al. (2013) investigated whether professional athletes return to sport at a higher rate than recreational athletes following arthroscopic repair of FAI. The author found that professional athletes tended to return to sport quicker than recreational athletes but the rate of return to play and the subsequent increases in training loads tolerated was similar across both (Malviya, Paliobeis, & Villar, 2013). Menge et al. (2016) reported on the careers of professional ice hockey players who had previously undergone hip arthroscopies and found that of 60 patients, 67% played a minimum of 5 years post-surgery. It was found that players who played for a longer amount of time following the intervention were younger than those who did not and had a shorter duration of symptoms compared to those who did not play for as long following the procedure (Menge, Briggs, & Philippon, 2016).

Some surgeons may prefer the open surgery technique as it can give 360° access to the joint and a full view of the bony morphology and tissue damage (Botser et al. 2011). Due to the significant differences in technique and the fact that open treatment for FAI syndrome is a major surgery which involves the dislocation of the hip joint and substantial incision requirements, athletes may be deterred from this procedure due to the prolonged rehabilitation times. It is important to consider the return to play data following these procedures to properly inform patients as to what results can be expected and whether they should chose open or arthroscopic treatments. In a case study involving 5 professional ice hockey players who were treated with open surgery, three returned to professional ice hockey thereafter while two competed in the minor league. The average time for return to full play was 9.6 months following the open technique (Bizzini, Notzli, & Maffiuletti, 2007). In a subsequent report involving a greater number of athletes and an open dislocation procedure which included 26 professional athletes, 22 of whom were available for follow up at approx. 45 ± 22 months Naal et al. (2011) reported that 21 were still competing at professional level while one had reduced activity to recreational level. Thirteen patients reported an increased level of sports ability following surgery; six reported no change and three indicated a drop in functional ability (Naal, Miozzari, Wyss, & Nötzli, 2011).

In a follow up report, Naal et al. (2014) retrospectively examined 126 patients who were engaged in sports prior to surgery; 107 (85%) were still involved following open dislocation surgery for FAI. Nineteen patients (15%) had not returned to any involvement in sport while some patients did change the type of sport played. Prior to surgery skiing had been the most popular sport among the athletes while postoperative sports participation geared more towards cycling (Naal, Schär, Miozzari, & Nötzli, 2014). This is an important finding as it indicates that some patients may not be able to tolerate weight bearing activities following open surgery, and may need to switch to non-weight bearing open chain activities if they wish to continue engaging in physical activity. Further complications were noted using a mini-direct anterior approach to surgery when Cohen and colleagues (2012) reported that of 44 athletes, 24 (55%) returned to preoperative sports participation. Nine patients (20%) developed meralgia paresthetica (nerve pain in the thigh) as a result of the procedure, although these had all resolved within one year (Cohen, Huang, Ciccotti, Dodson, & Parvizi, 2012). In a recent meta-analysis, Reiman et al. (2018) reported an overall return to pre-injury sport participation rate of 74% but highlighted that the level of performance is currently unknown.

Regardless of approach it would appear that surgical intervention for the treatment of FAI syndrome yields improved results (Minkara, Westermann, Rosneck & Lynch, 2018) with regard to return to play both for professional and recreational athletes (O'Connor, Minkara, Westermann, Rosneck & Lynch, 2018) although some complications have been identified with the midi direct approach (Nakono, Lisenda, Jones, Loveday & Khanduja, 2017). Arthroscopic surgery may be a more appealing treatment option simply due to the less invasive nature of the procedure and reduced rehabilitation times. Caution should be advised when interpreting retrospective research involving surgical data as results may be subject to selection bias as well as the distinct lack of control groups included in the research. More prospective data involving athletes not only looking at the return to play outcomes of surgery but also examining the physical performance changes over time following intervention, is required in this field. Although for now it can be concluded that surgical intervention yields favourable results for athletes wishing to return to competitive sport.

2.2.9 Summary of FAI Syndrome Research

The research of femoroacetabular impingement syndrome has increased exponentially over the last number of years which has served to advance our understanding of this condition, which is now considered a major risk factor for the development of osteoarthritis of the hip previously reported as idiopathic. The prevalence of bony morphologies is thought to lie between 5 and 35% of healthy asymptomatic males and between 3 and 20% for females, although the differences in techniques used to determine prevalence levels greatly limits the accuracy of comparing population prevalence rates. It is clear, however, that this exists in young athletic populations which can have severe consequences to both activities of daily living and sports participation as patients with FAI syndrome will report pain during prolonged sitting, stair climbing and particularly during or following physical activity. Conservative management of FAI syndrome which relies heavily on behaviour modification may not be a preferred solution for athletes, in particular professional athletes, and so surgical intervention, in particular arthroscopic surgery becomes a more favourable treatment option. The aim of the surgery is to remove the excessive bone which is causing the impingement and to repair where possible the intraarticular tissue within the joint. While subjective measures that assess surgery effectiveness are widely available, objective measures which aim to ascertain the level of functional pre-surgical deficits in FAI syndrome patients and changes in those measures following surgery are less so. The need for research investigating outcomes of surgery using objective measures is imperative as subjective questionnaires cannot truly identify the physical performance needs of the athletes who are being treated for this condition.

2.3 Current approaches to kinematic profiling of athletic movements

2.3.1 Kinematics

Kinematics is a branch of mechanics primarily concerned with the temporal and spatial components of motion without referring to the causes of that motion and include velocity, position and acceleration (Cheze, 2014; Enoka, 2015). Kinematics also includes the movement of joints within the human body, measured in degrees, this is particularly relevant as joints have limits to the ranges of motion they can achieve and torque and force production may vary at depending on joint positioning (Maud & Foster, 2006) Understanding these aspects of movement is important not only in a sport science capacity where improvement of techniques required for sporting performance are needed, but also particularly relevant in clinical practice. By understanding the true ranges of motion in which a joint travels during motion and having the ability to accurately measure them can help diagnose and treat alterations in normal gait and locomotion patterns (Mündermann, Corazza, & Andriacchi, 2006) . There are a number of both field-based and lab-based methods for the measurement of kinematic data. Discussed below are a number of current approaches to the measurement of kinematics in a human performance capacity.

2.3.2 Laboratory based measurement of human movement

2.3.2.1 Optoelectronic motion capture

Conducting laboratory based assessments of movement provides distinct control of the testing environment by the investigator from which substantial amounts of information regarding movements required for sporting activities can be recorded. Biomechanical assessment of movement can give substantial amounts of kinematic and kinetic details of sporting activities. A number of 3D assessments of human movement have been described, these include marker based motion capture and non-marker (marker-less) e.g. Organic motion analysis systems. Sensor based systems of measurement are also commercially available e.g XSENS. Marker based 3D analysis involves placing reflective makers on anatomical landmarks around the body used to define segments of the body (Figure 2.5) as well as cluster marker-sets which are used to track movement of the segments.

Figure 2.5 Segment makers (Epicondyle markers) and cluster markers (Thigh and calf)

Infrared cameras are used to record actions with tracking software e.g. Cortex 5, then being used to track each marker throughout each frame for the entire movement. To do so, a static trial must be recorded by the cameras where the athlete stands still for the duration of the recording, all movement files are then normalised to this one static trial. Raw data of human movement and in particular, complex sporting movements can generate a high level of “noise”. Noise is essentially an error in measurement which can arise due to a number of factors including skin movement artefact, electrical interference and accidental digitisation of reflective markers (Winter, Sidwall, & Hobson, 1974). There are a number of filtering processes that can be used to reduce noise, including a low pass filter; this type of filter will have a predefined cut-off value which will allow signals below this threshold to pass and will then attenuate signals higher than this frequency resulting in smoother data. A residual analysis can be carried out, this involves smoothing data at different frequencies and residuals between the filtered and raw data are determined for the different cut off frequencies (Yu, Gabriel, Noble, & An, 1999).

Kinematic data can be analysed in visual 3D software, or alternatively can be exported to software such as Microsoft Excel which can then be used to easily manipulate data and generate graphs based on defined parameters. Marker based motion capture systems have been found to be both accurate and reliable although both variables are influenced by the accuracy of the marker placement on the athletes (Gorton, Hebert, & Gannotti, 2009). There are a number of disadvantages to the marker based motion analysis systems, including the time-consuming nature of the analysis, the variances between marker placement, and the inflated cost of operating systems as sophisticated as these (Aminian & Najafi, 2004). To address this, marker-less motion capture systems have become commercially available, which also involve the use of infrared cameras however, instead of placing makers to define anatomical segments, the system estimates bone length and position based on the subject’s height and based on their standard T pose (Figure 2.6). Maker-less motion capture has the added ability to track movement in real time and generate data without the necessity of tracking individual markers throughout movement (Brooks & Czarowicz, 2012). However, a significant draw back to the use of marker-less motion capture is the reduced accuracy of the systems when calculating rotational data (Yang et al., 2014). Therefore, to quantify kinematic data from athletic movement which involves extreme joint rotation may not be appropriate.

[redacted]

Figure 2.6 T-Pose

2.3.3 Field Based assessment of human movement

2.3.3.1 Video analysis

More mobile, field-based measurement techniques of human movement are of great benefit to coaches and sports performance analysts as they can provide a wealth of information from the environment in which athletes routinely perform (Hughes & Franks, 2004). Video analysis and Global Positioning Systems technology (GPS) are both extremely popular field-based methods of performance measurement and have become routine practice in the assessment of performance analysis (Barris & Button, 2008). Video analysis or notational analysis, involves recording footage of the movements and manually assessing the videos for key performance indicators which the analyst has chosen to assess. The analyst may replay the video using simple video playing software on a computer or use appropriate software to aid with quantitative analysis of the footage. There are many examples of software available to help analyse video footage and can be operated using a computer, tablet or smartphone. Dartfish is one of the most well-known computer softwares commercially available for such analysis and has many useful features including a tagging panel for identifying elements of play that can be customised for the analyst's individual needs. A free software called Kinovea is also available and works in much the same manner as Dartfish. Both Dartfish and Kinovea have been reported as reliable methods for analysing kinematic variables in the frontal and sagittal planes (Elrahim et al., 2016; El-Wardany et al., 2016; Norris & Olson, 2011). While software such as these are reliable the quality of the video footage can influence the accuracy of the data obtained. There are several important factors to consider when video recording human movement and depend largely on the nature of the movement being performed (Payton & Bartlett, 2008). It is beneficial to place the camera on a tripod for capturing footage to avoid unnecessary movement of the camera itself. The type of camera used is an important consideration with a number of low cost cameras commercially available with varying sampling frequencies, picture quality and light sensitivity. When recording match footage where all athletes are to be included in the analysis, the distance of the camera form the field of play should be increased and preferably at a height to ensure as much of the play can be recorded at any one time. When recording movements carried out in a fixed position such as an Olympic lift, the camera must be placed perpendicular to the plane of motion and placed as far away from the movement as possible to avoid perspective error during analysis. A common method of ensuring the camera is perpendicular to the plane of motion uses a 3-4-5 triangle approach (Payton & Bartlett, 2008). Finally, a scale whose dimensions are known must be included in the frame in the same plane of motion as the movement being carried out, to act as a reference for all further measurements carried out using the video footage. Subjective analysis of video footage may be appropriate for larger more distinct type movements; for example kicking in soccer, however the accuracy and reliability of assessing kinematic data subjectively from video is poor (Krosshaug et al., 2007).

2.3.3.2 Global positioning systems

With the advancement of technology, reduction in cost and increased accuracy (Coutts & Duffield, 2010) global positioning systems (GPS) have become an attractive tool for the measurement of speed and distance in field sport assessment. Athletes place the unit in a vest which holds the unit between the shoulder blades and once calibrated can track player movement for the entirety of a game regardless of sport. GPS units have been used previously in in rugby union (Cunnife, Proctor, Baker, & Davies, 2000), Australian rules football (Wisbey, Montgomery, Pyne, & Rattray, 2010) and more recently in Gaelic Football and Hurling (Malone et al., 2016; Malone et al., 2013) and have provided invaluable information regarding the demands of match play and are routinely used in monitoring training load. Advantages of the units include portable nature of the system and the considerable quantity of information that can be gained in real time regarding speed and distance profiles of athletes throughout a training session or competitive game. However, with the main variables of GPS being speed and distance they are unable to differentiate between specific movements.

2.3.3.3 Body fixed sensors

Three-dimensional recording of movement can be restrictive on some of the types of movements that can be assessed as there is a limit to the size of testing area that can be created and this testing area is fixed and cannot be moved or altered following calibration. To address this problem a number of sensor based systems have been created for the purpose of generating kinematic data and use a combination of sensors that measure difference aspects of human movement and include accelerometers and gyroscopes, these systems have the potential to provide invaluable information regarding human movement in a both a clinical and non-clinical environment. Given the fact that the sensors do not require receivers or cameras and are portable in nature (Fong & Chan, 2010) means they can be used outside, making them an attractive option in the assessment in human movement. Compared to marker based motion capture (e.g. Vicon) these relatively inexpensive pieces of equipment have been found to be accurate in gait analysis and while may be more cumbersome than reflective markers, does not impede movement of the joint (Mayagoitia, Nene, & Veltink, 2002). In a systematic review of the literature involving wearable sensors Fong and Chan (2010) report that the “noise” generated during data processing from these systems can be quite severe and a substantial volume of work is involved in the data logging and processing phase of analysis. Real time data generation is also not possible with these systems and so while data collection may be simplified the work involved and time taken to process data after collection is a concern.

2.3.4 Benefits of combining Lab and field based methods

To date there is very little research available which utilises more than one method of motion analysis for the purpose of kinematic profiling of human movement despite the potential benefits of using a multifactorial approach (Bartlett, 2001). Video analysis may not be capable of giving accurate kinematic data but can be used to categorise robust movement patterns, while 3D biomechanical assessment can give detailed information with regard to kinematic data but cannot quantify movement patterns in a larger or unpredictable environment. Using both video and biomechanical assessment could give complementary and more detailed information regarding movement patterns carried out in field sports. This would be of great benefit to both coaching staff and clinical practitioners.

2.3.5 Summary of kinematic profiling methods

There are number of methods used in the generation of kinematic data in human movement analysis and depend largely on the type of movement being examined and range from sophisticated measures such as 3D analysis to more simplistic and subjective notational analysis methods. There is a distinct paucity of research which uses more than one motion analysis in the generation of kinematic data, and no specific research which uses motion analysis methods such as these to generate a kinematic profile for a specific joint for the entirety of a field sport game.

Chapter 3: Differences in athletic performance between sportsmen with symptomatic FAI syndrome and healthy controls

3.1 Introduction

Symptomatic femoroacetabular impingement syndrome is common in young athletes and unlike injuries such as a complete anterior cruciate ligament rupture or broken bone; it is not uncommon for athletes to continue with training and competition up to and following diagnosis of FAI syndrome. As well as typical symptoms of difficulty with stair climbing, during and following physical activity; FAI syndrome has the potential to significantly reduce athletic performance should athletes continue without some measure of intervention. Previous literature investigating the effect of FAI syndrome on performance is sparse. There has been published research investigating squatting mechanics of persons with FAI syndrome however, and the results are conflicting. Lamontagne et al. (2009) found that patients with symptomatic cam impingement could not squat as low as healthy controls, a finding which was supported by Bagwell et al. (2016) who found that not only could patients not squat as low as controls but also had increased anterior pelvic tilt and decreased peak hip internal rotation while squatting. However, Diamond et al. (2017) found no differences in the achievable squat depth by those with FAI syndrome and those without. Squatting is an integral component of any training program involving athletes (Schoenfeld, 2010) and if athletes are unable to squat appropriately, physical preparation for competition could be effected. Other important aspects of athletic performance namely; acceleration, changing direction and jumping have not been examined extensively with regard to FAI syndrome. Sprinting, especially over short distances is critical to athletic performance particularly in field sports where the objective is to beat an opponent. Likewise, changing direction quickly is paramount to avoid tackling by opponents and conversely to tackle an invading opponent. In field sports such as Hurling and Gaelic football which are widely played in this country, a large emphasis is placed on the ability to catch a ball in the air (McIntyre, 2005). The ability to jump in as little time as possible is an important aspect of performance as producing greater force and jumping in a faster time than challengers is of great advantage in securing possession (Zatsiorsky & Kraemer, 2006).

The aim of this research was to quantify the functional performance deficits in athletes with FAI syndrome compared to a group of healthy controls with no history of hip/groin pain. To that end patient reported outcomes and opinion regarding functional capacity were not included in this study and objective measures of function were assessed. Pain reporting was however recorded. The rationale for this study includes gaining a clearer understanding of the functional deficits that are likely to be present in athletes with this condition. This will inform coaching staff that work with these athletes as to the areas of performance that athletes are likely to underachieve in. Following this, alterations to training loads may be implemented as required.

3.1.1 Research Questions

1. What are the differences in acceleration, agility power and range of motion between symptomatic patients with FAI syndrome compared to a control group with no evidence of a hip pathology?
2. What are the differences in agility, power, and range of motion between the affected and unaffected limbs of unilateral patients?
3. Is pain/stiffness present during functional performance tasks?
4. What aspects of performance exacerbate pain symptoms among patients.

3.2 Methods

3.2.1 Recruitment

Ethical approval for the study was granted by the ethics committee in Waterford Institute of Technology in conjunction with hospital policy in the Whitfield Clinic. Male participants between the ages of 18-35 were recruited for this study and divided into two distinct groups; patient and control. Participants were excluded if they had any prior hip surgery, a secondary lower limb injury at the time of testing, or did not regularly participate in sport. Patients were also excluded from the results if they had evidence of osteoarthritis on X-Ray and MR Arthrogram. Control participants were recruited from various GAA and rugby teams within the Waterford region and were recruited specifically to match the patient group with regard to age, height, weight, sporting type and sporting level. An example of this would include, whereby an elite intercounty hurler was recruited in the patient group, an elite inter county hurler was recruited for the control group. Patients were contacted at least two days prior to their appointment at the Whitfield Clinic, and sent an email copy of the consent form. Patients were tested on the same day as they were due to have an arthrogram and consultation with the orthopaedic surgeon Mr Patrick Carton. Testing was carried out before the arthrogram, as the injection used to administer the contrast dye into the hip joint for the scan can often leave patients with hip pain and stiffness. If a patient was subsequently diagnosed with a separate injury other than impingement they were then excluded from the results.

Once the functional tests had been completed patients reported to the Whitfield Clinic where the dye was administered one hour prior to MRA scanning. Both MRA and X-ray imaging were carried out and patients then presented to Mr Carton for their physical examination and diagnosis. A standardised AP Pelvis, Dunn view and false-profile x-rays of all patients were taken and used to aid in confirmation of the diagnosis of FAI syndrome; The presence and extent of chondrolabral pathology in supporting the diagnosis was also assessed using MRA scanning.

3.2.2 Pre-testing Protocols

Each participant was instructed to refrain from engaging in any strenuous physical activity or alcohol consumption 48 hours prior to experimentation to facilitate optimal performance during testing. Participants were instructed to wear a light t-shirt, running shoes and a standard pair of tight bicycle shorts which the researcher provided. A pre-testing questionnaire (Appendix 8.2) was carried out to assess the type of sport and performance level at for each participant. Patients were asked to indicate whether they continued to engage in both training and competition with hip pain or if they had not continued, how long it had been since they were able to participate fully in training and competition.

3.2.3 Warm-up and Anthropometric Measurements

All participants were tested individually, before which a ten minute dynamic warm up was carried out which consisted of heel flicks, forward lunges, side lunges, single leg hops, bounds, and walkouts carried out over ten meters, twice. Ten squats were also carried out. Following the warm-up, participants removed shoes and socks; height (cm) and mass (kg) was measured using a standard stadiometer and weighing scales.

3.2.4 Ten Metre Sprint (Acceleration)

The ability to accelerate is paramount in field sports especially GAA sports where on average 166 ± 41 accelerations per game are completed and can have major consequences to the outcome of the game (Ryan, Malone and Collins, 2018). Acceleration is often measured by way of a 10m-Sprint and has been validated in previous research (Wilson, Newton, Murphy and Humphrys, 1993). In the current study this test was used with time (s) as the main variable measured for the comparison with normative data. To achieve this, dual beam timing gates with a start pad were used (Witty Wireless timing Gates, Microgate, Italy) and recorded time to two decimal places. Dual beam timing gates were chosen rather than single beam timing gates to improve accuracy and reduce the likelihood of false signals from arm swing with the use of single beam timing gates (Haugen et al., 2014). Each subject was required to stand with one foot on the start pad and one foot behind, without any audible cue, the participant sprinted as fast as possible through the timing gates located ten metres from the start pad. Three trials of the test were carried out with 45 seconds of seated recovery in between trials. An average of the two fastest times was recorded as the overall result. The sprints were carried out on a portable rubber non-slip track, ensuring that all participants sprinted on the same surface while also acting as a safety measure to prevent participants slipping. The onset of pain and/or stiffness was also recorded. If a participant reported either pain of stiffness they were asked to quantify this on a scale of 1-5, with 5 being the most severe.

3.2.5 Modified Agility T-Test

Another important aspect of field sports is the ability to change direction as quickly as possible in response to an external stimulus and was highlighted in the methodology planning phase as a typical complaint of patients in clinic when describing their symptoms. To assess the ability of the participants to change direction, a modified agility T-test was carried out using the same non-slip flooring as the sprint test and the same dual beam timing gates. However, in this instance no start pad was required. A modified T-test is carried out in the exact same manner as the original test (Semenick, 1990) although the overall distance is halved, therefore the subject was required to sprint forward five metres, side shuffle laterally to touch a cone (28.6 cm high) located 2.5 metres from the centre, then side shuffle to a cone located 2.5 metres on the opposite side of the centre of the mat and touch a cone placed there. They then back pedalled back through the timing gates located at the start of the course (Figure 3.1). A modified T-test was chosen largely due to the space available within the testing centre and due to the fact that there was a control group used in the testing procedure, therefore comparing patients to normative data for the original T-test was less important. To initiate the test the participant was instructed to stand with one foot at the edge of the mat, immediately behind the speed gates which were placed at the edge of the mat. Upon an audible cue the participant sprinted forward and the test began. Each participant was instructed not to cross their feet while side shuffling and only foot to foot contact was allowed. Three trials of the test were carried out with 45 seconds seated recovery in between and an average of the fastest two times was recorded as the overall result. As with the previous test the participants were asked to report any anterior groin pain and rate the pain on a scale of 1-5 if present. A secondary aim of this test was assess whether there was a difference in the time taken to change direction on either leg in the case of unilateral patients only. To achieve this, two poles were placed directly in front of the course at the point at which subjects begin the side shuffle. A high speed camera (Nikon s6500, Japan) set to record at 120 Hz was placed in front of the course as far back as possible which allowed for manual calculation of the time taken to pass one pole, touch the cone and pass the pole a second time using Dartfish 7 (ConnectPlus) software.

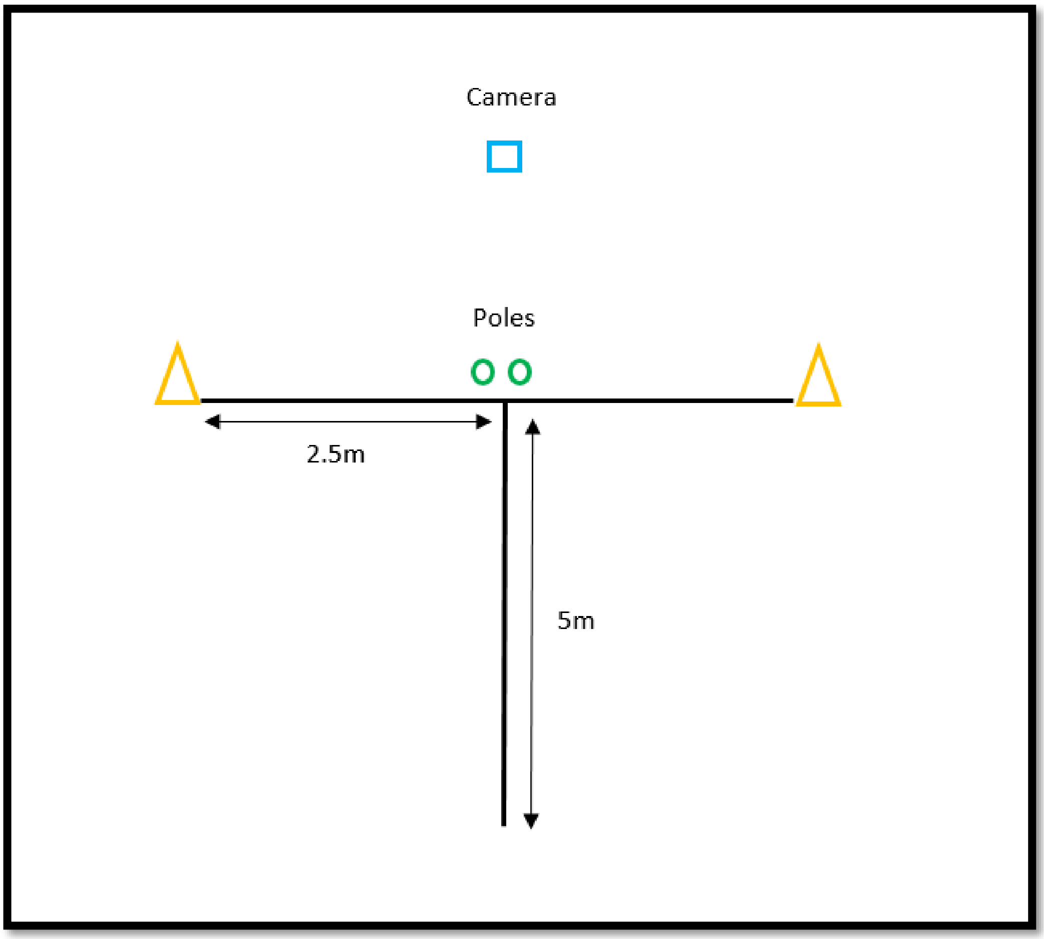


Figure 3.1 Modified agility T-test

3.2.6 Deep Squat

Squatting is an integral component of physical preparation for field sports and typically includes large ROM at the hip joint. Considering a common symptom of FAI syndrome is for patients to exhibit lower ROM values, assessing the ability of athletes with FAI syndrome to squat is logical. Similar to the study conducted by Lamontagne et al. (2009), the participants in this testing protocol were required to squat as low as possible to determine whether FAI syndrome patients can squat as low as healthy controls. Reflective markers were first placed on the greater trochanter, lateral epicondyle of the femur and the lateral malleolus of the affected leg. In the case of bilateral patients, markers were placed on the side which was most affected, while for the control group an even mixture of left and right legs were recorded. All participants were instructed to squat as low as possible while keeping heels on the ground, toes pointing forward. Avoiding excessive trunk lean was encouraged but not enforced. Five trials of the squat were carried out, and a Nikon camera (Nikon s6500, Japan) was placed as far back from the squat as possible to reduce perspective error and recorded the squat in the sagittal plane.

The stadiometer which was used to record height, is placed to the rear of the participant which acted as a scale for the Dartfish software. All video images were analysed using Dartfish Connect Plus software and the distance from the greater trochanter to the floor was recorded both while standing and at the base of the squat, the difference between the two values was recorded as the total squat depth (Figure 3.2). A random selection of both patient and controls were selected for further analysis of the squat at baseline to determine whether differences in the techniques were used to achieve optimal squat depth. To that end, both trunk lean and the distance between both central patellae at the base of the squat were determined. Trunk lean was determined by creating an angle using a straight line from the greater trochanter marker, which was parallel to the floor and a second line which extended to the middle ear. To measure the distance between the central patellae, two reflective makers were placed in the centre of the patella and a frontal camera was placed facing the participant to record frontal plane movement. Dartfish software was used to measure the distance between the markers in the standing position and at the base of the squat. The change in that distance was recorded in centimetres.

Figure 3.2 Example of deep squat and sagittal marker locations

3.2.7 Single Leg Drop Jump

To jump high is advantageous in field sports, yet to jump high in as little time as possible can determine whether possession is gained or lost. Reactive strength index (RSI) is a measure commonly used to assess this ability and is an indicator of lower limb power (Flanagan, Ebben & Jenson, 2008). RSI was chosen over a countermovement jump as it required the athletes to consciously attempt to reduce contact time with the floor and also allowed only single leg comparisons. To calculate the RSI of both legs for each participant a single leg drop jump was used. This test was carried out using a 30-cm box and Optojump system (Microgate, Italy) Optojump is a valid and reliable tool for measuring jump height (Glatthorn et al., 2011) consisting of two panels with LED lights which are set up parallel to one another so that the LEDs communicate with each other. The time in which the LEDs are connected for (no obstruction of LEDs by athlete), or when that connection is broken (when an athlete is standing in between the bars) is recorded by the Optojump system. Optojump was chosen for this research not only as it is considerably more cost effective than a force plate but also due to its ease of portability which facilitated testing in several locations.

Participants were required to step off the box and upon landing on one leg, jump as high as possible; participants were instructed to spend as little time a possible in contact with the ground while still achieving maximal jump height. Both contact time (s) and flight time (s) were recorded from the Optojump system, from which the RSI was manually calculated (flight time/contact time). Owing to the fact that some of the participants may not have been familiar with the test, five practice trials on each leg were allowed. Three actual trials were then carried out on each leg with ten seconds recovery in between jumps. The reason a single leg drop jump was chosen rather than a double leg drop jump to assess power output was to have the ability to separately analyse unilateral patients and compare performance between affected versus non-affected limb.

3.2.8 Hip Range of Motion

Decreased ROM is commonly associated with FAI syndrome yet there is a limited number of studies which report the decreases in ROM compared to healthy controls and less still which report on the changes in ROM following intervention. ROM was therefore chosen as a measure to compare athletes and also to shed light on possible changes in more ambulatory movements following treatment. To assess range of motion about the hip, the participant was required to lie in the supine position on a mat which was placed on the floor. A goniometer was used to measure hip flexion, hip abduction and hip internal rotation in degrees, on both sides. Flexion was measured by flexing the knee to ninety degrees and the vertex of the goniometer was placed on the greater trochanter. The stationary arm of the goniometer was placed in line with the lateral epicondyle of the femur when the leg was fully extended at the beginning of the test and remained in that position for the duration of the test (i.e parallel to the floor). The adjustable segment of the goniometer moved with the leg which was passively moved into flexion and the degree at which flexion was no longer available was recorded on the protractor of the goniometer. Care was required to ensure that the contralateral hip remained in contact with the floor during the test (Norkin and White, 2009).

Hip abduction was recorded by placing the participant in the neutral supine position again ensuring the hip not being tested remained in contact with the floor. The centre point of the goniometer was placed on the ASIS of the hip being examined, with the stationary arm in line with the femur, as the limb was passively abducted the movable arm travelled with the leg to the end range of abduction, and a reading was then taken from the protractor (Norkin and White, 2009; Nussbaumer et al., 2010). To ensure external rotation did not occur participants were instructed to keep their toes pointed towards the ceiling throughout the test.

Determination of hip internal rotation was completed by again placing the patient in the supine position and flexing the knee to ninety degrees, the goniometer was placed on the central patella and the leg was passively internally rotated until it could no longer move or until discomfort was felt in the hip. The stationary arm stayed parallel to the floor and the movable arm followed the portion of the leg that was being rotated (Norkin and White, 2009; Nussbaumer et al., 2010).

Two trials of flexibility were carried out, except in the case where the values were more than four degrees apart for the same measurement. In such cases a third reading was taken. The average of the two closest readings was taken as the overall result. For analysis of ROM, individual “cases” of FAI syndrome were included (meaning the symptomatic side of unilateral patients was included) with values for both sides of bilateral patients included in the analysis. Finally, an average of both sides of the healthy controls were used as a comparison.

3.2.8.1 Reliability Testing

For the 10-m Sprint, agility, deep squat and RSI assessments high quality, validated equipment was used to measure each variable to ensure accurate and reliable results. In the case of ROM measurements where a standard goniometer was used by the researcher, reliability testing was carried out to determine whether results from repeated measurement differed. Intra-rater reliability was assessed by assessing twelve females who regularly compete in ladies football for hip flexibility using the same protocols mentioned above at two time points; one week apart. The absolute (whereby the direction of the difference was removed) and the and relative (direction included) differences were calculated and presented in Table 3.1. Absolute differences were calculated due to the potential for positive and negative numbers to cancel one another out and lead to overall smaller differences observed. Intra-class correlation coefficients (ICCs) were also used to determine reliability, all of which were >0.75. The results indicated a small margin of error in measurement and excellent agreements (ICCs) with one another and so no further reliability testing was carried out.

Table 3.1 Relative and absolute differences for hip flexibility measurements

Measurement	Average Relative Difference (Degrees)	Average Absolute Difference (Degrees)
Left Leg Flexion	0.50 (2.4)	1.80 (1.6)
Right Leg Flexion	0.08 (2.3)	1.75 (1.4)
Left Leg Abduction	0.92 (3.9)	2.75 (2.8)
Right Leg Abduction	1.50 (4.3)	2.80 (3.5)
Left Leg Internal Rotation	-2.30 (1.4)	2.30 (1.4)
Right Leg Internal Rotation	0.08 (2.2)	1.75 (1.1)

Table 3.1 Mean (SD). Relative Difference; Day 2-Day 1 (Negative value = Day 2<Day 1)

3.2.9 Unilateral Patients

Unilateral patients were also assessed as an independent group where affected versus unaffected limb were compared with regard to the time taken to change direction on the modified agility T-test, RSI, and all three flexibility measures of flexion, abduction and internal rotation.

3.2.10 Data Analysis

Using G*Power 3.0.10 software to determine the sample size required, based on a p value of 0.05 or less and an effect size of >0.60 a power test was carried out (Faul, Erdfelder, Lang, & Buchner, 2007). To allow appropriate control of the type II error rate and give a statistical study power of >0.80, it was estimated that a sample group of at least 90 participants would be needed (minimum of 45 in each group).

Descriptive statistics were employed for participant demographics; following which, the data collected was assessed for normality using the Shapiro-Wilk test. An independent samples t-test or non-parametric equivalent (Mann-Whitney U Test) was used to determine between group differences for each measure with p<0.05 considered significant. The percentage differences between the groups were also calculated for all measures. In all cases patients and controls were asked to report any anterior groin stiffness/pain during any of the testing. If pain was reported they were asked to quantify the pain level using a self-reported pain scale form 0-5 with 5 equating to the worst pain felt. Descriptive analysis was used to determine the percentages of those stiffness and/or pain. Unilateral patients were assessed by comparing affected versus unaffected limb for the measures of agility, RSI and ROM using a paired samples t-test or Wilcoxen signed ranks test in the case of non-parametric data.

3.3 Results

3.3.1 Participant Demographics

In agreement with the Warwick consensus on the diagnosis of FAI syndrome (Griffin et al., 2016), all patients presented with a classical history and clinical examination in keeping with the condition (activity related groin pain and hip stiffness, reduction in adduction/internal rotation of the flexed hip with a positive impingement sign, in the absence of other pathology). Patients were diagnosed with CAM impingement if an alpha angle >55° on Dunn view or >65° on AP view X-rays was detected. Pincer lesions were identified if patients had a lateral centre edge angle >35°, a clear ‘cross-over sign’ on AP pelvic view or a clear anterolateral rim deformity evident on the false profile view. For diagnosis of combined impingement; a CAM lesion on either AP or Dunn view, in conjunction with a pincer lesion on either AP or false profile view was necessary.

A patient group (n=76), consisting of 18-35 year old competitive sportsmen were recruited for the study. Eight were removed from results due to prior hip surgery, while 3 were removed due to the presence of OA on radiograph leaving a patient group consisting of 65 patients. A control group of 69 participants was recruited from various local sporting clubs. Two were excluded due to prior hip surgery and one was excluded due to the presence of persistent hip pain that required treatment. The subsequent control group consisted of 66 participants (Figure 3.3). The demographics of both patient and controls groups are described in Table 3.2. The majority of both patients and controls were Gaelic games players (Figure 3.4) with most athletes in both groups competing at senior club level (Figure 3.5). The levels of competition engaged in by athletes who were not involved in Gaelic games are also listed below (Figure 3.6).

Thirty four patients were diagnosed with unilateral impingement, while 31 patients were diagnosed bilateral impingement yielding a total of 96 hips. Two were diagnosed with a pure CAM impingement, 21 were diagnosed with a pure pincer impingement and the remaining 73 were diagnosed with combined impingement. Patients on average had been suffering from symptoms for 19.4 ± 21 months. The average alpha angle on Dunn view was 61° and 64° on AP view. The average centre edge angle was 34°.

