

Characterizing Range of Motion, Strength and Performance Outcomes in Patients with
Femoroacetabular Impingement Syndrome Prior to Hip Arthroscopy

By

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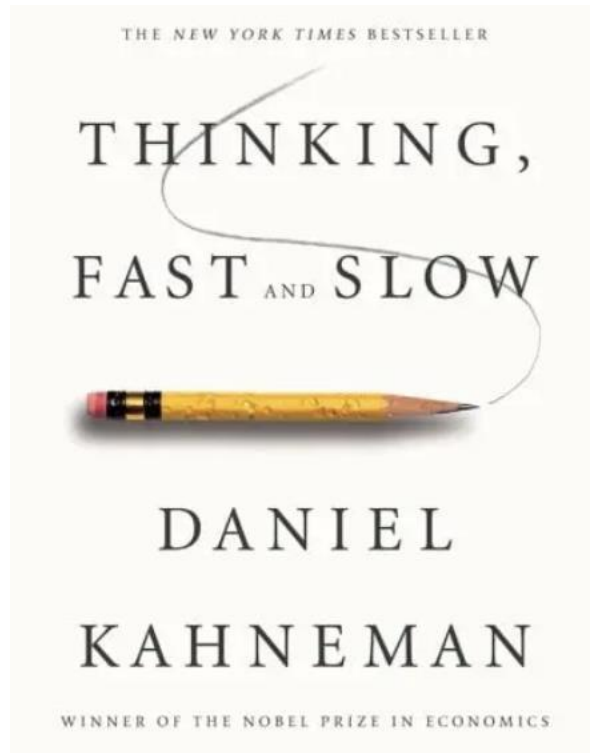
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ABSTRACT

Hip arthroscopy has historically focused on patient-reported outcome measures with limited evaluation of range of motion (ROM), strength, and dynamic performance to determine a successful outcome. The purpose of this study was to characterize active ROM, strength, and dynamic performance of participants who have elected to undergo hip arthroscopy for femoroacetabular impingement. It was hypothesized that measurements isolated to the hip (active ROM and strength) will be lower in the affected limb with less limitation in multi-joint, dynamic outcomes. Participants were included if they were 16-50 years of age, had a confirmed diagnosis of Femoroacetabular impingement syndrome (FAIS) based on the Warwick Agreement, had no improvement with conservative management, had symptomatic relief with an intra-articular injection, and required unilateral surgical intervention. Participants completed an assessment including active hip ROM, clinical special tests, isometric hip abduction and extension strength, isokinetic hip flexion and extension strength, and dynamic performance measures including change of direction, hopping and jump tests. Clinical special tests were evaluated with the X^2 test and between limb performance was compared with paired T-Tests except for SL-CMJ vGRFS (ANOVA, $p < 0.05$). Range of motion was greater on the unaffected limb across all movements in our participants. Isokinetic hip flexion (mean difference 0.15 nm/kg, $p = 0.01$) and extension (mean difference 0.28 nm/kg, $p < 0.001$) were reduced in the affected limb; However, the only statistically significant finding was for abduction ($p < 0.001$). A between-limb difference in performance occurred in the single leg countermovement jump (mean difference 0.93 cm, $p = 0.018$). Measures isolated to the hip joint itself, including active ROM of abduction and isokinetic flexion and extension strength, were lower in the affected limb, while

multi-joint performance measures that required the lower extremity to function in multiple planes of motion were unable to objectively confirm the subjective reports of performance impairments in people diagnosed with FAIS.

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“Nothing in life is as important as you think it is, while you are thinking about it”
— Daniel Kahneman, Thinking, Fast and Slow

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ABBREVIATION GLOSSARY

ACL	Anterior cruciate ligament
AP	Anteroposterior
BW	Body weight
CMJ	Countermovement jump
COD	Change of direction
FABER	Flexion-Abduction-External rotation
FADIR	Flexion-Adduction-Internal rotation
FAI	Femoroacetabular impingement
FAIS	Femoroacetabular impingement syndrome
HHD	Handheld dynamometry
LCEA	Lateral centre edge angle
MDC	Minimum Detectable Change
MCID	Minimal clinically important difference
MRI	Magnetic resonance imaging
MVIC	Maximum voluntary isometric contraction
n	Newton
nm	Newton-meter
OA	Osteoarthritis
PASS	Patient acceptable symptomatic state
PCM	Primary cam morphology
PROMs	Patient-reported outcome measures
RCT	Randomized controlled trial

ROM	Range of motion
RFD	Rate of force development
RTS	Return to sport
SD	Standard deviation
SEM	Standard Error of Measure
SL-CMJ	Single limb countermovement jump

CHAPTER I: INTRODUCTION

Hip arthroscopy has historically focused on patient-reported outcome measures (PROMs), diagnostic imaging, and revision rates to determine surgical success, while measures of range of motion (ROM) and strength have been underreported (Reiman et al., 2018). The use of PROMs captures the essence of the biopsychosocial model by providing insight regarding subjective abilities related to quality of life, activity participation, and readiness to return to sport (RTS); However, there can be a mismatch between patient's expectations, perceptions and postintervention outcomes (Mannion et al., 2013). A cornerstone of this mismatch is the discrepancy between self-reported and objective measures of physical performance (Kapteyn et al., 2018). This bolsters the argument for a comprehensive assessment to include objective measures of ROM, strength, and dynamic performance to determine successful outcomes. The evaluation of baseline characteristics of a person undergoing surgical intervention allows the clinician to collect objective measures of physical abilities from which impairments can be recognized and prioritized to streamline the rehabilitation process to promote a successful outcome.

There has been a world-wide exponential increase in the diagnosis, treatment, and surgical intervention for femoroacetabular impingement syndrome (FAIS). Appropriately, academic publications dedicated to femoroacetabular impingement (FAI) have shown a similar trend, with a dramatic increase since 2009, a doubling by 2013, and >45% of total publications noted between 2016-2019 (Tang et al., 2021). Initially, studies focused on mechanistic views including topics such as etiology, pathogenesis, and morphological changes. Since 2016, the

research foci have shifted towards topics based on application such as population incidence, prevalence, outcome evaluation, and prognosis prediction (Tang et al., 2021).

To qualify an intervention as successful, evidence of a comprehensive objective assessment, including ROM, strength, and dynamic performance, should be required alongside patient-reported outcomes. To date, a standardized objective assessment to determine successful clinical outcomes has not been established (Mosler et al., 2020), and there is considerable variability in the use and reporting of outcome measures following hip arthroscopy (Reiman et al., 2018). The use of standardized, objectively measured outcomes could serve multiple purposes: to establish baseline levels of function, as benchmarks to document goal setting and progress, to determine predictive factors, and to evaluate the relative effectiveness of interventions. Currently, there is no standardized objective assessment battery that matches this goal.

CHAPTER II: LITERATURE REVIEW

Femoroacetabular Impingement: History and Diagnostic Criteria

Conceptually, hip impingement dates to 1936 when Smith-Peterson theorized that hip pain could result from the contact of the femoral neck against the anterior margin of the acetabulum (Smith-Petersen, 1936). By 1986, radiographic observations in non-dysplastic hips led Harris to describe an “idiopathic” degenerative hip disease which was characterized by a “pistol grip” deformity involving the femoral head-neck junction (Harris, 1986). In the early 2000’s, the role of the acetabular labrum as a fluid seal that maintains hydrostatic pressure which is critical for preserving the hip joint structure by reducing contact stresses between the femoral and acetabular cartilage surfaces was included as a potential pathological feature in the diagnosis of hip impingement (Ferguson et al., 2003). Moving forward, hip impingement would not solely involve bony morphological features and would now be inclusive of labral and chondral pathology. Various locations of labral and chondral pathology may occur as a sequela of morphological features present in hip impingement. Co-existing labral (79%) and chondral (37%) pathology are prevalent findings in patients undergoing hip arthroscopy (Reiman et al., 2018). This has led to surgical interventions to correct bony morphological features, repair, or reconstruct the labrum, and modify chondral pathology with microfracture. It has been postulated that morphological changes left untreated are a risk factor for the development of hip osteoarthritis (OA), as there is an association of the presence of larger α angles with the development of hip OA (Agricola et al., 2013).