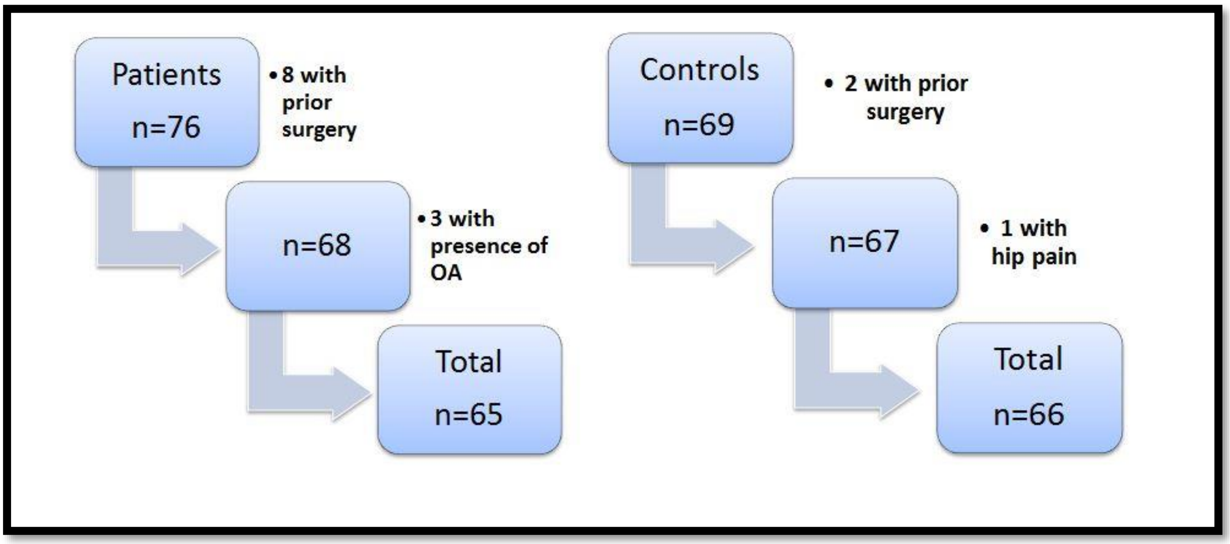


Figure 3.3 Recruitment of Participants

Table 3.2 Patient and Control Demographics

Group	Age (yrs)	Body mass (kg)	Height (cm)
Patient	25.52 ± 4.7	81.5 ± 9.3	179.2 ± 5.8
Control	24.08 ± 4.2	83.1 ± 7.5	180.2 ± 6.5

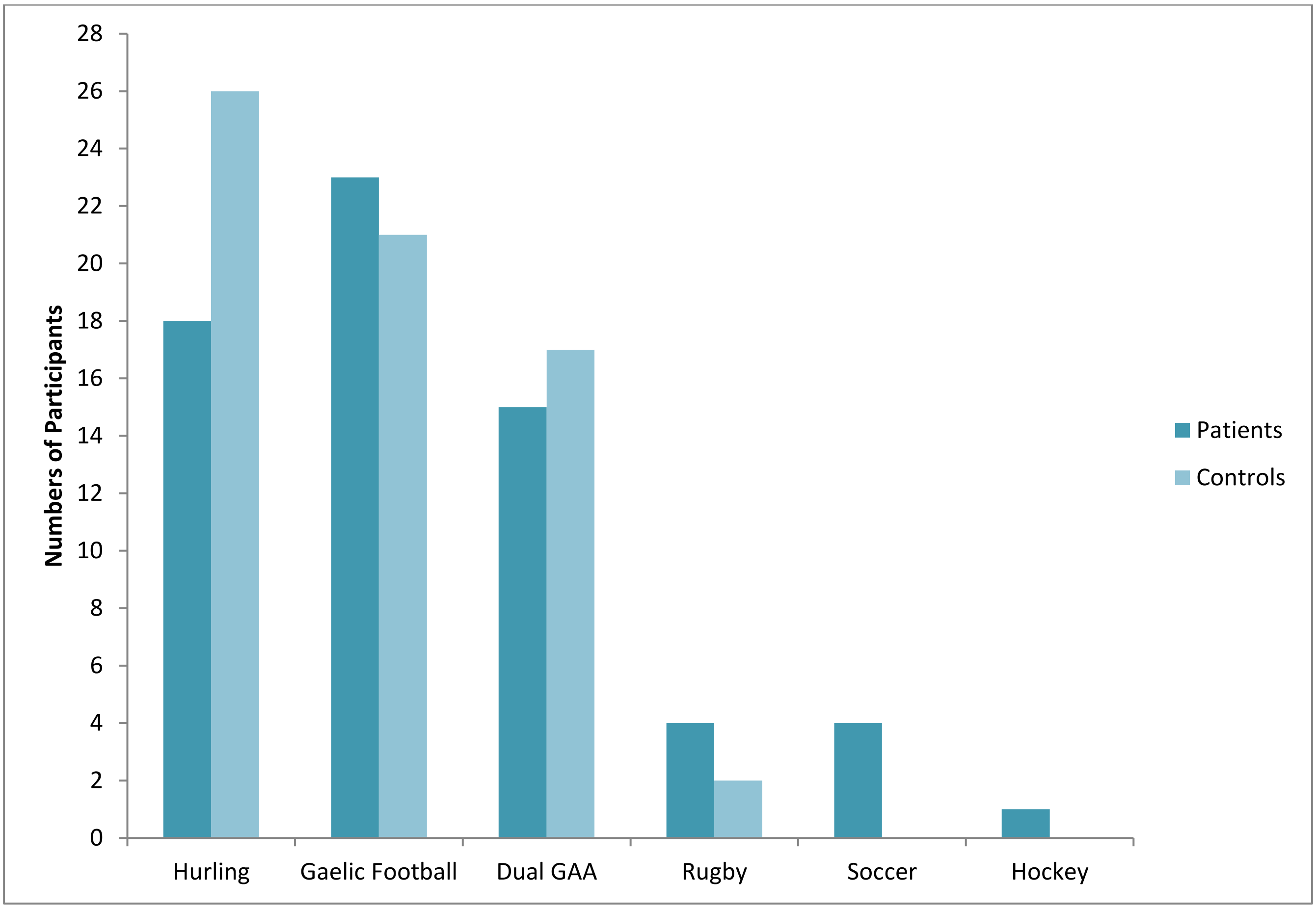


Figure 3.4 Types of Sport Played by Participants

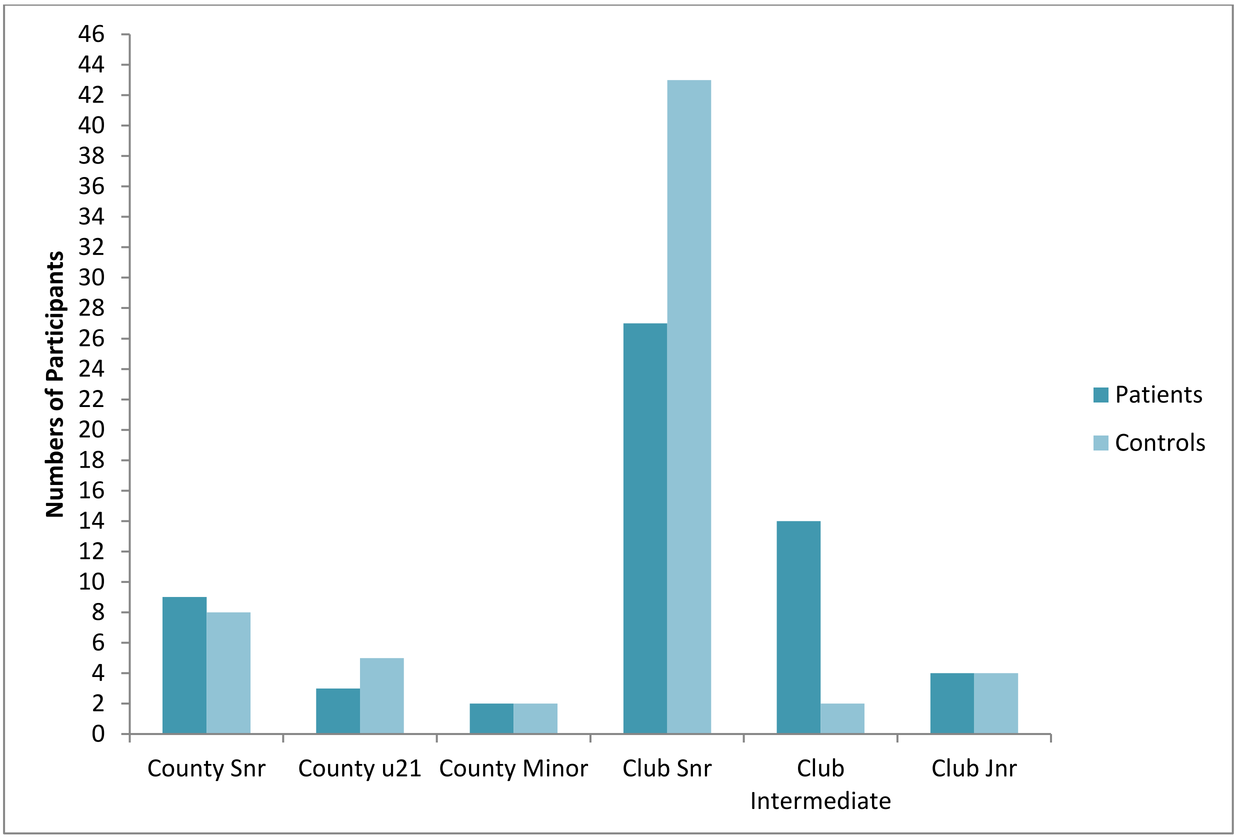


Figure 3.5 Highest level of Competition among GAA Players

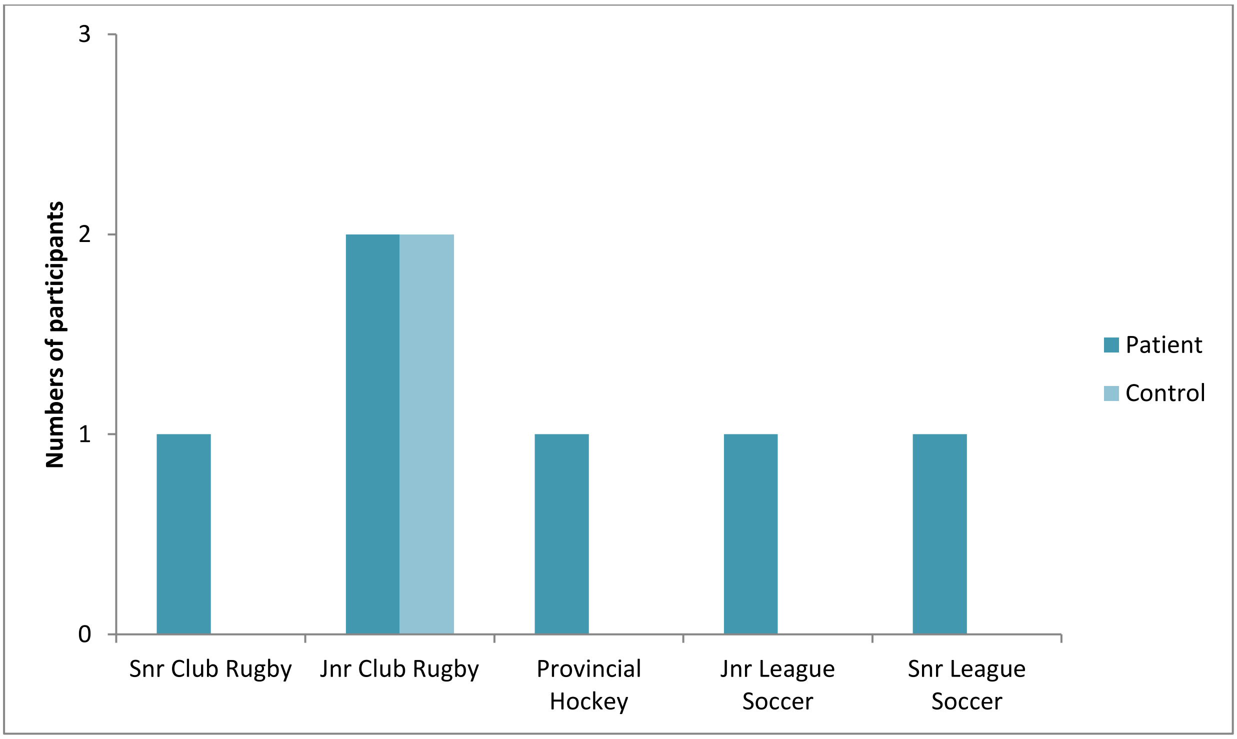


Figure 3.6 Highest Level of Competition among Non GAA Players

3.3.2 Functional Tests

At baseline, patients were significantly slower than controls for the 10-m sprint (p=0.001) and modified agility t-test (p<0.001) (Table 3.3). Patients also recorded a high incidence of anterior groin pain for both measures (Figure 3.7 to 3.10). Patients had significantly lower levels of flexion, abduction and internal rotation (p<0.001). While no differences were detected between patients and controls for RSI (p=0.425) or squat depth (p=0.692), a high occurrence of anterior groin pain while squatting was highly indicative of FAI syndrome with no control reporting any pain or stiffness during this test (p<0.001).

Table 3.3. Differences between patients and controls across all functional measures

Measure	Patient scoring (n=65)	Control scoring (n=66)	Percentage Difference (%)
(M)10-m sprint (s)	1.70 ± .10* (1.68-1.72)	1.65 ± .07* (1.63-1.67)	-3.0
(M)Modified agility T-test (s)	7.83 ± .67* (7.67-7.99)	7.27 ± .43* (7.17-7.37)	-7.7
(t)Squat depth (cm)	48 ± 13 (45-51)	50 ± 13 (47-53)	-4
(t)Reactive strength index (RSI)	1.14 ± .20 (1.09-1.19)	1.15 ± .22 (1.10-1.20)	-1.7
(t)Average maximal hip flexion (Deg.)	113 ± 7* (111-115)	117 ± 5* (116-119)	-3.4
(t)Average maximal hip abduction (Deg.)	32 ± 6* (31-33)	44 ± 8* (42-46)	-27.3
(t)Average maximal hip internal rotation (Deg.)	31 ± 10* (29-33)	53 ± 10* (51-55)	-41.5

Values are expressed as mean ± standard deviation *Significant difference p<0.05. (-) indicating patients less than controls. 95% CI of the mean included in brackets below each mean and SD. (M) Indicates a non-parametric Mann-Whitney u test while (t) indicates an independent samples t test used to assess statistical differences between the groups.

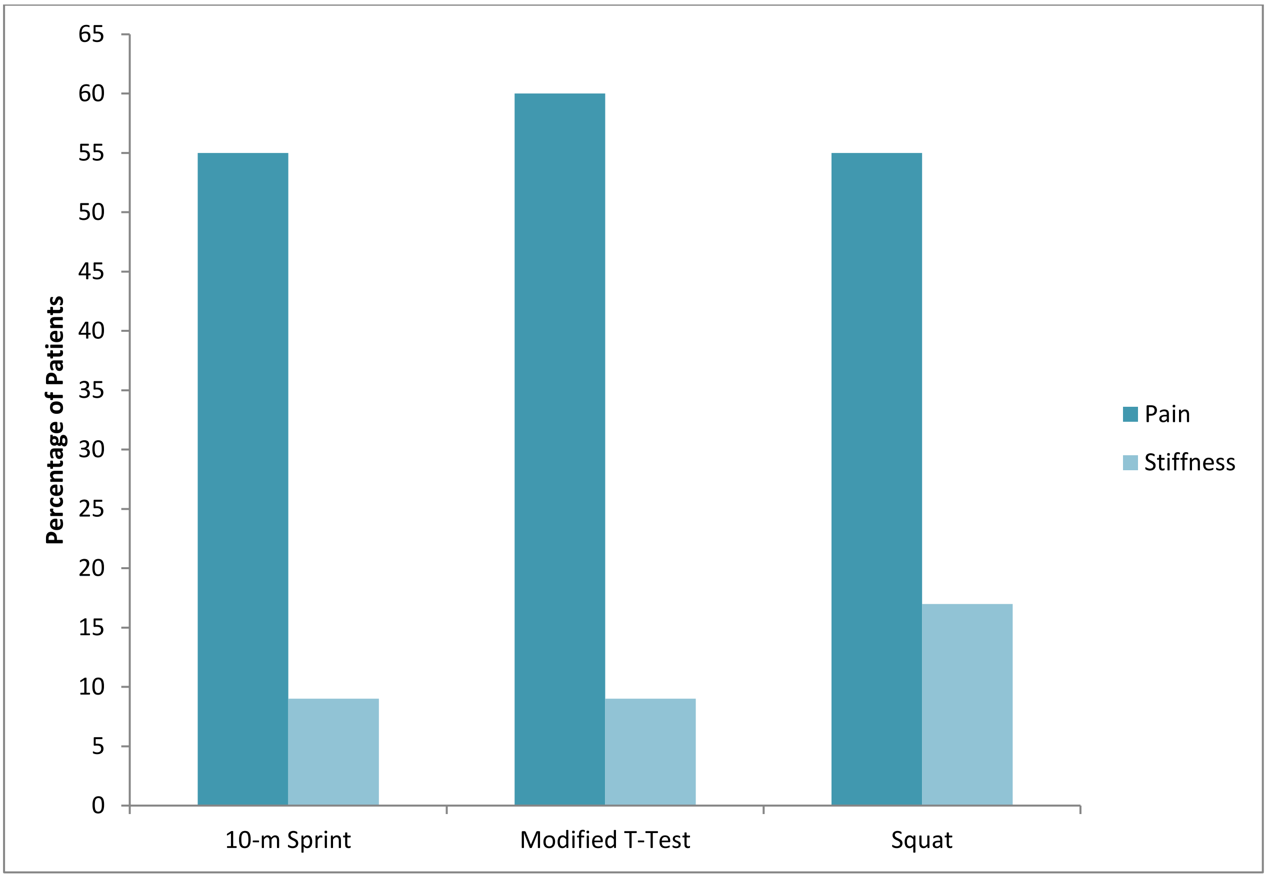


Figure 3.7 Percentage of patients reporting pain or stiffness

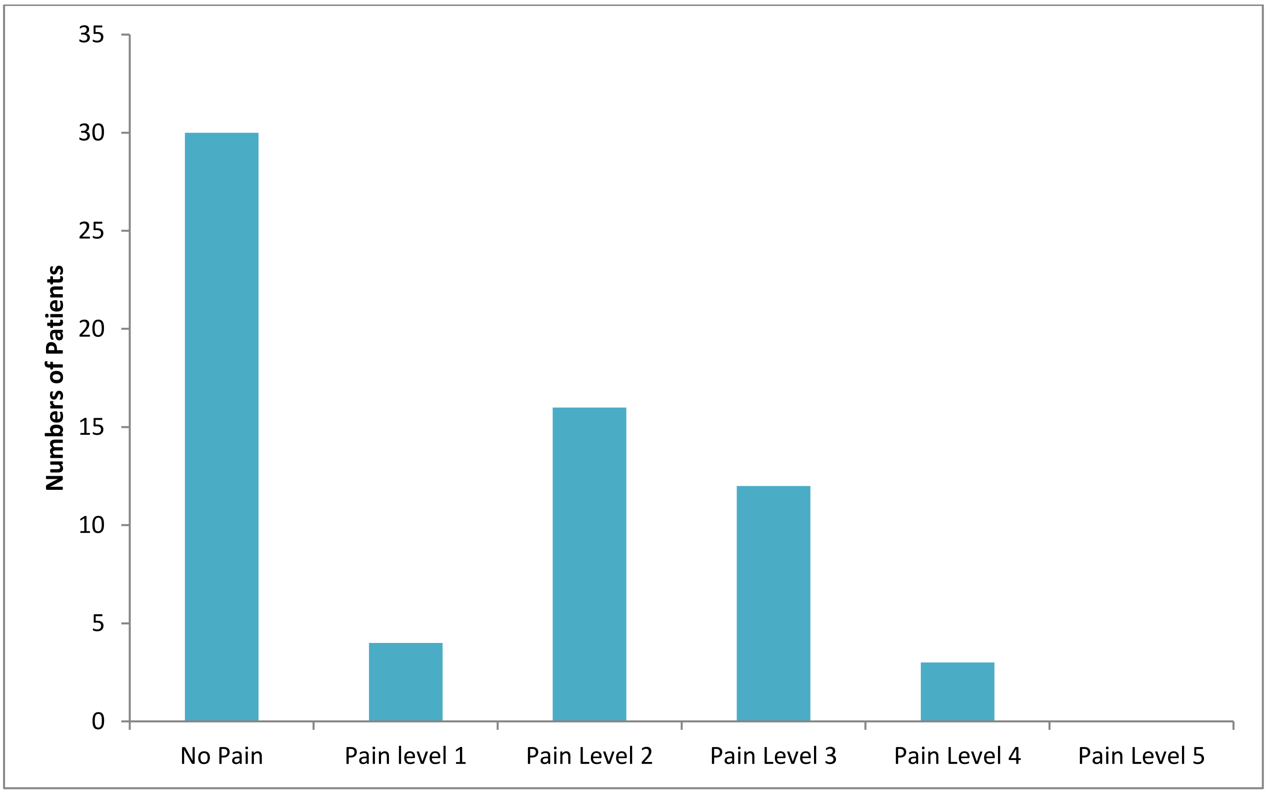


Figure 3.8 Pain Levels for 10-m Sprint. Pain was reported using a self-perceived pain rating of 1-5, with 5 equating to the worst pain possible.

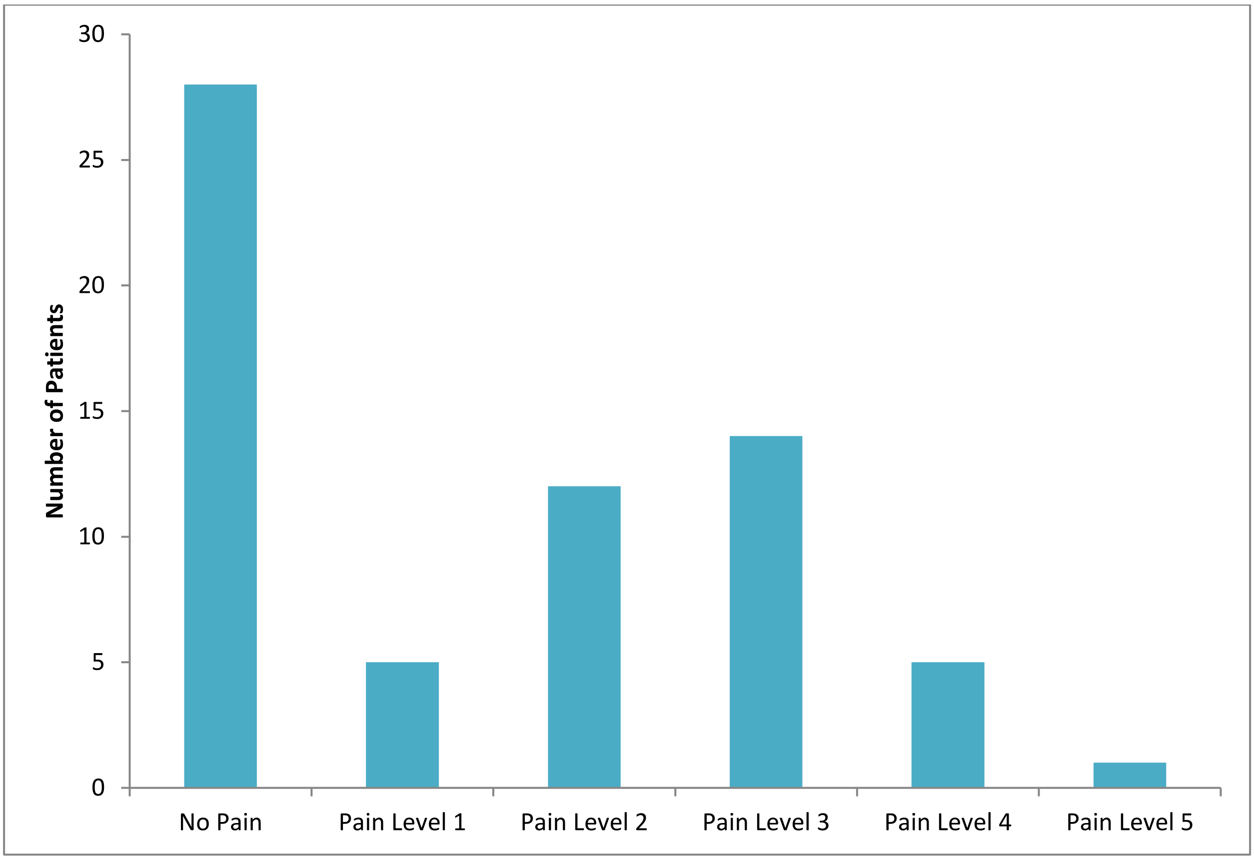


Figure 3.9 Pain Levels for Modified T-test. Pain was reported using a self-perceived pain rating of 1-5, with 5 equating to the worst pain possible.

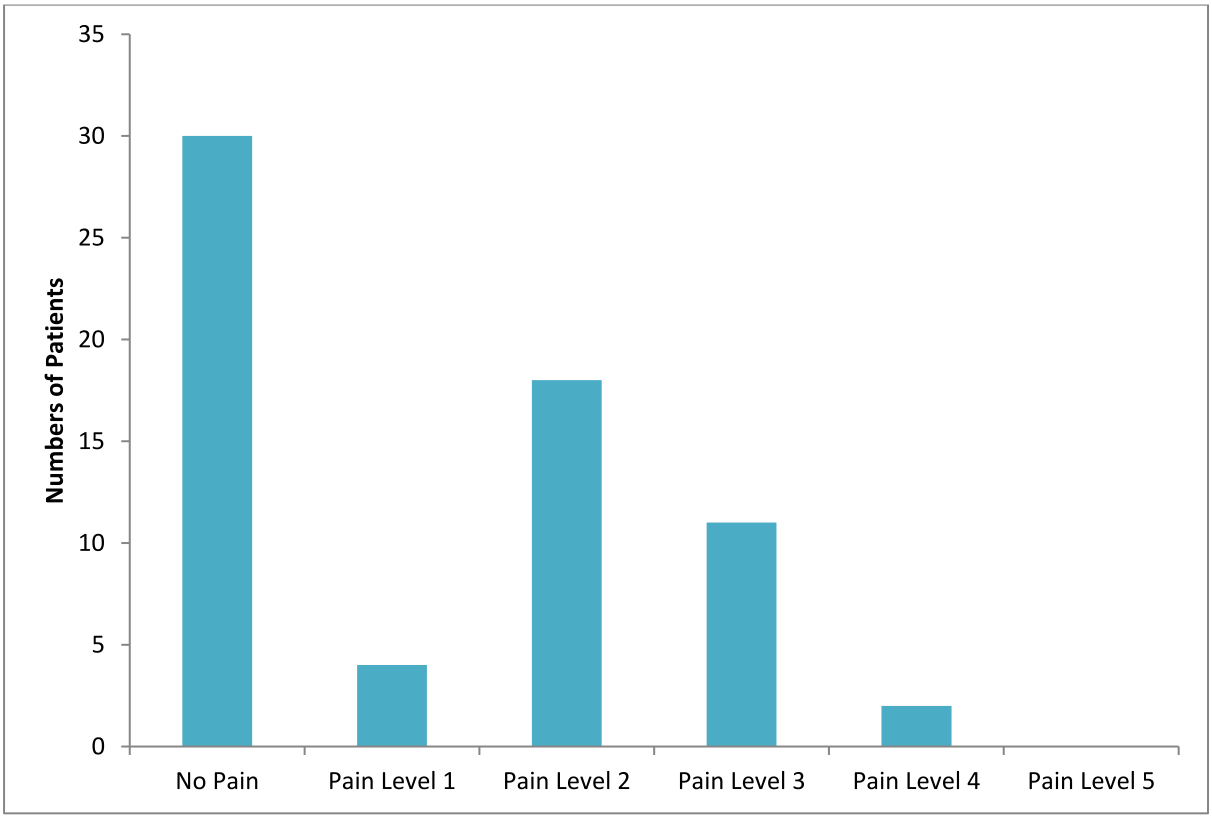


Figure 3.10 Pain Levels for Squat. Pain was reported using a self-perceived pain rating of 1-5, with 5 equating to the worst pain possible.

3.3.1.1 Further investigation of Squat

Due to the limited availability of another camera, ten controls and ten patients were included in the analysis to determine knee distance at the base of the squat. No significant differences were recorded between the average patellae distance at the base of the squat between patients and controls ($p=0.549$). A random selection of 39 patients and 39 controls taken from the main sample, were assessed for forward trunk lean at the base of the squat, there were no significant differences ($p=0.857$) found between the groups in this regard (Table 3.4).

Table 3.4 Patellae distance at the base of the squat

Type	Knee Distance (cm)	Trunk Lean (Deg.)
Patient (N=10)	$^{(M)}$14.7 ± 9.0 (CI$_{diff}$	$^{(M)}$41.57 ± 7.9
Control (N=10)	$^{(M)}$12.7 ± 5.5	$^{(M)}$41.21 ± 9.7

Values are expressed as mean ± standard deviation. (^{M}) Indicates a non-parametric Mann-Whitney u test

3.3.1.2 Unilateral Patients

Thirty four patients were diagnosed with unilateral impingement, 23 patients had impingement on the right side with 11 presented with impingement on the left side (Table 3.5). There were significant differences recorded between the side affected with FAI syndrome and the contralateral healthy limb for the measures of reactive strength index ($p=0.003$), maximal hip flexion, abduction and internal rotation ($p<0.001$). When assessing the ability of athletes to change direction on one side compared to the other, some correcting of data needed to be carried out to ensure accurate results. All players were instructed to shuffle to the left side first, and so could have been faster turning on the opposite side because they were already moving at speed by the time they needed to turn on the right side. To allow for this, the average difference between left and right side was calculated (0.004s) and added to all right-hand side scores for all of the unilateral patients included in this assessment. Subsequently, no significant differences were noted between the time taken to change direction on the affected limb compared to the unaffected limb.

Table 3.5 Differences between affected and unaffected limbs among unilateral patients

Measure	Affected Limb (n=34) (95% CI)	Unaffected Limb (n=34) (95% CI)	Percentage Difference (%)
^(P)^Change of Direction (s)	1.74 ± .14 (1.69-1.77)	1.74 ± .16 (1.69-1.79)	0
^(P)^RSI	1.10 ± .22* (1.03-1.15)	1.17 ± .20* (1.10-1.24)	-6.7
^(W)^Flexion (Deg.)	112 ± 8 * (109-114)	117 ± 6 * (115-119)	-3.4
^(W)^Abduction (Deg.)	33 ± 7 * (31-35)	37 ± 7 * (25-39)	-10.8
^(W)^Internal Rotation (Deg.)	32 ± 10* (29-34)	42 ± 9 * (39-45)	-23.8

Values are expressed as mean ± standard deviation *Significant difference p<0.05 (-) indicating patients less than controls. (W) Indicates a non-parametric Wilcoxen Signed Rank test while (P) indicates a paired samples t test used to assess statistical differences between the affected and unaffected limb.

3.4 Discussion

Researchers have only recently turned their attention to the functional consequences of FAI (Bagwell et al., 2016; Kennedy et al., 2009; Lamontagne et al., 2009), although there has been very little research to date which examines the athletic performance deficits among athletes with FAI (Brunner et al., 2015) and none specifically with athletes requiring treatment. This is an important consideration as it is not uncommon for athletes to continue with sports participation in the presence of hip pain and stiffness. The primary aim of this phase of research was to compare functional performance measures in athletes with confirmed FAI syndrome, with an age, gender and, activity-matched control group to determine the extent of functional discrepancies between groups.

All patients were competing in field sports, which place a great importance on agility and sprinting over short distances (Sleivert & Taingahue, 2004). Assessment of agility and acceleration demonstrated significant deficits in athletic performance along with a high occurrence of groin pain/stiffness during testing among athletes with FAI syndrome compared to controls. There is no published research to date describing normative data for acceleration (10-m speed) among GAA athletes, however in comparison to previously reported acceleration data for soccer (approx. 1.83s) and rugby league (range 1.61-1.98s) all participants including patients in this study appear to have slightly faster times for this measure (Baker & Newton, 2008; Baker & Nance, 1999; Little & Williams, 2006; Little & Williams, 2005; Wisløff et al, 2004). Possible reasons for this include the differences in anthropometric attributes of the GAA players compared to other athletes, or the rubber sprint running surface used in this study. Differences in times recorded could also be attributed to the fact that participants in this study were instructed to start with their front foot on the start pad and other foot behind, meaning some initial body movement occurring prior to initiation of the timer switch, ultimately leading to reduced overall time. While both groups in the current study were faster than previously reported, the fact that patients were slower than controls is the most important finding and indicates a distinct performance disadvantage (3% and 8% slower for acceleration and agility respectively) for those with FAI syndrome compared to those without. When considering agility times, the modified agility T-test has not been used extensively throughout the literature despite being a reliable measure of agility (Sassi et al, 2009) and therefore comparison of the results recorded in this study to previous research is not possible. However, the fact that a matched control group was used in this research indicates that athletes with FAI syndrome have a distinct performance disadvantage in movements that require changing direction, without the need for comparison with normative data.

In relation to FAI specific research, the results of this report are contrary to the findings described previously by Brunner and colleagues (2015) who reported no significant differences in sprinting or agility performance between young ice hockey players with symptomatic FAI, those with asymptomatic FAI and those without any clinical or radiological indication of a bony abnormality. Differences in participant selection may account for these differences, with Brunner's study using younger athletes (mean age 16.3 versus 25.5 years in the present study). The participants with symptomatic FAI in Brunner's research did not require treatment whereas the participants in the current study required intervention indicating more advanced progression of the condition. The FAI group size was also considerably smaller in the Brunner study than in the results presented here (n= 16 vs n=68). Pain during the functional measures was not assessed in Brunner's research although it was found to be highly indicative of a pathological hip condition in the current research.

Research examining functional differences between patients with FAI syndrome and controls is limited, although squatting mechanics of persons with FAI and those without has been assessed previously. Both Lamontagne et al. (2009) and Bagwell et al. (2016) reported those with FAI could not squat as low as those without, while Kumar et al. (2014) reported differences in squatting mechanics among participants with FAI to achieve the required squatting depth compared to controls. The results of this study do not support these findings and are more in line with those of Diamond et al. (2017) who found no differences in squatting depths between a group of patients with diagnosed CAM or combined FAI, compared to an age, gender and leg dominance matched control group, although the patient group were significantly slower while squatting. The participants included in the Diamond research and in this research, were matched as closely as possible for activity levels, while in all three previous investigations no information regarding physical activity of either group was recorded. Therefore, there is no way to determine whether the control groups were simply better at squatting due to more exposure to movements such as those. Differences in squatting mechanics were reported by Bagwell et al. (2016) and measures were taken in the current research to assess possible compensatory mechanisms used by patients to achieve greater depth, including measuring the levels of trunk lean and differences in knee distance from the beginning of the squat to the base. No differences between groups were detected between trunk lean or knee distance in this research. However, the small numbers of participants in this subsection of analysis could account for the lack of significance observed. In comparison to the previous literature, the two-dimensional nature of this analysis is also a considerable difference from the previous reports which all utilised 3D biomechanical assessments of the squats. Three-dimensional video recording of squatting can give comprehensive detail regarding the mechanisms used to achieve maximal squat depth which were not possible using 2D analysis alone.

Though no differences in squat depth were found in this analysis, groin pain during squatting was found to be highly prevalent in the patient group. Of the previous research of this nature, only the Diamond research referred to groin pain during squatting with an average pain rating of “2” using a pain scale of 0-10 with 0 being no pain and 10 meaning worst pain possible. In the current study, 45% of patients reported the presence of pain with the most commonly reported pain levels being “2” and “3” when a smaller 0-5 scale was used. Differences in the measures used makes comparison difficult, however both studies found that patients could in fact squat as low as healthier counterparts but were in pain while doing so. Patients in both the Diamond study and the current study, were not asked to determine the point during the squat at which pain was noted. This could mean that pain was only present at the base of the squat while the hip was in a position of greater flexion. This is an important distinction, as athletes could potentially use quarter squatting (40-60° of knee angle) to improve power output (Rhea et al., 2016) for sport while still avoiding exacerbating symptoms in a full squat position and serve as a useful conservative management strategy for athletes who are continuing with sports participation.

Reactive strength index (RSI) is a valid measurement of the ability of an athlete to produce maximal eccentric and concentric force in the minimal amount of time, which is a prerequisite of many sports (Flanagan et al, 2008; Ebben & Petushek 2010). Athletes with FAI syndrome in this study showed no decrement in RSI compared to the matched controls, indicating minimal negative consequence of the condition on neuromuscular function during a simple vertical jump stretch-shortening activity. The similarity between controls and the athletes with FAI syndrome on this test highlights the effects of FAI syndrome on the more game-specific ambulatory tasks such as acceleration (patients 3% slower than controls) and agility (patients 8% slower than controls). Further research is required to understand the relative influences of anatomical defects/pain in possibly causing these deficits in athletic ambulatory performance. However, unilateral patients displayed significant differences between the affected versus non-affected limbs with regard to RSI. Significant differences may have been apparent in this cohort because the data analysis process involved the use of within subject comparisons rather than a between subject comparison. While reactive strength has not been examined in relation to FAI syndrome previously, it has been examined in relation to anterior cruciate ligament ruptures. Flanagan et al. (2008) compared the RSI of participants with a history of ACL reconstruction (ACL-R) to an age, gender and activity matched control group, and found no significant differences between the groups for RSI or between involved and uninvolved limbs of the ACL-R group. The retrospective nature of that research compared to the prospective nature of this study design makes comparisons of results difficult.

Hip range of motion is significantly reduced in persons with FAI syndrome compared to those with no hip pathology and has been well documented throughout the literature (Philippon et al., 2007; Siebenrock et al., 2013). The results of this baseline research are in accordance with those findings with patients displaying significantly lower levels of ROM in all three planes of motion. Furthermore, the unilateral patients had significantly lower levels of hip ROM in the affected limb compared to the unaffected limb which has been reported previously. Philippon et al. (2007) reported 8%, 9% and 11% lower levels of flexion, abduction and internal rotation respectively for the affected limb compared to unaffected side. While Clohisy et al. (2009) reported 4%, 4% and 3% lower levels for flexion, abduction and internal rotation in the affected limb of unilateral patients. The results of this study are similar to previous reports for flexion and abduction, however the differences in internal rotation between affected and unaffected limbs are substantially higher in the current study compared to previous reports. The differences in participant selection could account for this as in previous reports the patient samples included males and females with wider age ranges and were not specifically athletes with unilateral FAI. In the current study unilateral patients were young, male athletes. Therefore, it could be that younger male athletes with no hip pathology simply have greater internal rotation values than older, non-athletic males and females in the first instance. Reduced range of motion has the potential to cause further deficits in more functional tasks; decrements in speed could result if, in conjunction with pain, an athlete does not have appropriate range of motion within the joint, hindering a suitable body position to effectively produce force when accelerating the athlete forward (Kennedy et al. ,2009; Casartelli et al., 2011). Poorer abduction may restrict lateral motion involved in side stepping, while limitations in internal rotation may prevent an athlete from twisting and turning effectively, both of which are necessary for optimal agility; such restriction of motion may be a factor in the poorer agility scores for athletes with FAI syndrome observed during the T-test (Jovanovic et al., 2011; Parsons & Jones 1998)

3.4.2 Limitations

There are a number of limitations associated with the current study. Firstly, the control group were not clinically or radiographically assessed for FAI syndrome. Controls were excluded from the study based on any chronic hip/groin pain and had significantly greater of overall hip ROM, meaning that the likelihood of FAI syndrome in the control participants was reduced. However, the fact that an underlying hip pathology may have been present in control participants cannot be ruled out, with the likely effect of this being an underestimation of the true differences in athletic performance between those with FAI syndrome and those without. Secondly, the addition of a second camera in the squat assessment was included after testing had begun and so the subject numbers included in the analysis of trunk lean and knee mechanics are reduced, therefore increasing the risk of a type two error.

3.4.3 Strengths

This study is the first to assess functional performance among a group of athletes requiring treatment for FAI syndrome compared to a healthy matched control group. It is also among the first to determine pain during functional tasks required for sports participation. The strengths of this study include the large subject numbers involved compared to previous research involving FAI syndrome patients and healthy controls. Controls were also matched closely for age, sports played and levels played at. The tests used in the study include the main components required for field sports participation namely, acceleration, agility, power and range of motion giving a clearer understanding of the main aspects of sports which may be greater affected by the condition. The use of one tester for all testing adds consistency to the collection process and the use of a rubber sprinting track ensured that all participants ran on the same surface which reduced variability among the sprinting based measures from differences in floor surface. Dual beam timing gates were used instead of single beam timing gates to increase accuracy, while the Optojump system is a more sophisticated measure of jump performance than traditional jump mats.

3.4.4 Practical Implications

The results of this study highlight the serious nature of the condition, and serve to educate coaching staff involved with athletes with FAI syndrome as to the negative performance consequences of the condition. Intervention methods should be discussed to treat the athlete as soon as possible with appropriate treatment protocols. Training programs may need to be altered to avoid exacerbating symptoms while still improving physical fitness and tactical decisions regarding player position, and on-field playing time, may need to be considered during competition.

3.5 Conclusion

Athletic performance measures of speed, agility and hip range of motion are significantly reduced in the presence of underlying FAI syndrome. Such deficits in athletic ability in conjunction with activity related groin pain and hip stiffness may greatly impact on individual and ultimately team performance. Poor athletic performance poses a major concern for athletes, clubs and coaches as it is not uncommon for athletes with symptomatic FAI syndrome to continue playing for many years before diagnosis and treatment. Training programs may need to be altered for athletes with FAI syndrome who are continuing with sports participation without intervention. Not only does this research serve to identify areas of functional performance which are negatively affected by FAI syndrome, but it also provides a quantitative functional outcome measuring tool which may be more suitable for this population than traditional qualitative self-reported measures.

Chapter four Intervention

4.1 Introduction

The role of surgical intervention for the treatment of FAI syndrome has grown substantially over the last fifteen years with advances in modern medicine and a greater understanding of the nature of the disease and appropriate treatment procedures. In the earlier years of correction for FAI syndrome, open surgery was the standard protocol; with removal of damaged labral and articular cartilage tissue routine practice. However, subsequent reviewing of outcomes following this procedure found poorer results in groups where labral tissue had been removed completely as well as substantial rehabilitation times with open surgery (Philippon et al., 2011). With a greater understanding of the role of the labrum as a sealant and a stabiliser for the joint, surgeons now consider it important to preserve the labrum where possible (Mlynarek et al., 2015). Technical advances with arthroscopic surgery now facilitate labral preservation; labral repair is achieved by inserting bony suture-anchors into the acetabular rim and using the sutures to reattach the labrum to the bone. Prior to labral reattachment any bony rim deformity is corrected using a mechanical burr under x-ray guidance. The hip is then brought through a ROM examination to ensure sufficient bone has been removed to avoid further tearing of the tissue.

Much of the existing research has examined the effect of surgical intervention on FAI syndrome through the use of self-reported measures from athletic patients and frequencies of return to play (Byrd, 2012; Philippon et al., 2007). In recent years there have also been investigations into the effect of surgery on more functional movements including gait and squatting as they are considered vital for activities of daily living, however there is much room for further investigation of the effects of intervention on functional performance. By intensively examining the effects of arthroscopic treatment for FAI syndrome on functional performance in athletes with this condition, a more informed decision can be made with regard to their treatment options. This research can also provide a number of objective functional outcome measures which, in conjunction with more traditional self-reported measures assessing pain etc, will give a clearer indication of the effectiveness of surgical intervention.

The following chapter will address the effects of arthroscopic treatment of FAI syndrome including labral repair on athletic performance measures of acceleration, modified agility T-test, deep squat, reactive strength index and hip flexibility including maximal hip flexion, abduction and internal rotation. Patients were tested at twelve weeks and a minimum of 1-year post-surgery.

4.1.1 Research Questions

1. How does functional performance change in patients 12 weeks post-surgery compared to controls?
2. Does the level of hip pain and stiffness change from baseline to 12 weeks post-surgery?
3. How does functional performance change in patients 1-year post surgery compared to controls?
4. Does the level of hip pain and stiffness change from baseline to 1-year post-surgery?

4.2. Methods

4.2.1 Surgical Procedure

All patients were treated by the same surgeon between August 2014 and April 2016 at the Whitfield Clinic, Waterford. Patients were first anesthetised and placed in the standard supine hip arthroscopy position. The hip was placed in traction, following which two portals were created for the procedure; the anterolateral and modified mid-anterior portal. In the case of pincer impingement, the mid-anterior portal was used as the main working portal, including labral "take down", rim resection and labral reattachment, with the anterolateral portal used for camera positioning. A 4mm mechanical burr was used to resect acetabular bone; with a 17-gauge arthroscopy needle used to suture the labrum back into position using an arthroscopic sliding knot. The labrum was then probed to assess stability of the fixation. Following this procedure, a femoro-osteoplasty was carried out to remove excessive bone on the femoral head neck junction in cases where a cam deformity was also present. Following this, the traction was released and the joint dynamically assessed to ensure appropriate movement of the joint. Post-operatively patients were encouraged to mobilise the joint four hours following the procedure with use of a stationary bike on day 1. Crutches were used for five days following the treatment with hydrotherapy initiated as soon as the incision wounds had healed, usually around ten days post-surgery. No complications during or following surgery were reported among any of the patients.

4.2.2 Rehabilitation

Patients were given a standardised unsupervised rehabilitation program by the resident physiotherapist immediately following surgery (Appendix 8.3) and had follow up examinations with the surgeon at six weeks and 12 weeks' post-surgery and the physiotherapist as required. The rehabilitation protocol was standardised to a 12-week program given to all patients.

4.2.3 Testing Procedure

Prior to the testing at 12 weeks patients had a consultation with the orthopaedic surgeon and based on his recommendations were approved for 12-week testing. No patient was removed by the surgeon at the 12-week analysis following his examination. Patients were subsequently contacted at a minimum of 1-year post-surgery (range 12-15 months) to complete the final testing procedure. Control participants were tested 12 weeks and one year following their initial testing session with no disruption to habitual training and competition schedules except in cases where control participants received an injury. Details of the injury were recorded at the 12-week testing session, including nature of injury, duration of disruption to training schedule and current pain levels if any. Where controls were still experiencing pain, they were excluded from testing. For both the 12-week and 1-year assessments all participants were tested in the same manner as described in chapter 3 for 10m-sprint, modified agility T-test, deep squat, reactive strength index and hip ROM measures at both follow up time points. Patients and controls were also asked to report pain in the same manner as previously described throughout the testing procedure.