Commonly noted as having first coined the term “femoroacetabular impingement” (FAI), Ganz popularized the narrative that it was the interplay of the femoroacetabular anatomy, along with subsequent labral and cartilage pathology, that could lead to degenerative hip disease (Ganz

et al., 2003). At that time, three mechanisms of bony morphology were attributed to FAI: cam, pincer and combined.

Cam morphology describes a flattening or convexity of the femoral head-neck junction at the location where contact of the femur and the acetabulum may occur during hip flexion leading to an abutment causing shearing forces at the chondro-labral junction (M. Beck et al., 2005).

Pincer morphology describes an anatomical alteration of the acetabular rim which results in over coverage of the femoral head and may cause a direct injury to the labrum leading to labral degeneration and/or ossification (Siebenrock et al., 2003). When combined morphology is present, the relative over coverage of the femoral head may magnify premature contact of the convex femoral head-neck junction on the acetabular rim leading to chondral injury and producing a levering effect known as a “contrecoup” lesion which may lead to chondral injury at the posteroinferior acetabulum (Ganz et al., 2003; Ito et al., 2001).

Femoroacetabular impingement syndrome (FAIS) has been defined by the Warwick International Agreement as a “motion-related clinical disorder of the hip with a triad of symptoms, clinical signs, and imaging findings, representing the symptomatic premature contact between the proximal femur and the acetabulum” (Griffin et al., 2016). The primary symptom in FAIS is motion or position-related pain in the hip or groin with additional locations of pain reported in the back, buttock, knee, lateral hip, along with the anterior, lateral, and posterior thigh (Clohisy et al., 2009). Secondary mechanical symptoms may include clicking, catching, locking, stiffness, restricted range of motion or giving way (Griffin et al., 2016). While a variety of clinical signs have been described in the literature, hip range of motion, impingement and provocative tests, such as the Flexion-Adduction-Internal rotation (FADIR) and the Flexion-

Abduction-External rotation (FABER), that typically reproduce pain have been considered appropriate clinical diagnostic tests for FAIS (Griffin et al., 2016).

Confirmation of bony morphological features with imaging remains a component of FAIS diagnostic criteria. An anteroposterior (AP) pelvis and lateral view radiograph can serve as a basic screening tool to identify cam or pincer morphology. The α angle is a radiographic measurement used to describe the flattening or convexity of the femoral head-neck junction (Ganz et al., 2003) and diagnose cam morphology. A common threshold of $>55^\circ$ has been widely accepted (Griffin et al., 2018); However, a recent consensus statement on primary cam morphology has proposed using a threshold of $>60^\circ$ for clinical practice and research (Dijkstra et al., 2023). The cross-over sign and lateral centre-edge angle (LCEA) are radiographic measurements used to describe acetabular version and coverage (Arora & Whelan, 2017). A cross-over sign is considered positive for acetabular retroversion if the anterior acetabular rim lies lateral to the posterior rim (Jamali et al., 2007). An accepted standard for over coverage, and diagnosing pincer morphology, is a LCEA is $>39^\circ$ (Griffin et al., 2018). Magnetic resonance imaging (MRI) is the preferred modality to assess for intra-articular pathology. Despite its low specificity (33%) and high sensitivity (96%), Mintz et al. (2005) notes the overall accuracy of MRI to detect labral tears at 94% and thus, it continues to be the chosen modality used to detect labral pathology.

While the historical definition of hip impingement, which evolved to FAI, focuses on morphological changes as the cornerstone of the diagnosis, the modern diagnosis of FAIS, the symptomatic presentation of morphological radiological findings in combination with clinical signs, requires symptoms to be the prominent feature of the diagnosis.

Femoroacetabular Impingement: Epidemiology

Epidemiological studies on FAI have heavily relied on radiological evidence of morphological changes which does not represent the modern definition of FAIS requiring the presence of clinical signs and symptoms. The prevalence of FAI, the presence of morphological findings in the absence of symptomology, was found to be greater in men (57%) compared to women (43%), and in athletes (55%) compared to the general population (Frank et al., 2015). Cam-type FAI is more prevalent in young males resulting from either a decreased femoral head-neck offset, a non-spherical femoral head or femoral retrotorsion (Ganz et al., 2008; Siebenrock et al., 2004), while pincer-type FAI is more prevalent in active, middle-aged women with focal or global over coverage or global retroversion (Ganz et al., 2003). Combined-type morphology has been noted as the most common type of FAI (Ganz et al., 2003, 2008), and recognition of co-existing femoral and acetabular-sided changes are important surgical considerations.

Investigations of cam morphology are more common in the literature, while pincer or combined types are less frequently studied. Mascarenhas et al. (2016) found variability of pure pincer morphology across comparison groups which was consistent with previous studies that noted 67% prevalence of pincer FAI in the asymptomatic population (Frank et al., 2015). A case-control study examined asymptomatic volunteers with negative impingement tests and found the distribution of acetabular morphology on MRI was comparable to the FAIS population (Bensler et al., 2019).

Cam morphology can be viewed through two different lenses, one where natural developmental change to morphology occurs and a second where pathological processes lead to altered morphology. Primary cam morphology (PCM) represents a normal physiological response to loading in the prepubertal and pubertal skeleton whereby changes to the femoral

head-neck junction leads to bony cartilage prominences resulting in a change from a spherical to an aspherical femoral head (Dijkstra et al., 2023). Secondary cam morphology develops in response to trauma or preexisting disease, such as Legg-Calve-Perthes disease (Snow et al., 1993) and Slipped capital femoral epiphysis (SCFE) (Fraitzl et al., 2007), resulting in increased susceptibility for hip conditions and the development of morphological changes at the femoral head and head-neck junction.

A systematic review evaluating the prevalence of morphological features found cam morphology to be more common in the symptomatic versus asymptomatic populations and mean α angle to be significantly greater in the symptomatic population compared to asymptomatic or athletic groups (Mascarenhas et al., 2016). There is evidence of increased prevalence of FAI and a positive correlation between α angle and both age and activity level in sports that require deep hip flexion and repetitive rotational demands (Doran et al., 2022). When Collegiate level football players were evaluated, >90% of players exhibited radiological evidence of morphological changes regardless of symptoms with larger α angles as an independent predictor of pain (Larson et al., 2013). Nepple et al. (2014) compared a cohort of males and females prior to hip arthroscopy and found distinct sex-dependent patterns of radiological changes, physical function, and participation scores. Females were characterized as having milder morphological findings specifically when cam-type morphology was evaluated, and presented with greater symptomatology, while males exhibited higher activity levels and more extensive intra-articular disease.

Femoroacetabular impingement syndrome (FAIS) is primarily diagnosed in the young, active population in the third decade of life (Clohisy et al., 2013). Most athletes will continue to participate in sport without developing symptoms while others may develop FAIS (Griffin et al.,

2016) and potentially progress onto hip OA (Beaulé et al., 2018). While there is evidence of factors that may predispose an individual towards FAIS, it is unlikely for an algorithm to be established that would predict with certainty the progression from FAI to FAIS. Morphological changes, ROM restrictions, impaired muscle function and dynamic performance are all objective measures to consider. Alongside an individual's psychological and social factors, these objective measures may provide insight on management strategies for improved outcomes, rather than establish concrete mechanistic or pathophysiological processes.

Management of Femoroacetabular Impingement Syndrome

There is a lack of evidence to support a definitive treatment for FAIS (Griffin et al., 2016). Treatment is often categorized into conservative care, rehabilitation, or surgical intervention. Conservative interventions include education, watchful waiting, lifestyle, and activity modification, while rehabilitation, often in the context of physiotherapy, aims to improve hip stability, neuromuscular control, strength, ROM, and movement patterns (Griffin et al., 2016). Hip arthroscopy is typically performed in supine with the lower extremity placed in traction. A capsulotomy is performed to expose the femoral head-neck junction. The acetabular labrum may be debrided, repaired, or reconstructed. Osteochondroplasty at the head-neck junction of the femur and/or at the acetabular rim is completed based on the presence of cam or pincer morphology. The capsule is commonly repaired once the procedure is completed.

Many studies have supported the superiority of hip arthroscopy (Dwyer et al., 2020; Griffin et al., 2018; Hunter et al., 2021; S. D. Martin et al., 2021; Palmer et al., 2019) while one concluded hip arthroscopy was comparable to physical therapy (Mansell et al., 2018). The largest randomized controlled trial (RCT), the UK FASHIoN trial, concluded hip arthroscopy was clinically effective when evaluating PROMs at 12-months post intervention (Griffin et al., 2018). An RCT conducted by Mansell et al. (2018), while commonly referenced as showing favorable results for physical therapy, reported a 70% crossover rate of participants to surgical intervention, and thus challenges the conclusion that physical therapy was superior to hip arthroscopy. Reporting similar findings in favor of hip arthroscopy, Casartelli et al. (2021) concluded equivalent clinical improvements in hip pain, function, and quality of life in FAIS patients 6-8 months after either surgical or physical therapy interventions.

Current clinical practices encourage non-operative management for a minimum of 12 weeks prior to electing to undergo hip arthroscopy (Pennock et al., 2018), as short-term outcomes were found to be successful in 39-82% of potential surgical candidates (Schwabe et al., 2020). Comparing physiotherapy in the literature is challenging due to the vast heterogeneity of rehabilitation protocols. Physical therapy in the UK FASHIoN trial was based on the best conservative care model which boasts the concept of personalized hip therapy (Wall et al., 2016), yet the findings of the UK FASHIoN trial ultimately pointed in favor of hip arthroscopy. There is a lack of evidence for an effective rehabilitation protocol, and consequently, the tenants of what constitutes rehabilitation for FAIS must be considered a priority. With surgical intervention as a popular option to manage FAIS, further investigation to improve postoperative outcomes through the identification of baseline characteristics of the individual may result in knowledge of objective measures of impairments that when addressed through the rehabilitation process may lead to improved outcomes.

Physical Impairments

The extent to which physical impairments, such as ROM, muscle strength, and dynamic performance impact the symptomatic presentation of FAIS has been explored with particular interest in questions surrounding whether differences in physical impairments exist in FAIS compared to those with asymptomatic FAI morphology or in healthy controls.

Range of Motion

The Warwick Agreement included hip ROM as a component of the clinical assessment in FAIS (Griffin et al., 2016) despite the lack of evidence to support ROM is impaired in this population. The assumption that morphological changes lead to ROM limitations is not fully supported (Albertoni et al., 2023). The presence of symptoms is a requirement for the modern definition of FAIS, and comparisons of ROM between those with asymptomatic morphological changes on imaging (FAI) and healthy controls without morphological changes may provide insight as to ROM impairments that contribute to the symptomatic presentation of FAIS.

In a systematic review of 17 cross-sectional studies, Albertoni et al. (2023) considered three separate comparison groups: FAIS versus healthy controls, FAIS versus FAI, and FAI versus healthy controls. There is high certainty of the evidence for a restriction of adduction at 90° of flexion and moderate evidence for a reduction of internal rotation and abduction when comparing FAIS to healthy controls; However, there was low certainty of the evidence to support differences between FAIS and FAI or in FAI compared to healthy controls in any single or combined planes of ROM (Albertoni et al., 2023). While earlier systematic reviews (Diamond et al., 2015; Freke et al., 2016) reported conflicting evidence for ROM restrictions, the comprehensive comparison by Albertoni et al. (2023) firmly counters the argument that

morphology alone leads to ROM restrictions, and thus the conclusion can be made that symptoms in FAIS are the result of complex and multifactorial components which may include restrictions of ROM into positions of impingement.

Muscle Strength

A primary clinical finding in the assessment of chronic hip pain, including FAIS, is muscle weakness (Casartelli et al., 2011; Harris-Hayes et al., 2014). Despite this knowledge, the prevalence and consistency in reporting of surgical outcomes for FAIS has focused on diagnostic imaging and PROMs with only 2.5% of studies reporting on hip strength (Reiman et al., 2018). Postoperative guidelines do not provide a clear picture for the assessment and management of muscle strength in FAIS, rather the focus is on weightbearing, passive ROM exercises, and general rehabilitation guidelines (O'Connor et al., 2018). There may be clinically relevant benefits to objectively measuring strength which include the identification of individual strength deficits to guide treatment goals and progression, measuring improvement over time, and assisting in the decision-making process for return to sport (RTS).

Technological advances have created the opportunity to objectively measure strength in the clinical settings without the expense typically associated with research equipment. Isokinetic dynamometry is considered the gold standard laboratory measure of strength and power; However, they are expensive and inconvenient for routine clinical use (Stark et al., 2011). A variety of portable dynamometers, such as handheld, fixed frame, handheld load cells, or force gauges, have been characterized as being more cost-effective and accessible (Martins et al., 2017; Thorborg, Bandholm, & Hölmich, 2013). There is a movement towards the use of isometric handheld dynamometers (HHD) as a replacement to manual muscle testing, and as a

surrogate to isokinetic testing, to quantify baseline and subsequent changes in strength in the clinical setting.

To ensure HHD are reliable tools they must provide the ability to detect a small percentage of change either from affected to unaffected limb, or as a test re-test for change over time. In rehabilitation, a 10% improvement or deterioration of strength is a commonly used as a clinically relevant change, and similarly, return to sport testing targets a less than 10% deficit in peak muscle strength when compared to the unaffected limb. A systematic review and meta-analysis by Chamorro et al. (2017) reported limited ability for HHD to detect changes of <15% in muscle force, while isokinetic dynamometry may be a more sensitive instrument to detect smaller differences in muscle force.

There are several factors that can affect the reliability of HHD tools such as position of the subject and practitioner, strength of the evaluator, and fixation of the dynamometer (Thorborg, Bandholm, Schick, et al., 2013; Thorborg et al., 2010) Heterogeneity of these factors has led to difficulty establishing HHD as a reliable and valid comparator to isokinetic testing in the hip. A recent systematic review and meta-analysis by Waiteman et al. (2023) concluded that the use of portable dynamometers to assess hip muscle strength is reliable; However, there was a lack of high-quality evidence of criterion validity and the authors cautioned against using portable dynamometers as surrogates for isokinetic based outcomes.

Studies using an isokinetic dynamometer to assess maximum voluntary isometric contraction (MVIC) have reported hip flexor deficits ranging from 15-33% (Kierkegaard et al., 2017, Castaretelli et al., 2011, Castartelli et al., 2012, Castaretelli et al., 2014) with dynamic measures of hip flexor strength similarly reported (Casartelli et al., 2014; Kierkegaard et al., 2017). In a cross-sectional study, Kierkegaard et al. (2017) found impaired affected limb

maximal isometric hip flexion (15-21%) and extension (10-25%) with bilateral reductions in rate of force development (RFD) for hip extension in those with FAIS.

Handheld dynamometry is commonly used to evaluate hip abduction, adduction, internal rotation, and external rotation. Compared to controls, those diagnosed with FAIS exhibited hip abduction deficits ranging from 2-28% (Casartelli et al., 2011; Diamond et al., 2015; Frasson et al., 2020; Kemp et al., 2014; Maffiuletti et al., 2020; Nepple et al., 2015), and compared to both healthy controls and athletes, hip abduction strength was on average 19% and 30% lower, respectively (Bizzini et al., 2023). Hip adduction strength has been reported 15-31% lower in FAIS compared to controls (Bizzini et al., 2023; Casartelli et al., 2014), and 26.4% lower than athletes (Bizzini et al., 2023).