4.2.4 Return to Play Protocol

Patients progressed to the next stage of the rehabilitation process and gradual return to play based on the recommendations of the surgeon at the follow up consultations. Data was collected on the typical time taken for patients to return to habitual levels of play; as well as reasons for not returning. Data was collected on 32 patients at the 12-week follow up with regard to their return to play status following the procedure. At the 1 year follow up patients who had not completed this questionnaire at the 12-week follow up or those who had stated no to returning to play at 12 weeks completed the questionnaire again. If patients reported not returning to sport the reason was given. Secondary injuries sustained in the time between follow ups were also recorded.

4.2.5 Data Analysis

Each variable was assessed for normality using a Shapiro-Wilk test with $p<0.05$ considered non-parametric data. Changes within each group were assessed, from baseline to twelve weeks, twelve weeks to 1 year and from baseline to 1 year, in each case a paired samples t test or Wilcoxon signed rank test was used to assess within group changes from one time point to the next. A mixed model ANOVA was used to examine group by time interaction effects for all follow up data. Finally, for each measure at each time point significant differences between the groups were determined using an independent samples t test or in cases of non-parametric data, a Mann-Whitney U test. In all cases $p<0.05$ was considered significant.

Unilateral patients were assessed independently as well as part of the overall data set. The measures of reactive strength index, flexion, abduction and internal rotation were examined at both follow up times. All data was analysed for normality using a Shapiro-Wilk tests, following which a paired samples t-test or Wilcoxon signed ranks test was used to determine differences between the affected limb and unaffected limb for each measure at any one time point and to examine changes in the affected and unaffected limbs from one time point to the next. In all cases $p<0.05$ was considered significant.

Differences in pain were assessed to determine whether the changes in patients reporting pain and/or stiffness was significant following the intervention. To achieve this the patients were categorised into separate groups, those who had reported pain at baseline, those who reported stiffness and those who had reported no pain or stiffness at the baseline testing. Each group was assessed for pain/ stiffness for each measure at both 12-weeks and one year. Patients who had reported no pain prior to surgery who continued to report no pain following the procedure were not included. Patients who reported pain prior to surgery but either stiffness or no pain afterwards were considered to have “improved”, while patients who had previously reported no pain or stiffness but who reported pain following surgery were considered to have “More pain”. Finally, any patient who reported stiffness or pain prior to surgery and who still had stiffness or pain following the procedure were included in the “No change”. Increasing the number of repeated testing increases the risk of type 1 error although in this data no adjustment to the p value was made.

4.3 Results

4.3.1 Participants

The participants were recruited from the first phase of research and contacted at both 12 weeks and 1 year to complete follow up testing after surgical intervention. In this case one army officer, and two recreational athletes were also included in the patient group for analysis, demographics for all patients and controls tested at either 12 weeks or 1 year are presented below (Table 4.1). Forty-seven patients were tested at 12 weeks post-surgery with 32 controls, with 37 patients and 23 controls tested at the 1 year follow up.

Table 4.1 Demographics of Patients and Controls

	Age (yrs)	Height (cm)	Body Mass (kg)
Patient	24.6 ± 4.8	179.0 ± 5.3	80.6 ± 8.4
Control	24.3 ± 4.3	179.4 ± 7.4	83.1 ± 7.1

4.3.2 Changes from Baseline to 12 Weeks

For the 12-week follow up testing, 47 patients and 32 controls were tested. Significant improvements were detected within the patient group compared to baseline data for the modified T-test (7.82 s ± .69 to 7.50 s ± .73, $p<0.001$) as well as flexion, abduction and internal rotation (Table 4.2), although patients faired significantly worse for the 10m-Sprint test (1.69 s ± .10 to 1.72 s ± .10, $p<0.001$). The change in time for 10m-Sprint during this time period was not significantly different between the groups even though there were no significant changes among the control group for 10-m sprint or T-test recorded. There were also no significant changes in either group for the deep squat and RSI measures over the course of 12 weeks ($p>0.05$). Similarly, to the baseline findings, patients were still significantly worse than controls for 10m-Sprint, Modified agility T-test, and all three measures of hip ROM at 12 weeks ($p<0.05$). Time x group interaction effects indicated that the patient group changed significantly differently over this time frame compared to the control group for the measures of agility, abduction and internal rotation. The patient group improved on these measures while the control group did not change for these measures.

In relation to pain scoring the patients included in the analysis were those who had previously reported pain or stiffness (Figure 4.1). For the 10m-Sprint, 21 patients reported pain in the joint prior to surgery which had reduced to 12 following the procedure, the number of patients reporting stiffness increased from six to nine. For the agility T-Test, 25 patients reported pain prior to surgery with 15 reporting pain afterwards, stiffness levels increased from four patients to five (Figure 4.2). For the deep squat assessment (Figure 4.3), 24 patients reported pain at the baseline assessment which decreased to seven patients 12-weeks post-surgery, the ten patients reporting stiffness saw no increase or decrease.

Table 4.2 Changes from Baseline to 12 Weeks Post-Surgery for Patients (n=47) and Controls (n=32)

Measure	Baseline Result (95% CI)	12 Week Result (95% CI)	Time x Group Interaction Effect (p<0.05)
10m-Sprint (s)			
$^{(W)}$Patient	1.69 ± .10*† (1.66-1.72)	1.72 ± .10*† (1.69-1.75)	.062
$^{(W)}$Control	1.63 ± .09*(1.60-1.66)	1.64 ± .10* (1.61-1.67)	
Modified Agility T-test (s)			
$^{(W)}$Patient	7.82 ± .69*† (7.62-8.02)	7.50 ± .73*† (7.29-7.71)	.004
$^{(W)}$Control	7.12 ± .34* (7.00-7.24)	7.20 ± .30* (7.10-7.30)	
Squat Depth (cm)			
$^{(P)}$Patient	48 ± 12(45-51)	45 ± 12(42-48)	.246
$^{(P)}$Control	50 ± 12 (45-54)	50 ± 12 (46-54)	
RSI			
$^{(P)}$Patient	1.16 ± .22(1.10-1.22)	1.15 ± .22(1.09-1.21)	.405
$^{(P)}$Control	1.21 ± .22 (1.13-1.29)	1.23 ± .19 (1.16-1.30)	
Flexion (Deg.)			
$^{(P)}$Patient	113 ± 7*† (111-115)	115 ± 5*† (114-116)	.987
$^{(P)}$Control	116 ± 4*† (115-117)	119 ± 4*† (118-120)	
Abduction (Deg.)			
$^{(P)}$Patient	32 ± 6*† (1.66-1.72)	36 ± 6*† (1.66-1.72)	<0.001
$^{(P)}$Control	45 ± 8* (42-48)	43 ± 7* (41-45)	
Internal Rotation (Deg.)			
$^{(P)}$Patient	31 ± 9*† (30-34)	36 ± 7*† (34-38)	.008
$^{(P)}$ $^{(W)}$Control	42 ± 13* (38-47)	45 ± 11* (41-49)	

* Significant between group differences (p<0.05) at either time point, † significant within group changes over time. (W) Indicates a non-parametric Wilcoxen Signed Rank test while $^{(P)}$ indicates a paired samples t test used to assess within group changes over time.

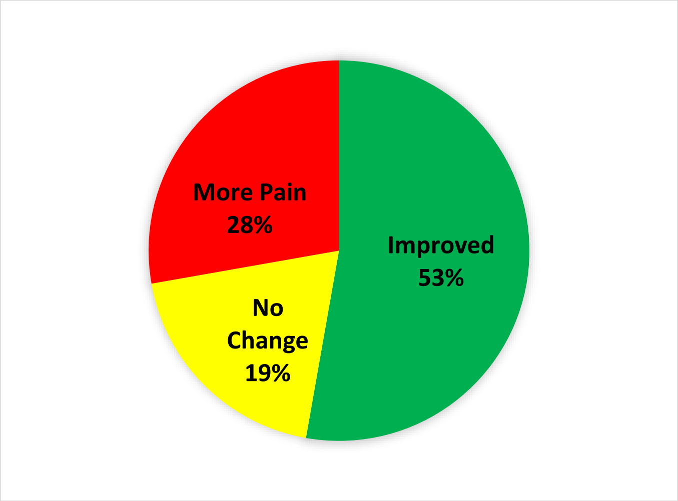


Figure 4.1 Changes in Pain/Stiffness Scoring for 10m-Sprint from baseline to 12 weeks post-surgery (n=36)

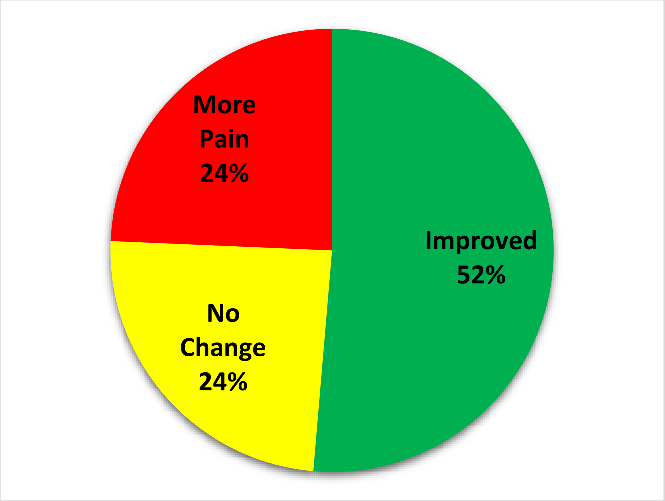


Figure 4.2 Changes in Pain/Stiffness Scoring for agility T-test at 12 weeks post-surgery (n=37)

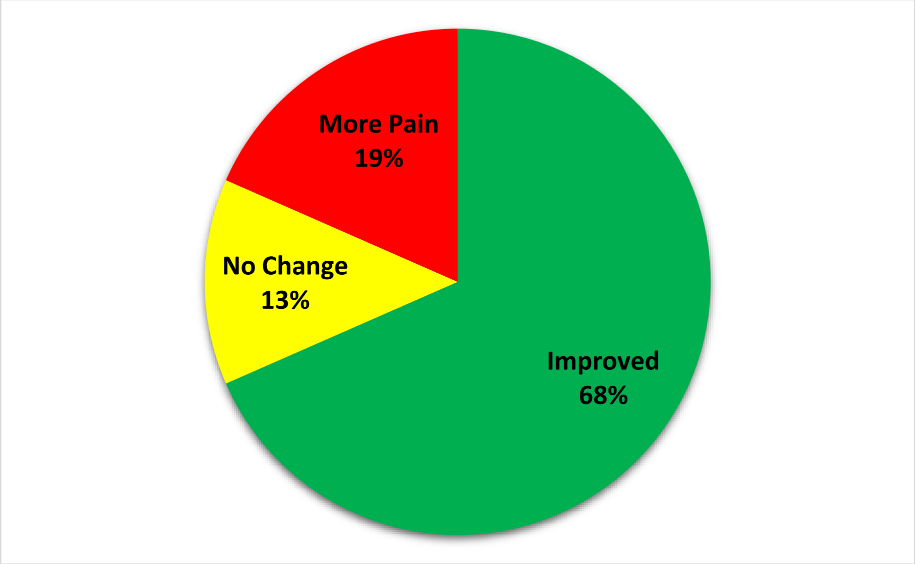


Figure 4.3 Changes in Pain/Stiffness Scoring for Squat Test at 12-weeks post-surgery (n=38)

4.3.2.1 Return to Play at 12 weeks post-surgery

Of the 32 patients who completed the questionnaire regarding return to play at the 12-week follow up, 22 patients had not returned to habitual levels of training or competition. Ten patients had returned fully to sport but one patient was playing with persistent hip pain and stiffness, with the average time to return among those being 10 weeks post intervention. Persistent hip pain was cited as the main reason for not returning while a lack of championship as well as work and university commitments also recorded (Figure 4.4). One patient sustained a work-related injury to the quadriceps muscle which prevented him from returning to sport even though he reported no hip pain/stiffness at the 12-week follow up.

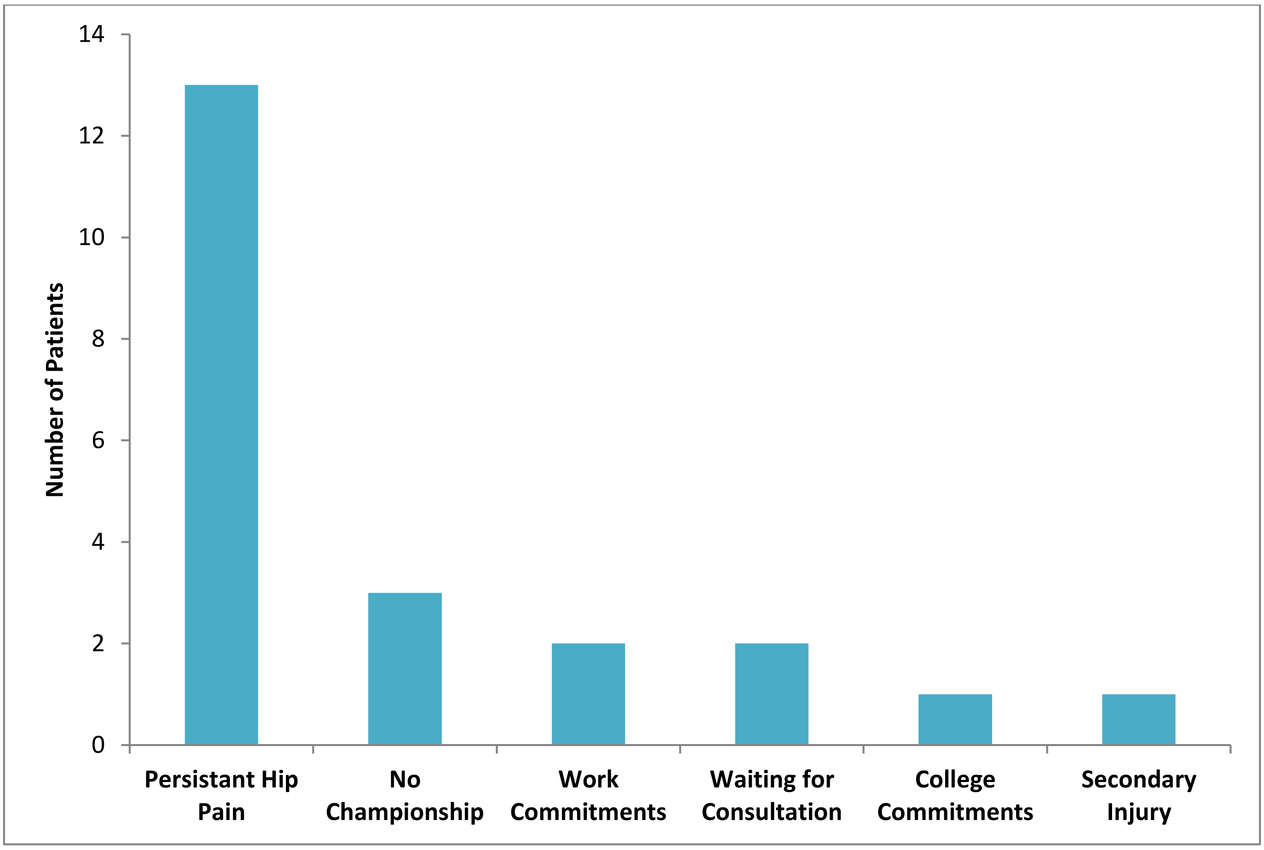


Figure 4.4 Reasons for not returning to play by 12 weeks post-surgery

4.3.3 Changes from 12 weeks to 1-Year

Thirty-five patients were tested at both 12 weeks and 1-year post surgery, with 15 control participants tested at those time periods (Table 4.3). In this time frame, patients significantly improved in acceleration, agility, squatting depth and reactive strength index ($p<0.05$). Significant reductions were recorded among the control group for both internal rotation and 10-m sprint. At the 12-week testing session patients were significantly slower than controls for the measures of acceleration and agility ($p<0.001$), and all three measures of hip range of motion. No further improvements in ROM were noted between the 12-week to 1- year analysis, with patients having significantly lower levels of flexion, abduction and internal rotation at both time points. However, there were no significant differences between the groups with regard to acceleration and agility. The time x group interaction effects indicated that the patient group and control groups changed significantly differently from one another for the measures of acceleration, agility, squatting depth and internal rotation. Patients improved for the measures of acceleration and agility while the controls did not change over time. In contrast the patient results for internal rotation did not change in between these two testing sessions, the control group showed a reduction in internal rotation values.

Changes in pain scoring indicated that those reporting pain for the 10-m Sprint reduced from 10 to 4, while stiffness reduced from 5 to 4 (Figure 4.5). The levels of pain for the agility T-test reduced from 9 to three, while stiffness levels remained constant with four patients reporting stiffness prior to and following the procedure (Figure 4.6). Finally, for the squat assessment, 3 patients reported pain prior to surgical intervention, with 3 patients reporting pain afterwards. Stiffness levels for this measure reduced from 6 to 5 in this time frame (4.7).

Table 4.3 Changes from 12 Weeks Post-Surgery to 1 Year Post-Surgery for Patients (n=35) and Controls (n=15)

Measure	12 Week Result (95% CI)	1 Year Result (95% CI)	Time x Group Interaction effect
10m-Sprint (s)			
$^{(W)}$Patient	1.73 ± .11*† (1.69-1.77)	1.68 ± .10† (1.65-1.71)	<.001
$^{(W)}$Control	1.64 ± .06*† (1.61-1.67)	1.67 ± .10† (1.62-1.72)	
Modified Agility T-test (s)			
$^{(W)}$Patient	7.56 ± .53*† (7.38-7.74)	7.34 ± .73† (7.10-7.58)	.001
$^{(W)}$Control	7.12 ± .35* (6.94-7.30)	7.28± .45 (7.05-7.51)	
Squat Depth (cm)			
$^{(P)}$Patient	46 ± 10† (43-49)	51 ± 10† (48-54)	.003
$^{(P)}$Control	48 ± 12 (42-54)	47 ± 14 (40-54)	
RSI			
$^{(P)}$Patient	1.14 ± .24† (1.06-1.22)	1.20 ± .23† (1.12-1.28)	.575
$^{(P)}$Control	1.23 ± .17 (1.14-1.32)	1.27 ± .11 (1.21-1.33)	
Flexion (Deg.)			
$^{(P)}$Patient	114 ± 6* (112-116)	114 ± 6* (112-116)	.817
$^{(P)}$Control	118 ± 3* (116-120)	119 ± 4* (117-121)	
Abduction (Deg.)			
$^{(P)}$Patient	36 ± 6* (34-38)	37 ± 6* (35-39)	.561
$^{(P)}$Control	43 ± 5* (41-46)	42 ± 6* (40-45)	
Internal Rotation (Deg.)			
$^{(P)}$Patient	36 ± 6* (34-38)	36 ± 7* (34-38)	.003
$^{(P)}$Control	51 ± 7*† (47-56)	45 ± 6*† (42-48)	

* Significant between group differences ($p<0.05$) at either time point, † significant within group changes over time. (W) Indicates a non-parametric Wilcoxen Signed Rank test while $^{(P)}$ indicates a paired samples t test used to assess within group changes over time.

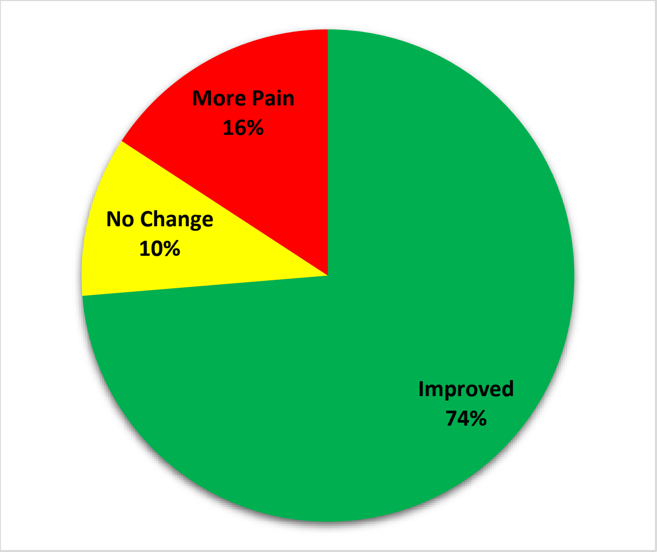


Figure 4.5 Changes in Pain/Stiffness Scoring for 10m-Sprint from 12 weeks to 1-year post-surgery (n=19)

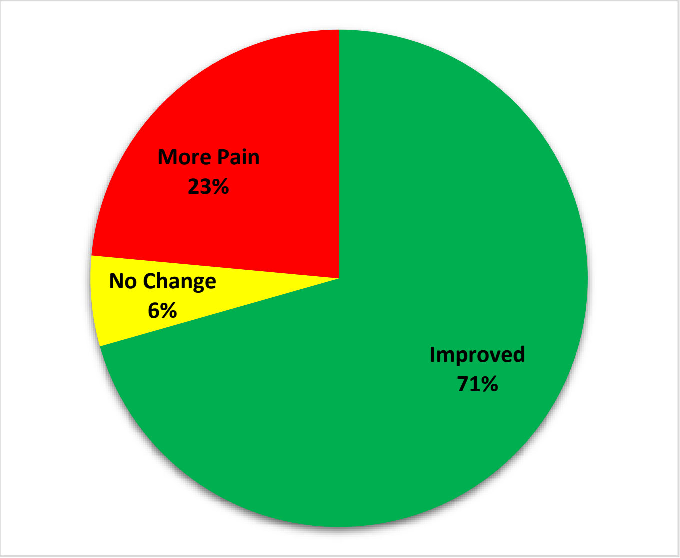


Figure 4.6 Changes in Pain/Stiffness Scoring for agility T-test from 12 weeks to 1-year post-surgery (n=17)

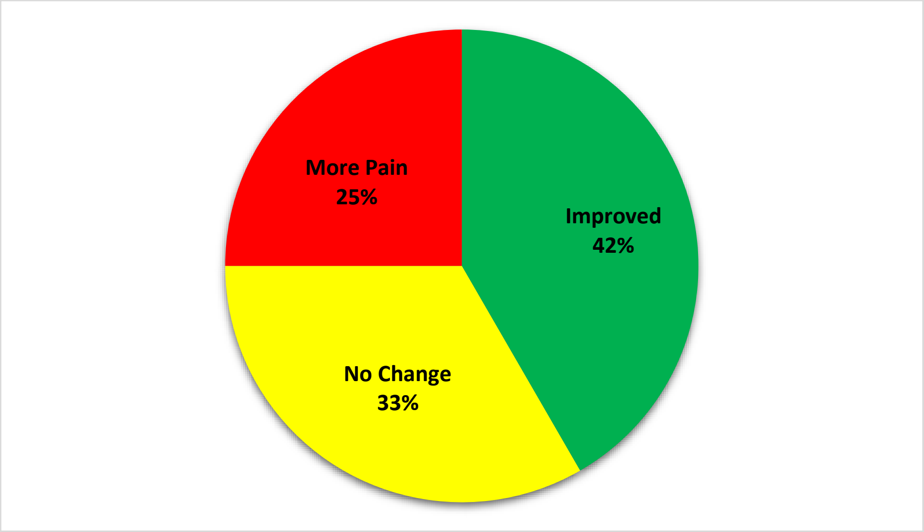


Figure 4.7 Changes in Pain/Stiffness Scoring for Squat Test from 12 weeks to 1-year post-surgery (n=12)

4.3.4 Changes from Baseline to One Year Functional Performance

Thirty-seven patients were tested at both baseline and 1-year post intervention with 23 controls tested at both time periods (Table 4.4). Significant improvements were recorded among the patient group from baseline to one year for the modified agility T-test, squat depth, RSI, flexion, abduction and internal rotation measures. The improvement among the patients for the 10m-Sprint test bordered on significant (p=0.059). The control group did not exhibit any significant changes across the two-time points except the internal rotation measure, for which they had significantly lower levels at one year compared to the baseline result (53° ± 8 to 45° ± 8). Significant differences between the groups existed both at baseline and one year for all three hip ROM measures, while previous significant differences between the groups for 10m-Sprint and modified agility T-test were not found at one year. Time x group interaction effects indicated that changes among the patient group were significantly different from the control group for the measures of agility, squatting depth, abduction and internal rotation. In each case the patient group improved on each measure while the control group did not change or in the cases of agility and internal rotation specifically fared worse than the previous testing session.

Pain measurements for the 10m-Sprint at 1 year indicated that the number of patients reporting pain decreased from 19 patients to 3, while stiffness levels had decreased from four to zero (Figure 4.8). For the agility T-test those reporting pain at baseline reduced from 23 to three, with stiffness levels reduced from two to one (Figure 4.9). For the squat test, the numbers of patients reporting pain had reduced from 14 to 3, with 7 of the 8 patients who had reported stiffness previously now reporting no pain/stiffness (Figure 4.10).

Table 4.4 Changes from Baseline to 1 Year Post-Surgery for Patients (n=37) and Controls (n=23)

Measure	Baseline Result (95% CI)	1 Year Result (95% CI)	Time x Group Interaction effect
10m-Sprint (s)			
(W)Patient	1.70 ± .10* (1.67-1.73)	1.68 ± .10 (1.65-1.71)	.140
(W)Control	1.65 ± .09* (1.61-1.69)	1.65 ± .10 (1.61-1.69)	
Modified Agility T-test (s)			
(W)Patient	7.90 ± .80*† (7.64-8.16)	7.36 ± .68† (7.14-7.58)	<.001
(W)Control	7.17 ± .41* 7.00-7.34)	7.29 ± .37 (7.14-7.44)	
Squat Depth (cm)			
(P)Patient	49 ± 12† (45-53)	52 ± 10† (48-55)	.028
(P)Control	50 ± 12 (45-55)	50 ± 13 (45-55)	
RSI			
(P)Patient	1.15 ± .24† (1.07-1.23)	1.20 ± .22† (1.13-1.27)	.598
(P)Control	1.17 ± .21 (1.08-1.26)	1.21 ± .16 (1.14-1.28)	
Flexion (Deg.)			
(P)Patient	113 ± 7*† (111-115)	115 ± 6*† (113-117)	.620
(P)Control	117 ± 5* (43-51)	119 ± 5* (43-49)	
Abduction (Deg.)			
(P)Patient	33 ± 6*† (31-35)	37 ± 7*† (35-39)	.005
(P)Control	47 ± 9* (43-51)	46 ± 7* (43-49)	
Internal Rotation (Deg.)			
(P)Patient	34 ± 10*† (31-37)	37 ± 7*† (35-39)	<.001
(P)Control	53 ± 8*† (50-56)	45 ± 8*† (43-47)	

* Significant between group differences (p<0.05) at either time point, † significant within group changes over time. (W) Indicates a non-parametric Wilcoxen Signed Rank test while (P) indicates a paired samples t test used to assess within group changes over time.

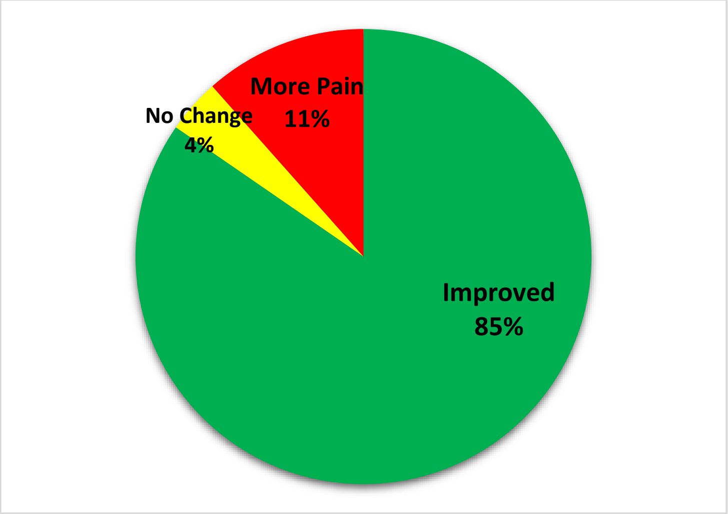


Figure 4.8 Changes in Pain/Stiffness Scoring for 10m-Sprint at 1-Year post-surgery (n=26)

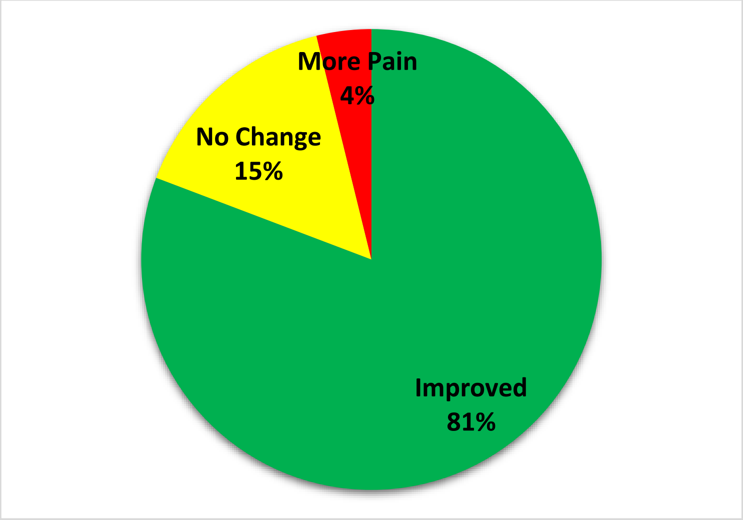


Figure 4.9 Changes in Pain/Stiffness Scoring for agility T-test at 1-Year post-surgery (n=26)

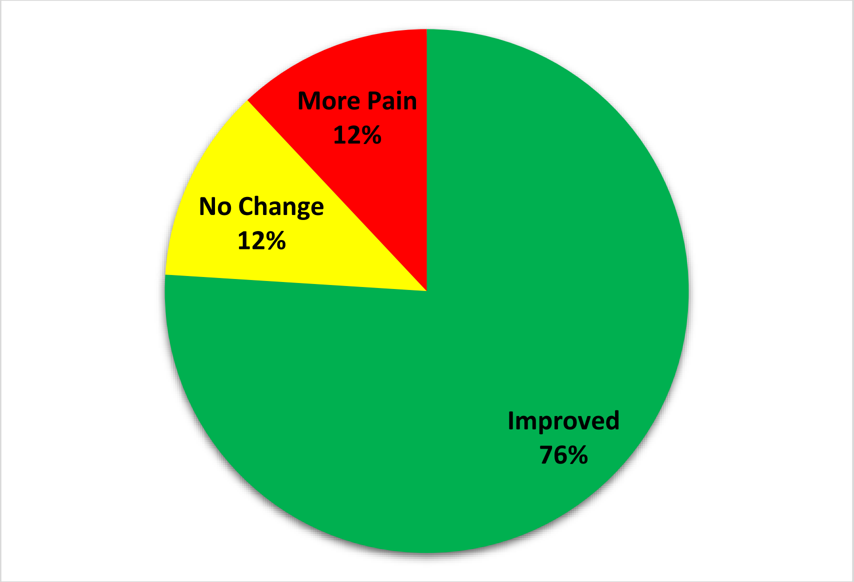


Figure 4.10 Changes in Pain/Stiffness Scoring for Squat Test at 1-Year post-surgery (n=25)

4.3.4.1 Return to play at 1-year post-surgery

At the one year follow up, 84% of patients had returned to full training and competition at an average of 17 weeks post-surgery, six patients did not return to sport, three of which were due to persistent hip pain (8%) while the other three patients (8%) did not report any further hip complications but other injuries aside from FAI syndrome (Figure 4.11). Two patients had recurring hamstring tears while one patient had a protruding disc which required further surgery.

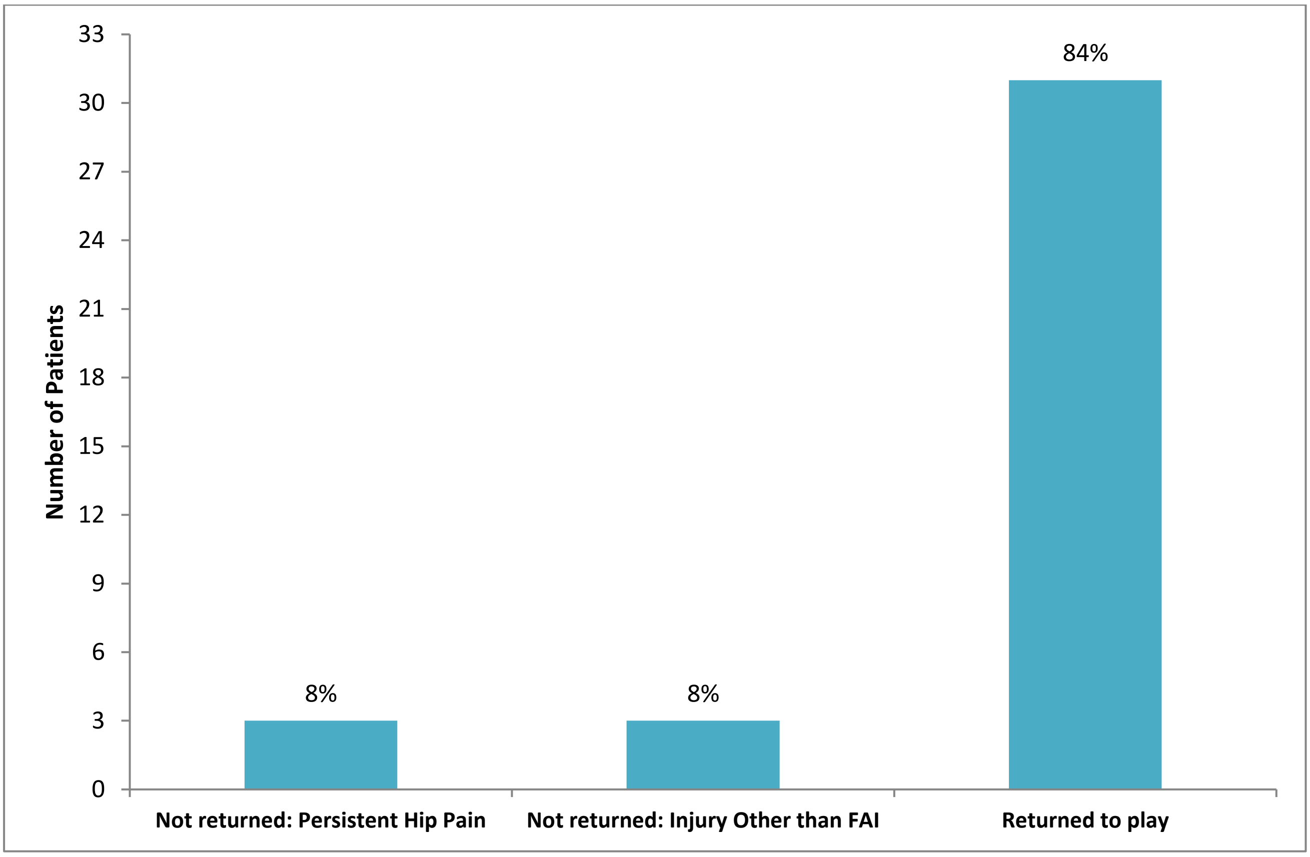


Figure 4.11 Patients return to play data

4.3.5 Unilateral patients

4.3.5.1 Baseline to 12- weeks post-surgery

Twenty-six unilateral patients were tested at the baseline and 12-week follow up and the results are presented in Table 4.5. Only the measures of abduction and internal rotation in the affected limb saw any significant improvement over the course of 12 weeks ($p<0.05$). There were no significant changes in RSI in either limb ($p>0.05$).

4.3.5.2 Twelve weeks to 1-year post-surgery

Twenty unilateral patients were tested at both 12 weeks and 1-year post-surgery (Table 4.6). In this sample, there were significant differences between the affected and unaffected limbs for the RSI and internal rotation measures at the 12-week analysis ($p<0.05$). At the one year follow up there were no differences between the limbs for any measure, the changes in the affected limb bordered on significant for the reactive strength index ($p=0.063$) but not for any of the flexibility measures.

4.3.5.3 Baseline to 1-year post-surgery

Twenty-one patients were tested baseline and at the 1-year analysis (Table 4.7), in this instance there were no differences in RSI between the limbs at either testing stage. The only significant change in the hip ROM was a significant improvement in the abduction measure ($p<0.05$) in the operated limb, with no significant improvements in the RSI of the operated limb.

Table 4.5 Changes in both limbs of unilateral patients (n=26) from baseline to 12 weeks

Measure	Baseline		12 Week	
	Affected Limb (95% CI)	**Unaffected Limb (95% CI)**	**Affected Limb (95% CI)**	**Unaffected Limb (95% CI)**
$^{(P)}$RSI	1.13 ± .25 (1.25-1.45)	1.17 ± .22 (1.09-1.25)	1.13 ± .25* (1.25-1.45)	1.19 ± .22* (1.11-1.27)
$^{(W)}$Flexion (Deg.)	112 ± 9* (109-115)	115 ± 7*† (112-118)	115 ± 5* (113-117)	118 ± 6*† (116-120)
$^{(W)}$Abduction (Deg.)	32 ± 8*† (29-35)	37 ± 6* (35-39)	39 ± 7† (36-42)	39 ± 6 (37-41)
$^{(W)}$Internal Rotation (Deg.)	32 ± 9*† (29-35)	42 ± 9* (39-45)	38 ± 7*† (35-41)	42 ± 8* (39-45)

*Significant differences between affected and unaffected limb ($p<0.05$), † Significant within limb changes over time ($p<0.05$). $^{(W)}$ Indicates a non-parametric Wilcoxen Signed Rank test while $^{(P)}$ indicates a paired samples t test used to assess statistical differences between the affected and unaffected limb.

Table 4.6 Changes in both limbs of unilateral patients (n=20) from 12 weeks to 1 year

Measure	12 Week		1 Year	
	Affected Limb **(95% CI)**	**Unaffected Limb** **(95% CI)**	**Affected Limb** **(95% CI)**	**Unaffected Limb** **(95% CI)**
$^{(P)}$RSI	1.07± .24* (0.96-1.18)	1.17 ± .22* (1.07-1.27)	1.17 ± .25 (1.06-1.28)	1.22 ± .22 (1.12-1.32)
$^{(W)}$Flexion (Deg.)	115 ± 7 (112-118)	116 ± 7 (113-119)	114 ± 7 (111-117)	115 ± 6 (113-118)
$^{(W)}$Abduction (Deg.)	38 ± 8 (34-42)	38 ± 6 (35-41)	37 ± 7 (32-40)	38 ± 6 (35-41)
$^{(W)}$Internal Rotation (Deg.)	38 ± 7* (33-41)	42 ± 7* (39-45)	35 ± 7 (32-38)	37 ± 10 (33-41)

*Significant differences between affected and unaffected limb ($p<0.05$), † Significant within limb changes over time ($p<0.05$). $^{(W)}$ Indicates a non-parametric Wilcoxen Signed Rank test while $^{(P)}$ indicates a paired samples t test used to assess statistical differences between the affected and unaffected limb

Table 4.7 Changes in both limbs of unilateral patients (n=21) from baseline to 1 year

Measure	Baseline		1 year	
	Affected Limb **(95% CI)**	**Unaffected Limb** **(95% CI)**	**Affected Limb** **(95% CI)**	**Unaffected Limb** **(95% CI)**
$^{(P)}$RSI	1.11 ± .28 (.99-1.23)	1.13 ± .20† (1.04-1.22)	1.19 ± .25 (1.08-1.30)	1.21 ± .22† (1.12-1.30)
$^{(W)}$Flexion (Deg.)	111 ± 10 (107-115)	114 ± 7 (111-117)	115 ± 7* (112-118)	116 ± 6* (113-119)
$^{(W)}$Abduction (Deg.)	34 ± 6*† (31-37)	38 ± 7* (35-41)	38 ± 7† (35-41)	39 ± 7 (36-42)
$^{(W)}$Internal Rotation (Deg.)	31 ± 9* (27-35)	42 ± 7*† (39-45)	35 ± 7* (32-38)	38 ± 10*† (34-42)

*Significant differences between affected and unaffected limb ($p<0.05$), † Significant within limb changes over time ($p<0.05$). $^{(W)}$ Indicates a non-parametric Wilcoxen Signed Rank test while $^{(P)}$ indicates a paired samples t test used to assess statistical differences between the affected and unaffected limb

Table 4.8 Summary of Major Results

	Patients		Control	
	Baseline to 12-Week	Baseline to 1-Year	Baseline to 12-Week	Baseline to 1-Year
10m-Sprint	Decreased Performance	No Change (bordered sig.)	No Change	No Change
Agility T-Test	Improved	Improved	No Change	No Change
Deep Squat	No Change	Improved	No Change	No Change
RSI	No Change	Improved	No Change	No Change
Flexion	Improved	Improved	Improved	No Change
Abduction	Improved	Improved	No Change	No Change
Internal Rotation	Improved	Improved	No Change	Decreased

4.4 Discussion

There is a paucity of research which examines functional outcomes following the surgical intervention of FAI syndrome, and none specifically with an athletic population. This research is novel in the fact that it includes a young athletic population and a matched control group for comparison of changes in functional performance following arthroscopy. The main outcomes measured were acceleration, by use of a 10-m sprint test, agility, squatting mechanics, reactive strength index and hip range of motion. As discussed in the previous chapter, patients were significantly slower than controls for the 10-sprint and agility T-test as well as having lower levels of hip ROM in all three planes of motion at baseline. Patients were tested at 12 weeks post-surgery following the consent of the orthopaedic surgeon, at this point all patients would have completed the standardised rehabilitation protocol prescribed by the physiotherapist. At this phase, patients significantly improved on the agility test, and all three measures of hip ROM compared to the baseline results. In the same instance, patients were significantly slower during the acceleration assessment compared to their baseline results. At the 1-year testing phase patients had improved results for the 10-m sprint, with further improvement in the agility T-test, improved squatting depth and improved reactive strength index. No further improvements in hip ROM were observed, indicating a plateau in increased ROM following the initial improvements observed, at three months.

4.4.1 Functional Testing

Differences in hip ROM between patients with FAI and those without have been well documented, i.e decreased flexion, internal rotation and adduction (Philippon et al. 2007), however, the changes in ROM following intervention have not been discussed at length which is surprising considering ROM is often used to diagnose FAI in the first instance. For example, Philippon et al. (2009) demonstrated significant differences between the affected and unaffected limb in unilateral patients with FAI prior to surgery but did not disclose any range of motion results following arthroscopy. While there is very little published research in this regard; in a small-scale study involving 5 professional ice hockey players with unilateral impingement, Bizzini et al. (2007) reported increases in hip ROM following an open-surgical procedure. At average time of 10.3 weeks the five players had regained hip internal and external rotation that was comparable to the unaffected limb. The nature of the current study involved collecting hip ROM data at 12 weeks following surgery, and while improvements in ROM were recorded, whether the improvements could be seen earlier than this time frame cannot be determined. The results for unilateral ROM data mirrored the ROM findings from the full data set, in that any improvement over time was mostly noted in the first 12 weeks following surgery, after which no significant improvements recorded between 12 weeks and 1-year post-surgery. Finally, it is important to note that while patients did improve in the flexibility measures, they were still significantly lower on those measures than the control group. Therefore, hip ROM may be regained but may not be comparable to a hip with no pathology even after surgical intervention. This may have implications in later life and whether these improvements will regress over time is unknown, any longitudinal research regarding long term implications of hip preservation surgery has used self-reported measures or conversion to total hip replacement as an indicator of long term benefits of initial surgery (Byrd & Jones, 2010; Byrd & Jones, 2009). Systematic follow up which includes passive assessment of hip ROM may give a more rounded view of the effectiveness of surgery and whether initial improvements begin to deteriorate over time. Furthermore, coaching staff involved with athletes should be aware of the disparity in hip ROM between athletes who were treated for FAI syndrome and those without hip pathology and it may not be appropriate to treat both athletes equally when designing training programs especially when including flexibility exercises.

When acceleration was assessed, results indicated that patients were significantly slower at the 12-week testing session compared to their baseline results. However, significant improvements were recorded between the 12-week and 1-year testing phase. Improvements from baseline results to 1-year values were bordering on significant (p=0.059) indicating that this measure only improved after athletes had returned to training and competition. Possible reasons for the decline in acceleration at the 12-week analysis could be attributed to the fact this is too early in the recovery phase following surgery. While there were recommendations for continuous running to improve cardiovascular fitness in the program, acceleration specifically was advised only from week 10 onwards and was restricted to approximately 75% of maximum. This is an important finding as acceleration is an essential component of field sports where a large emphasis is placed on the ability to change velocity quickly in reaction to an outside stimulus. Going forward, it could be recommended that the rehabilitation protocol be extended to include specific sprint/plyometric drills to improve acceleration after the 12-week consultation (Lockie, Murphy, Schultz, Knight, & de Jonge, 2012), this will help ensure athletic patients are more prepared for the demands of field sports upon returning to training/competition. Pain measures for the 10m-sprint indicated that 41% of the patient group had improved at the 12-week analysis in relation to pain scoring while 38% did not change, this included patients who had not reported pain or stiffness previously, while 21% of the group described increased pain than previously reported. This could be due to damage to the muscular tissue surrounding the joint that was damaged through surgery and the build up of scar tissue. Patients were not asked whether the pain reported at this stage was the same type of pain felt prior to surgery which may have given a clearer idea as to the possible cause of pain. At the 1-year follow up, 8% of patients reported more pain/stiffness than the baseline reports, this included two patients who reported hip pain specifically. Both of these patients had bilateral surgery with partial and complete chondro-labral separation respectively according to surgical notes. More severe intraarticular damage have been cited previously as risk factors for poorer outcomes (Clohisy, St John, & Schutz, 2010; Philippon, Briggs, Yen, & Kuppersmith, 2009)

Improvements in agility were noted at the 12-week testing session and athletes continued to improve at the 1-year analysis. Of the tests which included more whole-body movements (i.e. excluding hip ROM measures) the agility T-test had the greatest differences between patients and controls at baseline, and saw the fastest and most consistent improvements. The rehabilitation carried out up to the 12-week analysis included no agility type exercises until 10-weeks post-surgery, increases in ROM and decreases in pain may have allowed the athletes to employ a better body position to change direction quicker at this early phase. Subsequently when athletes returned to training with more frequent and intense change of direction drills, allowed further improvement in this measure. The effects of agility training on injury prevention (Goodall, Pope, Coyle, & Neumayer, 2013; Hewett, Ford, Myer, Wanstrath, & Scheper, 2006; Reis, Rebelo, Krustrup, & Brito, 2013) and injury reoccurrence (Sherry & Best, 2004) have been documented previously yet there is a substantial lack of research which examines changes in agility following on intervention to treat an injury; surgical or otherwise. This is a substantial paucity considering agility is a component of all field sports and invading games, where reactions to outside stimuli are a factor. In accordance with the pain measures for the 10m-Sprint, with 41% of patients improving at the 12-week assessment, which subsequently increased to 57% at the 1-year follow up. At one year, 3% of patients reported more pain/stiffness than previously reported, with three patients reporting pain specifically. As well as intra-articular damage, possible reasons for pain at 1-year include micro-instability or adhesions.

Squatting is a fundamental movement required for activities of daily living but also widely used in a sporting content as a whole-body movement for the development of athletic strength and power. Previous research has indicated that squatting mechanics may be altered in persons with FAI syndrome compared to those without (Bagwell et al., 2016; Lamontagne et al., 2009). No differences were noted between the groups with regard to squat depth at any of the three time points, however significant improvements were recorded among the patient group between 12 weeks and 1 year post-surgery. The lack of changes seen earlier in the rehabilitation phase could be due to the fact that the tissues in and around the joint were still healing, as well as the fact that smaller numbers of patients were reporting pain for this measure at the 1 year follow up compared to the 12-week analysis. Due to the poor blood supply in the hip joint, healing to the labrum and articular cartilage sutures could be slow and therefore body movements which require extensive active flexion might not improve immediately. The results of the squat measure are somewhat contradictory to the hip ROM measures which all improved within the first 12 weeks, the improvements in squatting ability were not noted until later in the recovery process, this could be due to the fact that the assessment for hip ROM included passive movement of the hip with the patient in the supine position, while the squat involved a whole-body movement with the added weight of the trunk possibly causing more discomfort. Again, pain measures indicate, 8% of patients reported hip pain at this time frame. The three patients who reported pain for each measure these were not the same three patients in all three cases; rather, there were six patients in total who reported pain for any of the functional measures.

Of the previous research which examined the ability of FAI patients to squat, only Lamontagne et al. (2011) carried out follow-up testing following surgery and reported increased squatting depth among a group of cam impingement patients. However, the authors found no differences in the squat kinematics and attributed increased squatting depth to increases in knee flexion and ankle dorsiflexion. The results of the current study indicate greater squatting depths at 1 year, although the 2D nature of the current study does not allow determination of the causes of greater squatting depths. However, in the current research a control group was included, where Lamontagne's study did not; there were no changes observed among the control group for this measure indicating that the improvement in the patient group were most likely due to the increased ROM and decreased pain following surgery.

Reactive strength index is a measure of the ability of an athlete to change from concentric force to eccentric force in as little time as possible and gives an overall indication of lower limb power (Ebben & Petushek, 2010; Lloyd, Oliver, Hughes, & Williams, 2012; McClymont, 2003). In this study, RSI was calculated by way of a single leg drop jump from a 30cm box (Walsh, Arampatzis, Schade, & BrÜggemann, 2004). Results indicated improvements in RSI, but only after the 12-week testing session. Much like the 10-m sprint values, improvements in lower limb power only occur following the return to full training and competition where these movements are required. Currently, there is very little research which includes the measure of RSI, especially those which involving injured athletes. As discussed in chapter four, Flanagan et al. (2008) examined the differences in RSI in unaffected limb and affected limb in athletes who were treated for unilateral ACL rupture and found no significant differences between involved and uninvolved limbs. The small subject numbers included in the unilateral analysis in the current study at both follow up time points led to some conflicting results compared to the full data set results. In this analysis, there were no differences observed between affected limb and unaffected limb for RSI, with little changes noted apart from the unaffected limb which significantly improved from baseline to 1-year post surgery. Smaller numbers in this sub-section could have led to the non-significance observed. The fact that no differences were detected between the groups at baseline for RSI (Chapter 3) and improvements in RSI were only noted once the athletes had returned to full training could indicate that RSI is a more reliable indicator of the stretch shortening cycle (Flanagan & Comyns, 2008) and therefore muscle function and is perhaps minimally affected by biomechanical alterations to the hip joint either as a result of FAI syndrome or corrective surgery for FAI syndrome. The results of the current study concur with the findings of Kierkegaard et al. (2016) who carried out a systematic analysis and found that patients return to activities of daily living faster than more sporting and functional activities. In the current study passive hip movement saw improvement within the first 12-weeks with athletic function improving at 1 year.

4.4.2 Return to Play

Eighty three percent of the patient group had returned to full training and competition at 1-year post-surgery at an average time of 17 weeks. This is comparable to previous literature involving arthroscopy for this condition. Three prior investigations have reported on the return to play in professional athletes following the arthroscopic correction of FAI syndrome. Philippon et al. (2007) included 45 athletes, 93% of whom returned to professional play, however 1.6 years following the procedure this figure had reduced to 78%. The reasons for not returning to sport were not reported in the Philippon paper. In another study by the same author involving 28 professional hockey players, all players returned to professional play at a mean time of 3.8 months (Philippon et al., 2010). While Singh and O'Donnell (2010), reported on the return to play status of 24 Australian football players, and found that 23 had returned to top level football following the procedure. Six patients had not returned to play in the current study, three were due to persistent hip pain or were recommended to stop playing, all three of whom had complete chondro-labral separation, with one patient having significant articular cartilage damage with areas of exposed sub-chondral bone. The other three patients who did not return to sport were due to injuries other than FAI syndrome, two players had reoccurring hamstring tears while the final player had a protruding disc which required surgical intervention. Whether the patients involved in this study will continue to play at a competitive level long term following the procedure remains to be seen, although the initial findings are optimistic.

4.4.3 Strengths

In comparison to previous research in the area, an advantage of this study was the fact it included a control group which were tested at three time points. Of the prior investigations which included a control group, the controls were only tested at one time point with the patient groups tested at multiple times. In this research, the repeated testing of controls allows for not only between group comparisons but also the assessment of time X group interaction effects. Essentially, did one group change differently over time compared to the other, if so changes are more likely due to improved performance rather than any improvement due to familiarity with repeated testing. Changes among the control group were small across the three testing sessions apart from internal rotation values which declined significantly over the course of the year. The objective nature of the testing is also a considerable advantage of the study, as these results do not rely on patient opinion alone and give an unbiased account of changes following surgery. As mentioned in the previous chapter, the use of higher quality testing equipment including the dual beam timing gates and Optojump system increase the accuracy of the results.

4.4.4 Limitations

As with any prospective research a number of participants in both groups did not complete follow up testing. All participants were contacted a minimum of three times where possible to arrange testing and the reasons given for noncompliance at the one year follow up are listed in Table 4.9. The most common reason for patients not returning for follow up was the travel involved in coming to the clinic. Many of the patients had to travel substantial distances to the clinic and were reluctant to take time from work to travel especially if there were no further issues with their hip. This could have led to an underestimation of the true improvements among the patient group if satisfied and improved patients could not be tested. The most commonly cited reason for dropout among the control group was they did not wish to be tested with injury accounting for the second most common reason for dropout. While considerable efforts were made to retain control group participants including giving participants a detailed performance profile after each testing session, participation among the control group saw a steady decline over time. The fact that the rehabilitation program was unsupervised may have a confounding effect on the results if adherence to the program was low. All athletes were asked to report how well they adhered to the rehab program but all reported 100% compliance. Athletes may have felt pressurised to report complete adherence to the program and so this was not included in the results. The level of competition that the athlete returned to may also have influenced the results. Athletes involved in elite teams have access to better training and are constantly monitored by strength & conditioning coaches, physiotherapists and doctors. This may have allowed for better results among this sub group because training could have been tailored to meet specific demands and altered when needed. Another limitation of the study is the fact that the number of repetitions included for each test were small with a set recovery period, while this was necessary for accurate measurement, they may not have been a true representation of the demands placed on the athlete during competitive match play.

Table 4.9 Dropout among patients and controls 1-year post-surgery

Reason	Patient	Control
Did not wish to travel	15	N/A
Did not want to be tested	3	33
Unhappy with results of surgical procedure	3	N/A
Injury other than FAI syndrome	3	8
Moved abroad	3	3
Repeat surgery	2	N/A
Did not proceed with surgery	2	N/A
Retired from sport	0	1
Total	31	45

Drop out could also affect the overall statistical power of the analysis and increase the likelihood of type 2 error, however only one variable was identified where this might be the case. The 10m-Sprint assessment bordered on significant from baseline to one year (p=0.059) all other variable saw a statistically significant change following the procedure.

4.5 Conclusion

Femoroacetabular impingement syndrome has the potential to cause substantial decreases in athletic performance and in the absence of appropriate treatment are unlikely to improve. If patients undergo arthroscopic treatment of syndrome in conjunction with labral repair they can expect improvements in acceleration, agility, lower limb power and hip ROM as well as improved squatting depth, with a relatively high return to sport rate. The improvements in agility and hip range of motion are observed as early as 12 weeks, while improvements in acceleration, power and squatting ability are more evident between 12 weeks and 1-year post surgery. Rehabilitation programs could include exercises to improve these measures in the latter stages of rehabilitation so that patients are better prepared for the demands of field sport upon returning to training. Changes in the patient group but not in the controls indicate that changes were due to intervention measures taken rather than any familiarity with testing procedures over time.

This research provides objective measures of functional athletic performance which may be more beneficial when dealing with athletes, compared to some traditional self-reported measures. The tests allow athletic patients to monitor progress in terms of functional assessments which they may be more familiar with and allow athletes to focus on the rehabilitation process which can often be a frustrating time (Quackenbush & Crossman, 1994; Tracey, 2003). This not only applies to research in the area of FAI syndrome treatment but in the treatment of other injuries also.

Chapter Five: Links between higher training loads in adolescence and the development of symptomatic FAI syndrome

5.1 Introduction

Femoroacetabular Impingement syndrome is a cause for major concern among young male athletes and is characterised by insidious anterior groin pain with gradual loss of hip motion and function (Byrd, 2007; Ellis, Briggs, & Philippon, 2011), often exacerbated by bouts of physical activity (Philippon et al., 2007). FAI has been previously identified as a risk factor for the early development of osteoarthritis of the hip (Byrd, 2012; Ganz et al., 2003; Ganz, Leunig, Leunig-Ganz, & Harris, 2008). As previously discussed in chapter two (section 2.2.2), researchers have suggested that frequent involvement in physical activity during adolescence could lead to the development of a bony abnormality especially if the growth plates in the hip are still open. Siebenrock et al. (2004) proposed that during adolescence and prior to closing, the femoral epiphysis can extend to the anterior or anterosuperior neck region, creating a bony abnormality. The authors consider this a consequence of high mechanical loads that sporting activity places on the joint and as such this may represent a critical period for the development of FAI syndrome in the emerging athlete.

Johnston and colleagues (2012) reported on the incidences of cam deformity in former high-level youth soccer players (n=50, 25 males) and a control group (n=50, 25 males), using AP radiographs. High level soccer was defined as engaging in three or more games or training sessions per week for at least 36 weeks of the year between the ages of 8-12 for girls and 10-14 for boys. The study did not show any evidence of greater incidence of cam deformity in males or females who had previously engaged in high levels of soccer during adolescence than those who did not. However, this research compared two groups of asymptomatic normal volunteers and did not include any individual who had sought treatment for hip related problems, which could have led to a considerable underestimation of the problem.

Tak et al. (2015), sought to assess whether the frequency of football activity during adolescence could influence the prevalence of cam deformity in later life in a cohort of professional soccer players. Players were asked to recall the age at which they started playing football with a club and at what age they started playing with a professional club. The results of the study indicated that, of all participants included, 64% had radiological signs of a cam deformity (α angle $>60^o$) and 29% had evidence of a pathological cam deformity (α angle $> 78^o$) on either an AP radiograph or a Frog-leg lateral view. The prevalence of pathological cam deformity was significantly higher in those that had engaged in training four or more times per week prior to the age of 12 years compared to those training less than four times per week before that age. No significant differences in cam deformity were reported when a threshold of 11 years was used, however, overall the results of this study indicate that greater training frequency in the early stages of adolescence could be a risk factor for the development of a cam deformity.

In a more prospective orientated study, Siebenrock and colleagues (2011) compared high level basketball players, aged 9-25 years currently engaged in habitual levels of training and competition to an age and gender matched non athletic control group, subcategorised into four distinct age groups; 9-12, 13-15, 16-21 and 22-25 years old. MRI images indicated that overall, athletes had significantly higher mean alpha angles along the anterosuperior quadrant of the femoral head compared to controls. The athlete group also had reduced internal rotation values at each age group compared to controls indicating a progressive loss of mechanical function over time among the athletic group. The 22-25 year olds exhibited the greatest differences in ROM between the groups (12.4 degrees versus 27.8 degrees). The authors concluded that the formation of a cam deformity is developmental, which may be exacerbated by high intensity loading of the proximal femur due to frequent exercise.

In support of this finding, Agricola and colleagues (2014) proposed that cam morphologies develop during a period of increased mechanical load as a result of sporting activities, particularly while the growth plates are open, in a study that used male adolescent soccer players aged 12-19 years. However, the researchers observed a plateau in the development of further deformity once growth plates had closed. The study did not include a control group, and so it remains unclear as to whether soccer is solely responsible for these morphological changes in the athletes. In a related study, Philippon et al. (2013) used skiers as a control group when examining the incidence of cam morphology among underage ice hockey players based on MRI and clinical examination between the ages of 10 to 18 years. The authors reported a significantly higher rate of cam morphology among the ice hockey group in comparison to the skiers and particularly the 16-18 year old players. This suggests that a cam deformity is developmental and continues to increase with age and with sporting type particularly those with high volumes of twisting and turning.

One key limitation with existing research is that the linkage between symptomatic FAI and volume of training during adolescence using athletes requiring treatment has not been assessed. This may be of greater practical significance as individuals solely presenting with radiological cam impingement can often present with no symptoms (Griffin et al., 2016). There is no current research which compares athletes with FAI syndrome requiring intervention to a healthy athletic control group with regard to previous sports participation. The aim of this study was, therefore, to compare the structured training volumes during adolescence between a group of athletes with FAI syndrome and a matched athletic control group.

5.1.2 Research Questions

1. How many weekly hours of organised training were completed by patients and controls between the ages of 10 and 12?

2. How many weekly hours of organised training were completed by patients and controls between the ages of 13 and 15?

3. Is there a difference in the number of weekly training hours reported from the 10-12 to the 13-15 age category?

4. Is there a statistically significant difference between the hours reported by each group at either time point?

5.2 Methodology

5.2.1 Measures

Similarly to both Johnston et al. (2012) and Tak et al. (2015) who used athlete recall to determine levels of soccer participation, the current study adopted a similar approach. Both groups were asked to list the different sports played which required structured, organised training between the years of 10-15. They were then asked to recall the average weekly hours spent engaged in organised training for the sports listed between the ages of 10-12 (at the end of primary school) and 13-15 years (during the early stages of secondary school). Two age categories were chosen to differentiate between two different time-frames in skeletal development and are closely aligned to that of the Siebenrock study; the 10-12 age category was chosen to represent a period of development when growth plates are certainly open, while the 13-15 age category represented a time of rapid bone growth (MacKelvie, Khan, & McKay, 2002). Growth plates may still be open in the 13-15 age category although there was no way to determine whether they had begun to close or not, due to the retrospective nature of the study.

5.2.3 Data Analysis

SPSS version 22 was used for all analysis. All data was firstly assessed for normality using a Shapiro-Wilk test, an independent samples t-test or Mann-Whitney U test (in the case of non-parametric data) was then used to determine differences in the average weekly training hours between groups for both age categories. Differences in training volumes between both age categories was assessed using a paired samples t-test or non-parametric Mann Whitney U test.

5.3 Results

All patients were recruited as part of the research study discussed in chapters four and five with the same criteria used for diagnosis of FAI syndrome. Control participants were recruited from the study described in chapters four and five, and the same inclusion and exclusion criteria was used. A total of 67 patients and 71 controls were recruited for the study (Figure 5.1) with no significant differences between the groups with regard to age, body mass or height (Table 5.1). The different sports engaged in by both groups at the time of the study are listed in Figure 5.2.

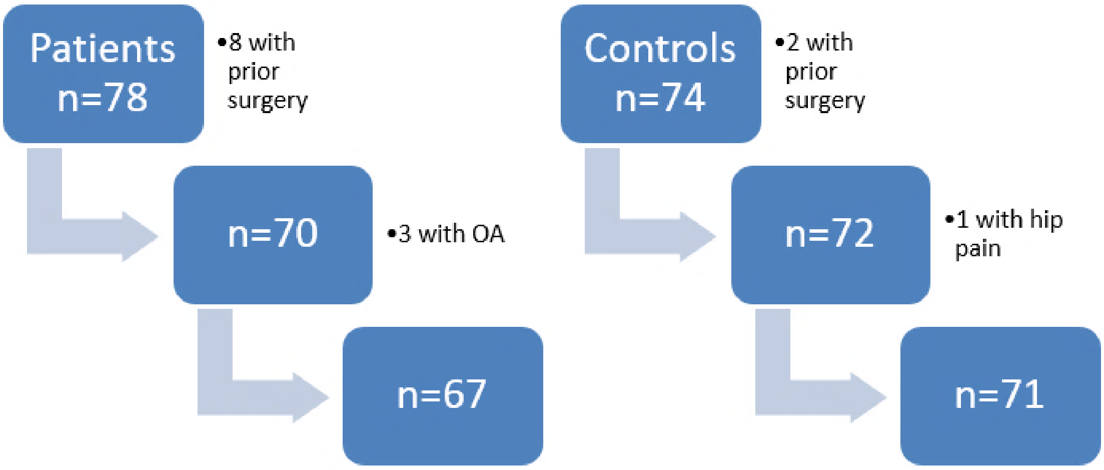


Figure 5.1: Recruitment of Patients and Controls

Thirty-six of the patients were diagnosed with unilateral impingement with the remaining 31 having bilateral impingement. There were three cases of isolated cam impingement, 13 patients with pincer impingement only and the remaining patients had combined impingement (n=51). A significant difference (p=0.020) was found between the patients and controls for the average organised weekly training/competition hours reported in the 10-12 age range (6.55 ± 3.1 and 5.69 ± 3.7; 95% CI_{diff} 5.52 to 6.69 hrs/week for patients and controls, respectively) (Figure 5.3). However, there were no significant difference (p=.397) observed for training/competition hours between groups for the 13-15 years age range (8.45 ± 3.4 versus 8.03 ± 3.7; 95% CI_{diff} 7.73 to 8.83 hrs/week). Both groups reported a significant increase in training hours from the 10-12 to the 13-15 age range (p<0.001).

Table 5.1 Participant Demographics

Group	**Age (years)**	**Body mass (kg)**	**Height (cm)**
Patient (n=66)	25.53 ± 4.8	81.5 ± 9.2	179.3 ± 5.7
Control (n=71)	24.56 ± 4.5	82.9 ± 7.5	180.2 ± 6.5

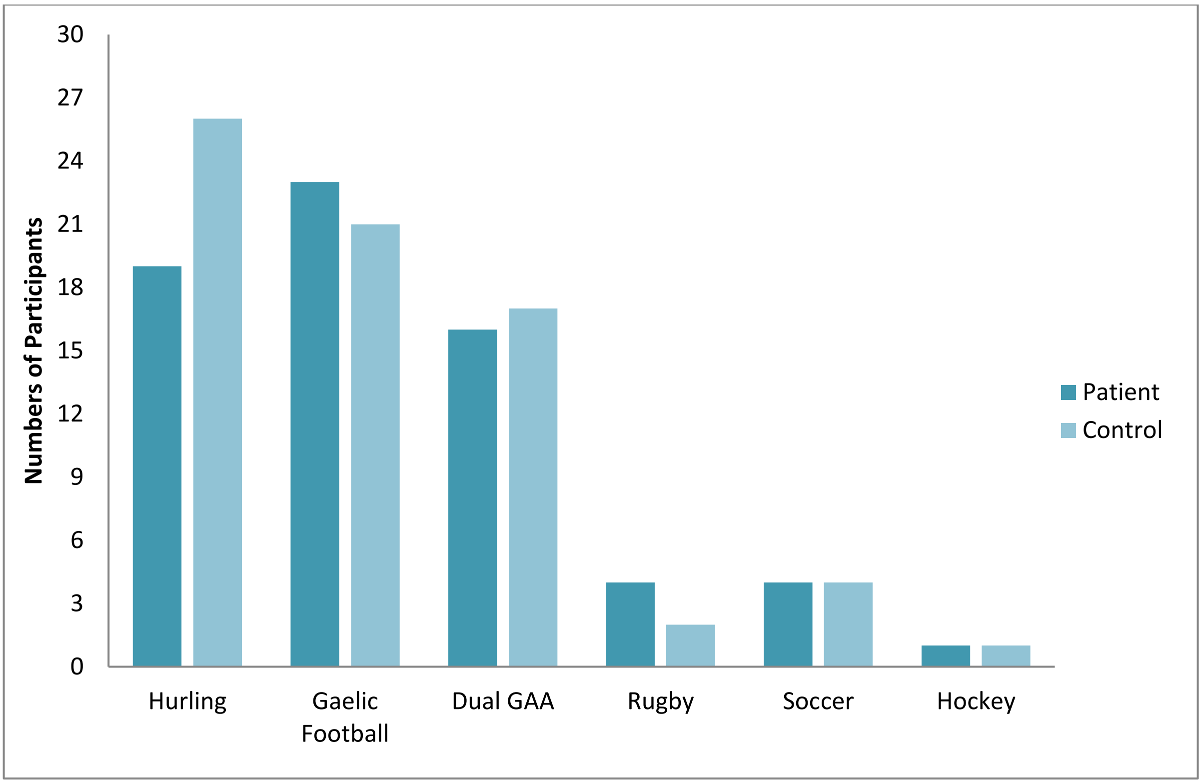


Figure 5.2: Sports currently engaged in by Patients and Controls. Dual GAA: Play both Hurling and Gaelic Football

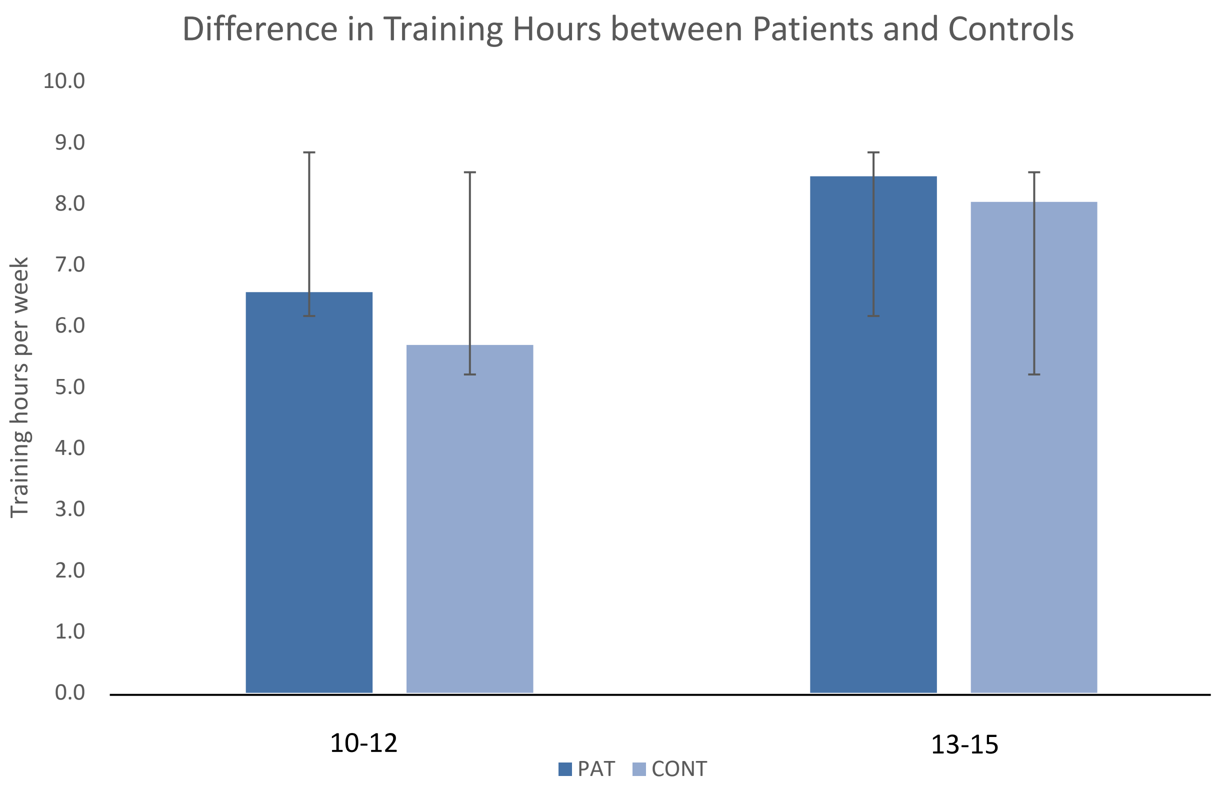


Figure 5.3: Differences in weekly training hours between groups. *Significance p<0.05

5.4 Discussion

Femoroacetabular impingement syndrome is a chronic, debilitating structural deformity of the hip joint characterised by progressive stiffness, pain and loss of function (Agricola et al., 2013; Ganz et al., 2003; Philippon et al., 2007). FAI syndrome has been found to be a common issue in young males and females, with those engaged in regular vigorous sporting activity particularly at risk (Byrd, 2007; Clohisy et al., 2013; Ellis et al., 2011). As discussed in chapter two (section 2.2.2), previous literature has alluded to heavy involvement in physical activity during skeletal development as a potential risk factor for the development of bony morphologies (Agricola et al., 2014; Epstein, McHugh, Yorio, & Neri, 2013; Nepple, Brophy, Matava, Wright, & Clohisy, 2012; Philippon et al., 2013; Siebenrock et al., 2011; Tak et al., 2015) in particular, cam morphologies. However, the research to date has focused on asymptomatic individuals with bony abnormalities rather than individuals displaying FAI syndrome. This study is the first to the author's knowledge to assess the levels of physical activity during adolescence, among athletes who required surgical treatment for FAI syndrome, and compare these to a matched athletic control group with no history of hip complaints.

Progressive loss of hip ROM is a commonly reported side effect of FAI syndrome (Philippon et al., 2007) and was demonstrated in this report, with patients displaying significantly lower levels of hip

ROM compared to controls. The time frame being examined in the current study included age categories similar to some of those reported in the Siebenrock et al. (2011) research who also reported significantly lower levels of internal rotation in the 13-15 age category between young athletes and non-athletic controls. Thus, indicating that a cam deformity may have evolved prior to the age of 13 and young athletes young than the age of 13 may be at risk for development of a bony morphology. Patients in the current study completed significantly more hours of structured training between the ages of 10-12 years than the control group with no differences between groups in training hours during the 13-15 years age range. However, both patients and controls reported an increase in training hours during the ages of 13-15 compared to the 10-12 age bracket. Mackelvie and colleagues (MacKelvie et al., 2002) describe the two year time frame of 13-15 years as the critical timeframe for peak bone velocity among adolescent boys, therefore a bony abnormality that develops prior to the age of 13 could then be amplified as training intensifies later in adolescence. The results of our study are in agreement with that of Tak et al. (2015) who suggested that the activity levels prior to the age of 12 were an important determining factor in the development of bony morphology in the hip. Agricola and colleagues[1] also reported cam deformity developments in young soccer players, which continued to develop until epiphyseal closure, following which the authors observed a plateau in cam deformity development. The results of the current research indicate that bony deformities may begin prior to the age of 12 (while the growth plates are open) as result of heavy involvement in high impact sports. However, Agricola's findings would also point to the importance of the 13-15 years age range when the growth plates are still open, yet our results showed no significant difference in training volumes during these years.

Previous research has identified sports such as soccer, baseball and ice hockey as sports commonly associated with FAI (Fukushima et al., 2016; Johnson, Shaman, & Ryan, 2012; Nepple et al., 2012; Philippon et al., 2013). The majority of sportsmen in both study groups included in this research consisted of Gaelic Games athletes, the most popular field sports in Ireland. Gaelic Football and Hurling are both multidirectional, high intensity field sports (McIntyre, 2005) similar to rugby, soccer and hockey (the other sports in this study) where children may participate in organised and structured training as early as the 'under-6' age category with their club. It is common in Gaelic games to play both Gaelic football and hurling concurrently (O'Connor, McCaffrey, Whyte, & Moran, 2015) and to also play for teams at more than one age category in the same year leading to risks of overtraining. This is often further compounded by also competing for school and inter-county teams. There are no current regulations within the Gaelic Games Association (GAA) which limits the amount of weekly structured training a child can complete and so the demand on children to train/play for each team they are involved with can be substantial.

There are many benefits associated with participation in organised sports during adolescence including the development of motor skills (Wrotniak, Epstein, Dorn, Jones, & Kondilis, 2006), social and cognitive developments (Page & Tucker, 1994; Sibley & Etnier, 2003) as well as many increased health benefits. However, with the possible increased risk of hip injury further down the line, the balance between injury risk and health benefits must be looked at. Further research is needed to determine which aspects of training and competition are most associated with the development of bony morphologies and to examine how children can acquire the skill sets and physical capacities required for sports participation while minimising any negative long term physical adaptations.

There are a number of limitations within the study design. Firstly, the control group were not clinically or radiographically assessed for FAI syndrome but were merely free from groin/hip pain or stiffness at the time of testing. However, we believe the fact that the control group, as well as being closely matched for age, height, body mass and sport type, were actively engaged in equivalent levels of competitive sport with no history or hip/groin pain or stiffness, decreases the likelihood of an underlying hip pathology being present. Secondly, the use of retrospective athlete recall is a limitation in terms of the accuracy of training volume data. To address this, future prospective studies greater than 15 years in length would be required.

5.5 Conclusion

Greater involvement in structured training and competition in sports between the ages of 10 and 12 years may increase the risk of developing symptomatic FAI syndrome in athletic populations. This study is the first to be conducted among athletes that required surgical intervention and highlights the need for extensive prospective research which assesses the links between training volume, duration, intensity and type with the development of bony morphologies which are symptomatic. If such research supports the links shown in this study it will serve to educate coaching staff involved with younger athletes and measures can be put in place to reduce risk.

Chapter 6: An examination of the levels of hip range of motion during hurling match play

6.1 Introduction

Whether specific movement patterns associated with field sports predispose athletes to chronic hip injury is unknown. Understanding the demands routinely placed on a joint during movement to determine whether they could be a cause for injuries reported within the types of sports played is an attractive possibility for coaching and clinical staff if this can help reduce the numbers of injuries sustained. The inclusion criteria for the patients in the study described in chapter three were males, within the ages of 18-35 with confirmed femoroacetabular impingement syndrome, all of whom played field sports; 28% of which were exclusively hurlers, 35% Gaelic footballers and a further 25% played both hurling and Gaelic football. Both hurling and Gaelic football are high velocity, multidirectional, contact field sports native to Ireland (McIntyre, 2005; Reilly & Collins, 2008), which predispose players to a significant risk of injury (Murphy et al., 2010; Murphy et al., 2012).

Hurling is a stick and ball game played on a grass playing field of up to 145m long and 90m wide (Murphy et al., 2010) and it has been compared to lacrosse, hockey and shinty. The objective is to strike the ball past the opposition’s defence into or over the crossbar of the opposition’s goal. If the ball passes over the bar it constitutes as one point, while under the bar equates to three points (goal). Key skills of the game include sprinting while carrying the ball on the stick, striking the ball while running, catching the ball in the air and shoulder to shoulder contact between players, which is allowed. Gaelic football is not a stick and ball game but is played in much the same style and to the same rules, although a larger ball is used. Games are played over two 35-minute halves for elite GAA players or two thirty-minute halves for underage and sub elite players.

While the research to date assessing the incidence of hip injury rates in the Gaelic games of Hurling and Gaelic football, has not suggested the hip to be one of the most commonly injured sites, annual congress reports published by the Gaelic Athletic Association (GAA, 2015), have shown a substantial rise in the numbers of hip related claims from 2010 onwards. In 2010, the number of claims made for treatment of hip related injuries was 83 for football players and 23 for hurlers. In 2014 however, that number has risen dramatically to 202 for footballers and 102 for hurlers, these represent a 143% and 343% increase in claims made for hip treatments for footballers and hurlers respectively over the course of four years. Claims made for other common injury sites such as the knee increased by just 11% for footballers and 44% for hurlers, while this demonstrates that injuries as a whole may be on the rise, there is a significant increase in relation to the claims made for the hip injuries alone in four years. Hip injuries, in particular femoroacetabular impingement syndrome can be a chronic issue, with patients suffering from painful symptoms up to 2 years without a proper diagnosis (Philippon et al., 2007) surgical intervention for treatment can have a rehabilitation time of 12 weeks and over, meaning that players who suffer from FAI syndrome may have prolonged absence from participation. Therefore, while the frequency of hip injuries may be less than other types of injury, the severity of a hip problem is substantially greater than others. As demonstrated in chapter three, patients can suffer reductions in functional performance vital to their sports including reductions in speed and agility. Both hurling and Gaelic football have seen a substantial increase in the number of claims made for hip related injuries, although hurling seems to have seen a greater increase in hip related claims than football. Whether the movement patterns of hurling can influence the rate of intra-articular damage if a predisposing bony abnormality is already present has not been established. Gaining a greater understanding of the movement patterns involved in hurling can inform clinical practitioners as to whether specific movement patterns required for the game may exacerbate symptoms of hip impingement in particular if a bony abnormality has been identified.

Research which aims to link regular movement patterns to either FAI syndrome or any other chronic injury is limited. Only by expanding on these concepts can we begin to fully understand the etiology of injury. One paper however carried out by Stull et al. (2011) examined the kinematics of the ice hockey sprint start and found that the position employed to carry out this manoeuvre was considered an “at risk” hip position (internal rotation during flexion and external rotation during abduction). In the presence of underlying FAI this hip positioning could serve to aggravate symptoms or accelerate intra-articular damage. The authors made no reference to how many times per game/training session that this hip position is required which would undoubtedly influence the rate of disease progression. The hip positioning required to carry out certain movements in hurling could also be considered “at risk” positions, although a detailed kinematic breakdown of hurling movement patterns is required to examine this further. To understand the movement of a joint a multifaceted approach must be taken. As discussed in chapter two (section 2.3.4) there are a number of benefits to using more than one performance analysis method simultaneously. The use of video analysis can give a broad view of what movements athletes carry out over a longer period of time, while more sophisticated software including 3D analysis can give the exact kinematic profile of movements identified previously on video. The aim of this research was to determine the movement patterns associated with the game of hurling and to quantify hip kinematic data during these movements.

6.1.1 Research Questions

1. What are the typical cyclical movement patterns involved in a 70-minute inter county hurling game?
2. What are the typical discrete skill movements involved in a 70-minute inter county hurling game?
3. How often and for how long do these movements occur?
4. What are the angles of hip flexion, extension, abduction, adduction and internal and external rotation during these movements?

6.2 Methods

The current research involved two distinct phases of research (Figure 6.1). The initial phase was composed of field based data collection, where hurling athletes were video recorded during a competitive game. Movements were then categorised and the second phase of analysis included laboratory based 3D assessments of the movement patterns identified in phase 1.