Objective measurements of strength in FAIS subjects prior to hip arthroscopy may provide insight to improve postoperative outcomes by monitoring progression of strength over time to inform recovery of muscle function. Beck et al. (2020) found that preoperative isometric hip extension and abduction strength positively correlated with 6-month postoperative PROMs; However, greater preoperative ipsilateral isometric hip extension strength was the only independent predictor of achieving a patient acceptable symptomatic state (PASS) or minimal clinically important difference (MCID).

Analysis of muscle function in a systematic review by Freke et al. (2016) concluded that there was moderate evidence for reduced strength in FAIS for hip adduction and external rotation, limited evidence for hip flexion, and limited conflicting evidence for hip extension and abduction. The benefit of a systematic review is to evaluate a body of evidence and report on the totality of those findings. Due to the heterogeneity in methodologies across studies, along with

the context related to preoperative measures, postoperative comparisons or nonoperative cohorts, there is limited evidence for consistent findings in strength deficits in the FAIS population.

Dynamic Performance

Pain and activity limitations which lead to the inability to participate and perform at a desired level are central themes of a person seeking out care for musculoskeletal conditions. In an epidemiological study, 71% of young, active adults with a diagnosis of FAIS reported activity limitations of walking, navigation of stairs, running, and pivoting (Clohisy et al., 2009). There is evidence of reduced physical activity in this population as they spend less time participating in moderate to vigorous activity, take fewer steps, and score lower values on quality-of-life measures compared to a control group (Alrashdi et al., 2023). The International Hip-related Pain Research Network (IHipPRN) recommended physical activity be quantified using objective sport and occupational specific activities along with self-reported measures (Mosler et al., 2020). A recent international consensus statement for non-arthritis intra-articular hip pain suggested that classification of functional performance tests to low, medium, high, and sport-specific intensity may be appropriate to implement at initial evaluation, re-evaluation, discharge, and to assess RTS (R. L. Martin et al., 2023).

Ambulation is an essential activity of daily living and represents a repetitive dynamic motion. There are reports of hip frontal, sagittal and transverse plane impairments in FAIS during the evaluation of gait (Hunt et al., 2013); However, a systematic review reported inconsistent findings of sagittal plane motion deficits and agreement amongst a small number of studies for reduced ROM in the frontal plane (Diamond et al., 2015). The biomechanical demands of

ambulation do not require end ROM at the hip and regardless of statistical significance, the clinical relevance of relatively small kinematic changes during gait analysis are questionable.

Stair climbing challenges the hip in multiple planes and may represent a more sensitive pattern of motion to detect altered kinematics at the hip as it requires a greater flexed position at and increased effort to control the pelvis in the frontal plane compared to flat ground ambulation (Nadeau et al., 2003). The reporting of altered biomechanics in stair climbing has been inconsistent. Stair climbing kinematics have been shown to be similar in FAIS compared to controls, except for greater peak trunk forward flexion and peak external hip flexion moments (Hammond et al., 2017). In contrast, Rylander et al. (2013) found abnormal hip sagittal and transverse plane kinematics and a significant increase in transverse plane pelvic ROM and maximum anterior pelvic tilt in a preoperative FAIS cohort compared to controls. Interestingly, when comparing the stair climbing task in the same cohort postoperatively, abnormal kinematics remained despite correction of morphological features associated with FAI pointing to the need to determine which factors contribute to kinematic and symptomatic differences (Rylander et al., 2013).

A bilateral dynamic task, such as a squat, may be more representative of an athletic position. Previous reports of cam-type FAI limiting maximal squat depth compared to controls (Lamontagne et al., 2009) have been countered by Mullins et al. (2018) who found no difference in squat depth between athletes with FAIS and activity-matched controls. ~~When evaluating maximal squat compared to MRI findings for cam-type morphology, high sensitivity (75%) and low specificity (41%) concluded the maximal squat test to have marginal diagnostic ability (O. Ayeni et al., 2014).~~ There is evidence that a squat test provokes symptoms, with 56% of those with FAIS reporting anterior groin pain and 18% reporting stiffness, while no discomfort was

noted in a control group (Mullins et al., 2018). While there is limited evidence to support a squat test as a diagnostic test correlating to limited ROM it is likely that the symptom provocation is meaningful in this population.

Activity limitations that interfere with participation in sport are assessed through performance-based measures of agility, change of direction, jumping, and hopping. The use of performance-based testing for hip-related conditions is a growing area of study which borrows heavily from the ACL RTS literature and focuses on expert opinion and postoperative outcomes (O'Connor et al., 2018). Currently, there are limited high-quality studies examining the clinimetric properties of recommended performance-based outcomes and no evidence to support the validity and reliability of these measures as baseline or RTS testing in the FAIS population (Day et al., 2023).

The ability to rapidly change direction is measured by stimulus response agility and predictive change of direction tests. Although they do not comprehensively assess agility, change of direction (COD) tests are used for simplicity and ease of implementation, (Kozinc & Šarabon, 2022). The 5-0-5 COD test has good discriminant validity, allowing for assessment of athletes at various levels (Ryan et al., 2022). At this time, the 5-0-5 COD test has not been widely adopted for RTS testing in the FAIS population. The modified T-test has been found to have excellent test-retest reliability in healthy athletes (Sassi et al., 2009), and in the FAIS population age may play a role in performance outcomes and symptom provocation. In a cohort of young adult field sport athletes diagnosed with FAIS, Mullins et al. (2018) found slower sprint speeds and scores on agility tests with 44% and 62% of athletes reporting anterior groin pain during sprinting and agility testing, respectively, and 8% reporting stiffness compared to the healthy controls who reported neither pain nor stiffness. In contrast, young male hockey players displayed no on-ice

performance differences with respect to acceleration, speed or agility when compared to an asymptomatic and control group (Brunner et al., 2016). Despite their common usage in athletic performance evaluation, little is known on how FAIS impacts performance, kinetics, and kinematics in agility and COD tasks.

Vertical jump testing has been used to evaluate athletic performance and limb asymmetries following ACL reconstruction using both a bilateral and single countermovement jump (CMJ) (R. Kotsifaki et al., 2023). The bilateral CMJ can evaluate interlimb compensatory patterns, while a single limb CMJ (SL-CMJ) provides information on each limb's capacity in isolation. A SL-CMJ was found to require relatively equal contribution from the hip, knee, and ankle during the propulsion and landing phases whereas a horizontal single limb hop shows higher contributions from the hip and ankle at propulsion and much less contribution on landing (A. Kotsifaki et al., 2021). There is limited evaluation of SL-CMJ deficits in hip-related injuries; However, when acute groin injuries in tennis players was evaluated, there were no differences in SL-CMJ height between limbs or when comparing to a non-injured cohort were found despite adductor/abductor strength ratio deficits (Moreno-Pérez et al., 2017).

The benefit of hop testing is the ease of accessibility to clinicians as there is minimal equipment and space requirements (Hamilton et al., 2008), while at the same time functioning as a proxy for higher impact multiplanar demands of a sport-specific task in the lower extremity. Hop testing has been included in protocols for hip arthroscopy rehabilitation (Hugenberg et al., 2023) and as a testing measure in non-arthritic hip pain (R. L. Martin et al., 2023), yet there continues to be a lack of high-quality studies to support the conclusion that hop testing performance is impaired in the FAIS population (Mosler et al., 2020).