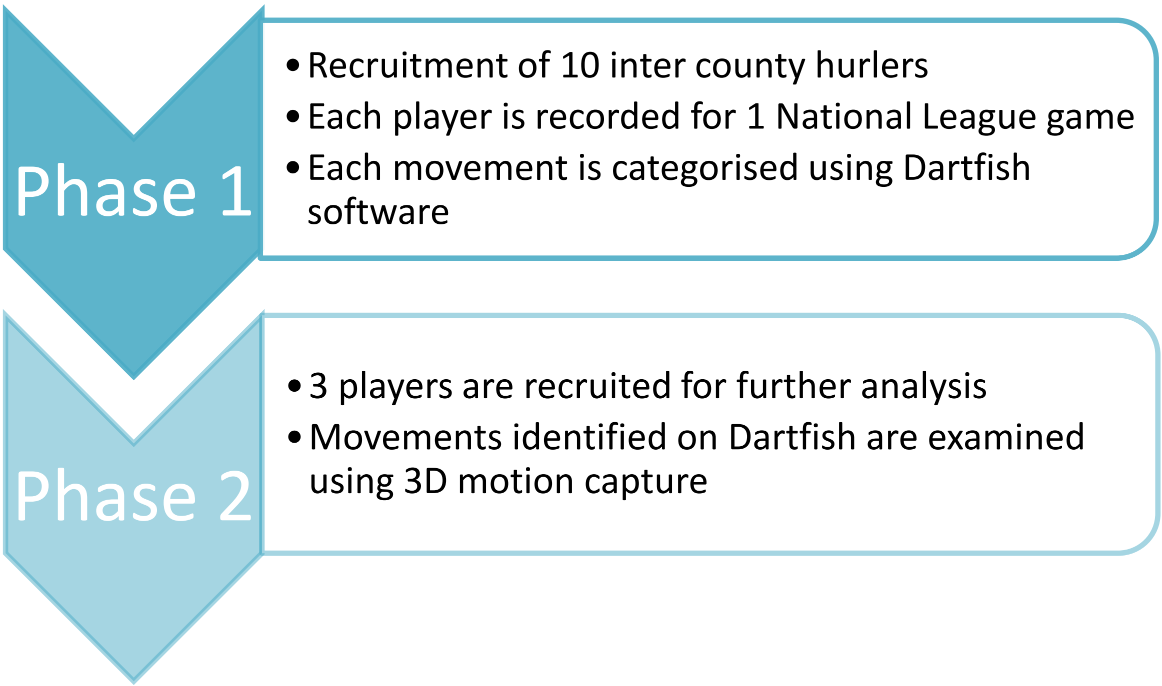


Figure 6.1 Schematic of methodology carried out

6.2.1 Recruitment

Following permission from the Ethics Committee, 10 inter county hurlers were recruited from four inter county hurling teams in the South East, three of which compete in Division 1 of the National Hurling League while the fourth team compete in Division 1b of the competition (Table 6.1). The management of each team was first contacted to seek permission to speak with individual players. Players were subsequently contacted, and a consent form was sent via email and once permission was granted they were considered participants within the study. Athletes were recruited specifically from different positions to give an overall indication of what movements an average hurler carries out as previous literature has highlighted the fact that the workload in hurling differs based on position (Malone et al., 2016). All subjects were free from chronic hip or groin pain and had no history of a hip/groin injury that required treatment. Participants were contacted directly by phone once permission had been granted by the manager of the team.

Table 6.1 Participant Demographics

n=10	**Age (yrs)**	**Height (cm)**	**Body Mass (kg)**
Mean (± SD)	24.3 ± 2.3	181.6 ± 4.6	85.2 ± 5.8

6.2.2 Video Recording

Ten hurlers in total were recruited for the study, two from the full back line, two from the half back line, two midfielders, two from the half forward line and two from the full forward line. Each of the ten hurlers were recorded for one competitive league match (Figure 6.2) with a video camera (Canon Legria HF R66) capturing their movements for the full match (70 minutes). In cases where the player was substituted the incoming player was recorded for the remainder of the game.

Figure 6.2 Video footage of a competitive hurling match

6.2.3 Dartfish Analysis

A customised tagging panel was created on Dartfish Connect Plus software for the analysis of videos (Figure 6.3). Videos were converted to smaller file sizes using Any Video Converter software and then uploaded in Dartfish for analysis. Each 70-minute game was analysed for patterns that were characterised as either cyclical movements e.g. walking/jogging or discrete skill based activities e.g. striking, free taking, or ruck (Figure 6.4) and are fully described in Table 6.2 and Table 6.3. Each of the cyclical movements were timed while the incidences of discrete skills were noted. Once the games had been fully analysed, all relevant files were exported to MS Excel for the generation of a compacted breakdown of the movement and skill based activities that occur during a typical inter county game.

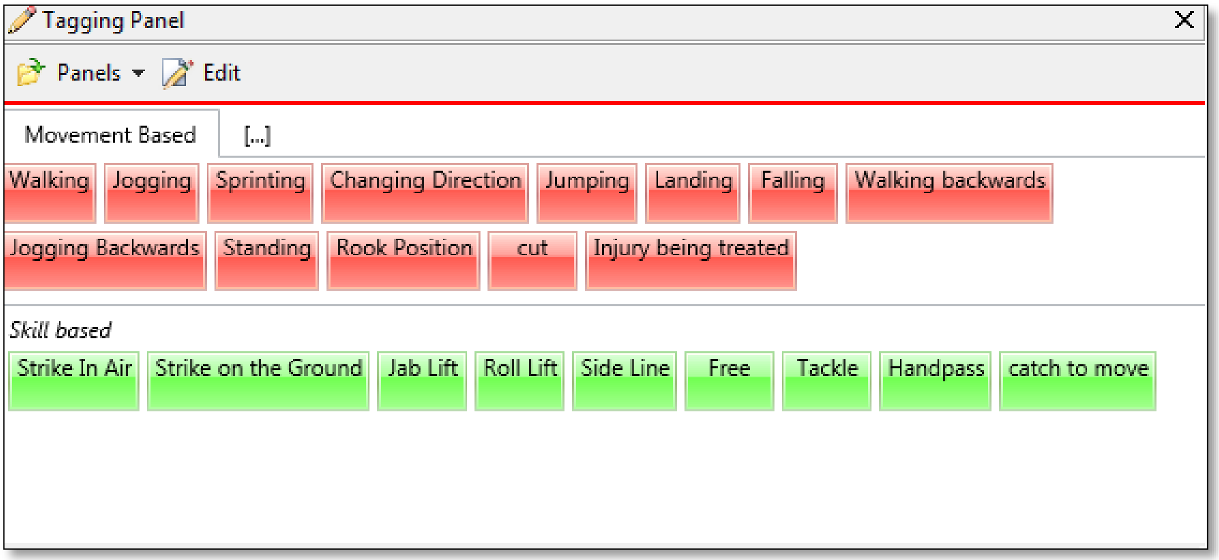


Figure 6.3 Customised Tagging Panel

Figure 6.4 Players involved in a ruck

Table 6.2 Cyclical movements definitions

Cyclical Movement	Definition
Walking	walking
Walking backwards	Low intensity walking backwards
Jogging	Running but not sprinting in a forward direction
Jogging Backwards	Running but not sprinting in a backward direction
Sprinting	Players running as fast as possible
Standing	Player is motionless
Changing direction	Any low intensity change of direction where players altered the course of direction or in instances when they changed their body movement while still travelling in the same direction
Cutting	All sharp high intensity changes of direction throughout the game
Jumping	Jumping in the air to gain possession or prevent an opponent from gaining possession
Landing	Landing from a jump
Ruck Position	A ruck position was tagged when players were involved in a ruck, in this instance players are engaged in high intensity tackling to win possession of a ball on the ground but the tackling itself is static

Table 6.3 Discrete movements definitions

Discrete Movement	Definition
Strike in the air	Player throws ball into the air to strike with the hurley
Strike on the ground	Player strikes ball on the ground
Jab Lift	Player rises the ball by placing the hurley underneath ball and flicking it into the air to catch
Roll Lift	Player rolls the ball backward onto the hurley from the ground to rise it
Side-line	Striking the ball back into the field of play from the ground, once the ball has gone out of the bounds of play
Free	Player rises and strikes the ball in one movement from a static position, following a rule infraction by an opposing player
Tackle	Any action that involved contact between two or more players with the view to gaining possession. Whether the player being recorded was being tackled or they themselves tackling another player was not recorded, only the fact that a tackle had taken place was recorded.

6.2.4 Laboratory Analysis

Pilot testing of gait analysis was first carried out using an Organic Motion capture system using two inter county hurlers (aged 22 and 26 years old). Results were not comparable to previously reported data for hip kinematics during gait and so this system was not used for future analysis, further details for not continuing with that system can be found in the appendices (Appendix 8.5). Three dimensional kinematic data from 42 reflective surface markers (3 cm diameter) were recorded at 200 Hz using a 10-camera passive infra-red system (MAC 3D system; Motion Analysis Corporation, Santa Rosa, CA, USA) as part of a second pilot test (Figure 6.5).

Figure 6.5 Lab set up

For the pilot test, a 28 year old male with no prior history of hip or groin pain was used and was required to wear tight fitting black clothing. Three trials of walking at a self-selected pace were then carried out, followed by three trials of walking backwards at comfortable pace. Next the participant carried out three trials of a light, comfortable jog going forwards followed by three trials of a comfortable jog in the backwards direction. In each case the results were compared to previously published literature of a similar nature, there were no major differences in the kinematic data of the hip collected in this instance and of those published in the literature previously.

Subsequently, three inter county hurlers were brought to the University of Limerick for analysis (demographics Table 6.4). Athletes were instructed to bring their own hurley which they are used to playing with, and that is measured specifically for them. Camera set up was the same as that carried out in the pilot test using the same equipment. Ten cameras which included 3 Kestrels, and seven Eagles, were placed around the perimeter of the testing area at varying heights to ensure all movements within the area were recorded. In line with manufacturer recommendations, a static calibration of the capture volume was performed using a calibration L frame and wand. This set the origin and orientation of the capture volume in which the athlete performed the tasks. A metal L-shaped bar with 3 reflective markers on the surface was placed in the centre of the testing area, once all cameras detected the bar, it was removed and a T-shaped wand was used and waved in a figure of eight movement as well as side to side ensuring the wand was both high and low. When all cameras had detected the wand the calibration was complete.

Table 6.4 Participant Demographics

	Age (yrs)	Height (cm)	Body Mass (kg)	Playing Position
Participant 1	22	188.0	90.8	Midfield
Participant 2	21	196.0	98.5	Forward
Participant 3	29	185.4	83.5	Defender

A modified Helen-Hayes marker set (Collins et al., 2009) was used to identify upper and lower segments of each participant. Reflective markers were subsequently palpated to anatomical landmarks around the body on both sides and included both acromion processes, the sternum, anterior superior iliac spine (ASIS), greater trochanter, posterior superior iliac spine (PSIS), sacrum, lateral and medial femoral epicondyle, lateral and medial bony protrusions of the ankle joint, the heel, the fifth metatarsal head, mid foot, and finally the medial portion of the first cuneiform (Figure 6.6) Clusters of markers specifically for tracking were fixed to a plastic segment (to reduce skin movement artifact) and then taped to the outside of the thigh and calf using kinesio tape.

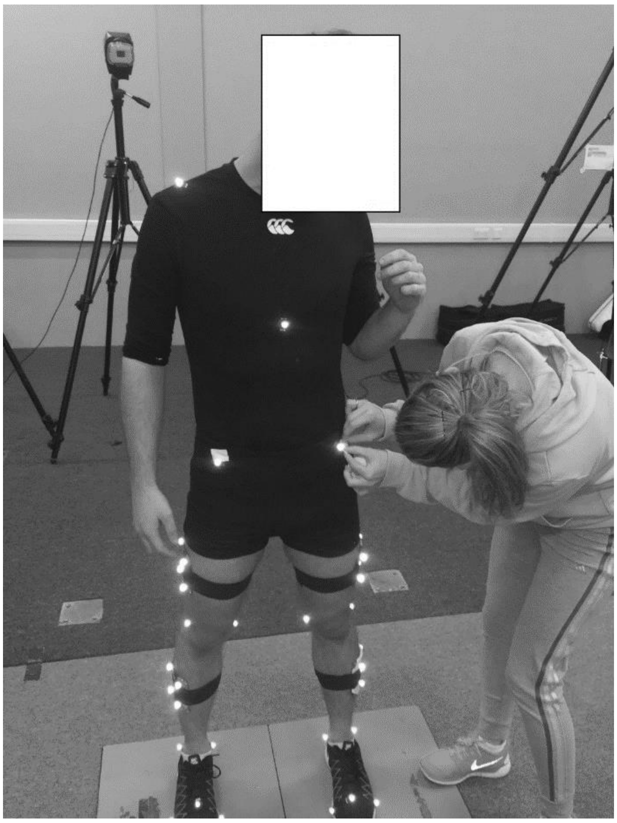


Figure 6.6 Marker Placement

Following the standardised warm up mentioned in chapter three (section 3.2.3), participants carried out two trials of the walking and running tests in both the forward and backward direction, due to the decreased size of the lab it was not possible to carry out the sprinting trials. Assessment of the ruck position was carried out by placing two athletes in the testing area (one with markers, one without) and have them employ a ruck position to contest for a tennis ball placed on the ground in front of the athletes, two trials of this assessment were carried out. Low intensity change of direction was assessed by allowing the athletes to lightly jog around the testing area while changing direction intermittently. Assessment of the discrete skills including high intensity change of direction (by use of a drop jump) are described in Table 6.5 with three trials of each discrete skill carried out. Cortex 5 software (Motion Analysis Corporation, Santa Rosa, CA, USA) was used to track makers throughout the movements recorded and then export raw three-dimensional (C3D) coordinate data. Visual 3D (C-Motion, Rockville, MD) software was subsequently used to filter the exported data using a low pass filter (Butterworth) with a 10 Hz cut off frequency. Generation of a scaled musculoskeletal model using height, body mass and segment length from the static trial was carried out in Visual 3D also. Following this it was possible to generate hip kinematic data for the trials recorded.

Table 6.5 Description of the assessment for each discrete movement

Discrete Skill	Description
Drop Jump	Athletes stood on a 30cm box and stepped off onto the ground landing on both feet, they then immediately jumped into the air. Upon the second landing, they were given a visual cue as to which direction to sprint towards.
Free	The tennis ball was placed on the ground. In one fluid movement the athletes, either jab lifted or roll lifted the ball and without catching it, struck the ball into the netting which was located outside of the camera capture area.
Side-line	Side-line cuts were taken by placing the ball on the ground and the athletes struck the ball at an angle underneath so that the ball was chipped into the air, into the netting which was located outside of the camera capture area.
Jab Lift	The tennis ball was placed in the centre of the testing area on the floor, participants ran from outside the capture area, inside and jab lifted the ball to pick it from the ground while moving.
Roll Lift	The tennis ball was placed in the centre of the testing area on the floor, participants ran from outside the boundary, inside and roll lifted the ball to pick it from the ground while moving.
Strike in the Air	Athletes ran from outside of the perimeter into the testing area and struck the tennis ball from their hand out of the capture area.
Strike on the Ground	Athletes ran from outside of the perimeter into the testing area and struck the tennis ball on the ground out of the capture area.

6.2.5 Developing hip zones

To quantify the hip movement patterns during hurling match play it was necessary to generate zones to categorise hip ranges of motion (Table 6.6). Hip zones were originally determined based on a traffic light system whereby the total range of motion was divided into three categories of specific ranges. For example, flexion has a typical maximum range of 120°, in that case, the green zone would include values from 0-40°, the yellow zone would include values from 41-80°, while the red zone would include values ranging from 81-120°. However, during initial data analysis it was found that four zones would be more appropriate so that not all the data would be concentrated in one particular zone and differences would be more apparent. Secondly, for extension, and the frontal and transverse planes, when data was first visually assessed, in only one instance did values exceed 30°. It was then decided that four zones with a maximum value of between 30 and 40° would suffice.

Table 6.6 Zone Definitions

	Flexion	Extension	Abduction/ Adduction	Internal/External Rotation
Zone 1	1-30°	1-10°	1-10°	1-10°
Zone 2	31-60°	11-20°	11-20°	11-20°
Zone 3	61-90°	21-30°	21-30°	21-30°
Zone 4	90-120°	>30°	>30°	>30°

6.2.6 Data Analysis

6.2.6.1 Video Analysis

Ten games were analysed using Dartfish software and tagged using the customised tagging panel. Each game was divided into cyclical movement patterns and discrete movements. The final ten minutes of one game were missing due to a technical issue with the camera on the day, while another game included 20 minutes of extra time, to account for these changes in playing time all data was normalised to 70 minutes. An average of the ten games was determined to quantify the movement patterns and average number of discrete skill based tasks performed by a typical hurler across 70 minutes.

6.2.6.2 Biomechanical Analysis

For cyclical movements, the entire game was divided into percentage of time spent in specific hip zone using the zone criteria mentioned above. Planes of motion were analysed in this instance separately due to the fact that the cyclical movements were not thought to require excessive levels of flexion in conjunction with higher levels of internal rotation or external rotation in combination of abduction and therefore were not considered “at risk” hip positioning in the presence of underlying FAI.

For discrete movement tasks, each movement was categorised into percentage of the movement spent in each specific hip zone as above, in this instance movement in each plane was analysed separately. Secondary analysis of the discrete skills included creating percentage time series graphs for the side-line cut movement as this discrete skill was had the greatest levels of rotation with both flexion and abduction upon visual inspection of the raw data, which have been cited previously as “at risk” hip positioning in the presence of underlying FAI. To achieve this, data from each participant including both the leading leg (the leg which is placed closest to the ball during the strike) and the trail leg were plotted on a time (% of movement) vs angle graph (smooth line scatter plot). The free taking discrete skill was also analysed using percentage time series graphs and can be found in the appendices (Appendix 8.6).

6.3 Results

6.3.1 Dartfish Analysis

The breakdown of each cyclical and discrete movement that occur in a typical 70-minute hurling game are described below (Table 6.7 & 6.8). Walking was the most common cyclical movement carried out, accounting for 42% of the game, with jogging the second most common cyclical movement carried out. Standing accounted for 10% of a total game with players involved in rucks for approximately 1% of a 70-minute game. Low level intensity change of direction was the most common discrete movement, occurring on average 284 times per game. Side-line cuts and free taking were not identified on video analysis in any of the 10 games while jab lifting was the most common method of rising the ball from the ground. Finally, striking in the air was the preferred method of striking the ball with striking on the ground a relatively low occurrence.

Table 6.7 Time in minutes and Percentage of the Game Movement Patterns

Movement	Time (mins)	Percentage of Game
Walking	29.5	42
Walking backwards	4.9	7
Jogging	22.2	32
Jogging Backwards	1.5	2
Sprinting	4.2	6
Standing	7.0	10
Ruck Position	0.7	1
Total	70	100

Table 6.8 Typical Tasks carried out in 70 minutes of Hurling Match Play Per Player.

Task	N/70 minutes
Changing Direction	284
Cutting	38
Roll Lift	2
Jab Lift	6
Strike in the air	8
Strike on the ground	1
Side-line	0
Free	0

6.3.2 Kinematic Profile of the Hip during Hurling match play

6.3.2.1 Cyclical Movements

Due to the space available in the biomechanics laboratory, sprinting was not recorded or assessed for kinematic variables, furthermore the data collected for both the low-level change of direction and ruck movements were not deemed accurate upon analysis and so were not included in the results section. Excluding, sprinting and the ruck total time included for analysis was 64 minutes of a typical game (91%). For the entire game (cyclical movements) athletes spend the majority of time between 1 and 10 ° of flexion followed by 21-30° of flexion. Less than five percent of the game involves cyclical movements that are above 30° (Figure 6.7, 6.8, 6.9). The entire game of hurling is carried out between 0 and 20° of abduction, adduction, internal and external rotation.

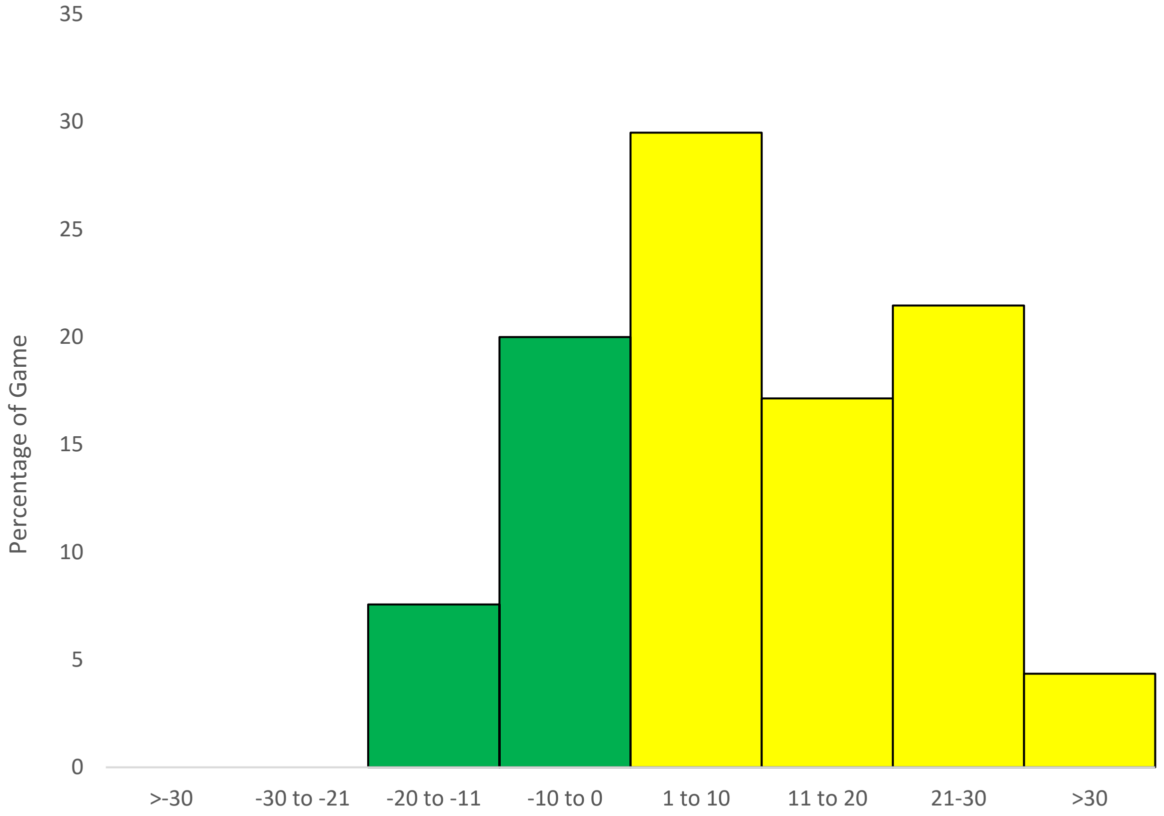


Figure 6.7 Percentage of the Game spent in Hip extension in green (-30 to 0°) and flexion in yellow (1 to 30°)

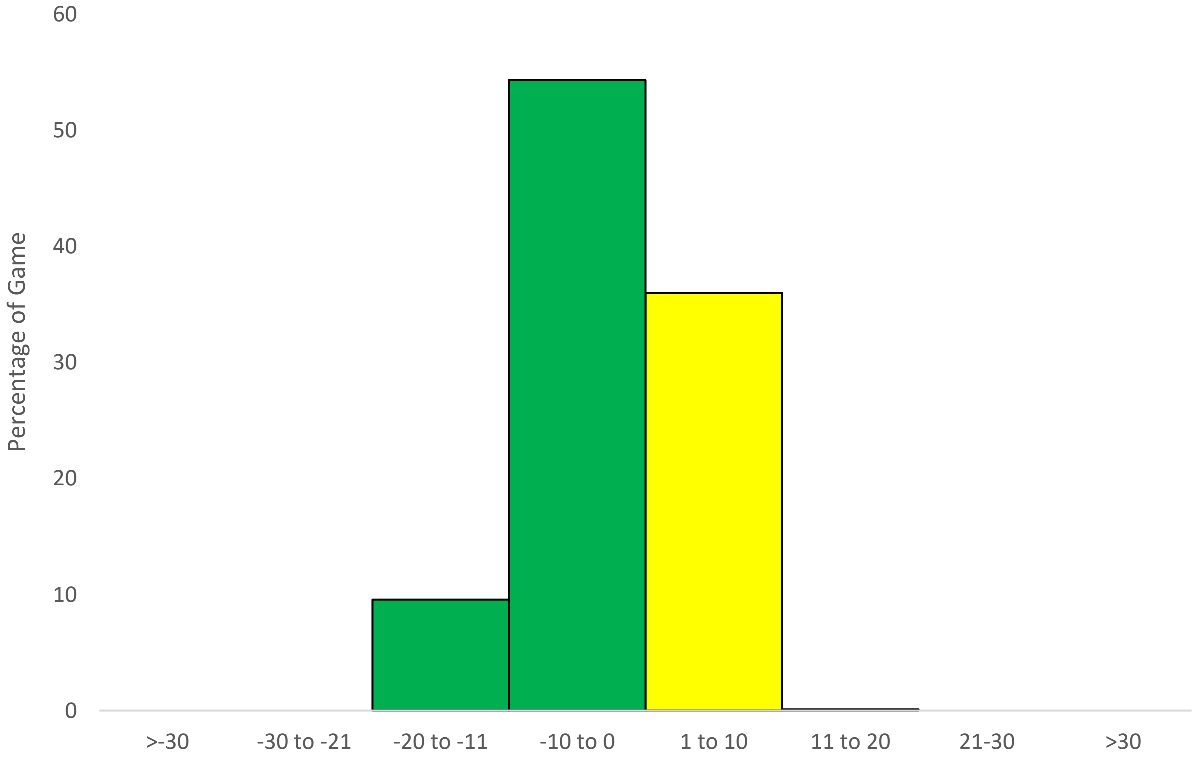


Figure 6.8 Percentgae of the Game spent in Adduction in green (-30 to 0 °) and Abduction in yellow (1 to 30 °)

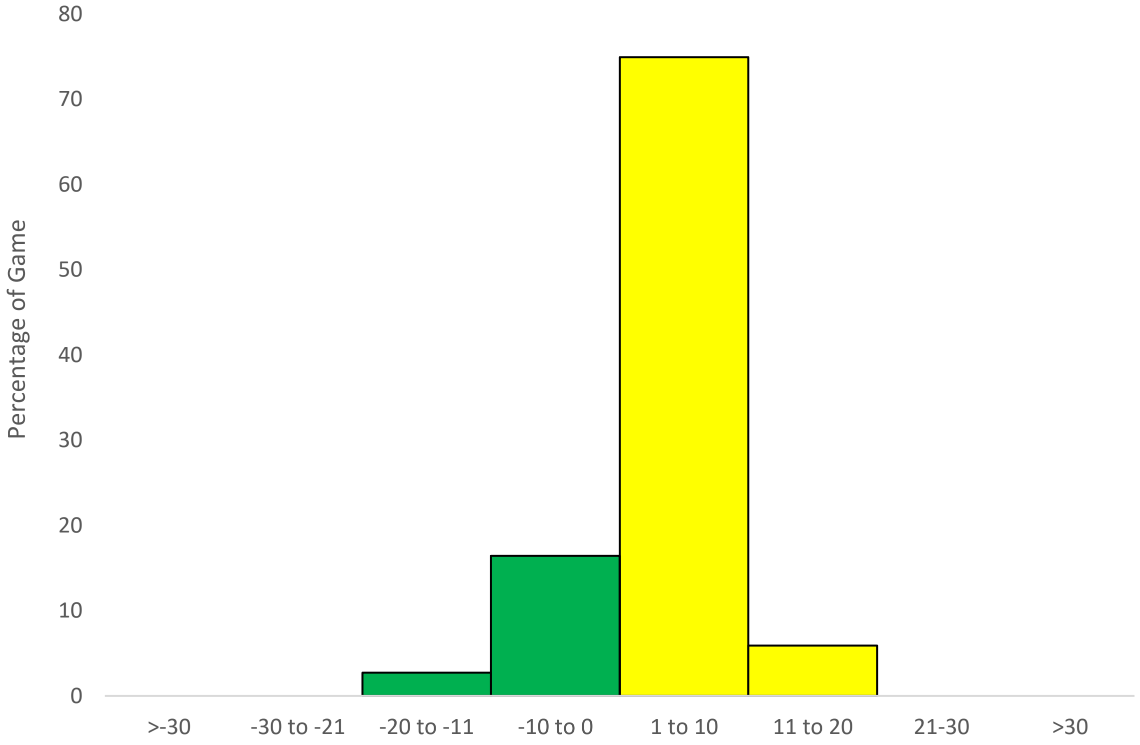


Figure 6.9 Percentgae of the Game spent in Internal Rotation in green (-30 to 0) and External Rotation in yellow (1 to 30 °)

6.3.2.2 Discrete Skills

The breakdown for each discrete skill for each plane of motion are described below. The side-line cut was the only discrete skill with more than 90° of hip flexion although only one percent of the movement was found to be in zone 4 (Table 6.9). Table 6.10 and 6.11 give the zone percentages for Abduction-Adduction and Internal-External rotation respectively. The side-line cut was the only action that required, more than 30° of abduction, for all other skills the hip remained within in zones 1-3 in all three planes of motion.

Table 6.9 Zone Percentages Flexion/Extension.

	Extension				**Flexion**				
	> 30°	**29 to -20 °**	**19 to 10 °**	**9 to 0 °**	**1 to 30 °**	**31 to -60 °**	**61 to 90 °**	**90 to 120 °**	**Total**
	Zone 4	Zone 3	Zone 2	Zone 1	Zone 1	Zone 2	Zone 3	Zone 4	
Drop Jump	0	2	5	7	**51**	31	4	0	100
Free	0	0	4	11	**42**	31	12	0	100
Side-line	0	3	10	16	**34**	16	20	1	100
Jab Lift	0	3	8	14	32	**40**	3	0	100
Roll Lift	0	4	7	7	30	**50**	2	0	100
Strike in the Air	0	1	11	18	**47**	23	0	0	100
Strike on the Ground	0	2	9	16	**50**	23	0	0	100

***Values highlighted in red indicate the greatest percentage of the movement carried out in the corresponding zone**

Table 6.10 Zone Percentages Abduction/Adduction

	Abduction				Adduction				
	>30	21-30	11-20	0-10	0-10	11-20	21-30	>30	Total
	Zone 4	Zone 3	Zone 2	Zone 1	Zone 1	Zone 2	Zone 3	Zone 4	
Drop Jump	0	4	28	40	19	7	2	0	100
Free	0	10	23	38	20	7	1	0	100
Side-line	2	4	15	24	39	15	1	0	100
Jab Lift	0	0	2	27	58	12	1	0	100
Roll Lift	0	1	6	41	38	11	3	0	100
Strike in the Air	0	2	16	35	34	12	1	0	100
Strike on the Ground	0	6	14	22	35	19	4	0	100

***Values highlighted in red indicate the greatest percentage of the movement carried out in the corresponding zone**

Table 6.11 Zone Percentages Internal/External Rotation

	Internal Rotation				External Rotation				
	>30	21-30	11-20	0-10	0-10	11-20	21-30	>30	Total
	Zone 4	Zone 3	Zone 2	Zone 1	Zone 1	Zone 2	Zone 3	Zone 4	
Drop Jump	0	2	18	42	36	2	0	0	100
Free	0	1	27	41	27	4	0	0	100
Side-line	0	5	12	44	31	8	0	0	100
Jab Lift	0	0	1	46	48	5	0	0	100
Roll Lift	0	3	15	43	34	5	0	0	100
Strike in the Air	0	0	10	36	45	8	1	0	100
Strike on the Ground	0	1	13	31	47	8	0	0	100

***Values highlighted in red indicate the greatest percentage of the movement carried out in the corresponding zone**

6.3.2.3 Side-line cut assessment

Below (Figure 6.10, 6.11 & 6.12) are percentage time series data for the side-line cut discrete skill in which movement in all three planes for the skill are included. In each case the beginning of the movement was determined when the athletes began moving from a standing position, the movement was considered to have stopped when the athletes had returned to an upright standing position. Positive values indicate flexion, abduction and external rotation, alternatively negative values indicate extension, adduction and internal rotation (Table 6.12). In each case the maximum levels of internal rotation occurred closer to the highest levels of flexion for the movement in the leading leg. Conversely, in two of the participants the trail leg exhibited increasing levels of external rotation in both abduction and extension.

Table 6.12 Interpretation of graphs including movement in all three planes

Movement	Direction
Flexion	Positive Value
Extension	Negative Value
Abduction	Positive Value
Adduction	Negative Value
Internal Rotation	Negative Value
External Rotation	Positive Value

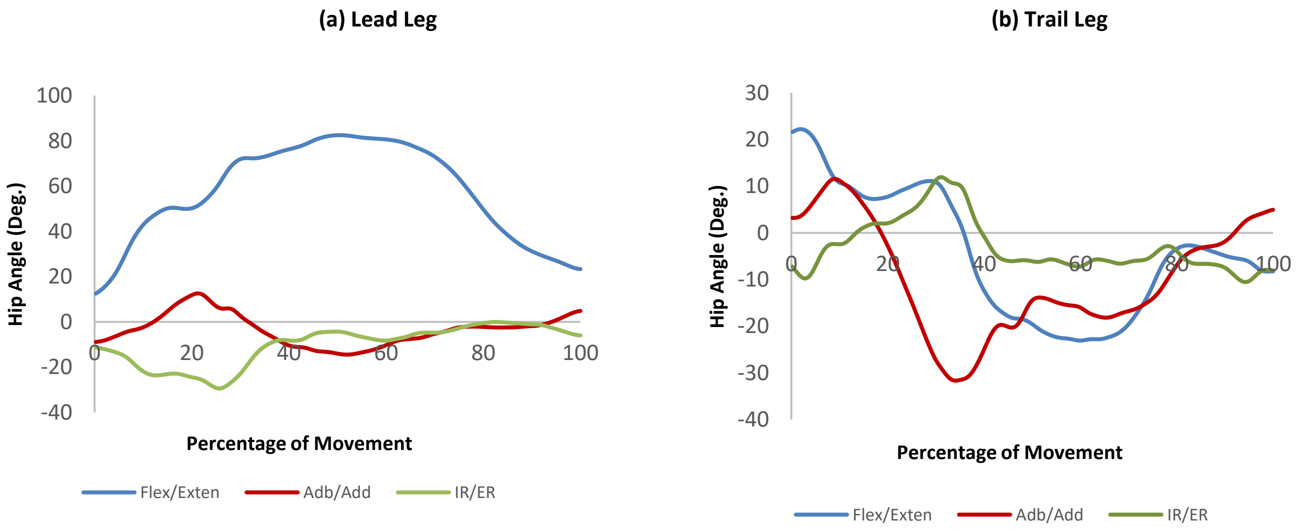
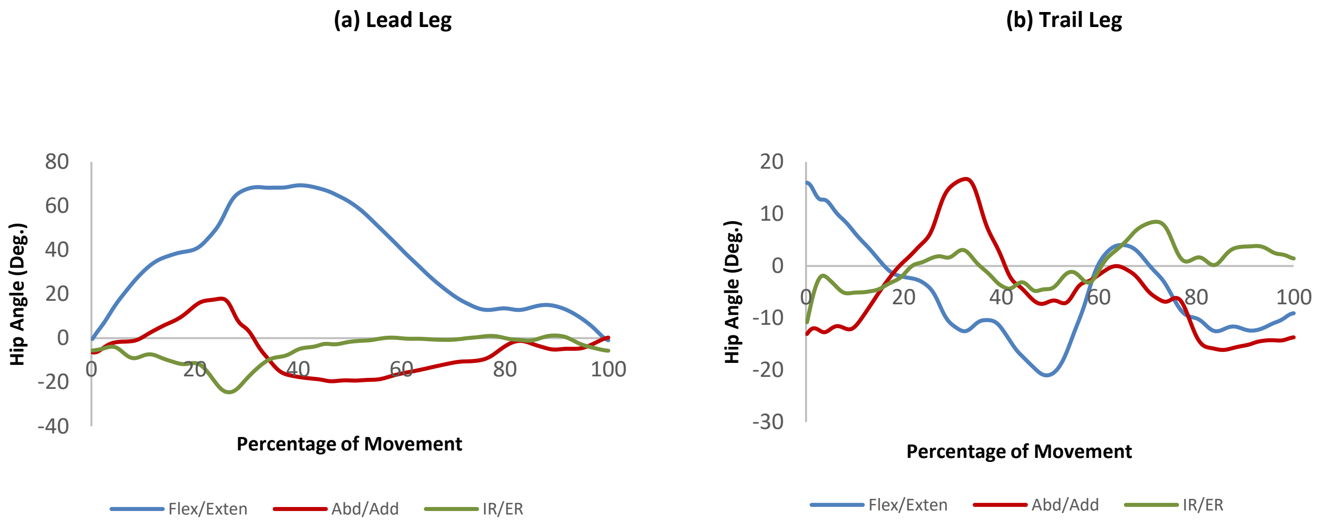
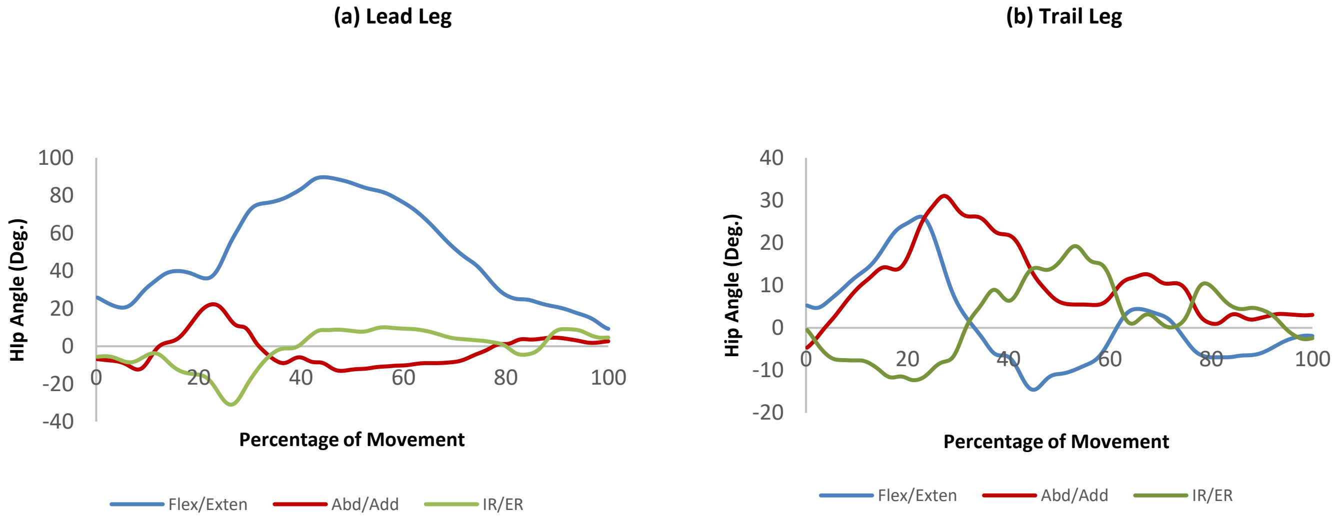


Figure 6.10 Side-line cut participant A
Postive values indicate; flexion, abduction & External Rotation


(a) Lead Leg

(b) Trail Leg

Figure 6.11 Side-line cut participant B
Postive values indicate; flexion, abduction & External Rotation


(a) Lead Leg

(b) Trail Leg

Figure 6.12 Side-line cut participant C
Postive values indicate; flexion, abduction & External Rotation

6.4 Discussion

6.4.1 General Movement patterns of Hurling match play

The aim of this study was to determine the levels of hip flexion-extension, abduction-adduction and internal-external rotation throughout a standard 70-minute inter county hurling game. To do this a multifactorial approach including notational and optoelectronic analysis was used. The results indicate that hurlers spend the majority of the game (42%) walking, followed by jogging (32%), all out sprinting only accounted for 6% of the entire game and was less than that of standing (10%). Previous literature investigating the game of hurling is lacking although a time motion analysis study of hurling revealed that while the duration of a hurling game was approximately 75 minutes, the time in which the ball was in play accounted for just 41% (30.75 minutes) of that duration (Collins et al., 2008). The high volumes of walking and low intensity activity observed in the current study could be attributed to the fact that the ball is out of play for considerable proportions of the game.

Although research investigating hurling games are limited, there have been video and time motion analysis studies carried out previously in other field sports. Field hockey has been compared to hurling (Collins et al., 2014; McIntyre, 2005), and also consists of two 35-minute halves. Using time motion, Spencer and colleagues carried out two reports involving elite men's field hockey. The first study reported that the majority of the game was spent carrying out low intensity movements such as walking (47%) jogging (41%) and standing (7%) which is quite comparable to the findings of the current study (42, 32 & 10% respectively). All out sprinting accounted for 1.5% of a field hockey game and 6% of the hurling games assessed in the current study, differences in these values may be attributed to the fact that Spenser and colleagues included "striding" movements which were of an intensity between that of jogging and sprinting whereas the current study did not (M. Spencer et al., 2004). In a follow-up report, Spencer et al. (2005) analysed three consecutive elite hockey games using the same criteria as before for movement patterns, the results were broadly similar to the first report with walking accounting for the majority of the movement. The purpose of the follow up study was to determine whether there were significant changes in the percentage of time spent in each movement category over consecutive games as a result of fatigue. The authors found that the percentage of time spent standing significantly increased across the three games which were carried out over four days. The games analysed in the current study were carried out during the national Hurling league which is conducted over an eight-week period. Considering hurling is an amateur sport and athletes often have full time working hours, it could be suggested that fatigue could have been a factor in the current study although could not be measured. Fatigue as a result of both training and competitive games each week could have lead to a reduction in the overall global movements within the game and therefore hip movements also. Other field sports such as soccer and rugby union have also been analysed previously to categorise movement patterns. Depending on position, rugby union players will spend on average between 35-50% of the game walking, 15-22% jogging and 0.11-1.3% sprinting (Deutsch et al. 2007; Deutsch et al., 1998; Duthie et al., 2003; Roberts et al., 2008). Soccer players have been reported to spend approximately 40% of a 90 minute elite soccer game walking, between 35 and 40% jogging, between 1 and 6% sprinting, with approximately 19% of the time standing still (Bloomfield et al., 2007; Mohr et al., 2003). These are comparable to the results of the current study, although the percentage of time spent sprinting is higher than that of rugby and at the higher end of those reported in elite soccer. The speed at which the ball travels at in the game of hurling (Reilly & Collins, 2008) , in conjunction with greater relative pitch sizes (435 m^2 per player) than rugby (233 m^2 per player) and soccer (409 m^2 per player) could account for the higher sprinting times of elite hurlers compared to rugby and soccer players.

As demonstrated by the previous time motion analysis research of soccer and rugby, movement patterns and game demands are often diverse depending on playing position. This is possibly the case in hurling also, only one GPS analysis research of hurling movement patterns have determined that there are differences in demands of the game depending on position (Collins et al., 2017). The limited players per position included in the current study meant that comparisons between playing position could not be carried out.

Only one previous notational analysis study has been carried out to quantify the skill execution in a typical hurling game, Gilmore (2008) examined four championship hurling games, (although the level of competition was not disclosed). The skills included in that analysis, incorporated all of the skills included in the current study. The study reported that the ball is struck approximately 136 times per game, with striking on the ground a relatively low occurrence which coincides with the current study. Frees and side-line cuts were also rare incidences in the current study with players carrying out none of these skills, while in contrast, Gilmore reported approximately 13 and 25 side-line cuts and frees respectively. Both skills are often considered to be specialised skills and are generally carried out by select players within the team, therefore the players recorded in the current study may not have been required to carry out these skills and led to the non-occurrence observed. Jab lifting was used more than the roll lift in both the current study and Gilmore's investigation. Job lifting is often a preferred method of rising the ball from the ground as it does not require the player to stop and athletes can lift the ball while running without breaking stride.

6.4.2 Kinematic movements during Hurling match play

The cyclical activities of a hurling game do not exceed 20° of movement in any direction, apart from flexion, in which 5% of the game was spent in greater than 30° of flexion. These results are to be expected when compared to previous literature, hip kinematic data for walking suggest that hip flexion and extension levels range between 40 and 10° respectively (Kadaba et al., 1990; Kerrigan et al., 2001; Lee & Hidler, 2008). Hip abduction/adduction and hip rotation kinematics for walking can range from 5 to 14° (Isacson et al., 1986; Kadaba et al., 1990; Sutherland et al., 1980). Jogging and sprinting hip kinematic patterns are similar to that of walking although the degree of movement is often reported to be less than that of walking for the frontal and transverse planes (Fellin et al., 2010; Ferberet al., 2003). The kinematics of walking and jogging backwards, have not been reported to the same extent as walking or running in the forward direction however, hip kinematics are thought to be similar in both directions for gait (Grasso, Bianchi, & Lacquaniti, 1998; Thorstensson, 1986; Winter, Pluck, & Yang, 1989). While previous investigations involving backward running have shown variances in hip movement compared to that of forward running, typically there is less hip extension during backward running (DeVita & Stribling, 1991). In the current study, the hip internal and external rotation ranges appear to be higher than those of previous investigations involving gait and/or running (Fellin et al. 2010; Kadaba et al. 1990), however, kinematic data in the transverse plane particularly involving the hip joint have often larger standard deviations and higher ranges throughout the literature compared to that of the other two planes of motion. This is due to the calculation of joint centres which is often problematic for the hip joint in particular (Camomilla et al., 2006; Stagni, et al., 2000) and so data is often varied for this plane of motion. For the entirety of a competitive hurling match involving cyclical motion, the hip joint never approaches the limits of movement in any direction.

Hip kinematics for sprinting have been reported previously (Mann & Hagy,1980; Willy & Davis, 2011; Souza & Powers, 2009; Hardin et al,. 2004), and consist of higher flexion values compared to that of running and walking. Some reports have cited peak flexion values as high as 80° of flexion (Mann & Hagy, 1980). Extension values are thought decrease compared running and walking (Mann & Hagy, 1980). While the kinematics of sprinting have also reported to include approximately 5° adduction/abduction and 5-10° of internal/external rotation (Willy & Davis., 2011; Souza & Powers., 2009; Hardin et al., 2004). The six percent of the game in which sprinting was carried out would therefore slightly increase the percentage of the game carried out in zone four for hip flexion (60-90°) as peak values of sprinting could reach 80° although the entire stride would not be completely concentrated in that zone. The percentage of the game carried out in zone one (0-10°) for the other planes of movement (Abd/Add and IR/ER) would also therefore increase.

The discrete skills included in the current study are unique to hurling although some aspects could be compared to a golf swing or baseball batting in terms of the rotational component required to strike a ball over large distances. The results of the current study indicate that the majority of rotation at the hip joint during the free taking, side-line cut, and both methods used to strike the ball were carried out between 0-10° of movement in any given direction. Internal rotation values of between 21 and 30° did occur but in no instance, did they exceed 30° with the side-line cut including the longest duration of 21-30° (5% of the movement). This gave a maximum range of movement of approximately 50° of rotation in total for each of the movements, this is not unlike ranges previously cited for a golf swing where hip rotational data has been cited to range from 17° (during the backswing) to 37° (during downswing); 54° of movement in total (Burden et al. 1998). These results are similar to research evaluating the angular displacement of the hip joint during a baseball swing, in which approximately 46° of movement have been recorded (Welch, Banks, Cook, & Draovitch, 1995). Very little hip rotation was observed in both the jab lift and roll lift skills which was to be expected considering the movements require the athletes to bend forward to retrieve the ball from the ground, all the while moving in a linear direction. A drop jump was used in the current research to replicate the cutting movement in field sports which hurlers carry out approximately 40 times per game. The drop jump was used due to the small space in which the testing was carried out, regardless of direction, hip rotation did not exceed 30° during the change of direction component following the drop jump. Normal end range of rotation include 40-45° of internal rotation and 44-50° of external rotation (Norkin & White, 2009), in no instance did any of the discrete skills in the game of hurling require the hip to move close to these reported end range values. However, as previously discussed in chapter 3 and 4, athletes with FAI syndrome will have reduced internal rotation both prior to (approximately 30°) and even following Intervention (approximately 37°). Therefore, should an athlete with FAI syndrome continue to engage in the game of hurling, the demands of rotation may serve to accelerate damage to the joint by placing the hip in a position whereby the impinging bone is forced into the joint.

The combination of movements in more than one plane of motion especially internal rotation with increasing flexion and external rotation in abduction and extension are considered at risk hip positions (Stull et al. 2011). Furthermore, the development of intraarticular damage from a bony deformity may not be equal in both hips in sports which involve large volumes of rotational velocity (Dickenson et al., 2016). The discrete skills of hurling were examined to determine whether any of these routine skills place the hip in a position which promotes impingement. The discrete skill assessment, saw only one instance of flexion greater than 90°, this occurred during the side-line cut, and only 1% of the movement was carried out between 90 and 120° of flexion. All of the discrete skills spent the majority of the movement between 0 and 30° of flexion bar the roll lift and jab lift, in both cases most of the movement were carried out between 30 and 60° of flexion. The majority of extension for each of the discrete skills lay between 0 and 10°, although maximum extension values of between 20 and 30° did occur, albeit for a shorter duration than time spent in the lower zones. The side-line cut included the greatest range of movement from extension to flexion, from between 20 and 30° of extension to 90 and 120° of flexion. Abduction/Adduction movement patterns were similar to that of the transverse and sagittal plane data, again the side-line cut was the only discrete skill in which any percentage of the movement was carried out in zone 4 (>30°), athletes spend 2% of the side-line cut in greater that 30° of abduction. Stull et al. (2011) examined hip movement during the sprint start in ice hockey, the authors reported that the hip position required to push the body forward involved increased internal rotation in flexion in the push leg with external rotation in abduction in the following leg. The results of the side-line cut mirror these findings, with the greatest levels of internal rotation of any other discrete skill but also in conjunction with greater levels of flexion. The trail leg in the side-line cut exhibits similar movement patterns to that reported in the Stull research with increasing hip external rotation in conjunction with hip abduction. Both movements have been cited as "at risk" and are often used to diagnose FAI (Philippon et al. 2007). The Stull investigation did not quantify the amount of times in a typical ice hockey game, that this hip position is required, although it would be presumed to be high. In contrast the side-line cut is not a frequent occurrence in the overall game of hurling however, the potential risk to the joint by forcefully rotating the femoral head into the joint trying to strike the ball could accelerate intra-articular damage if a bony deformity has been identified. Secondly, the amount of practice required to perfect a skill such as the side-line cut may mean that the amount of side-line cuts being taken could be far greater than observed in a typical game. As discussed in Chapter 5, periods of accelerated bone development maybe a critical time-frame in the development of a bony abnormality through repetitive microtrauma to the femoral head/neck junction through repeated contact with the pelvis (Agricola et al., 2014; Leunig & Ganz, 2007; Siebenrock et al., 2004). The side-line cut movement could be one such movement that is avoided during times of bone growth to avoid the development of a bony morphology.

6.4.3 Limitations

A limitation of the current study includes the small size of the testing area in comparison to the natural environment in which these hurling patterns are normally carried out. The size of the biomechanics lab and the fact that the cameras needed to be placed around the athletes to gain a full view of the hip, meant that there was a small area in which the athletes could strike the ball out of bounds in the discrete based skills. To this end, the athletes could have been striking for accuracy rather than maximum distance and could have struck the ball more from the upper portion of the body rather than using their hips to strike the ball further. The small subject numbers in the 3D assessment may be perceived as a limitation, however, most studies involving biomechanical assessment have small subject numbers due, in part, to the large quantities of data collected per participant. Furthermore, those studies usually only assess one movement at a time, in the current study each participant carried out over 30 movements each leading to over 100 data sets in total which we believe was substantial for the purpose of the research. The increased volume of data processing and analysis involved in marker based motion capture is a limitation when using the system in routine practice, advances in organic motion which can analyse data in real time make an attractive alternative if accuracy was improved, especially if assessing multiple athletes per session.

6.4.5 Strengths

This is the first study to which uses both 2D and 3D performance analysis methods to quantify the movement patterns in a field sport and specifically to track the movements of a particular joint for the entirety of a game. Two pilot testing sessions were carried out; one with marker-less motion capture and one with a marker based system, the latter was chosen for the study due to increased accuracy of the system especially in the frontal and transverse planes. The athletes used in this study were inter county hurlers who all played hurling, and were chosen because as they are considered elite hurlers who would have the best technique and who play at the highest intensity. This is the first study to determine how often athletes are required to carry out particular skills relevant in order to quantify the levels of hip ROM movement throughout the entirety of a game.

6.5 Conclusion

Elite hurlers will spend the majority of a 70-minute competitive game engaged in lower intensity activity interspersed with bouts of high intensity running and change of direction movements. The discrete skills of the game involve lower ranges of motion in comparison to the maximal ROM available to the joint in any given direction. However, the combinations of these movements required for the discrete skills of the game have the potential to exacerbate symptoms if an underlying bony deformity is present. The side-line cut in particular is a movement in which increasing levels of internal rotation in combination with increased flexion in the leading leg occur, while the trail leg exhibits external rotation (range 8-19^{o}) movement in conjunction with abduction (range 17-30^{o}). This discrete skill, although a relatively low occurrence during the actual game, requires large volumes of practice to perfect and should be considered an "at risk" hip position. This research serves to educate clinical and coaching staff involved with athletes who have an identified or suspected hip pathology as to the potential for movements such as the side-line cut to exacerbate symptoms or accelerate damage to the joint. Coaching and medical staff can then adjust training to allow for appropriate recovery following games and training. Understanding that movements that potentially increase the risk of exacerbating symptoms can also allow coaches to determine which players are tasked with carrying out these skills.

Chapter 7: Conclusion and Future work

7.1 Conclusion

Femoroacetabular impingement syndrome is a prominent anatomical variation of the hip joint which causes disruption to the fluid movement of the femoral head into the acetabulum during motion. Repetitive contact of the bony deformity causes severe degrading of the underlying tissue within the joint, and if conditions are not altered there is potential to lead to a complete separation of the tissue from bone which has the potential then to cause osteoarthritis of the hip. Many researchers have focused on the prevalence of the condition among general and athletic populations although there have been many inconsistencies regarding the definition of a bony deformity. It is clear however, that young athletes, in particular male athletes are at greatest risk. Previous research has quantified the effects of FAI syndrome and interventions to treat the condition with self-reported measures, however, functional assessments have not been examined in relation to FAI syndrome.

The aim of the research was to quantify athletic performance differences between athletes with FAI syndrome and healthy matched controls. The results of the study indicated that athletes with FAI syndrome will have reduced athletic performance compared to healthier counterparts, with higher levels of pain while carrying out athletic movements required for sport. Acceleration, agility and range of motion are the aspects of functional movements most affected by the condition. Arthroscopic intervention is an appropriate treatment option for athletes to improve functional performance, reduce pain and allow athletes to return to sport at a previous level. The implications for the current research include providing an objective analysis of surgical outcomes appropriate for athletic populations which can allow athletes and clinical practitioners to make a more informed decision as to the viability of surgery as a treatment option. The other noteworthy finding of the research was that athletic patients with FAI syndrome recorded significantly greater structured training hours than the healthy controls. While taking into consideration the limitations of athlete recall in the methodology, the findings suggest a possible link between increased training load and the development of a bony deformity during skeletal growth. This is an important finding in the area of FAI syndrome epidemiology and supports a growing body of research within the area although highlights that bony deformity development may begin earlier than previously reported (Agricola et al., 2014). Longitudinal prospective research is required to fully examine links between higher training load and alterations to hip anatomy and protocols can then be developed to avoid hip pathology.

Linking chronic injuries to movement patterns involved in sport requires an understanding of the typical movements carried out in the sport. The aim of the second phase of research in this thesis was to determine the common movement patterns carried out in a 70-minute hurling game and to quantify hip specific angular data during these movements. These results also aimed to provide a template for further research in the area of sports performance by using two distinct performance analysis methods simultaneously. The results indicated that hip ranges of motion during a hurling game are concentrated in lower zones of movement for the entire match with the hip rarely approaching the typical limits of movement of a healthy hip (Norkin & White, 2009), however, this may not be the case for athletes with reduced hip range of motion due to an underlying hip pathology. Athletes with FAI syndrome typically have significantly reduced hip ROM and are unlikely therefore to carry out these movements appropriately which could affect overall performance. The combination of movement in more than one plane in particular increasing flexion with increasing internal rotation, can place the hip in a position that may exacerbate symptoms and accelerate damage in the presence of underlying FAI. In the game of hurling the side-line cut is an example of this. Coaches and athletes should be aware of the greater risk posed by the side-line cut in exacerbating symptoms. The implications for the second phase of the current research includes gaining a clearer understanding of the hip movement patterns of the game of hurling, a population which has seen a considerable increase in the need for hip treatment in recent years. The approach used in the current study which combined both optoelectronic and video analysis together has the potential to be applied to many field sports to determine game demands and determine aspects of sport which may be causing certain injuries observed in that sport.

7.2 Implications of the Research

The implications of the first phase research include, educating athletic coaches as to the likely deficits in performance among athletes with FAI syndrome should their athletes wish to continue with sports participation. Phase 1 also provides patients with objective information regarding expected outcomes of arthroscopic surgery which will allow them to make a more informed decision regarding treatment. Relevant stakeholders

Phase two (Chapter 6) provides a detailed account of the hip kinematics during a 70-minute hurling game which gives a clearer understanding of the movement patterns required to play the game and can inform clinicians and coaching staff as to the demands that the game places on the hip joint. Phase 2 also provides a template for using video and 3D motion capture interchangeably to generate kinematic profiles for field sports.

7.2.1 Relevant Stakeholders and Dissemination of Research

The stakeholders in this research include athletes, coaches, physiotherapists and doctors. The governing bodies of the sports in which field athletes are involved should also take note of the findings of this research. The results indicate that underage athletes are potentially at risk of developing a bony morphology which can progress to symptomatic FAI syndrome later in life which will require some measure of treatment. Reducing injury, especially lower limb injury (Roe, Blake Gissane & Collins, 2017) can decrease the annual medical costs of the organisations. Governing bodies such as the GAA could look to implement more structured screening protocols especially of adolescent athletes to detect changes in bone structure which would see earlier preventive measures being taken to prevent symptomatic FAI syndrome from becoming a problem. Increasing awareness of all relevant stakeholders is paramount to combating this issue. The current research has been presented at a number of scientific conferences, however the audiences at these conferences are largely scientific researchers in health science and there is a risk of missing the target audience who work at grassroots level with these athletes. To combat this issue a number of measures to communicate this research could be taken. For example, the GAA hold a "players" conference each year which is targeted at the individual athletes and coaching staff. This research could be presented here to make players and coaching staff aware of symptoms, consequences for performance and treatment options. More engagement with local sports partnerships will open a number of avenues to provide information for people working with both recreational and elite athletes. Finally, strategic use of social media platforms can provide meaningful and prolific discussion around the topic area to medical, coaching and administrative personnel.

7.3 Recommendations for Future Research in the area of FAI Syndrome

Based on the outcomes of this thesis a number of areas for future research will be discussed in this section: 1) The evolution of performance analysis in the area of hip impingement research, 2) The link between higher training volumes during skeletal maturation and the development of FAI syndrome, 3) The long-term implications of surgery among athletes and progression of FAI syndrome to OA and 4) The necessity of a randomised control trail for the comparison of treatment interventions among patients with FAI syndrome.

7.3.1 Analysis of Performance

While this thesis has provided novel information regarding the functional consequences of FAI syndrome among athletes there are several questions which remain unanswered. The ability of an athlete to perform the demands of their chosen sport is vital to determining the true outcomes of any intervention. While the tests carried out in this thesis do reflect aspects of sport necessary for performance, there are a number of areas which could be expanded upon. Firstly, the tests included in this research included a small number of repetitions and a definite recovery period, however, during field sports the work to rest ratio is often unpredictable. Participants in this study may not have experienced any element of fatigue which could have either not exacerbated symptoms enough to decrease performance or physical fitness of the athletes could have allowed them to score well on the individual tests, especially the sprint related tests. Further research protocols could include more fatiguing measures which have been utilised in previous research protocols among soccer athletes (Greig & Siegler, 2009), alternately a repeated sprint ability protocol, or the measurement of competitive game metrics. The use of GPS or related tracking software could be used in this scenario to assess the decrease in performance over time compared to athletes in related positions on the field (Malone et al., 2016). The patients in the current study reported greater levels of hip pain and stiffness with severe reductions in ROM both of which have been cited previously as signs of the condition (Philippon et al., 2007). Another useful method to achieve this would be the measurement of hip range of motion prior to and following competitive games to determine hip stiffness following intense physical exertion as well as grading pain and stiffness following activity.

7.3.2 Increased training volume as a risk factor for FAI syndrome

In the case of the development of a bony abnormality during skeletal maturation the results of this thesis indicate that an otherwise healthy group of athletes who developed FAI syndrome reported greater training volumes than a matched control group who did not develop a pathological hip condition. While the cause of FAI syndrome is undoubtedly multifactorial in nature, the results of this thesis support a growing body of research within the area (Agricola et al., 2014; Johnson et al., 2012; Siebenrock et al., 2004; Siebenrock et al., 2011; Tak et al., 2015) and highlight the need for extensive prospective research examining the development of hip morphologies among athletes as they progress throughout their playing career. Whether increased structured training for sport is indeed a modifiable risk factor for the development of bony deformities needs to be determined, the frequency, intensity and rest periods would need to be monitored also to gain a clearer understanding of the role of increased sports participation on bone development. Prospective studies involving systematic radiological screening of adolescent athletes are therefore required. This would include collecting x-rays and clinical examination of adolescent athletes over a prolonged period of time to measuring changes in hip morphology and detect symptoms in keeping with FAI syndrome. Implications of such research could increase the rate of screening of adolescent athletes and would allow for early detection of bony deformities. Furthermore, physical therapy interventions and behaviour modifications can then be implemented to reduce the risk of a bony deformity from developing to FAI syndrome requiring more invasive treatment. This type of research would need a large cohort to allow for drop out of sports participation during adolescence and to account for children who may be involved in multiple sports in comparison to those that compete in one discipline. Any potential results from a study such as this needs to be carefully disseminated, considering the potential to discourage parents from involving their children in competitive sport which would be counterproductive when tackling the already growing obesity epidemic among children worldwide (Ogden et al., 2016).

7.3.3 Long term effects of corrective surgery for FAI syndrome

The links between FAI syndrome and the development of osteoarthritis of the hip are becoming more apparent (Agricola et al., 2013) and the aim of corrective surgery is to prevent progression to total hip arthroplasty (THA). Long term benefits of corrective surgery appear to be effective in reducing the risk of THA (Byrd & Jones, 2009), however there is a paucity of research which follows the progression of pathological hip conditions among athletes who were treated for FAI syndrome surgically (or conservatively) and who returned to competitive play. Whether exposing the hip to higher mechanical loading could lead to further complications down the line, in terms of placing higher demands than general populations on a labrum that has been repaired or removed is unknown. The results of this thesis indicate immediate short-term benefits to sports participation following surgery and support much of the existing literature (Byrd, 2007; Byrd et al., 2016; Ellis et al., 2011; Philippon et al., 2010; Philippon et al., 2008; Philippon et al., 2007) with improvements in aspects required to compete, namely acceleration and agility with greater ranges of motion, and reductions in pain. However, the long-term effects of returning to competitive play after intervention are not known. Longitudinal prospective research which systematically examines function among this athletic group following return to play and retirement are therefore needed.

7.3.4 Randomised Control Trials

The current study includes a healthy control group for comparison with the athletic patients to examine the time x group interactions to assess whether the groups changed differently over time to one another. It was not possible to include a symptomatic patient group within the study design as a control group, which would have given a more distinct indication of the effect of surgery versus not undergoing surgical intervention for the correction of FAI syndrome. All patients included in the current research had undergone a measure of conservative treatment which did not improve symptoms before referral to the consultant. Recommendations for the comparison of physical therapy treatment group versus a surgical intervention group have been published previously (Griffin et al., 2016), any research of this nature should include three groups; a surgical treatment group, physical therapy group and control group with no treatment. This will allow for direct comparison of two treatment options versus not receiving treatment. The outcome measures used to determine efficacy of these treatments needs to be carefully considered and with the results of the current study in mind, need to be appropriate for the populations treated to assess the ability of the patient to meet their specific demands of daily living or sporting endeavours. A number of high profile randomised control trial proposals have been published recently and detail the procedures which will be put in place to compare the effects of arthroscopy versus conservative treatment for FAI syndrome. The proposals include a targeted conservative treatment protocol which includes pain management, strengthening exercises and administration of non-steroidal anti-inflammatories. The main limitation with the proposals which could lead to substantial variability among the arthroscopy group is the fact that a number of different surgeons will be used. The consultant experience and technique used could influence results observed. The second issue includes the fact that there is no standardised rehabilitation protocol being used for the surgery group, in comparison to the specific and uniform conservative treatment protocol for the non-surgical group. Preliminary results from the first of the reports (Griffin et al., 2018) has highlighted significant improvements among both group but the arthroscopy group had greater improvements than the physical therapy group.

7.4 Future recommendations in kinematic assessments of field sports

This research provides a template for further examination of joint kinematics in field sports by using different methods of performance analysis interchangeably. While a novel approach, the methodology in this thesis could be expanded upon further to gain a greater understanding of the range of motion a joint moves through during competitive play. The main limitation with the current study was the space available within the biomechanics laboratory to carry out the testing. To allow athletes greater freedom of movement a portable apparatus which measures hip movement may be more appropriate, this could include the use of sensor based equipment as discussed in Chapter 2.

In terms of use of kinematic profiling to determine risk of chronic injury, Stull et al. (2011) examined hip positioning during an ice hockey stride and defined at risk positioning as internal rotation during flexion and external rotation during abduction. The authors suggested that the hip position necessary for the ice hockey stride was a risk factor for labral damage in the presence of underlying FAI syndrome. That study did not include the frequency of strides throughout and entire game which would have given a greater understanding of the demands of the game on the joint. The current study does provide a more detailed analysis of the frequency of the movements carried out during the game as well as the breakdown of hip movement within each movement. Further research could assess athletes specifically with FAI syndrome to determine if movement patterns are altered to carry out the movements required for the game of hurling. This potential compensatory mechanism could lead to either further injury elsewhere, or a decrease in performance if athletes are unable to employ a suitable body position carry out the movements efficiently.

Both kinematic and kinetic variables may be quantified for a field sport using the template provided in the current study, including angular velocity, to determine the rate of angular displacement at a joint. This could be employed to quantify changes in the quality of movement following fatigue (Tamura et al., 2017) associated with 70 minutes of intense hurling play. Notational analysis combined with 3D assessment of this measure may reduce injuries associated with fatigue due to more informed decision making among coaching staff involved with field sport athletes. Three-dimensional optoelectronic assessment could be used to quantify the level of reduction in movement quality and notational analysis to determine the point at which this is likely to occur during a game. In terms of injury surveillance in field sports, it is important that coaching staff be aware of the demands placed on the body both in training and competition. Research that utilises as many performance analysis techniques as possible to gain a greater understanding of these demands may serve to educate coaching and physical therapy staff involved with athletes who can then implement more informed strategies to reduce the risk of injury. Future research in the area of FAI syndrome could look to examine the hip kinematics of an athlete with FAI syndrome both prior to and following intervention, whether that be arthroscopy or physical therapy. This will serve to determine how athletic patients are carrying out these movements as a result of the condition compared to healthy athletes and whether significant changes in movement patterns are employed following intervention.

Appendices

8.1 Informed Consent

Waterford Institute *of* Technology
INSTITIÚID TEICNEOLAÍOCHTA PHORT LÁIRGE

WATERFORD INSTITUTE OF TECHNOLOGY

RESEARCH - INFORMED CONSENT FORM

I. <u>Project Title</u>:

Femoroacetabular Impingement: Prevalence and performance changes following arthroscopic surgery.

II. <u>Introduction to this study:</u>

Femoroacetabular Impingement is a condition which affects the tissues in the hip joint causing pain and reduced range of motion. This is a chronic condition and conservative treatments have been found to be unsuccessful in most cases with surgery usually being required to repair the damaged tissue. This type of hip dysfunction is particularly prevalent in young athletic populations. Results from previous studies have shown a high percentage of athletes return to competitive sport without further complications, although the tests used to assess the patients have been pain related tests. Research regarding arthroscopic surgery and tests that assess the functional capabilities of athletes requires further investigation

III. <u>I am being asked to participate in this research study. The study has the following purposes:</u>

1. To assess the effect of impingement on functional performance.
2. To track changes in performance following arthroscopic surgery.

IV. <u>This Testing will take place in the Waterford Institute of Technology Sports Campus</u>

V. <u>This is what will happen during the research study:</u>

I will be required to undertake a number of functional movement tests before surgery, 3 months and one year post-surgery. These tests include:

- 10m Sprint.

- Agility T Test
- Single Leg Drop Jump
- Deep Squat.
- Flexibility Testing

The tests will be video recorded so that they can be analysed in further detail at the Waterford Institute of Technology.

VI. There are no envisaged risks or side effects associated with participation in this study:

The risks involved in this study are minimal; there may be a mild feeling discomfort during some of the tests.

VII. There may be benefits from my participation in this study. These are:

As a result of participating within the trial, you will receive a performance profile which will track your scores and give you a clearer indication of how they have changed over time following your surgery and return to competitive sport.

VI. My confidentiality will be guarded:

Waterford Institute of Technology will protect all the information about you and your part in this study. Your identity or personal information will not be revealed, published or used in future studies. The study findings including some associated diagnosis information from the surgeon will form the basis for preparation of a postgraduate thesis, academic publications, conference papers and other scientific publications. The video records of my tests will be kept only for analysis purposes and will be destroyed immediately following analysis.

VII. If I have questions about the research project, I am free to call Karen Mullins at telephone no.0851322287:

VIII. Taking part in this study is my decision.

If you do agree to take part in the study, you may withdraw at any point. There will be no penalty if you withdraw before you have completed all stages of the study. Your medical treatment will not be affected in any way.

IX. Signature:

I have read and understood the information in this form. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I consent to take part in this research project entitled: "*Femoroacetabular Impingement: Prevalence and Performance outcomes following arthroscopic surgery*"

Signed: ____

Date: ____

Witness: ____

Signature

8.2 Participant Questionnaire

Patient Questionnaire

Name______________________ **D.O.B**__________________

Please tick all the sports that you currently engage in/ Train for regularly

Hurling	Gaelic Football	Rugby	Soccer
Club Senior	Club Senior	Senior Club	Club U18
Club Intermediate	Club Intermediate	Junior Club	Club/League of Ireland U19
Club Junior	Club Junior	Senior Provincial	Senior League of Ireland
Club U21	Club U21	U20 Club	Provincial Senior League
Club Minor	Club Minor	U20 Provincial	International u18
County Senior	County Senior	U20 National Team	International U21
County U21	County U21	U19 Club	Senior International
County Minor	County Minor	U19 Provincial	College
Freshers	Freshers	U19 National Team	School
Fitzgibbon	Sigerson	School/College	
School Team	School Team		

If other please state and include grade/s____

Which hip is causing pain?

Left ☐ **Right** ☐

Which Leg do you kick with?

Left ☐ **Right** ☐

Other Lower Limb Major Injury History (injuries requiring greater than 3 weeks recovery)

Injury	Time lost from full Training/Competition	When did the injury occur	Leg (Right or Left)

How long did you have hip/groin pain before you were diagnosed with impingement?

____

Have you continued to play since being diagnosed (up to now)?

Yes ☐ No ☐

If No, please indicate <u>how long</u> it has been <u>since participation in sport</u>

____

To what extent has your participation in training been diminished/ reduced since the onset of hip pain?

No Reduction ☐

To a minor Extent ☐

To a moderate extent ☐

To a major extent ☐

Cannot participate at all ☐

To what extent has your participation in competition been diminished/ reduced since the onset of hip pain?

No Reduction ☐

To a minor Extent ☐

To a moderate extent ☐

To a major extent ☐

Cannot participate at all ☐

Activity levels in previous 48 hours

Example: Hurling Match, 60 minutes, High Intensity

Activity	**Duration**	**Intensity (Low, Moderate , High)**

When was your last meal? ____

What did you have? ____

Approximately how much water have you consumed within the last 24 hours?

____

Please List the different <u>organised</u> sports you trained for/played during the week between the ages of 10 - 15 years?

Sport	**School/Club/Both**

On an average week, between the ages of <u>10-12 years</u> (just prior to secondary school) how many <u>hours per week</u> (total) did you engage in organised training for the sports listed above?

____

On an average week, between the ages of <u>13-15 years</u> (early years of secondary school) how many <u>hours per week</u> (total) did you engage in organised training for the sports listed above?

____

8.3 Rehabilitation Protocol

Rehabilitation Programme following Hip Arthroscopy

Date of Procedure:		
During your surgical procedure you have had:	Labral repair ☐ Labral debridement ☐ Osteoplasty/removal of bone from femoral neck ☐ Osteoplasty/removal of bone from acetabulum/cup ☐ Debridement of Articular Cartilage ☐ Removal of Loose Body ☐ Microfracture ☐	
You will be on crutches for approx 1 week	Non-weightbearing x week	Partial-weightbearing x week
Restrictions	No forced Hip Extension i.e Hip flexor Stretches for first 4 weeks No external rotation (turning foot outwards) of hip for first 4 weeks No Weight Bearing hip Rotation until after first review No Deep Squats until after second review Don’t force your knee into your chest No impact exercise i.e Power walking/Running	

❖ The Hip Joint

The hip is a ball-and-socket joint and is the largest weight-bearing joint in the body. The head of the femur (thigh bone) forms the ball which fits into the acetabulum, a cuplike cavity in the pelvic bone that forms the socket.

Ligaments connect the ball to the socket. The joint surfaces are covered with a strong smooth layer of articular cartilage. The acetabulum has a layer of fibrous cartilage around the rim called the labrum, which holds the head of the femur securely in the joint. Other surfaces of the joint are covered with a synovial membrane, this produces synovial fluid which lubricates the joint and reduces the friction that occurs with movement.

❖ Procedure for Hip Arthroscopy

Due to the development of techniques and instruments, hip arthroscopy has become an option for evaluating and treating a variety of hip conditions, particularly hip problems in the young, active patient. Hip arthroscopy is a minimally invasive procedure.

Traction is placed on your leg to create more space within your hip joint to allow the entry of surgical instruments. Several small incisions are made around your hip. These small incisions allow the passage of a thin telescope/camera (arthroscope) to inspect your hip joint and passage of surgical instruments which are used to shave, trim, cut, smooth or repair the affected areas.

X-Rays are used to guide the arthroscope and the surgical instruments. Hip arthroscopy can be a lengthy procedure lasting between 2-3 hours.

If examination of your hip with the arthroscope indicates further surgical treatment, this will be performed at the time of your surgery. It may not be possible to gain access to your hip safely and arthroscopic surgery therefore would not be possible. You may have some numbness associated with the traction and local anaesthetic used at the end of the surgery which can take some time to resolve.

Indications for Hip Arthroscopy

The majority of patients who require hip arthroscopy are young and active with a history of hip pain.

Common causes of hip pain are –

- Labral tears
- Hip impingement
- Articular cartilage injuries
- Loose bodies

Less common causes of hip pain are –

- Tendon or ligament injuries
- Instability of the hip joint
- Synovial disorders
- Infections in the hip

If you are young and active and have experienced hip pain that has not improved with conservative treatment consisting of anti-inflammatory medications and physiotherapy for greater than six-months, you may be a candidate for arthroscopic surgery.

❖ Common causes of hip pain and their treatment

What is Hip Impingement?

Hip impingement is due to reduced clearance between the head and neck of the femur and the rim of the acetabulum. Activities that result in the femur and the rim of the acetabulum rubbing together, such as, running, bending over and sitting can cause an increase in symptoms.

What is the treatment for Hip Impingement with Hip Arthroscopy?

Surgical instruments will be used to trim the head and neck of the femur and the acetabulum to enable more joint clearance. This should relieve hip impingement.

What is a Labral Tear?

The acetabulum has a layer of fibrous cartilage around the rim called the labrum, which holds the head of the femur securely in the joint. Injury or wear and tear can result in a labral tear. Common symptoms of labral tears are locking or catching in the joint and hip and groin pain.

What is the treatment for a Labral Tear with Hip Arthroscopy?

Surgical instruments are used to remove the torn tissue and smooth the edges of the torn labrum. In some cases, sutures may be used to repair the labral tear.

What is an Articular Cartilage Injury?

Articular cartilage covers the joint surfaces of the head of the femur and the acetabulum, allowing smooth movement between them without causing damage. Articular cartilage tears can result from activities like running or jumping, friction due to hip impingement or wear and tear of the hip j`oint.

What is the treatment for Articular Cartilage Injury with Hip Arthroscopy?

Surgical instruments are used to remove the damaged tissue and smooth the edges of the tear.

What are Loose Bodies?

Loose bodies are often due to trauma, such as a fall, a sports injury or a road traffic accident and may also occur as a result of wear and tear. A common symptom of a loose body is a feeling of catching in the joint.

What is the treatment for Loose Bodies with Hip Arthroscopy?

Surgical instruments are used to remove the loose bodies.

❖ What are the Benefits of Hip Arthroscopy?

- To confirm what is causing your symptoms and treat the problem
- To relieve pain - hip arthroscopy resolves or reduces symptoms for most patients. Unfortunately, some patients experience no benefit and some patients may be worse after surgery.
- Relieve symptoms of locking or catching.
- Improves the stability of your hip joint.

Most patients have a little discomfort following hip arthroscopy. You may experience postoperative muscle and soft tissue pain, particularly around the hip and thigh.However, if your pain becomes severe, or if you develop a fever, prolonged calf pain, shortness of breath, or chest pain, please **contact us** or your GP immediately (see contact details on last page).

Your first review at a clinic will be approximately 6 weeks following your operation.If you have any concerns before your review, please **contact us** (see contact details on last page).

❖ Possible Complications

- Increase in symptoms

- Prolonged traction can result in temporary weakness or numbness in the groin and thigh, this normally resolves.
- Instrumentation breakage – a small incision may be required for removal of the broken instruments.
- It may not be possible to gain access to your hip arthroscopically.
- Infection
- Trochanteric bursitis, which is inflammation of the fluid-filled sac that lies over the bony prominence on the outside of the thigh bone.

Rehabilitation Programme

- This booklet provides guidance through each stage of your rehabilitation.

- *It is important that you participate and progress though the following rehabilitation programme as your hip will have reduced strength and movement after surgery. This programme will help you to regain stability at your hip enabling your return to sporting and day to day activities.*
- You should progress through therapy according to the protocol described in this leaflet. Your physiotherapist will guide you through each stage of your exercise programme and provide you with detailed explanations of the exercises described in this booklet. The times specified for each stage are guidelines only.
- Mr Carton may advise you to spend longer at each stage due to your operative treatment. You will be advised of this before discharge.

- If you develop excessive pain or your swelling increases following exercise, the exercise may be too vigorous. If this occurs return to your previous level of activity and gradually build your activity up again.

Stage 1- Initial phase Week 0 - 2

Aims

- Reduce pain and swelling
- Normalise your walking pattern
- Improve your hip muscle strength and core strength
- Improve movement at your hip in abduction, flexion and light ext.rotation
- Regain static balance

How to use stairs

- If you come across stairs/steps then lead with the un-operated (Good) leg going up and bring the operated (Bad) leg up to the same step.
  Going down bring the operated (Bad) leg down first then the un-operated (Good) leg to the same step.
- The easiest way to remember this is:
  'Good Leg goes up to Heaven, Bad Leg goes down to Hell'
- As soon as you're comfortable however try to negotiate stairs normally i.e. one step past each other.

❖ Home Exercise Programme

The following exercises can be started once you have been seen by the physiotherapist and continued on returning home.

- Activity/Exercise/Movement should be performed for 5-10 minutes, every couple of hours that you are awake to maintain freedom of movement and strength in the early stages. **Little and Often.** This 5-10 minutes should be filled with a combination of sitting/lying/standing/bike and mobilising.
- The activity/exercise can vary depending on the position that you find yourself **(Bed or Sitting or Standing)** i.e. you do not need to lie down to do exercises as there are chair/standing ones instead.
-

Improve / Maintain cardiovascular fitness

- **Walking** – You will usually be on **crutches for approximately 1-2 weeks**. You may start to go for short 5-10 minute walks around the house to retain hip mobility, improve circulation and prevent adhesions forming within the hip.

- **Stationary bike** (This can be started the day following surgery)- Beginwith high saddleand low resistance programme, then gradually increase resistance and speed. **The purpose of the bike is to retain the mobility and normal movement within the hip joint while the structures surrounding are settling and healing.**

Begin with 5 minutes and increase this by 5 minutes every 3-4 days up to a maximum of 30 minutes

You can begin to add the resistance at the end of the 3rd week.

Chair/Sitting Exercises

When you find yourself sitting during the day then this is an excellent opportunity to do some seated exercises. You will probably be sitting more often than any other position.

Foot and Ankle pumps/Hip flexion

Lift your hip up into slight flexion by rising up and down onto your toes. This will allow some small movement at your hip. Progress this exercise by slightly lifting your foot from the floor and holding for 2/3 seconds. You don't need to go very high, just get the feeling of taking pressure off your foot.

Hip Abduction

Keep your feet close together. Move your two knees in and out from each other. You can use your hands to provide some support/control.

Quadriceps/Knee Extension

Pull your toes up, tighten your thigh muscle and lift your leg out straight. Return to start position.

If you have any soreness around the knee with this exercise then do not perform.

Static hip adduction/abduction

Place your fists between your knees and squeeze against them to feel a pull in the groin. Hold 2/3 seconds.

Place your hands on the outsides of your knees and push knees out to feel a pull around the outer thigh/incision area. Hold 2/3 seconds

Standing Exercises

Any time you find yourself standing for a few minutes then take the opportunity to do some exercises e.g. while standing by a worktop/sink, while brushing teeth, having a wash, talking to someone

Lateral Weight shifts – Hold onto a stable object like the worktop or sink. Sway side to side shifting your weight from one leg to the other.

Hip Pendulum Exercise

Stand holding onto a stable object. Swing your operated leg forwards and back to midline, slowly like a pendulum.

Perform this exercise gently at first especially when it moves backwards into extension

Hip abduction

Stand holding on to a support, raise your affected leg out to the side and return to start position keeping your trunk straight throughout the exercise.

Knee Lifts/Marching on the spot

Standing holding onto a stable support and take slow steady steps on the spot

Heel/Toe raises

Stand holding onto a stable surface and rock your weight back onto your heels so your toes lift a little, then rock forward onto your toes so your heels rise up

Stage 2 - Approximately Week 3 and 4

Criteria for Progression:

- **Have NO difficulty with first 2 weeks exercises**
- **Have minimal or no swelling**
- **Be able to stand on single leg for 5 seconds without pain**

Aims

- Improve muscle strength
- Improve core strength
- Improve balance
- Improve / maintain cardiovascular fitness

Continue with above exercises

Improve strength

Straight leg raise

Tighten thigh muscle as with static quadriceps/hamstrings co-contraction and lift your leg straight off the bed. Keep your knee as straight as possible. Then, gently lower.

If this exercise causes deep pain then leave it or perform it sitting in a chair and raising the foot from the floor.

Bridging Exercise

Lie on your back with your knees bent and feet flat on the bed. Tighten your bottom muscles and push your feet onto the bed so that your bottom

lifts until your torso and thighs are level (see picture)

Progress core stability exercises

For information on appropriate core stability exercises go to www.hipandgroinclinic.ie > Rehabilitation> Groin Strain > 'Core Muscles' pdf

Improve movement

- **No weight bearingrotation at your hip until after your first review**
- **Hip rotation in standing**
  Stand holding onto something stable. Keep your knee straight rest the heel of your foot on the floor and then turn your foot out and then return to staring position, without rotating your pelvis. Repeat 10 times.