To determine whether hop tests were feasible clinical proxies for isometric strength, Kollock et al. (2015) evaluated recreationally active healthy adults and found strong indicators between triple hop work and isometric peak force at the hip adductors, and rate of force developments at the hip abductors and flexors in men. Normative data for hop testing in healthy active adults has been calculated at a limb symmetry index (LSI) of 91-96% (Madsen et al., 2020) which may indicate levels above an LSI of 90% are reasonable targets. Reporting of performance-based measures in FAIS is typically limited to postoperative outcomes without baseline measures. Comparing the postoperative limb to the unaffected limb and to healthy controls, Wörner et al. (2019) was unable to demonstrate a consistent pattern of impairments in medial and lateral triple hop tests in a 6–10-month postoperative cohort. Similarly, Tijssen et al. (2016) reported full recovery of performance on 3 variations of single leg hop tests with an LSI of >100%.

The reliability and validity of hop testing has not been established in persons diagnosed with FAIS. Kivlan et al. (2013) demonstrated reliability in the medial, lateral, and cross-over hop tests in dancers with unilateral hip pain; However, the medial triple hop was the only test that demonstrated evidence of validity. While the medial triple hop test demonstrated side to side differences between the affected and unaffected limbs, a larger sample size would be required to determine whether the magnitude of the difference was meaningful. Consequently, future studies should seek to determine the minimal clinically important difference (MCID) of the medial hop test in a variety of athletes as the results from Kivlan et al. (2013) cannot be generalizable given the homogeneity of the participants.

Despite the lack of strong evidence supporting the use of hop testing as a dynamic performance measure in FAIS, there remains a knowledge gap in the relationship between

symptoms, strength and hop testing in this population. In ACL reconstruction, passing a battery of hop tests has been shown to reduce re-tear rates by 78-84% (Capin et al., 2019; Grindem et al., 2016; Kyritsis et al., 2016), yet it is unknown how these results would translate to the FAIS population as continued hip and groin pain, rather than re-tear, is the prominent feature reported for lack of RTS (Ishøi et al., 2018).

Summary

Morphological features alone cannot predict the symptom development of FAIS. There are conflicting results and low certainty of the evidence that ROM differs in a single or combined plane of motion in FAIS. Strength deficits have been found in multiple studies; However, the heterogeneity of testing protocols, devices, and comparison groups has resulted in limited evidence of which deficits may be present in FAIS. Dynamic performance-based testing for FAIS has not been studied to the same extent as RTS testing following ACL reconstruction yet when tasked with the goal to evaluate RTS we borrow from this body of evidence for hip arthroscopy.

Given the current lack of high-quality evidence for ROM, strength, and dynamic performance deficits, it is likely that multifactorial biological processes, in combination with activities that repetitively load the hip during skeletal maturation, lead to a unique set of physical impairments and symptoms in the FAIS population. There is currently no battery of objective tests to assess physical impairments at the hip (Day et al., 2023). The purpose of characterizing impairments in ROM, strength, and dynamic performance is to determine specific deficits that are present in FAIS and tailor rehabilitation to resolve deficits and improve symptoms while returning to participation.

CHAPTER III: METHODOLOGY

This study was a cross-sectional observational comparison using a subset of data collected from a larger randomized controlled trial (RCT) that has been approved by the Human Research Ethics Board (HS25309(B2022:001)) and is registered with Clinicaltrials.gov (NCT05280899).

Purpose

The purpose of this study was to characterize active ROM, strength, and dynamic performance of participants who have elected to undergo hip arthroscopy for femoroacetabular impingement.

Objectives

1. To compare affected to unaffected limb measures of active ROM, isometric hip abduction and extension strength using a handheld dynamometer, and isokinetic hip flexion and extension strength in participants electing to undergo hip arthroscopy for femoroacetabular impingement.
2. To quantify dynamic performance measures including a bilateral countermovement (CMJ), a single limb countermovement jump (SL-CMJ), a series of hop tests, and the 5-0-5 change of direction (COD) test in participants electing to undergo hip arthroscopy for femoroacetabular impingement.

Hypothesis

In participants electing to undergo hip arthroscopy for Femoroacetabular impingement syndrome, measurements isolated to the hip, such as active ROM and strength, will be lower in the affected limb with less limitation in multi-joint dynamic performance-based outcomes.

Methods

Participants

Subjects were recruited from the patient population of one fellowship trained orthopaedic surgeon. All consecutive patients with FAIS presenting to the surgeon-investigator were screened for eligibility by the surgeon in clinic at the time of initial consult. Potential candidate patients had the study introduced by the surgeon (permission to contact). Those who agreed spoke with a Research Coordinator, who explained the study in greater detail and obtained informed consent. After signing the consent form, patients were scheduled for an assessment including active ROM, symptom provocation, strength, and dynamic performance tests as a component of their baseline assessment prior to surgery.

Participant Inclusion and Exclusion Criteria

Participants were eligible for inclusion if they were: 16 – 50 years of age at time of surgery, had a confirmed diagnosis of FAIS (cam, pincer, mixed) based on the 2016 Warwick Agreement (symptoms of motion- or position-related pain in the hip or groin, clinical signs consistent with FAIS such as: decreased hip flexion and internal rotation, or positive impingement sign, and radiographic evidence (on both x-ray and non-contrast MRI) of intra-articular pathology consistent with FAIS as determined by the treating surgeon), no improvement

with conservative interventions of at least 3 months (i.e. physiotherapy), had symptom relief with intra-articular injection of local anaesthetic, and required only unilateral surgical intervention (unilateral symptomology).

Participants were excluded for the following reasons: previous surgery on the affected hip, or other major lower extremity orthopaedic surgery, active joint or systemic infection, significant muscle paralysis, significant lower extremity or medical comorbidity that could alter the effectiveness of the surgical intervention (e.g. polymyalgia rheumatica), unable to speak or read English, presence of chronic pain syndromes, history of pediatric hip disease (i.e. Slipped Capital Femoral Epiphysis, Legg-Calve-Perthes Disease), ongoing litigation or compensation claims related to the hip (including Workers' Compensation), and for the following radiographic criteria: osteoarthritis greater than Tönnis Grade 1 on affected hip, lateral central edge angle $<19^\circ$, dysplasia in patients with broken Shenton line (i.e. Severe acetabular deformity present).

Study Visit Procedure

Clinical Assessment

Standardized demographic and anthropometric measures were collected to assist in the analysis of performance measures. Patient reported outcome measures were collected at this time. Participants completed a warm-up consisting of 5 minutes of stationary cycling with minimal resistance, 10 body weight squats, 10 toe raises, and 5 warm-up jumps. After completing the standardized warm up, the clinical assessment and isometric measurements were completed, followed by dynamic performance testing, and concluding with isokinetic strength

measurements. The length of time to complete the clinical assessment in the research lab setting was approximately 90 minutes.

Active ROM assessment included hip flexion, extension, adduction, and abduction in a supine position measured with standard goniometry. Combined Flexion/Adduction/Internal rotation (FADIR) and combined Flexion/Abduction/External rotation (FABER) were assessed in supine with a positive test indicated by the presence of symptoms in the hip.

Strength Measures

Isometric hip abduction and extension were measured in the side-lying and prone positions with a hand-held dynamometer (Chatillon DFX2, Ametek, PA, USA) positioned 5 cm proximal to the most prominent aspect of the malleolus. Four maximal holds of 5 seconds separated by 15 seconds rest were completed after two submaximal familiarizations with 30 seconds of rest between attempts.

Five repetitions of concentric, isokinetic hip flexion and extension peak torque were measured on an isokinetic dynamometer (Biodex, Medical System 3, NY, USA) with the patient in the supine position (0° to 50° hip flexion at $60^{\circ}/s$ and $180^{\circ}/s$). No rest was provided between coupled repetitions, thirty seconds rest was provided between speeds on the same limb, and two minutes rest was provided between limbs.

Performance Measures

A standardized battery of hop tests was completed including a single leg forward, medial, and lateral hop, the triple hop, and the triple crossover hop for distance. Participants completed one to two practice trials and two test trials per limb, starting with the unaffected limb, and alternating limbs between attempts. Thirty seconds rest was given between attempts and one to

two minutes between tests was given, although this was extended when requested by the patient. All attempts were measured to the nearest half centimeter. Patients were re-tested if progressive attempts varied by more than 10%. The participant stood on the testing leg and hopped as far forward, medially, or laterally as possible, landing on the same limb and maintaining the landing for a minimum of 2 seconds. Attempts were not measured if the patient stumbled, shuffled the landing foot, or placed their other foot on the ground on landing. Distance was recorded to the nearest half centimeter from the aspect of the foot closest to the starting line on landing (anterior of landing foot for forward facing hops, medial surface for the lateral hop and lateral surface for medial hops).

Participants completed three practice and three measured attempts of the bilateral countermovement jump (CMJ). The participant stood in a neutral position with each leg on a force plate and the hands placed on their hips. When instructed to jump they performed a countermovement, descending towards a knee flexion angle of 90 degrees, then quickly reversed the position to complete the jump, attempting to maximize the height of the jump. There was a period of quiet standing for 3-5 seconds between the 3 attempts. For the SL-CMJ the participant stood in a neutral position with one foot on a force plate with the hands placed away from their body to facilitate balance and testing was completed as noted for the bilateral CMJ.

For the 5-0-5 change of direction (COD) test, participants started at the 0m mark and were instructed to run as quickly as they could towards the 15m mark. At that point, they were instructed to complete a 180° pivot, and run as fast as they could to return to the 10m point then slow down back to the 0m starting point. A timing gate was positioned at the 10m mark measured the COD time to the nearest 0.1 sec. One jogging attempt was completed for

familiarization on each side, followed by four trials were completed alternating the left and right leg at the point of the contact (turning).

Patient Reported Outcome Measures

International Hip Outcome Tool (iHOT-33)

The iHOT-33 uses 33 questions to measure health-related quality of life. The iHOT-33 is the primary PROM. It has been validated for use in this population (Mohtadi et al. 2012).

Hip Sports Activity Scale (HSAS)

The Hip Sport Activity Scale will indicate the patient's pre surgical and current level of sports participation using a nine-point scale ranging from no recreational or competitive sports ("0") to competitive, elite level sport ("8") (Naal et al. 2013).

Numeric Pain Rating Scale (NPRS)

The NPRS is an ordinal 11-point scale (0-no pain and 10-most intense pain) was used to evaluate pain intensity.

Single Assessment Numeric Evaluation (SANE) Score

The SANE score is a single question that asks patients to rate their affected hip as a percentage of normal to provide a simple and efficient measure of patient outcome (Gowd et al. 2019) All patients will be asked the following question during their assessment: *"How would you rate your affected hip today as a percentage of normal (0% to 100% scale with 100% being normal)?"*

Analysis

Sample Size Determination

Power Calculation

G*Power was used to complete an a priori analysis using the mean difference between a convenience sample of strength and the iHOT33, with an alpha of 0.05 and a beta of 0.20. The average of the affected and unaffected limbs was calculated to be 64.04 N +/- 36.6 N and 90.1 N +/- 38.4 N respectively (effect size = 0.70). These values determined a sample size of 20 was appropriate.

Data Processing and Statistical Analysis

Vertical Ground Reaction Force (vGRF) Processing

Force time curves were generated and subdivided into the propulsive, flight and landing phases in the MyoForce software (Noraxon MyoResearch 3.18, Phoenix, AZ, USA). The propulsive phase was defined as the period after unweighting where positive velocity leads into the flight phase. The landing phase was defined as the point of contacting the force plates after the flight phase to the stabilization of bodyweight (within 5%), and the flight phase was defined as the period between the propulsive and landing phase where no force was registered as they were in flight. Peak vGRFs were extracted in each phase and averaged across the three trials. Jump heights were calculated within the MyoForce software with the following equation: jump height = $\frac{1}{2} g (t/2)^2$, where g is the acceleration due to gravity (9.81 m/s²) and t is flight time.

Jump height was expressed in absolute (n), relative to BW (x BW) and as an LSI (affected/unaffected *100%) depending on the variable of interest.

Statistical Analysis

Demographics are reported as means with standard deviations for continuous outcomes and median with range for ordinal outcomes. The χ^2 test was used to evaluate the proportion of positive findings for the clinical special tests ($p < 0.05$). Paired T-Tests were used to compare performance scores between limbs for ROM, isometric and isokinetic strength, and the dynamic performance measures (i.e. hop distances, jump heights), with statistical significance considered at $p < 0.05$. Two-way analysis of variance (ANVOA) for phase (propulsive, landing) and limb (affected, unaffected) were completed on vGRFs in the SL-CMJ.

CHAPTER IV: RESULTS

Patient Characteristics and Clinical Testing

A total of 19 participants completed testing. Participant characteristics are displayed in Table 1. There was a greater number of positive findings for the affected limb for the FADIR (74% vs 26%, $X^2 = 8.53$, $p = 0.009$), FABER (58% vs 11%, $X^2 = 9.47$, $p = 0.005$; Table 2).

Hip Range of Motion

Range of motion was greater on the unaffected limb across movements; However, the magnitude and statistical significance varied (Table 3). Hip flexion had a mean difference of 6° (95%CI $-0.77 - 12.45^\circ$), $t_{(18)} = 1.86$, $p = 0.08$) and extension a mean difference of 1.79° ((95%CI $-0.04 - 3.62^\circ$), $t_{(18)} = 0.03$, $p = 0.06$) both favoring the unaffected limb. Internal rotation at 90° hip flexion had a mean difference of 3.05° ((95%CI $-2.50 - 8.60^\circ$), $t_{(18)} = 1.16$, $p = 0.26$) favoring the unaffected limb, and external rotation was also greater on the unaffected limb (mean difference 5° (95%CI $-0.07 - 9.86^\circ$), $t_{(18)} = 2.07$, $p = 0.053$). The largest difference was found for hip abduction with a mean difference of 12° ((95%CI $6.50 - 17.08^\circ$), $t_{(18)} = 4.68$, $p < 0.001$) favoring the unaffected limb, while adduction approached significance (mean difference 2° (95%CI $-0.27 - 4.69^\circ$), $t_{(18)} = 1.871$, $p = 0.078$).

Muscular Strength

While hip muscular strength was reduced on the affected side, the differences were statistically significant and of greater magnitude when assessed with isokinetics as compared to HHD isometric contractions. A minimal reduction in isometric hip abduction (mean difference 0.11 n/kg (95%CI $-0.04 - 0.26$ n/kg), $t_{(18)} = 1.58$, $p = 0.131$) and isometric hip extension (mean

difference 0.12 n/kg (95%CI -0.02-.26 n/kg), $t_{(18)} = 1.828$, $p = 0.84$) was found, with resultant LSI values of $94 \pm 16.6 \%$ and $93.9 \pm 15.4\%$ respectively. Affected limb hip strength was reduced for isokinetic hip flexion (mean difference 0.15 nm/kg (95%CI 0.04 - 0.26 nm/kg), $t_{(18)} = 2.88$, $p = 0.01$) and extension (mean difference 0.28 nm/kg (95%CI 0.13 – 0.42), $t_{(18)} = 3.945$, $p < 0.001$; Table 4).

Dynamic Performance

Change of direction, Hop and Jump Testing

The only between-limb difference in performance occurred in the jump height for the single leg countermovement jump (SL-CMJ), whereby the affected limb was reduced relative to the unaffected limb (mean difference 0.93 cm (95%CI 0.19 – 1.68 cm), $89.66 \pm 15.54 \%$ LSI, $t_{(16)} = 2.65$, $p = 0.018$). Performance was comparable between limbs for the 5-0-5 COD (mean difference -0.03 s (95%CI -0.07 – 0.02 s), $p = 0.25$), and the single leg (mean difference 3.28 cm (95%CI -2.97 – 9.53 cm), $p = 0.284$), triple (mean difference 16.25 cm (95%CI -4.67 – 37.17 cm), $p = 0.12$), crossover (mean difference 18.72 cm (95%CI -7.29 – 44.73 cm), $p = 0.147$), medial single (mean difference 0.78 cm (95%CI -3.18 – 4.75 cm), $p = 0.682$), and lateral single hops (mean difference 1.06 cm (95%CI (-3.64 – 5.77 cm), $p = 0.639$; Table 5).