  Progress this by bending knee and placing knee of operated leg onto a chair. Rotate the hip by moving your foot outwards from your body.

- **Begin Gentle Stretches**
  Try to spend 5 minutes doing stretches twice a day. Each stretch should be held for 15-20 seconds and you should do each of them 3-5 times.

  - **Adductor/ Groin Stretch**
  - **Quadriceps Stretch**
  - **Calf Stretch**
  - **Hamstring stretch**

  For information on these stretches go to www.hipandgroinclinic.ie >Rehabilitation> Groin Strain > 'Main Hip Muscles' pdf

Improve balance – begin when able to walk without crutches

- Lateral weight shifts – moving from side to side
- Single leg stance
- Walking along lines / beam

Hydrotherapy / Swimming – Once your wounds have fully healed

Start with 5 minutes of exercises including those below. If you can swim then break up the 5 minutes sessions with 2 lengths of either front crawl or backstroke, then continue with another set of 5 minutes.

- Attend the swimming pool daily
- Forward and backward walking
- Hip strengthening exercisesin standing –
  Briskly swing your leg forwards and backwards like a pendulum.

  Bring your affected leg out to the side and back to thestart position, don't lean to the side.

  Move your leg briskly through the water as this increases the resistance provided by the water.

- Straight leg kick
- Walking on your heels/toes/walking on the spot
- Calf Raises
- **NO BREASTSTROKE**

Improve / Maintain cardiovascular fitness

- **Walking** – You may start to go for short 5-10 minute walks and do more around the house to break down any scar tissue inside the hip
- **Stationary bike**
-

Stage 2- Intermediate phase Week 4 – 6

Spend 10 minutes 2-3 times per day with a combination or stretching/core stability/hip strengthening and 30-45 minutes 5 days per week on cardio exercises

Criteria for progression:

- **Able to contract and hold Transversus Abdomonus muscle while performing bridging exercise**

Aims

- Mobilise anterior hip muscles
- Improve muscle strength /core strength
- Improve balance
- Improve / maintain cardiovascular fitness

Improve strength

Begin gentle progressive resistive exercises, no resistance initially then slowly increase resistance using light weights

- **Straight Leg raise with resistance (ankle weight)**
- **Hip extension**
  Lying on your front, tighten your tummy, squeeze your bottom and lift your thigh off the bed

Improve balance

- Side-stepping
- Single-leg standing with movement e.g. brushing teeth

Improve Movement

- **Progress Stretches (See Website)**
    - **Hip Flexor Stretch (this must only be performed gently)**
    - Combined Groin Stretch

Improve / Maintain cardiovascular fitness

- Continue with pool work but increase time/resistance
- Stationary bike–Keep the high saddleand gradually increase resistance and speed.
- Stepper
- **Walking – It is now beneficial to go for short 15-20 minute walks to break down scar tissue**

Hydrotherapy / Swimming

- Continue with some of the previous pool exercises and add:
  - Kicking legs lying on your back
  - Kicking legs lying on your front
  - Using float/noodle around foot and pushing legs up/down
  - Mini-squats
  - Lunging
  - Bouncing
  - Marching on the spot with high knee lifts

Stage 3 - Advanced phase **Weeks 6 – 12**

Spend 10 minutes twice per day on stretching/strengthening exercises and 45+ minutes on cardio exercises 5+ days per week

Criteria for progression:

- **Able to hold straight Leg Raise for 5 seconds and repeat 5 straight leg lifts**
- **Able to repeat 5-10 double-leg bridging lifts and hold for 10-15 seconds**

Aims

- Improve functional strength of hip flexors

- Improve core strength and stability
- Improve hip extension and rotation movements
- Improve Cardiovascular fitness

Week 6- 9

Improve strength

- Progressively increase resistance
- Bridging – Progress now onto single-leg bridging
- Functional strengthening exercises, such as,
    - Step-downs
    - Single-Leg mini squats
    - Lunges
    - **No deep squats**

Improve movement and maintain flexibility

- Begin hip rotation movements at Week 6
- Progress Stretches (see Website):
    - Figure 4 stretch (FABER)
    - Piriformis (buttock) stretches (be careful with this if labral repair or bone removed)
    - Hip Flexor stretch
    - Iliotibial Band (be careful with this if labral repair or bone removed)

Improve cardiovascular fitness

- Exercise bike- Maintain high seat and then gradually lower as comfortable
- Aqua-jogging (from about 6 weeks)
- Breaststroke – You may start this from about 8 weeks
- Rowing machine – Gradual increase in hip flexion without rotation

Week 9+

Criteria:

- **Single leg bridging hold for 5-10 seconds**
- **Good knee control during single-leg mini squat**
- **No pain during previous stretches**

Improve cardiovascular fitness

Rowing Machine

Cross-trainer from about 8 weeks when comfortable with other cardio exercises and walking outdoors

Hydrotherapy / Swimming

Aqua-aerobics

Breast-stroke

Initiate activity specific exercises

Recreate your intended activity in a controlled way. e.g. golf swing

Initially complete all drills at 50%, then progress to 70%, then to 85%, and finally to 100%

Stage 4 – Return to Activity Week 12-16

Criteria:

No difficulty with any of the first 12 weeks worth of exercises or pain following exercise.

- **Following most procedures return to activities could be achieved by week 12 but may be longer.**

Return to Activity guidelines

Swimming	At 2 weeks provided wound has healed. Straight leg kick only. No Breaststroke
Cycling	Exercise bike from 1-2 weeks Cycle outside on level terrain at 8-8 weeks (depending on comfort and safety)
Aerobics	Low impact at 10 weeks
Golf	Full swing from 12 Weeks

❖ *Review Appointments*

Patients will be reviewed at 6 weeks and 12 weeks with Mr Carton, and 1 year post-op at a practitioner led clinic. Outcome Measures will be taken at 12 weeks, 1 year, 2 years and 5 years.

If you require any furtheradvice or have any concerns, please contact us – see contact details below.

- **Please contact our physiotherapy team should you have any questions or concerns:**

Physiotherapy:

Shane Walsh, Orla Dunphy, Derek O Neill

Telephone: 051 33743

8.4 Informed Consent Phase 2

Waterford Institute *of* Technology
INSTITIÚID TEICNEOLAÍOCHTA PHORT LÁIRGE

WATERFORD INSTITUTE OF TECHNOLOGY

RESEARCH - INFORMED CONSENT FORM

I. Project Title:

An examination of the levels of hip range of motion during hurling match play

II. Introduction to this study:

Both hurling and Gaelic football have seen a substantial increase in the number of claims made for hip related injuries, although hurling seems to have seen a greater increase in hip related claims than football. Whether the movement patterns of specific sports can influence the rate of damage to the hip joint has not be established. Gaining a greater understanding of the movement patterns involved in hurling can inform clinical practitioners as to whether specific movement patterns required for the game may exacerbate symptoms of hip impingement in particular if the athlete is predisposed to that particular condition.

III. I am being asked to participate in this research study. The study has the following purposes:

1. To allow video recording of you playing a competitive hurling match which will be analysed
2. You may be asked to complete a non-invasive lab based assessment at a further date

IV. This research study will take place where the hurling matches are scheduled to be played

V. This is what will happen during the research study:

I will be required to play a hurling match as normal where I will be video recorded. Three dimensional assessments include reflective markers which will be placed on bony landmarks around the body. I will then be required to carry out movement patterns common to hurling which the cameras will record.

VI. There are no envisaged risks or side effects associated with participation in this study:

None

VII. There may be benefits from my participation in this study. These are:

.

VI. My confidentiality will be guarded:

Waterford Institute of Technology will protect all the information about me and my part in this study. My identity or personal information will not be revealed, published or used in future studies. The study findings will form the basis for preparation of a postgraduate thesis, academic publications, conference papers and other scientific publications. The video records of my tests will be kept only for analysis purposes and will be destroyed.

VII. If I have questions about the research project:

I am free to call Karen Mullins at 0851322287 or Dr. Michael Hanlon at telephone no. 051-302166

VIII.Taking part in this study is my decision.

If I do agree to take part in the study, I may withdraw at any point. There will be no penalty if I withdraw before I have completed all stages of the study.

IX. Signature:

I have read and understood the information in this form. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I consent to take part in this research project entitled: “*An examination of the levels of hip range of motion during hurling match play”*

Signed: ______________________________

Date: ______________________________

8.5 Pilot work with Organic Motion

Pilot Testing -Organic Motion Analysis

Two intercounty hurlers were brought to the Organic Motion Capture system at for analysis of three dimensional kinematic patterns of the hip associated with hurling match play. Twenty-two infrared cameras were used to record the movements while Motion Monitor software was used for subsequent generation of hip angular data during the movements analysed.

To calibrate the system all lighting was firstly switched off, and using a linear plastic wand with an LED attached to the tip, a figure of eight motion was carried out while moving around the entire testing area, ensuring to raise the wand high and low as well as to the outer limits of the testing area. This was used to determine the size of the area and was completed when all 22 cameras have found the LED. Next, a L-shaped metal bar with 3 LEDs with specific distances apart from one another was placed in the centre of the laboratory. A minimum of two cameras that could identify all 3 LEDs was considered sufficient to give the cameras orientation and scale.

Assessment

To examine the accuracy of the system in comparison to previous literature, athletes carried out a walking and running protocol. The athletes were required to wear tight black clothing and black footwear for the duration of the assessment as lighter colours may fade into the background of the system and may not be picked up by the cameras. Players first completed a 10 minute dynamic warm up which included 2X10m jogging, skipping, lunging, sprinting and then stretching mainly of the lower limbs. An electronic goniometer was placed around the waist of the athletes and was worn for all movements.

Due to the small size of the particular 3D lab used, all running based assessments were carried out on a standard treadmill. While there has been previous research to suggest that there are significant differences between overground and treadmill running with regard to hip kinematics (Schache et al., 2001) the authors did note that the differences were subtle and a high powered treadmill could be used for laboratory based assessment of typical kinematic patterns of the pelvic/lumbar and hip complex during running. The main differences identified in this research were seen in the differences in hip flexion and extension during treadmill running. It was found that treadmill running was associated with increased hip extension at “toe off” during the running cycle. This was attributed to the likelihood that the belt itself was dragging the hip joint into extension during the prolonged stance phase and decreased stride length that was noted with treadmill running. While these subtle differences have been identified, there is much inconsistency throughout the remaining literature with regard to the differences between over ground and treadmill running and walking. Researchers used a variety of different treadmill types, and making comparisons is difficult due to variations in belt speeds with different treadmill models. The benefits of using a treadmill for such assessment includes the fact that speed can be controlled and limited space is required to complete the testing. To begin the tests participants began walking on the treadmill at a speed of 4km and once participants were comfortable, the cameras recorded for a total of ten consecutive steps. Participants then increased the speed to 8km and when in a comfortable jogging rhythm, cameras again recorded for ten consecutive steps.

Results

Maximum hip angular data was determined in three planes of motion for four basic tests which included forward walking at a speed of 4km/hr, backward walking at a speed of 3km/hr, forward running at a speed of 8km/hr and backward running at a speed of 7km/hr and are presented in the tables (Table 8.1, 8.2, 8.3 & 8.4) below. Values that were considered to be considerably higher than normal reported values are highlighted in yellow.

Table 8.1 Maximum values for hip angular data during forward walking in three planes of motion

Movement	Participant 1		Participant 2	
	Left Leg	Right Leg	Left Leg	Right Leg
Hip Flexion (deg.)	24.9	32.6	28.7	27.8
Hip Extension (deg.)	28.6	17.1	18.9	19.4
Hip Abduction (deg.)	11.5	8.7	4.1	2.1
Hip Adduction(deg.)	8.9	7.0	6.9	7.1
Hip Internal Rotation (deg.)	5.1	27.0	24.5	6.6
Hip External Rotation (deg.)	45.2	43.7	16.9	25.3

Table 8.2 Maximum values for hip Angular data during backward walking in three planes of motion

Movement	Participant 1		Participant 2	
	Left Leg	Right Leg	Left Leg	Right Leg
Hip Flexion (deg.)	34.5	37.7	23.7	28.5
Hip Extension (deg.)	12.4	3.4	12.9	9.5
Hip Abduction (deg.)	24.7	8.1	5.6	3.4
Hip Adduction(deg.)	4.1	35.3	7.0	5.3
Hip Internal Rotation (deg.)	0	81.0	14.1	16.3
Hip External Rotation (deg.)	51.4	22.3	20.7	27.7

Table 8.3 Maximum values for hip angular data during forward running in three planes of motion

Movement	Participant 1		Participant 2	
	Left Leg	Right Leg	Left Leg	Right Leg
Hip Flexion (deg.)	31.1	33.2	34.1	30.7
Hip Extension (deg.)	21.4	18.1	17.1	17.6
Hip Abduction (deg.)	10.7	3.4	0.9	3.8
Hip Adduction(deg.)	6.4	6.6	8.2	6.9
Hip Internal Rotation (deg.)	0	10.1	8.2	2.1
Hip External Rotation (deg.)	37.6	16.1	24.2	26.7

Table 8.4 Maximum values for hip angular data during backward running in three planes of motion

Movement	Participant 1		Participant 2	
	Left Leg	Right Leg	Left Leg	Right Leg
Hip Flexion (deg.)	44.4	39.9	26.9	26.9
Hip Extension (deg.)	15.0	6.0	4.4	7.5
Hip Abduction (deg.)	22.6	9.0	5.2	5.1
Hip Adduction(deg.)	3.1	22.9	4.8	5.2
Hip Internal Rotation (deg.)	4.4	45.0	3.0	13.4
Hip External Rotation (deg.)	48.1	21.8	26.9	23.5

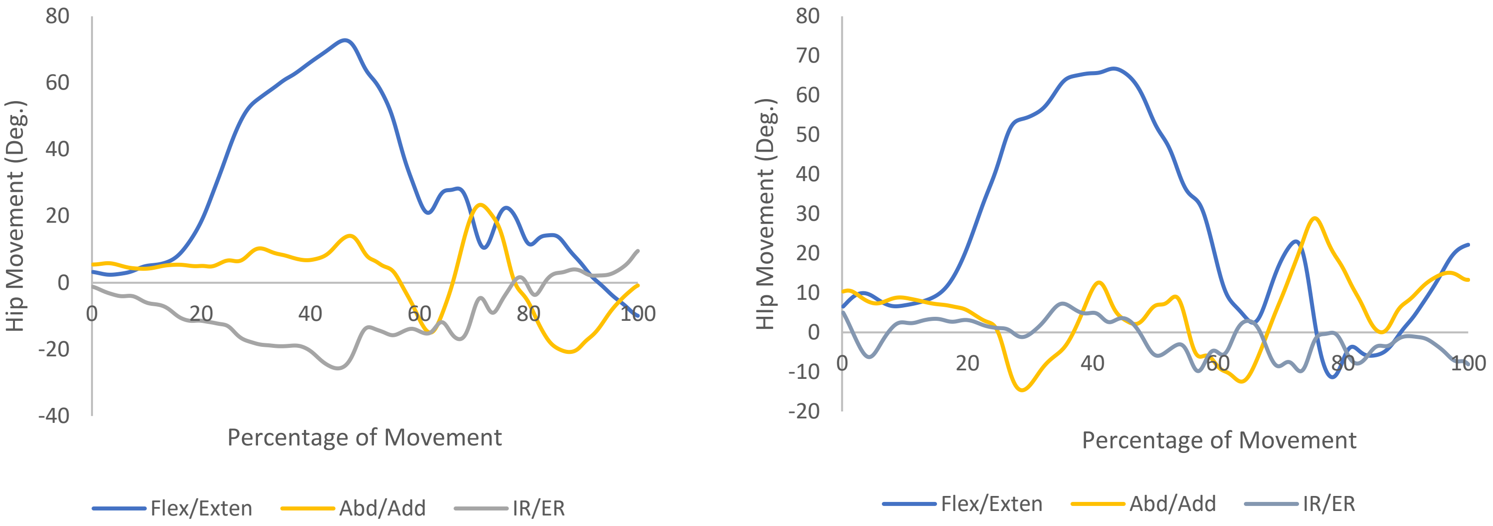
Comparison to previous literature

The data collected was visually inspected and compared to that which has been previously reported throughout existing literature. In the sagittal plane values recorded in the current study are comparable to that which has been reported previously with approximately 40° of flexion, and 10° of extension (Kadaba et al., 1990). However, the values recorded in the transverse plane appeared to be significantly greater than those reported preciously for all four walking/running tasks; 81° compared to 5-10° reported previously (Isacson et al., 1986; Kadaba et al., 1990; Sutherland et al., 1980). In some cases, the values recorded exceed end range of motion for the hip joint and therefore were considered inaccurate. The frontal plane data was somewhat consistent with previously literature however, due to the large emphasis on rotation during hurling movement patterns, e.g. striking the ball, side-line cut, etc transverse plane data was a vital component in the assessment of hurling movement patterns and could not be excluded.

Conclusion

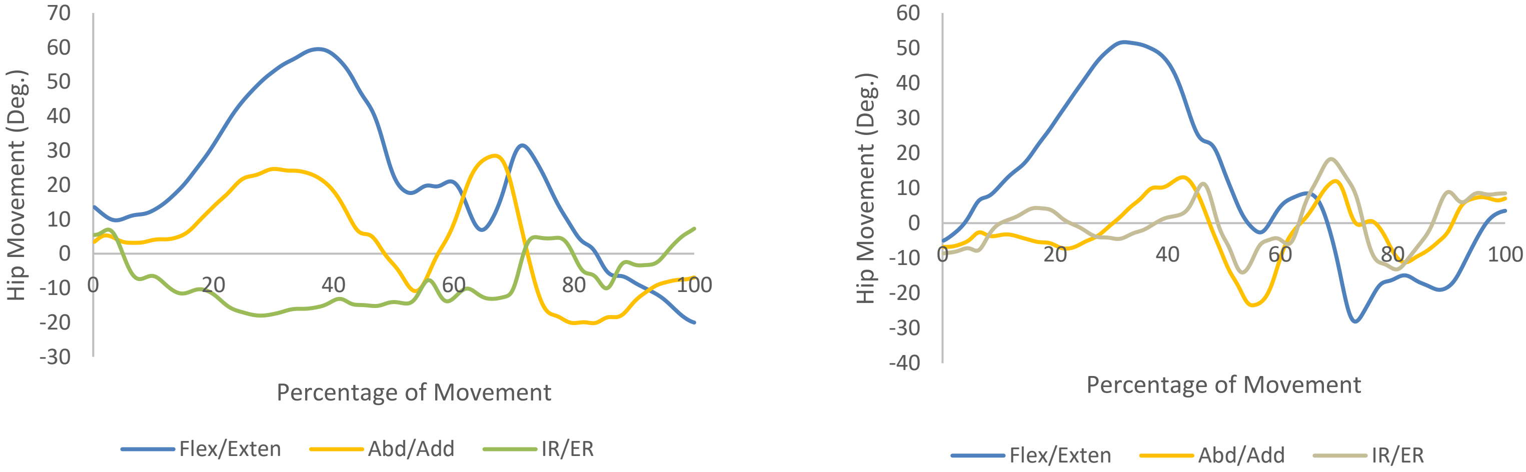
Due to the considerable inconsistencies with data reported from previous literature and the fact that some values exceeded the limits of movement in the hip joint the Organic Motion software was accurate enough for transverse movements and therefore excluded from use within the assessment of hurling movement patterns. A marker based motion capture system which has been reported to be a more accurate indication of 3D movement was therefore used for the study.

8.6 Time Series Graphs for Free taking


(a) Left Leg

(b) Right Leg

Figure 8.6.1 Side-line cut participant A
Postive values indicate; flexion, abduction & External Rotation


(a) Left Leg

(b) Right Leg

Figure 8.6.2 Side-line cut participant B
Postive values indicate; flexion, abduction & External Rotation

Figure 8.6.3 Side-line cut participant C
Postive values indicate; flexion, abduction & External Rotation

8.7 Bibliography

Aalto, T. J., Airaksinen, O., Härkönen, T. M., & Arokoski, J. P. (2005). Effect of passive stretch on reproducibility of hip range of motion measurements. *Archives of Physical Medicine and Rehabilitation*, *86*(3), 549–57.

Agricola, R., Heijboer, M. P., Bierma-Zeinstra, S. M. A., Verhaar, J. A. N., Weinans, H., & Waarsing, J. H. (2013). Cam impingement causes osteoarthritis of the hip: a nationwide prospective cohort study (CHECK). *Annals of the Rheumatic Diseases*, *72*(6), 918 LP-923. Retrieved from http://ard.bmj.com/content/72/6/918.abstract

Agricola, R., Heijboer, M. P., Ginai, A. Z., Roels, P., Zadpoor, A. A., Verhaar, J. A. N., … Waarsing, J. H. (2014). A Cam Deformity Is Gradually Acquired During Skeletal Maturation in Adolescent and Young Male Soccer Players A Prospective Study With Minimum 2-Year Follow-up. *The American Journal of Sports Medicine*, *42*(4), 798–806.

Agricola, R., Waarsing, J. H., Arden, N. K., Carr, A. J., Bierma-Zeinstra, S. M. A., Thomas, G. E., … Glyn-Jones, S. (2013). Cam impingement of the hip—a risk factor for hip osteoarthritis. *Nature Reviews Rheumatology*, *9*(10), 630–634.

Allen, D., Beaulé, P. E., Ramadan, O., & Doucette, S. (2009). Prevalence of associated deformities and hip pain in patients with cam-type femoroacetabular impingement. *Bone & Joint Journal*, *91*(5), 589-594.

Amenabar, T., & O'Donnell, J. (2013). Return to sport in Australian football league footballers after hip arthroscopy and midterm outcome. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*, *29*(7), 1188–1194.

Aminian, K., & Najafi, B. (2004). Capturing human motion using body-fixed sensors: outdoor measurement and clinical applications. *Computer Animation and Virtual Worlds*, *15*(2), 79–94.

Aprato, A., Jayasekera, N., & Villar, R. N. (2012). Does the modified Harris hip score reflect patient satisfaction after hip arthroscopy? *The American Journal of Sports Medicine*, *40*(11), 2557–60.

Astorino, T., Baker, J., Boone, T., Dalleck, L., Drury, D., Engals, D. H., & Gotshall, R. (2005). Comparing methods for setting saddle height in trained cyclists. *JEP online*, *8*(1).

Audenaert, E. A., Peeters, I., Vigneron, L., Baelde, N., & Pattyn, C. (2012). Hip morphological characteristics and range of internal rotation in femoroacetabular impingement. *The American journal of sports medicine*, *40*(6), 1329-1336.

Bagwell, J. J., Snibbe, J., Gerhardt, M., & Powers, C. M. (2016). Hip kinematics and kinetics in persons with and without cam femoroacetabular impingement during a deep squat task. *Clinical Biomechanics*, *31*, 87–92.

Baker, D. G., & Newton, R. U. (2008). Comparison of lower body strength, power, acceleration, speed, agility, and sprint momentum to describe and compare playing rank among professional rugby league players. *The Journal of Strength & Conditioning Research*, *22*(1), 153–158.

Baker, D., & Nance, S. (1999). The Relation Between Running Speed and Measures of Strength and Power in Professional Rugby League Players. *The Journal of Strength & Conditioning Research*, *13*(3), 230–235.

Bardakos, N. V., & Villar, R. N. (2009). Predictors of progression of osteoarthritis in femoroacetabular impingement. *Bone & Joint Journal*, *91*(2), 162-169.

Barris, S., & Button, C. (2008). A review of vision-based motion analysis in sport. *Sports Medicine*, *38*(12), 1025–1043.

Bartlett, R. (2001). Performance analysis: can bringing together biomechanics and notational analysis benefit coaches? *International Journal of Performance Analysis in Sport*, *1*(1), 122–126.

Barton, C., Salineros, M. J., Rakhra, K. S., & Beaulé, P. E. (2011). Validity of the alpha angle measurement on plain radiographs in the evaluation of cam-type femoroacetabular impingement. *Clinical Orthopaedics and Related Research®*, *469*(2), 464-469.

Bennell, K. L., O'Donnell, J. M., Takla, A., Spiers, L. N., Hunter, D. J., Staples, M., & Hinman, R. S. (2014). Efficacy of a physiotherapy rehabilitation program for individuals undergoing arthroscopic management of femoroacetabular impingement–the FAIR trial: a randomised controlled trial protocol. *BMC musculoskeletal disorders*, *15*(1), 58.

Bennett, A. N., Nixon, J., Roberts, A., Barker-Davies, R., Villar, R., & Houghton, J. M. (2016). Prospective 12-month functional and vocational outcomes of hip arthroscopy for femoroacetabular impingement as part of an evidence-based hip pain rehabilitation pathway in an active military population. *BMJ Open Sport & Exercise Medicine*, *2*(1),

Bizzini, M., Notzli, H. P., & Maffiuletti, N. A. (2007). Femoroacetabular Impingement in Professional Ice Hockey Players A Case Series of 5 Athletes After Open Surgical Decompression of the Hip. *The American Journal of Sports Medicine*, *35*(11), 1955–1959.

Bloomfield, J., Polman, R., & O'Donoghue, P. (2007). Physical demands of different positions in FA Premier League soccer. *Journal of Sports Science and Medicine*, *6*(1), 63–70.

Botser, I. B., Smith, T. W., Nasser, R., & Domb, B. G. (2011). Open surgical dislocation versus arthroscopy for femoroacetabular impingement: a comparison of clinical outcomes. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*, *27*(2), 270–278.

Boykin, R. E., Patterson, D., Briggs, K. K., Dee, A., & Philippon, M. J. (2013). Results of arthroscopic labral reconstruction of the hip in elite athletes. *The American journal of sports medicine*, *41*(10), 2296-2301.

Brisson, N., Lamontagne, M., Kennedy, M. J., & Beaulé, P. E. (2013). The effects of cam femoroacetabular impingement corrective surgery on lower-extremity gait biomechanics. *Gait & Posture*, *37*(2), 258–263.

Brooks, A. L., & Czarowicz, A. (2012). Markeless Motion Tracking: MS Kinect and Organic Motion OpenStage. In *9th International Conference on Disability, Virtual Reality and Associated Technologies,* 9, 435–437).

Brunner, R., Maffiuletti, N. A., Casartelli, N. C., Bizzini, M., Sutter, R., Pfirrmann, C. W., & Leunig, M. (2015). Prevalence and Functional Consequences of Femoroacetabular Impingement in Young Male Ice Hockey Players. *The American Journal of Sports Medicine*, 46–53.

Byrd, J. W., & Jones, K. S. (2010). Prospective analysis of hip arthroscopy with 10-year followup. *Clin Orthop Relat Res*, *468*(3), 741–746.

Byrd, J. W. T. (2007). Hip arthroscopy in the athlete. *North American Journal of Sports Physical Therapy : NAJSPT*, *2*(4), 217–30.

Byrd, J. W. T. (2012). Hip Arthroscopy in the Athlete. *Operative Techniques in Sports Medicine*, *20*(4), 310–319.

Byrd, J. W. T., & Jones, K. S. (2009). Hip arthroscopy for labral pathology: prospective analysis with 10-year follow-up. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*, *25*(4), 365–368.

Byrd, J. W. T., & Jones, K. S. (2011). Arthroscopic management of femoroacetabular impingement in athletes. *The American Journal of Sports Medicine*, *39*(1 suppl), 7S–13S.

Byrd, J. T., Jones, K. S., & Gwathmey, F. W. (2016). Arthroscopic management of femoroacetabular impingement in adolescents. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*, *32*(9), 1800-1806.

Camomilla, V., Cereatti, A., Vannozzi, G., & Cappozzo, A. (2006). An optimized protocol for hip joint centre determination using the functional method. *Journal of Biomechanics*, *39*(6), 1096–1106.

Casartelli, N. C., Maffiuletti, N. a, Item-Glatthorn, J. F., Staehli, S., Bizzini, M., Impellizzeri, F. M., & Leunig, M. (2011). Hip muscle weakness in patients with symptomatic femoroacetabular impingement. *Osteoarthritis and Cartilage / OARS, Osteoarthritis Research Society*, *19*(7), 816–21.

Charbonnier, C., Kolo, F. C., Duthon, V. B., Magnenat-Thalmann, N., Becker, C. D., Hoffmeyer, P., & Menetrey, J. (2011). Assessment of congruence and impingement of the hip joint in professional ballet dancers: a motion capture study. *The American journal of sports medicine*, *39*(3), 557-566.

Cheatham, S. W., & Kolber, M. J. (2012). Rehabilitation after hip arthroscopy and labral repair in a high school football athlete. *International journal of sports physical therapy*, *7*(2), 173.

Cheze, L. (2014). *Kinematic Analysis of Human Movement*. Wiley.

Chow, R. M., Engasser, W. M., Krych, A. J., & Levy, B. A. (2014). Arthroscopic capsular repair in the treatment of femoroacetabular impingement. *Arthroscopy techniques*, *3*(1), e27-e30.

Christensen, C. P., Althausen, P. L., Mittleman, M. A., Lee, J. A., & McCarthy, J. C. (2003). The nonarthritic hip score: reliable and validated. *Clinical orthopaedics and related research*, *406*(1), 75-83.

Clohisy, J. C., Baca, G., Beaulé, P. E., Kim, Y.-J., Larson, C. M., Millis, M. B., … Sink, E. L. (2013). Descriptive epidemiology of femoroacetabular impingement: a North American cohort of patients undergoing surgery. *The American Journal of Sports Medicine*, *41*(6), 1348–1356.

Clohisy, J. C., Knaus, E. R., Hunt, D. M., Lesher, J. M., Harris-Hayes, M., & Prather, H. (2009). Clinical Presentation of Patients with Symptomatic Anterior Hip Impingement. *Clinical Orthopaedics and Related Research*, *467*(3), 638–644.

Clohisy, J. C., St John, L. C., & Schutz, A. L. (2010). Surgical treatment of femoroacetabular impingement: a systematic review of the literature. *Clinical Orthopaedics and Related Research*, *468*(2), 555–64.

Cohen, S. B., Huang, R., Ciccotti, M. G., Dodson, C. C., & Parvizi, J. (2012). Treatment of Femoroacetabular Impingement in Athletes Using a Mini–Direct Anterior Approach. *The American Journal of Sports Medicine*, *40*(7), 1620–1627.

Collins, K., Doran, D. A., & Reilly, T. P. (2010). The Physiological Demands of Hurling Match-

Play. *Contemporary Ergonomics and Human Factors*, 591-595.

Collins, D. K., Reilly, T., & Morton, J. P. (2014). Journal of Athletic Anthropometric and Performance Characteristics of Elite Hurling Players, 3–6.

Collins, T. D., Ghoussayni, S. N., Ewins, D. J., & Kent, J. A. (2009). A six degrees-of-freedom marker set for gait analysis: repeatability and comparison with a modified Helen Hayes set. *Gait & Posture*, *30*(2), 173–180.

Coutts, A. J., & Duffield, R. (2010). Validity and reliability of GPS devices for measuring movement demands of team sports. *Journal of Science and Medicine in Sport*, *13*(1), 133–135.

Crossley, K. M., Pandy, M. G., Majumdar, S., Smith, A. J., Semciw, A. I., Kemp, J. L., ... & Souza, R. B. (2018). Femoroacetabular impingement and hip OsteoaRthritis Cohort (FORCe): protocol for a prospective study. *Journal of physiotherapy*, *64*(1), 55.

Cunnife, B., Proctor, W., Baker, J., & Davies, B. (2000). an Evaluation of the Physiological Demands Ofeliterugbyunionusingglobalpositioning System Tracking Software. *Spring*, *3*(4), 1187–1195.

Degen, R. M., Fields, K. G., Wentzel, C. S., Bartscherer, B., Ranawat, A. S., Coleman, S. H., & Kelly, B. T. (2016). Return-to-play rates following arthroscopic treatment of femoroacetabular impingement in competitive baseball players. *The Physician and Sportsmedicine*, 1–6.

Deutsch, M. U., Kearney, G. A., & Rehrer, N. J. (2007). Time–motion analysis of professional rugby union players during match-play. *Journal of Sports Sciences*, *25*(4), 461–472.

Deutsch, M. U., Maw, G. J., Jenkins, D., & Reaburn, P. (1998). Heart rate, blood lactate and kinematic data of elite colts (under-19) rugby union players during competition. *Journal of Sports Sciences*, *16*(6), 561–570.

Derrickson, B. (2009). *Principles of anatomy and physiology: Maintenance and continuity of the human body*. John Wiley & Sons.

DeVita, P., & Stribling, J. (1991). Lower extremity joint kinetics and energetics during backward running. *Med Sci Sports Exerc*, *23*(5), 602–610.

Diamond, L., Bennell, K., Wrigley, T., Hinman, R., O'Donnell, J., & Hodges, P. (2016). Squatting biomechanics in individuals with symptomatic femoroacetabular impingement: Unconstrained and constrained tasks. *Osteoarthritis and Cartilage*, *24*, S100–S101.

Diamond, L. E., Dobson, F. L., Bennell, K. L., Wrigley, T. V, Hodges, P. W., & Hinman, R. S. (2014). Physical impairments and activity limitations in people with femoroacetabular impingement: a systematic review. *British Journal of Sports Medicine* .

Diamond, L. E., Van den Hoorn, W., Bennell, K. L., Wrigley, T. V., Hinman, R. S., O'donnell, J., & Hodges, P. W. (2017). Coordination of deep hip muscle activity is altered in symptomatic femoroacetabular impingement. *Journal of Orthopaedic Research*, *35*(7), 1494-1504.

Dickenson, E., O'Connor, P., Robinson, P., Campbell, R., Ahmed, I., Fernandez, M., Griffin, D. (2016). Hip morphology in elite golfers: asymmetry between lead and trail hips. *British Journal of Sports Medicine* , *50*(17), 1081–1086.

Domb, B. G., Stake, C. E., Botser, I. B., & Jackson, T. J. (2013). Surgical dislocation of the hip versus arthroscopic treatment of femoroacetabular impingement: a prospective matched-pair study with average 2-year follow-up. *Arthroscopy: The Journal of Arthroscopic & Related*

Surgery, *29*(9), 1506-1513.

Doherty, M., Courtney, P., Doherty, S., Jenkins, W., Maciewicz, R. A., Muir, K., & Zhang, W. (2008). Nonspherical femoral head shape (pistol grip deformity), neck shaft angle, and risk of hip osteoarthritis: a case–control study. *Arthritis & Rheumatology*, *58*(10), 3172-3182.

Duthon, V. B., Charbonnier, C., Kolo, F. C., Magnenat-Thalmann, N., Becker, C. D., Bouvet, C., ... & Menetrey, J. (2013). Correlation of clinical and magnetic resonance imaging findings in hips of elite female ballet dancers. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*, *29*(3), 411-419.

Duthie, G., Pyne, D., & Hooper, S. (2003). Applied physiology and game analysis of rugby union. *Sports Medicine*, *33*(13), 973–991.

Ebben, W. P., & Petushek, E. J. (2010). Using the Reactive Strength Index Modified to Evaluate Plyometric Performance. *The Journal of Strength & Conditioning Research*, *24*(8), 1983–1987.

Eijer, H. (2001). Cross-table lateral radiography for screening of anterior femoral head-neck offset in patients with femoro-acetabular impingement. *Hip Int.*, *11*, 37-41.

EL-Wardany, S. H., EL-Sayed, W. H., & Ali, M. F. (2016). Interrater and Intrarater Reliability of Kinovea Computer Program in Measuring Cervical Range of Motion in Frontal Plane. *Physical Therapy*, *4*, 5.

Ellis, H. B., Briggs, K. K., & Philippon, M. J. (2011). Innovation in hip arthroscopy: is hip arthritis preventable in the athlete? *British Journal of Sports Medicine*, *45*(4), 253–8.

Elrahim, R. M. A., Embaby, E. A., Ali, M. F., & Kamel, R. M. (2016). Inter-rater and intra-rater reliability of Kinovea software for measurement of shoulder range of motion. *Bulletin of Faculty of Physical Therapy*, *21*(2), 80.

Emara, K., Samir, W., Motasem, E. H., & Ghafar, K. A. E. (2011). Conservative treatment for mild femoroacetabular impingement. *Journal of Orthopaedic Surgery*, *19*(1), 41-45.

Enseki, K. R., & Draovitch, P. (2010). Rehabilitation for hip arthroscopy. *Operative Techniques in Orthopaedics*, *20*(4), 278-281.

Enoka, R. M. (2015). *Neuromechanics of Human Movement-5th Edition:* . Human Kinetics.

Epstein, D. M., McHugh, M., Yorio, M., & Neri, B. (2013). Intra-articular hip injuries in National Hockey League players: a descriptive epidemiological study. *The American Journal of Sports Medicine*, *41*(2), 343–348.

Espinosa, N., Rothenfluh, D. A., Beck, M., Ganz, R., & Leunig, M. (2006). Treatment of femoro-acetabular impingement: preliminary results of labral refixation. *JBJS*, *88*(5), 925-935.

Fabricant, P. D., Heyworth, B. E., & Kelly, B. T. (2012). Hip arthroscopy improves symptoms associated with FAI in selected adolescent athletes. *Clinical Orthopaedics and Related Research®*, *470*(1), 261–269.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–91.

Fellin, R. E., Manal, K., & Davis, I. S. (2010). Comparison of lower extremity kinematic curves during overground and treadmill running. *Journal of Applied Biomechanics*, *26*(4), 407–414.

Fellin, R. E., Rose, W. C., Royer, T. D., & Davis, I. S. (2010). Comparison of methods for kinematic identification of footstrike and toe-off during overground and treadmill running. *Journal of Science and Medicine in Sport*, *13*(6), 646–650.

Ferber, R., Davis, I. M., & Williams Iii, D. S. (2003). Gender differences in lower extremity mechanics during running. *Clinical Biomechanics*, *18*(4), 350–357.

Flanagan, E. P., & Comyns, T. M. (2008). The use of contact time and the reactive strength index to optimize fast stretch-shortening cycle training. *Strength & Conditioning Journal*, *30*(5), 32–38.

Flanagan, E. P., Ebben, W. P., & Jensen, R. L. (2008). Reliability of the reactive strength index and time to stabilization during depth jumps. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, *22*(5), 1677–1682.

Fong, D. T.-P., & Chan, Y.-Y. (2010). The use of wearable inertial motion sensors in human lower limb biomechanics studies: a systematic review. *Sensors*, *10*(12), 11556–11565.

Freke, M. D., Kemp, J., Svege, I., Risberg, M. A., Semciw, A., & Crossley, K. M. (2016). Physical impairments in symptomatic femoroacetabular impingement: a systematic review of the evidence. *British Journal of Sports Medicine* , *50*(19), 1180.

Fukushima, K., Takahira, N., Imai, S., Yamazaki, T., Kenmoku, T., Uchiyama, K., & Takaso, M. (2016). Prevalence of radiological findings related to femoroacetabular impingement in professional baseball players in Japan. *Journal of Orthopaedic Science*, *21*(6), 821–825.

Ganz, R., Leunig, M., Leunig-Ganz, K., & Harris, W. H. (2008). The etiology of osteoarthritis of the hip: An integrated mechanical concept. *Clinical Orthopaedics and Related Research*, *466*(2), 264–272.

Ganz, R., Parvizi, J., Beck, M., Leunig, M., Nötzli, H., & Siebenrock, K. A. (2003). Femoroacetabular Impingement: A Cause for Osteoarthritis of the Hip. *Clin Orthop Relat Res*, *417*, 112–120

Gerhardt, M. B., Romero, A. A., Silvers, H. J., Harris, D. J., Watanabe, D., & Mandelbaum, B. R. (2012). The prevalence of radiographic hip abnormalities in elite soccer players. *The American journal of sports medicine*, *40*(3), 584-588.

Gilmore, J. H. (2008). The craft of the Caman; A notational analysis of the frequency occurrence of skills used in Hurling. *International Journal of Performance Analysis in Sport*, *8*(1), 68-75.

Glatthorn, J. F., Gouge, S., Nussbaumer, S., Stauffacher, S., Impellizzeri, F. M., & Maffiuletti, N. A. (2011). Validity and Reliability of Optojump Photoelectric Cells for Estimating Vertical Jump Height. *The Journal of Strength & Conditioning Research*, *25*(2), 556–560.

Goodall, R. L., Pope, R. P., Coyle, J. A., & Neumayer, R. (2013). Balance and agility training does not always decrease lower limb injury risks: a cluster-randomised controlled trial. *International Journal of Injury Control and Safety Promotion*, *20*(3), 271–281.

Gorton, G. E., Hebert, D. A., & Gannotti, M. E. (2009). Assessment of the kinematic variability among 12 motion analysis laboratories. *Gait & Posture*, *29*(3), 398–402.

Gosvig, K. K., Jacobsen, S., Sonne-Holm, S., & Gebuhr, P. (2008). The prevalence of cam-type deformity of the hip joint: a survey of 4151 subjects of the Copenhagen Osteoarthritis Study. *Acta Radiologica*, *49*(4), 436-441.

Grasso, R., Bianchi, L., & Lacquaniti, F. (1998). Motor Patterns for Human Gait: Backward Versus

Forward Locomotion. *Journal of Neurophysiology*, *80*(4), 1868 LP-1885.

Greig, M., & Siegler, J. C. (2009). Soccer-Specific Fatigue and Eccentric Hamstrings Muscle Strength. *Journal of Athletic Training*, *44*(2), 180–184.