SL-CMJ and vGRFs

There was a main effect of phase ($F_{(1,72)} = 36.48$, $p < 0.001$) but not limb ($F_{(1,72)} = 0.28$, $p = 0.60$) or interaction of limb and phase ($F_{(1,72)} = 0.09$, $p = 0.77$) for CMJ vGRFs. Vertical GRFs were greater in the landing phase as compared to the propulsive phase in the CMJ (mean difference -1.39x BW (95%CI -1.59 - -1.18 x BW, $p < 0.001$)). Similarly, there was a main effect of phase ($F_{(1,64)} = 151.13$, $p < 0.001$) with no effect of limb ($F_{(1,64)} = 0.75$, $p = 0.39$) or interaction

of limb and phase ($F_{(1,64)} = 0.29$, $p = 0.59$) in the SL-CMJ. Vertical GRFs were greater in the landing versus propulsive phase (mean difference 1.23 x BW (95%CI 1.03 – 1.43x BW), $p < 0.001$).

Table 1 – Patient Characteristics.

Age (yrs)	33.9 ± 6.7
Height (m)	1.77 ± 0.10
Weight (kg)	85.78 ± 17.72
Sex (%F)	7F/12M (37%)
iHOT33	43 ± 13
HSAS Pre	5 (1-8; 5)
HSAS Post	3 (0-5; 5) †
NPRS	4 (0-10; 7)
SANE	48 ± 22 %

* denotes $p < 0.05$, † denotes $p < 0.01$, and ‡ denotes $p < 0.001$.

HSAS Pre The Hip Sport Activity Scale Pre-symptomatology

HSAS Post The Hip Sport Activity Scale Post-symptomatology

Table 2. Positive clinical findings for clinical special tests

Special Test	Affected	Unaffected
FADIR	14/19 †	5/19
FABER	11/19 †	2/19

Values represent the number of positive clinical findings in 19 participants
Statistical significance denoted by † $p < 0.01$

Table 3. Hip active range of motion

Movement	Affected	Unaffected
Flexion	105 ± 19°	111 ± 15°
Extension	8 ± 4°	10 ± 6°
IR at 90° Flexion	20 ± 10°	23 ± 7°
ER at 90° Flexion	37 ± 14°	42 ± 14°
Abduction	32 ± 14° ‡	44 ± 11°
Adduction	20 ± 5°	22 ± 4°

Values represent mean ± standard deviation (SD).
Statistical significance denoted by ‡ p < 0.001

Table 4. Isometric and isokinetic hip muscular strength

Movement	Affected	Unaffected	LSI (%)
Isometric Hip Abduction	133.5 ± 47.4 n 1.57 ± 0.49 n/kg	142.2 ± 39.3 n 1.68 ± 0.42 n/kg	94.0 ± 16.6
Isometric Hip Extension	135.4 ± 50.5 n 1.60 ± 0.55 n/kg	146.5 ± 53.8 n 1.72 ± 0.57 n/kg	93.9 ± 15.4
Isokinetic Hip Flexion	63.8 ± 29.9 nm 0.72 ± 0.27 nm/kg	94.8 ± 44.1 nm 0.87 ± 0.24 nm/kg	83.74 ± 24.04 *
Isokinetic Hip Extension	119.0 ± 46.2 nm 1.09 ± 0.50 nm/kg	94.8 ± 44.1 nm 1.37 ± 0.45 nm/kg	81.09 ± 29.28 ‡

Values represent mean ± standard deviation (SD). *n* newton, *nm* newton-meter, *kg* kilogram
Statistical significance for LSI comparison denoted by * $p < 0.05$, and ‡ denotes $p < 0.001$.

Table 5 Change of direction, hop and jump testing

Test	Affected	Unaffected	LSI (%)
5-0-5 COD (s)	3.42 ± 0.74	3.47 ± 0.75	99.30 ± 2.44
Single Leg Hop (cm)	96.81 ± 95.28	100.1 ± 30.3	95.28 ± 16.67
Medial Single Hop (cm)	82.11 ± 30.34	31.33 ± 32.21	96.96 ± 15.63
Lateral Single Hop (cm)	81.61 ± 22.19	80.55 ± 21.55	99.43 ± 12.58
Triple Hop (cm)	372.14 ± 80.38	355.89 ± 98.31	94.91 ± 13.25
Crossover Hop (cm)	315.75 ± 85.95	297.03 ± 91.37	94.68 ± 16.03
SL-CMJ (cm)	9.52 ± 3.73	10.45 ± 3.45	89.66 ± 15.54 *

Values represent mean ± standard deviation (SD). *LSI* limb symmetry index, *COD* change of direction, *SL-CMJ* single limb countermovement jump
Statistical significance for LSI comparison denoted by * $p < 0.05$

Table 6. Vertical Ground Reaction Force (vGRF) characteristic per limb during the bilateral and unilateral countermovement jump.

	Affected	Unaffected	LSI (%)
SL-CMJ Propulsive Peak Force (n, x BW)	1341.56 ± 279.86 1.63 ± 0.18	1373.15 279.90 1.66 0.13	97.93 6.55
SL-CMJ Landing Peak Force (n, x BW)	2338.97 ± 726.10 2.81 ± 0.59	2440.52 661.77 2.95 0.54	95.06 8.49
‡			
CMJ Propulsive Peak Force (n, x BW)	787.35 ± 156.85 0.94 ± 0.07	813.69 ± 205.03 0.96 0.08	97.91 ± 7.97
CMJ Landing Peak Force (n, x BW) ‡	1911.07 ± 570.71 2.29 0.64	1992.17 ± 612.03 2.38 0.60	97.23 ± 14.77

Values represent mean ± standard deviation (SD). *CMJ* countermovement jump, *SL-CMJ* single limb countermovement jump, *n* newton, *BW* body weight
 Statistical significance for LSI comparison denoted by ‡ p<0.001 for main effect of phase (propulsive versus landing)

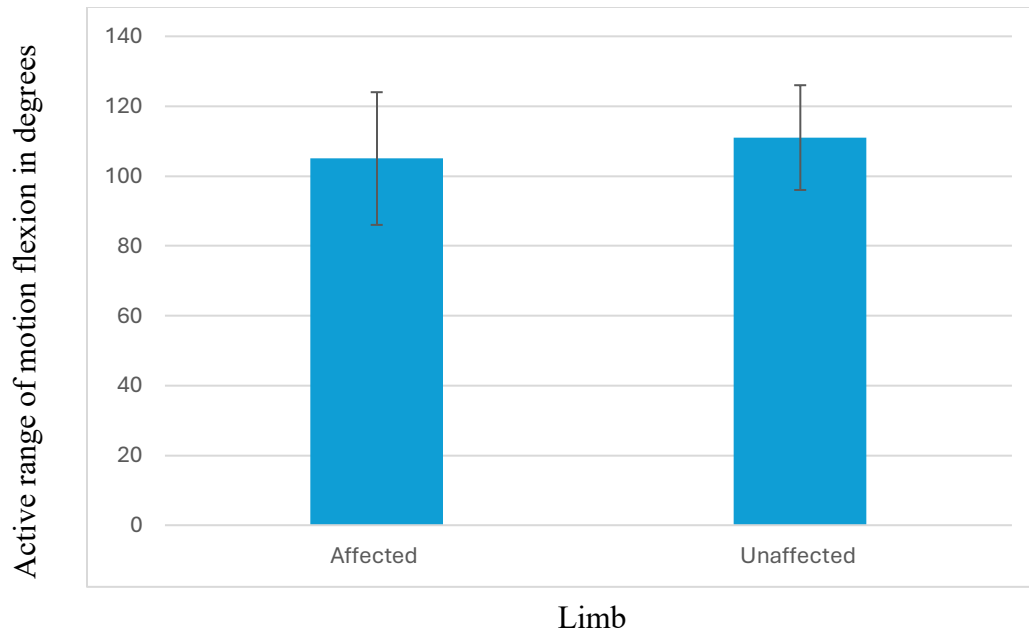


Figure 1. Active range of motion flexion
Mean and standard deviation of hip flexion active range of motion for both the affected ($105 \pm 19^\circ$) and unaffected ($111 \pm 15^\circ$) limbs of 19 participants