Griffin, D. R., Dickenson, E. J., O'Donnell, J., Agricola, R., Awan, T., Beck, M., … Bennell, K. L. (2016). The Warwick Agreement on femoroacetabular impingement syndrome (FAI syndrome): an international consensus statement. *British Journal of Sports Medicine* , *50*(19), 1169–1176.

Griffin, D. R., Dickenson, E. J., Wall, P. D. H., Donovan, J. L., Foster, N. E., Hutchinson, C. E., ... & Achana, F. (2016). Protocol for a multicentre, parallel-arm, 12-month, randomised, controlled trial of arthroscopic surgery versus conservative care for femoroacetabular impingement syndrome (FASHIoN). *BMJ open*, *6*(8), e012453.

Griffin, D., Wall, P., Realpe, A., Adams, A., Parsons, N., Hobson, R., Petrou, S. (2016). UK FASHIoN: feasibility study of a randomised controlled trial of arthroscopic surgery for hip impingement compared with best conservative care.

Griffin, D. R., Dickenson, E. J., Wall, P. D., Achana, F., Donovan, J. L., Griffin, J., ... & Petrou, S. (2018). Hip arthroscopy versus best conservative care for the treatment of femoroacetabular impingement syndrome (UK FASHIoN): a multicentre randomised controlled trial. *The Lancet*, *391*(10136), 2225-2235.

Hack, K., Di Primio, G., Rakhra, K., & Beaulé, P. E. (2010). Prevalence of cam-type femoroacetabular impingement morphology in asymptomatic volunteers. *The Journal of Bone & Joint Surgery*, *92*(14), 2436–2444.

Haugen, T. A., Tønnessen, E., Hisdal, J., & Seiler, S. (2014). The role and development of sprinting speed in soccer. *International journal of sports physiology and performance*, *9*(3), 432-441.

Hardin, E. C., Van Den Bogert, A. J., & Hamill, J. (2004). Kinematic adaptations during running: effects of footwear, surface, and duration. *Medicine & Science in Sports & Exercise*, *36*(5), 838–844.

Hewett, T. E., Ford, K. R., Myer, G. D., Wanstrath, K., & Scheper, M. (2006). Gender differences in hip adduction motion and torque during a single-leg agility maneuver. *Journal of Orthopaedic Research*, *24*(3), 416–421.

Heerey, J., Risberg, M. A., Magnus, J., Moksnes, H., Ødegaard, T., Crossley, K., & Kemp, J. L. (2018). Impairment-based rehabilitation following hip arthroscopy: postoperative protocol for the HIP ARThroscopy International randomized controlled trial. *journal of orthopaedic & sports physical therapy*, *48*(4), 336-342.

Hughes, M., & Franks, I. M. (2004). *Notational analysis of sport: Systems for better coaching and performance in sport*. Psychology Press.

Hunt, M. A., Gunether, J. R., & Gilbart, M. K. (2013). Kinematic and kinetic differences during walking in patients with and without symptomatic femoroacetabular impingement. *Clinical Biomechanics*, *28*(5), 519–523.

Isacson, J., Gransberg, L., & Knutsson, E. (1986). Three-dimensional electrogoniometric gait recording. *Journal of Biomechanics*, *19*(8), 627631–629635.

Ito, K., Leunig, M., & Ganz, R. (2004). Histopathologic features of the acetabular labrum in femoroacetabular impingement. *Clinical Orthopaedics and Related Research*, (429), 262–271.

Johnson, A. C., Shaman, M. a, & Ryan, T. G. (2012). Femoroacetabular impingement in former high-level youth soccer players. *The American Journal of Sports Medicine*, *40*(6), 1342–6.

Jovanovic, M., Sporis, G., Omrcen, D., & Fiorentini, F. (2011). Effects of speed, agility, quickness training method on power performance in elite soccer players. *The Journal of Strength & Conditioning Research*, *25*(5), 1285–1292.

Kadaba, M. P., Ramakrishnan, H. K., & Wootten, M. E. (1990). Measurement of Lower-Extremity Kinematics during Level Walking. *Journal of Orthopaedic Research*, *8*, 383–392.

Kadaba, M. P., Ramakrishnan, H. K., & Wootten, M. E. (1990). Measurement of lower extremity kinematics during level walking. *Journal of Orthopaedic Research*, *8*(3), 383–392.

Kang, A. C. L., Gooding, A. J., Coates, M. H., Goh, T. D., Armour, P., & Rietveld, J. (2010). Computed tomography assessment of hip joints in asymptomatic individuals in relation to femoroacetabular impingement. *The American Journal of Sports Medicine*, *38*(6), 1160–1165.

Kapron, A. L., Anderson, A. E., Peters, C. L., Phillips, L. G., Stoddard, G. J., Petron, D. J., ... & Aoki, S. K. (2012). Hip internal rotation is correlated to radiographic findings of cam femoroacetabular impingement in collegiate football players. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*, *28*(11), 1661-1670.

Kassarjian, A., Brisson, M., & Palmer, W. E. (2007). Femoroacetabular impingement. *European Journal of Radiology*, *63*(1), 29–35.

Kelly, B. T., Weiland, D. E., Schenker, M. L., & Philippon, M. J. (2005). Arthroscopic labral repair in the hip: surgical technique and review of the literature. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*, *21*(12), 1496–1504.

Kennedy, M. J., Lamontagne, M., & Beaulé, P. E. (2009). Femoroacetabular impingement alters hip and pelvic biomechanics during gait Walking biomechanics of FAI. *Gait & Posture*, *30*(1), 41–44.

Kerrigan, D. C., Lee, L. W., Collins, J. J., Riley, P. O., & Lipsitz, L. A. (2001). Reduced hip extension during walking: Healthy elderly and fallers versus young adults. *Archives of Physical Medicine and Rehabilitation*, *82*(1), 26–30.

Kemp, J. L., Coburn, S. L., Jones, D. M., & Crossley, K. M. (2018). The physiotherapy for Femoroacetabular Impingement Rehabilitation STudy (physioFIRST): a pilot randomized controlled trial. *journal of orthopaedic & sports physical therapy*, *48*(4), 307-315.

Kierkegaard, S., Langeskov-Christensen, M., Lund, B., Naal, F. D., Mechlenburg, I., Dalgas, U., & Casartelli, N. C. (2016). Pain, activities of daily living and sport function at different time points after hip arthroscopy in patients with femoroacetabular impingement: a systematic review with meta-analysis. *Br J Sports Med*, bjsports-2016.

King, M. G., Lawrenson, P. R., Semciw, A. I., Middleton, K. J., & Crossley, K. M. (2018). Lower limb biomechanics in femoroacetabular impingement syndrome: a systematic review and meta-analysis. *Br J Sports Med*, bjsports-2017.

Kivlan, B. R., Carcia, C. R., Christoforetti, J. J., & Martin, R. L. (2016). Comparison of Range of Motion, Strength, and Hop Test Performance of dancers with and without a Clinical Diagnosis of Femoroacetabular Impingement. *International journal of sports physical therapy*, *11*(4), 527.

Kocher, M. S., Solomon, R., Lee, B. M., Micheli, L. J., Solomon, J., & Stubbs, A. (2006). Arthroscopic debridement of hip labral tears in dancers. *Journal of Dance Medicine & Science*, *10*(3-1), 99-

105.

Kolo, F. C., Charbonnier, C., Pfirrmann, C. W., Duc, S. R., Lubbeke, A., Duthon, V. B., ... & Becker, C. D. (2013). Extreme hip motion in professional ballet dancers: dynamic and morphological evaluation based on magnetic resonance imaging. *Skeletal radiology*, *42*(5), 689-698.

Krosshaug, T., Nakamae, A., Boden, B., Engebretsen, L., Smith, G., Slauterbeck, J., … Bahr, R. (2007). Estimating 3D joint kinematics from video sequences of running and cutting maneuvers—assessing the accuracy of simple visual inspection. *Gait & Posture*, *26*(3), 378–385.

Krych, A. J., Thompson, M., Knutson, Z., Scoon, J., & Coleman, S. H. (2013). Arthroscopic labral repair versus selective labral debridement in female patients with femoroacetabular impingement: a prospective randomized study. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*, *29*(1), 46-53.

Krych, Aaron J., Sean Baran, Scott A. Kuzma, Hugh M. Smith, Rebecca L. Johnson, and Bruce A. Levy. "Utility of multimodal analgesia with fascia iliaca blockade for acute pain management following hip arthroscopy." *Knee Surgery, Sports Traumatology, Arthroscopy* 22, no. 4 (2014): 843-847.

Kuhns, B. D., Weber, A. E., Levy, D. M., & Wuerz, T. H. (2015). The Natural History of Femoroacetabular Impingement. *Frontiers in Surgery*, *2*.

Kubiak-Langer, M., Tannast, M., Murphy, S. B., Siebenrock, K. A., & Langlotz, F. (2007). Range of motion in anterior femoroacetabular impingement. *Clinical orthopaedics and related research*, *458*, 117-124.

Kumar, D., Dillon, A., Nardo, L., Link, T. M., Majumdar, S., & Souza, R. B. (2014). Differences in the association of hip cartilage lesions and cam-type femoroacetabular impingement with movement patterns: a preliminary study. *PM&R*, *6*(8), 681-689.

Kutty, S., Schneider, P., Faris, P., Kiefer, G., Frizzell, B., Park, R., & Powell, J. N. (2012). Reliability and predictability of the centre-edge angle in the assessment of pincer femoroacetabular impingement. *International orthopaedics*, *36*(3), 505-510.

Laborie, L. B., Lehmann, T. G., Engesæter, I. Ø., Eastwood, D. M., Engesæter, L. B., & Rosendahl, K. (2011). Prevalence of radiographic findings thought to be associated with femoroacetabular impingement in a population-based cohort of 2081 healthy young adults. *Radiology*, *260*(2), 494-502.

Lamontagne, M., Brisson, N., Kennedy, M. J., & Beaulé, P. E. (2011). Preoperative and postoperative lower-extremity joint and pelvic kinematics during maximal squatting of patients with cam femoro-acetabular impingement. *J Bone Joint Surg Am*, *93*(Supplement 2), 40–45.

Lamontagne, M., Kennedy, M. J., & Beaulé, P. E. (2009). The effect of cam FAI on hip and pelvic motion during maximum squat. *Clinical Orthopaedics and Related Research*, *467*(3), 645–50.

Laude, F., Boyer, T., & Nogier, A. (2007). Anterior femoroacetabular impingement. *Joint, Bone, Spine : Revue Du Rhumatisme*, *74*(2), 127–132.

Larson, C. M., Giveans, M. R., & Stone, R. M. (2012). Arthroscopic debridement versus refixation of the acetabular labrum associated with femoroacetabular impingement: mean 3.5-year follow-up. *The American journal of sports medicine*, *40*(5), 1015-1021.

Lee, S. J., & Hidler, J. (2008). Biomechanics of overground vs. treadmill walking in healthy individuals.

Journal of Applied Physiology, *104*(3), 747–755.

Leunig, M., & Ganz, R. (2007). Femoroacetabular Impingement, *15*(9), 561–570.

Little, T., & Williams, A. G. (2005). Specificity of acceleration, maximum speed, and agility in professional soccer players. *The Journal of Strength & Conditioning Research*, *19*(1), 76–78.

Little, T., & Williams, A. G. (2006). Effects of differential stretching protocols during warm-ups on high-speed motor capacities in professional soccer players. *The Journal of Strength & Conditioning Research*, *20*(1), 203–307.

Lloyd, R. S., Oliver, J. L., Hughes, M. G., & Williams, C. a. (2012). The Effects of 4-Weeks of Plyometric Training on Reactive Strength Index and Leg Stiffness in Male Youths. *Journal of Strength and Conditioning Research*, *26*(10), 2812–2819.

Lockie, R. G., Murphy, A. J., Schultz, A. B., Knight, T. J., & de Jonge, X. A. K. J. (2012). The effects of different speed training protocols on sprint acceleration kinematics and muscle strength and power in field sport athletes. *The Journal of Strength & Conditioning Research*, *26*(6), 1539–1550.

M. Burden, A., Grimshaw, P. N., & Wallace, E. S. (1998). Hip and shoulder rotations during the golf swing of sub-10 handicap players. *Journal of Sports Sciences*, *16*(2), 165–176.

MacKelvie, K. J., Khan, K. M., & McKay, H. A. (2002). Is there a critical period for bone response to weight-bearing exercise in children and adolescents? A systematic review. *British Journal of Sports Medicine*, *36*(4), 250–257.

Malone, S., Solan, B., Collins, K., & Doran, D. (2016). The Positional Match Running Performance of Elite Gaelic Football. *Journal of Strength and Conditioning Research/National Strength and Conditioning Association*, *8*(3), 2292–2298.

Malone, S., Collins, K., McRoberts, A., & Doran, D. (2013). A comparison of work-rate displayed by elite and sub-elite hurlers during match play. *Sciences*, *22*(3), 255–256.

Malone, S., Solan, B., Collins, K. D., & Doran, D. A. (2016). Positional Match Running Performance in Elite Gaelic Football. *The Journal of Strength & Conditioning Research*, *30*(8), 2292–2298.

Malviya, A., Paliobeis, C. P., & Villar, R. N. (2013). Do professional athletes perform better than recreational athletes after arthroscopy for femoroacetabular impingement? *Clinical Orthopaedics and Related Research®*, *471*(8), 2477–2483.

Mann, R. A., & Hagy, J. (1980). Biomechanics of walking, running, and sprinting. *The American Journal of Sports Medicine*, *8*(5), 345–350.

Mansell, N. S., Rhon, D. I., Meyer, J., Slevin, J. M., & Marchant, B. G. (2018). Arthroscopic surgery or physical therapy for patients with femoroacetabular impingement syndrome: a randomized controlled trial with 2-year follow-up. *The American journal of sports medicine*, 0363546517751912.

Mardones, R., Gonzalez, C., Cabanela, M. E., Trousdale, R. T., & Berry, D. J. (2005). Extended femoral osteotomy for revision of hip arthroplasty: results and complications. *The Journal of arthroplasty*, *20*(1), 79-83.

Martini, F. H., Timmons, M. J., & Tallitsch, R. B. (2006). Human anatomy 6th ed. *New York*.

Matsuda, D. K., Carlisle, J. C., Arthurs, S. C., Wierks, C. H., & Philippon, M. J. (2011). Comparative systematic review of the open dislocation, mini-open, and arthroscopic surgeries for femoroacetabular impingement. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*, *27*(2), 252–269.

Maud, P. J., & Foster, C. (2006). *Physiological Assessment of Human Fitness*. Human Kinetics.

Mayagoitia, R. E., Nene, A. V, & Veltink, P. H. (2002). Accelerometer and rate gyroscope measurement of kinematics: an inexpensive alternative to optical motion analysis systems. *Journal of Biomechanics*, *35*(4), 537–542.

McClymont, D. (2003). Use of the reactive strength index (RSI) as an indicator of plyometric training conditions. In *Science and Football V: The proceedings of the fifth World Congress on Sports Science and Football, Lisbon, Portugal* (pp. 408–416).

McDonald, J., Herzog, M., & Philippon, M. (2014). Performance outcomes in professional hockey players following arthroscopic treatment of FAI and microfracture of the hip. *Knee Surgery, Sports Traumatology, Arthroscopy*, *22*(4), 915–919.

McIntyre, M. C. (2005). A comparison of the physiological profiles of elite Gaelic footballers, hurlers, and soccer players. *British Journal of Sports Medicine* , *39*(7), 437–439.

Menge, T. J., Briggs, K. K., & Philippon, M. J. (2016). Predictors of Length of Career After Hip Arthroscopy for Femoroacetabular Impingement in Professional Hockey Players. *The American Journal of Sports Medicine*, *44*(9), 2286–2291.

Minkara, A. A., Westermann, R. W., Rosneck, J., & Lynch, T. S. (2018). Systematic Review and Meta-analysis of Outcomes After Hip Arthroscopy in Femoroacetabular Impingement. *The American journal of sports medicine*, 0363546517749475.

Mlynarek, R. A., Cowan, J. B., Larson, C. M., Kelly, B. T., & Bedi, A. (2015). Arthroscopic approach to femoroacetabular impingement. *The Journal of Arthroplasty*, *30*(7), 1096–1104.

Mohr, M., Krustrup, P., & Bangsbo, J. (2003). Match performance of high-standard soccer players with special reference to development of fatigue. *Journal of Sports Sciences*, *21*(7), 519–528.

Mündermann, L., Corazza, S., & Andriacchi, T. P. (2006). The evolution of methods for the capture of human movement leading to markerless motion capture for biomechanical applications. *Journal of NeuroEngineering and Rehabilitation*, *11*, 1–11.

Murphy, N. J., Eyles, J., Bennell, K. L., Bohensky, M., Burns, A., Callaghan, F. M., ... & Hall, M. (2017). Protocol for a multi-centre randomised controlled trial comparing arthroscopic hip surgery to physiotherapy-led care for femoroacetabular impingement (FAI): the Australian FASHIoN trial. *BMC musculoskeletal disorders*, *18*(1), 406.

Murphy, J. C., O'Malley, E., Gissane, C., & Blake, C. (2012). Incidence of injury in Gaelic football: a 4-year prospective study. *The American journal of sports medicine*, *40*(9), 2113-2120.

Murphy, J. C., Gissane, C., & Blake, C. (2012). Injury in elite county-level hurling: a prospective study. *Br J Sports Med*, *46*(2), 138-142.

Naal, F. D., Miozzari, H. H., Wyss, T. F., & Nötzli, H. P. (2011). Surgical hip dislocation for the treatment of femoroacetabular impingement in high-level athletes. *The American Journal of Sports Medicine*, *39*(3), 544–550.

Naal, F. D., Schär, M., Miozzari, H. H., & Nötzli, H. P. (2014). Sports and activity levels after open surgical treatment of femoroacetabular impingement. *The American journal of sports medicine*, *42*(7), 1690-1695.

Nakano, N., Lisenda, L., Jones, T. L., Loveday, D. T., & Khanduja, V. (2017). Complications following arthroscopic surgery of the hip: a systematic review of 36 761 cases. *Bone Joint J*, *99*(12), 1577-1583.

Nwachukwu, B. U., Fields, K. G., Nawabi, D. H., Kelly, B. T., & Ranawat, A. S. (2016). Pre-operative Thresholds for Achieving Meaningful Clinical Improvement after Arthroscopic Treatment of Femoroacetabular Impingement. *Orthopaedic journal of sports medicine*, *4*(7 suppl4), 2325967116S00191.

Nepple, J. J., Brophy, R. H., Matava, M. J., Wright, R. W., & Clohisy, J. C. (2012). Radiographic findings of femoroacetabular impingement in National Football League Combine athletes undergoing radiographs for previous hip or groin pain. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*, *28*(10), 1396–1403.

Nepple, J. J., Lehmann, C. L., Ross, J. R., Schoenecker, P. L., & Clohisy, J. C. (2013). Coxa profunda is not a useful radiographic parameter for diagnosing pincer-type femoroacetabular impingement. *J Bone Joint Surg Am*, *95*(5), 417–423.

Ng, V. Y., Arora, N., Best, T. M., Pan, X., & Ellis, T. J. (2010). Efficacy of surgery for femoroacetabular impingement: a systematic review. *The American journal of sports medicine*, *38*(11), 2337-2345.

Nho, S. J., Magennis, E. M., Singh, C. K., & Kelly, B. T. (2011). Outcomes after the arthroscopic treatment of femoroacetabular impingement in a mixed group of high-level athletes. *The American Journal of Sports Medicine*, *39*(1 suppl), 14S–19S.

Norkin, C. C., & White, D. J. (2009). *Measurement of joint motion: a guide to goniometry*. FA Davis.

Norris, B. S., & Olson, S. L. (2011). Concurrent validity and reliability of two-dimensional video analysis of hip and knee joint motion during mechanical lifting. *Physiotherapy Theory and Practice*, *27*(7), 521–530.

Nötzli HP, Wyss TF, Stoecklin CH, Schmid MR, Treiber K, Hodler J. The contour of the femoral head-neck junction as a predictor for the risk of anterior impingement. *Journal of Bone and Joint Surgery Br* 2002;84(4):556–560

Nwachukwu, B. U., Fields, K. G., Nawabi, D. H., Kelly, B. T., & Ranawat, A. S. (2016). Pre-operative Thresholds for Achieving Meaningful Clinical Improvement after Arthroscopic Treatment of Femoroacetabular Impingement. *Orthopaedic Journal of Sports Medicine*, *4*(7 suppl4)

Ochoa, L. M., Dawson, L., Patzkowski, J. C., & Hsu, J. R. (2010). Radiographic prevalence of femoroacetabular impingement in a young population with hip complaints is high. *Clinical Orthopaedics and Related Research®*, *468*(10), 2710-2714.

O'Connor, S., McCaffrey, N., Whyte, E. F., & Moran, K. A. (2016). Epidemiology of injury in male adolescent Gaelic games. *Journal of Science and Medicine in Sport*, *19*(5), 384-388.

O’Connor, M., Minkara, A. A., Westermann, R. W., Rosneck, J., & Lynch, T. S. (2018). Return to Play After Hip Arthroscopy: A Systematic Review and Meta-analysis. *The American journal of sports medicine*, 0363546518759731.

Ogden, C. L., Carroll, M. D., Lawman, H. G., Fryar, C. D., Kruszon-Moran, D., Kit, B. K., & Flegal, K. M. (2016). Trends in obesity prevalence among children and adolescents in the United States, 1988-1994 through 2013-2014. *Jama*, *315*(21), 2292–2299.

Page, R. M., & Tucker, L. (1994). Psychosocial discomfort and exercise frequency: an epidemiological study of adolescents. *Adolescence*, *29*(113), 183.

Palmer, A. J. R., Ayyar-Gupta, V., Dutton, S. J., Rombach, I., Cooper, C. D., Pollard, T. C., ... & Beard, D. J. (2014). Protocol for the Femoroacetabular Impingement Trial (FAIT): a multi-centre randomised controlled trial comparing surgical and non-surgical management of femoroacetabular impingement. *Bone and Joint Research*, *3*(11), 321-327.

Parsons, L. S., & Jones, M. T. (1998). Development of Speed, Agility, and Quickness for Tennis Athletes. *Strength & Conditioning Journal*, *20*(3), 14–19.

Payton, C. J., & Bartlett, R. M. (Eds.). (2008). Biomechanical Evaluation of Movement in Sport and Exercise: The British Association of Sport and Exercise Sciences Guide. *Journal of Sports Science & Medicine*, *7*(1), 194.

Pennock, A. T., Philippon, M. J., & Briggs, K. K. (2010). Acetabular labral preservation: surgical techniques, indications, and early outcomes. *Operative Techniques in Orthopaedics*, *20*(4), 217-222.

Philippon, M. J., Briggs, K. K., Yen, Y.-M., & Kuppersmith, D. A. (2009). Outcomes following hip arthroscopy for femoroacetabular impingement with associated chondrolabral dysfunction. *Bone & Joint Journal*, *91*(1), 16–23.

Philippon, M. J., Ho, C. P., Briggs, K. K., Stull, J., & LaPrade, R. F. (2013). Prevalence of Increased Alpha Angles as a Measure of Cam-Type Femoroacetabular Impingement in Youth Ice Hockey Players. *The American Journal of Sports Medicine*, *41*(6), 1357–1362.

Philippon, M. J., Maxwell, R. B., Johnston, T. L., Schenker, M., & Briggs, K. K. (2007). Clinical presentation of femoroacetabular impingement. *Knee Surgery, Sports Traumatology, Arthroscopy : Official Journal of the ESSKA*, *15*(8), 1041–7.

Philippon, M. J., Weiss, D. R., Kuppersmith, D. A., Briggs, K. K., & Hay, C. J. (2010). Arthroscopic labral repair and treatment of femoroacetabular impingement in professional hockey players. *The American Journal of Sports Medicine*, *38*(1), 99–104.

Philippon, M. J., Yen, Y.-M., Briggs, K. K., Kuppersmith, D. A., & Maxwell, R. B. (2008). Early outcomes after hip arthroscopy for femoroacetabular impingement in the athletic adolescent patient: a preliminary report. *Journal of Pediatric Orthopaedics*, *28*(7), 705–710.

Philippon, M., Schenker, M., Briggs, K., & Kuppersmith, D. (2007). Femoroacetabular impingement in 45 professional athletes: associated pathologies and return to sport following arthroscopic decompression. *Knee Surgery, Sports Traumatology, Arthroscopy : Official Journal of the ESSKA*, *15*(7), 908–14.

Poh, S.-Y., Hube, R., & Dienst, M. (2015). Arthroscopic treatment of femoroacetabular pincer impingement. *Operative Orthopädie Und Traumatologie*, *27*(6), 536–552.

Polesello, G. C., Cinagawa, E. H. T., Santa Cruz, P. D. S., de Queiroz, M. C., Borges, C. J., Junior, W. R., ... & Ono, N. K. (2012). Surgical treatment for femoroacetabular impingement in a group that performs squats. *Revista Brasileira de Ortopedia (English Edition)*, *47*(4), 488-492.

Pun, S., Kumar, D., & Lane, N. E. (2015). Review: femoroacetabular impingement. *Arthritis & Rheumatology*, *67*(1), 17–27.

Quackenbush, N., & Crossman, J. (1994). Injured athletes: A study of emotional responses. *Journal of Sport Behavior*, *17*(3), 178.

Ramisetty, N., Kwon, Y., & Mohtadi, N. (2015). Patient-reported outcome measures for hip preservation surgery—a systematic review of the literature. *Journal of hip preservation surgery*, *2*(1), 15-27.

Rebello, G., Spencer, S., Millis, M. B., & Kim, Y. J. (2009). Surgical dislocation in the management of pediatric and adolescent hip deformity. *Clinical orthopaedics and related research*, *467*(3), 724-731.

Reichenbach, S., Jüni, P., Werlen, S., Nüesch, E., Pfirrmann, C. W., Trelle, S., ... & Leunig, M. (2010). Prevalence of cam-type deformity on hip magnetic resonance imaging in young males: A cross-sectional study. *Arthritis care & research*, *62*(9), 1319-1327.

Reilly, T., & Collins, K. (2008). Science and the Gaelic sports: Gaelic football and hurling. *European Journal of Sport Science*, *8*(5), 231–240.

Reiman, M. P., Peters, S., Sylvain, J., Hagymasi, S., & Ayeni, O. R. (2018). Prevalence and Consistency in Surgical Outcome Reporting for Femoroacetabular Impingement Syndrome: A Scoping Review. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*.

Reis, I., Rebelo, A., Krustrup, P., & Brito, J. (2013). Performance enhancement effects of Federation Internationale de Football Association's "The 11+" injury prevention training program in youth futsal players. *Clinical Journal of Sport Medicine*, *23*(4), 318–320.

Rhea, M. R., Kenn, J. G., Peterson, M. D., Massey, D., Simão, R., Marin, P. J., … Krein, D. (2016). Joint-Angle Specific Strength Adaptations Influence Improvements in Power in Highly Trained Athletes. *Human Movement*, *17*(1), 43–49.

Riley, P. O., Dicharry, J., Franz, J., Della Croce, U., Wilder, R. P., & Kerrigan, D. C. (2008). A kinematics and kinetic comparison of overground and treadmill running. *Medicine & Science in Sports & Exercise*, *40*(6), 1093–1100.

Rimmasch, A., & Ravert, P. (2013). Femoroacetabular impingement: a guide to diagnosis in primary care. *The Journal for Nurse Practitioners*, *9*(9), 606-611.

Risberg, M. A., Ageberg, E., Nilstad, A., Lund, B., Nordsletten, L., Løken, S., ... & Crossley, K. M. (2018). Arthroscopic surgical procedures versus sham surgery for patients with femoroacetabular impingement and/or labral tears: study protocol for a randomized controlled trial (HIPARTI) and a prospective cohort study (HARP). *journal of orthopaedic & sports physical therapy*, *48*(4), 325-335.

Roe, M., Blake, C., Gissane, C., & Collins, K. (2016). Injury scheme claims in Gaelic games: a review of 2007–2014. *Journal of athletic training*, *51*(4), 303-308.

Roberts, S. P., Trewartha, G., Higgitt, R. J., El-Abd, J., & Stokes, K. A. (2008). The physical demands of elite English rugby union. *Journal of Sports Sciences*, *26*(8), 825–833.

Rylander, J. H., Shu, B., Andriacchi, T. P., & Safran, M. R. (2011). Preoperative and postoperative sagittal plane hip kinematics in patients with femoroacetabular impingement during level walking. *The American Journal of Sports Medicine*, *39*(1 suppl), 36S–42S.

Rylander, J., Shu, B., Favre, J., Safran, M., & Andriacchi, T. (2013). Functional testing provides unique insights into the pathomechanics of femoroacetabular impingement and an objective basis for evaluating treatment outcome. *Journal of Orthopaedic Research*, *31*(9), 1461-1468.

Sansone, M., Ahldén, M., Jonasson, P., Thomeé, C., Swärd, L., Baranto, A., … Thomeé, R. (2015). Good Results After Hip Arthroscopy for Femoroacetabular Impingement in Top-Level Athletes. *Orthopaedic Journal of Sports Medicine*, *3*(2),

Sassi, R. H., Dardouri, W., Yahmed, M. H., Gmada, N., Mahfoudhi, M. E., & Gharbi, Z. (2009). Relative and absolute reliability of a modified agility T-test and its relationship with vertical jump and straight sprint. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, *23*, 1644–1651.

Schache, A. G., Blanch, P. D., Rath, D. A., Wrigley, T. V., Starr, R., & Bennell, K. L. (2001). A comparison of overground and treadmill running for measuring the three-dimensional kinematics of the lumbo-pelvic-hip complex. *Clinical Biomechanics*, *16*(8), 667–680.

Schoenfeld, B. J. (2010). Squatting Kinematics and Kinetics and Their Application to Exercise Performance. *Journal of Strength & Conditioning Research*, *24*(12), 3497–3506.

Seeley, R. R., VanPutte, C. L., Regan, J., & Russo, A. (2011). *Seeley's anatomy & physiology*. McGraw-Hill.

Semenick, D. (1990). Tests and Measurements: The T-test. *Strength & Conditioning Journal*, *12*(1), 36–37.

Sherry, M. A., & Best, T. M. (2004). A comparison of 2 rehabilitation programs in the treatment of acute hamstring strains. *Journal of Orthopaedic & Sports Physical Therapy*, *34*(3), 116–125.

Sibley, B. A., & Etnier, J. L. (2003). The relationship between physical activity and cognition in children: a meta-analysis. *Pediatric Exercise Science*, *15*(3), 243–256.

Siebenrock, Kaschka, Frauchiger, Werlen, and S. (2013). Prevalence of Cam-Type Deformity and Hip Pain in Elite Ice Hockey Players Before and After the End of Growth. *The American Journal of Sports Medicine*, *41*(10), 2308–2313.

Siebenrock, K. A., Ferner, F., Noble, P. C., Santore, R. F., Werlen, S., & Mamisch, T. C. (2011). The cam-type deformity of the proximal femur arises in childhood in response to vigorous sporting activity. *Clinical Orthopaedics and Related Research*, *469*(11), 3229–40.

Siebenrock, K. A., Wahab, K. H. A., Werlen, S., Kalhor, M., Leunig, M., & Ganz, R. (2004). Abnormal extension of the femoral head epiphysis as a cause of cam impingement. *Clinical Orthopaedics and Related Research*, *418*, 54–60.

Silvis, M. L., Mosher, T. J., Smetana, B. S., Chinchilli, V. M., Flemming, D. J., Walker, E. A., & Black, K. P. (2011). High prevalence of pelvic and hip magnetic resonance imaging findings in asymptomatic collegiate and professional hockey players. *The American journal of sports medicine*, *39*(4), 715-721.

Singh, P. J., & O'Donnell, J. M. (2010). The outcome of hip arthroscopy in Australian football league players: a review of 27 hips. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*, *26*(6), 743-749.

Sleivert, G., & Taingahue, M. (2004). The relationship between maximal jump-squat power and sprint acceleration in athletes. *European Journal of Applied Physiology*, *91*(1), 46–52.

Souza, R. B., & Powers, C. M. (2009). Differences in hip kinematics, muscle strength, and muscle activation between subjects with and without patellofemoral pain. *Journal of Orthopaedic & Sports Physical Therapy*, *39*(1), 12–19.

Spencer, M., Lawrence, S., Rechichi, C., Bishop, D., Dawson, B., & Goodman, C. (2004). Time–motion analysis of elite field hockey, with special reference to repeated-sprint activity. *Journal of Sports Sciences*, *22*(9), 843–850.

Spencer, S., Millis, M. B., & Kim, Y. J. (2006). Early results of treatment of hip impingement syndrome in slipped capital femoral epiphysis and pistol grip deformity of the femoral head-neck junction using the surgical dislocation technique. *Journal of Pediatric Orthopaedics*, *26*(3), 281-285.

Spencer, R. A., Rehman, L., & Kirk, S. F. L. (2015). Understanding gender norms, nutrition, and physical activity in adolescent girls: a scoping review. *International Journal of Behavioral Nutrition and Physical Activity*, *12*(1), 1.

Spencer-Gardner, L., Eischen, J. J., Levy, B. A., Sierra, R. J., Engasser, W. M., & Krych, A. J. (2014). A comprehensive five-phase rehabilitation programme after hip arthroscopy for femoroacetabular impingement. *Knee Surgery, Sports Traumatology, Arthroscopy*, *22*(4), 848-859.

Streit, J. J., Fortun, C. M., & Salata, M. J. (2012). Cam-type femoroacetabular impingement. *Operative Techniques in Sports Medicine*, *20*(4), 295-300.

Stagni, R., Leardini, A., Cappozzo, A., Benedetti, M. G., & Cappello, A. (2000). Effects of hip joint centre mislocation on gait analysis results. *Journal of Biomechanics*, *33*(11), 1479–1487.

Stalzer, S., Wahoff, M., Scanlan, M., & Draovitch, P. (2005). Rehabilitation after hip arthroscopy. *Operative Techniques in Orthopaedics*, *15*(3), 280-289.

Steppacher, S. D., Anwander, H., Zurmühle, C. A., Tannast, M., & Siebenrock, K. A. (2015). Eighty percent of patients with surgical hip dislocation for femoroacetabular impingement have a good clinical result without osteoarthritis progression at 10 years. *Clinical Orthopaedics and Related Research®*, *473*(4), 1333–1341.

Steppacher, S. D., Huemmer, C., Schwab, J. M., Tannast, M., & Siebenrock, K. A. (2014). Surgical hip dislocation for treatment of femoroacetabular impingement: factors predicting 5-year survivorship. *Clinical Orthopaedics and Related Research®*, *472*(1), 337–348.

Stull, J. D., Philippon, M. J., & LaPrade, R. F. (2011). “At-risk” positioning and hip biomechanics of the Peewee ice hockey sprint start. *The American Journal of Sports Medicine*, *39*(1 suppl), 29S–35S.

Sutherland, D. H., Olshen, R., Cooper, L., & Woo, S. L. Y. (1980). The development of mature gait. *J Bone Joint Surg Am*, *62*(3), 336–353.

Tak, I., Weir, A., Langhout, R., Waarsing, J. H., Stubbe, J., & Kerkhoffs, G. (2015). The relationship between the frequency of football practice during skeletal growth and the presence of a cam deformity in adult elite football players. *British Journal of Sports Medicine*, *49*(9), 630–634.

Tamura, A., Akasaka, K., Otsudo, T., Shiozawa, J., Toda, Y., & Yamada, K. (2017). Fatigue influences lower extremity angular velocities during a single-leg drop vertical jump. *Journal of Physical Therapy Science*, *29*(3), 498–504.

Tannast, M., Murphy, S. B., Langlotz, F., Anderson, S. E., & Siebenrock, K.-A. (2006). Estimation of pelvic tilt on anteroposterior X-rays—a comparison of six parameters. *Skeletal Radiology*, *35*(3), 149–155.

Tannast, M., Siebenrock, K. a, & Anderson, S. E. (2007). Femoroacetabular impingement: radiographic diagnosis--what the radiologist should know. *AJR. American Journal of Roentgenology*, *188*(6), 1540–52.

Tanzer, M., & Noiseux, N. (2004). Osseous abnormalities and early osteoarthritis: the role of hip impingement. *Clinical Orthopaedics and Related Research*, (429), 170–177.

Thorstensson, A. (1986). How is the normal locomotor program modified to produce backward walking? *Experimental Brain Research*, *61*(3), 664–668.

Tijssen, M., van Cingel, R., van Melick, N., & de Visser, E. (2011). Patient-Reported Outcome questionnaires for hip arthroscopy: a systematic review of the psychometric evidence. *BMC musculoskeletal disorders*, *12*(1), 117.

Tijssen, M., van Cingel, R. E. H., Staal, J. B., Teerenstra, S., de Visser, E., & Nijhuis-Van der Sanden, M. W. G. (2016). Physical therapy aimed at self-management versus usual care physical therapy after hip arthroscopy for femoroacetabular impingement: study protocol for a randomized controlled trial. *Trials*, *17*(1), 91.

Tönnis, D., & Heinecke, A. (1999). Current concepts review-acetabular and femoral anteversion: relationship with osteoarthritis of the hip. *JBJS*, *81*(12), 1747-70.

Tracey, J. (2003). The emotional response to the injury and rehabilitation process. *Journal of Applied Sport Psychology*, *15*(4), 279–293.

Tran, P., Pritchard, M., & O'Donnell, J. (2013). Outcome of arthroscopic treatment for cam type femoroacetabular impingement in adolescents. *ANZ Journal of Surgery*, *83*(5), 382–386.

Vitale, J. A., Caumo, A., Roveda, E., Montaruli, A., La Torre, A., Battaglini, C. L., & Carandente, F. (2016). Physical Attributes and NFL Combine Performance Tests between Italian National League and American Football Players: A Comparative Study. *The Journal of Strength & Conditioning Research*, *30*(10), 2802–2808.

Voos, J. E., Mauro, C. S., & Kelly, B. T. (2010). Femoroacetabular impingement in the athlete: Compensatory injury patterns. *Operative Techniques in Orthopaedics*, *20*(4), 231-236.

Wagner, S., Hofstetter, W., Chiquet, M., Mainil-Varlet, P., Stauffer, E., Ganz, R., & Siebenrock, K. A. (2003). Early osteoarthritic changes of human femoral head cartilage subsequent to femoro-acetabular impingement. *Osteoarthritis and Cartilage*, *11*(7), 508–518.

Walsh, M., Arampatzis, A., Schade, F., & BrÜggemann, G. (2004). The effect of drop jump starting height and contact time on power, work performed, and moment of force. *The Journal of Strength & Conditioning Research*, *18*(3), 561–566.

Weinans, H. (2015). Femoroacetabular impingement: what is its link with osteoarthritis? *British Journal of Sports Medicine*, bjsports-2015.

Welch, C. M., Banks, S. A., Cook, F. F., & Draovitch, P. (1995). Hitting a baseball: A biomechanical description. *Journal of Orthopaedic & Sports Physical Therapy*, *22*(5), 193–201.

Willy, R. W., & Davis, I. S. (2011). The effect of a hip-strengthening program on mechanics during running and during a single-leg squat. *Journal of Orthopaedic & Sports Physical Therapy*, *41*(9), 625–632.

Winter, D. A., Pluck, N., & Yang, J. F. (1989). Backward Walking: A Simple Reversal of Forward Walking? *Journal of Motor Behavior*, *21*(3), 291–305.

Winter, D. A., Sidwall, H. G., & Hobson, D. A. (1974). Measurement and reduction of noise in kinematics of locomotion. *Journal of Biomechanics*, *7*(2), 157–159.

Wisbey, B., Montgomery, P. G., Pyne, D. B., & Rattray, B. (2010). Quantifying movement demands of AFL football using GPS tracking. *Journal of Science and Medicine in Sport*, *13*(5), 531–536.

Wisløff, U., Castagna, C., Helgerud, J., Jones, R., & Hoff, J. (2004). Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *British Journal of Sports Medicine*, *38*(3), 285–288.

Wright, A. A., Naze, G. S., Kavchak, A. E., Paul, D., Kenison, B., & Hegedus, E. J. (2015). Radiological variables associated with progression of femoroacetabular impingement of the hip: a systematic review. *Journal of Science and Medicine in Sport*, *18*(2), 122–127.

Wrotniak, B. H., Epstein, L. H., Dorn, J. M., Jones, K. E., & Kondilis, V. A. (2006). The relationship between motor proficiency and physical activity in children. *Pediatrics*, *118*(6), e1758–e1765.

Yaffe, M. A., & Terry, M. A. (2010). Recent and Upcoming Innovation in the Technology of Hip Arthroscopy. *Operative Techniques in Orthopaedics*, *20*(4), 242-247.

Yang, S. X. M., Christiansen, M. S., Larsen, P. K., Alkjær, T., Moeslund, T. B., Simonsen, E. B., & Lynnerup, N. (2014). Markerless motion capture systems for tracking of persons in forensic biomechanics: an overview. *Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization*, *2*(1), 46–65.

Yu, B., Gabriel, D., Noble, L., & An, K.-N. (1999). Estimate of the optimum cutoff frequency for the Butterworth low-pass digital filter. *Journal of Applied Biomechanics*, *15*(3), 318–329.

Zaltz, I., Kelly, B. T., Hetsroni, I., & Bedi, A. (2013). The crossover sign overestimates acetabular retroversion. *Clinical Orthopaedics and Related Research®*, *471*(8), 2463-2470.

Zatsiorsky, Vladimir M., and W. J. K. (2006). *Science and Practice of Sport*.