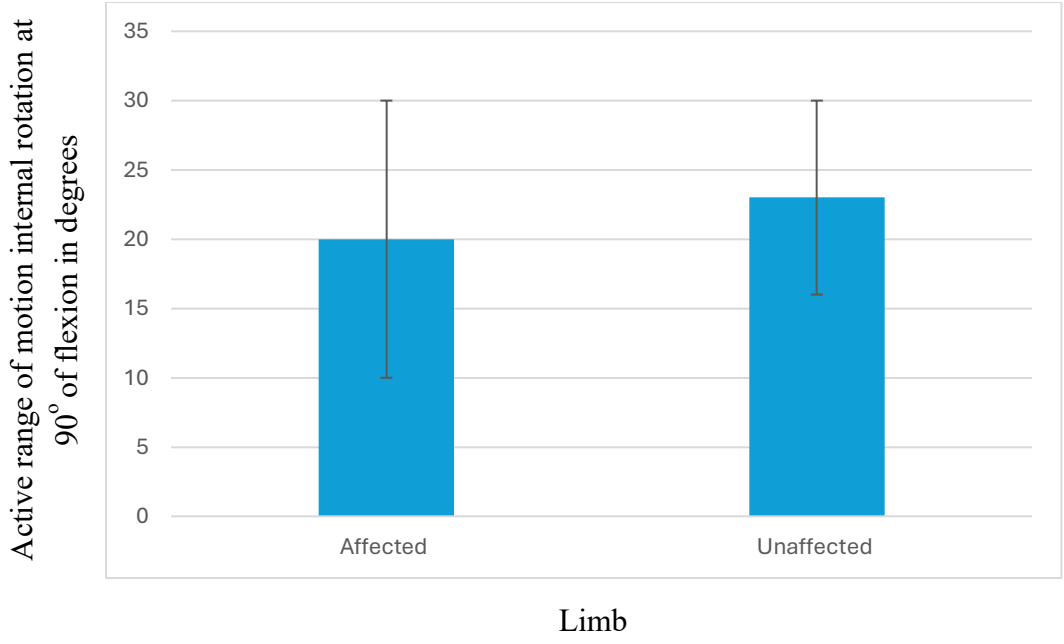


Figure 2. Active range of motion internal rotation at 90° of flexion
Mean and standard deviation of hip internal rotation at 90° of flexion active range of motion for both the affected ($20 \pm 10^\circ$) and unaffected ($23 \pm 7^\circ$) limbs of 19 participants

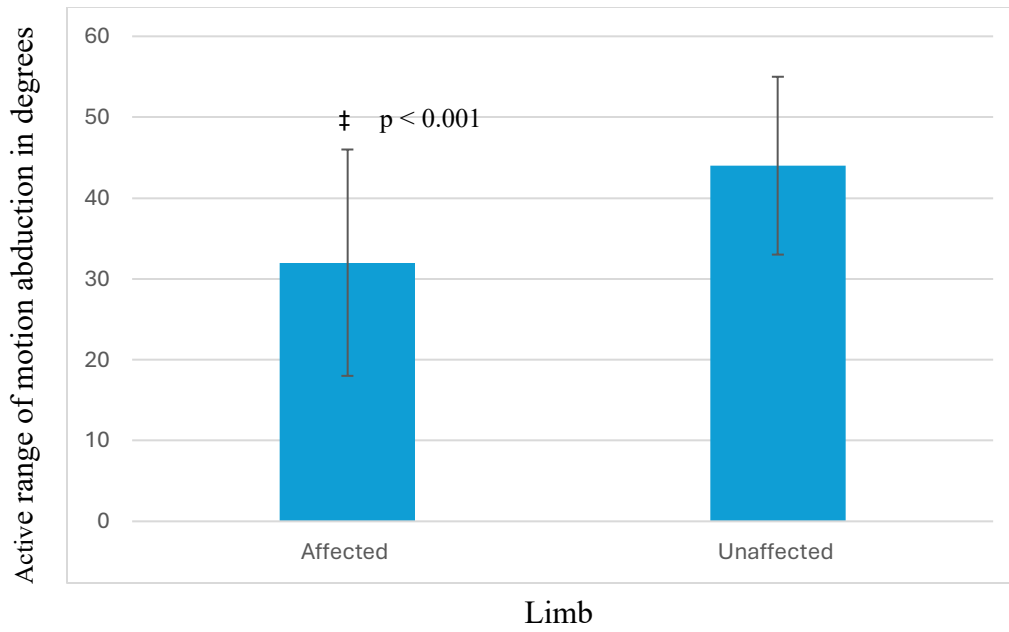


Figure 3. Active range of motion abduction

Mean and standard deviation of hip abduction active range of motion for both the affected ($32 \pm 14^\circ$ ‡) and unaffected ($44 \pm 11^\circ$) limbs of 19 participants

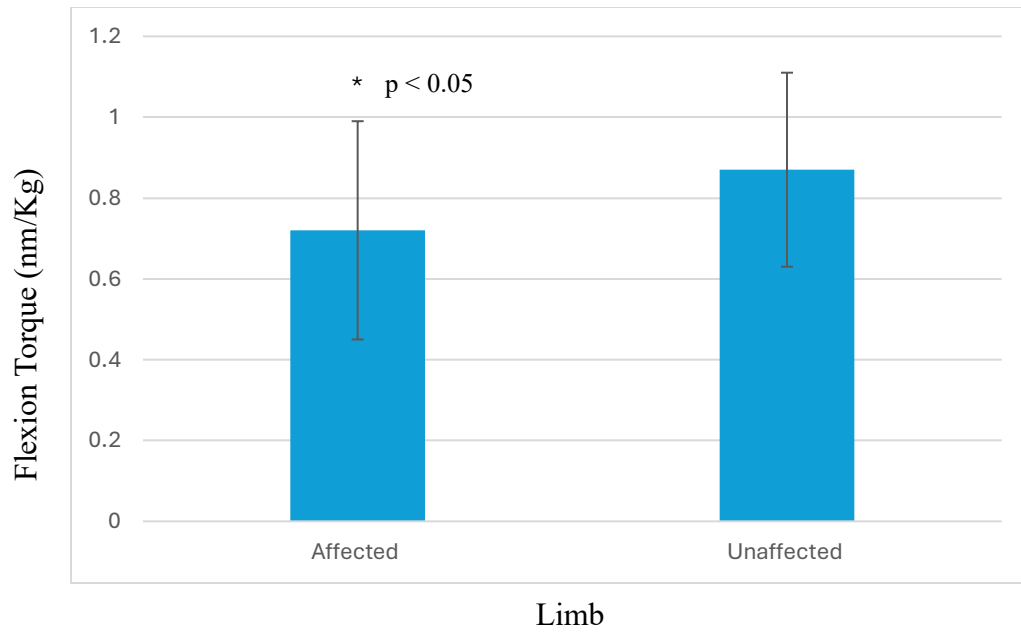


Figure 4. Isokinetic hip flexion muscular strength

Mean and standard deviation of isokinetic hip flexion strength for both the affected (0.72 ± 0.27 nm/kg*) and unaffected (0.87 ± 0.24 nm/kg) limbs of 19 participants

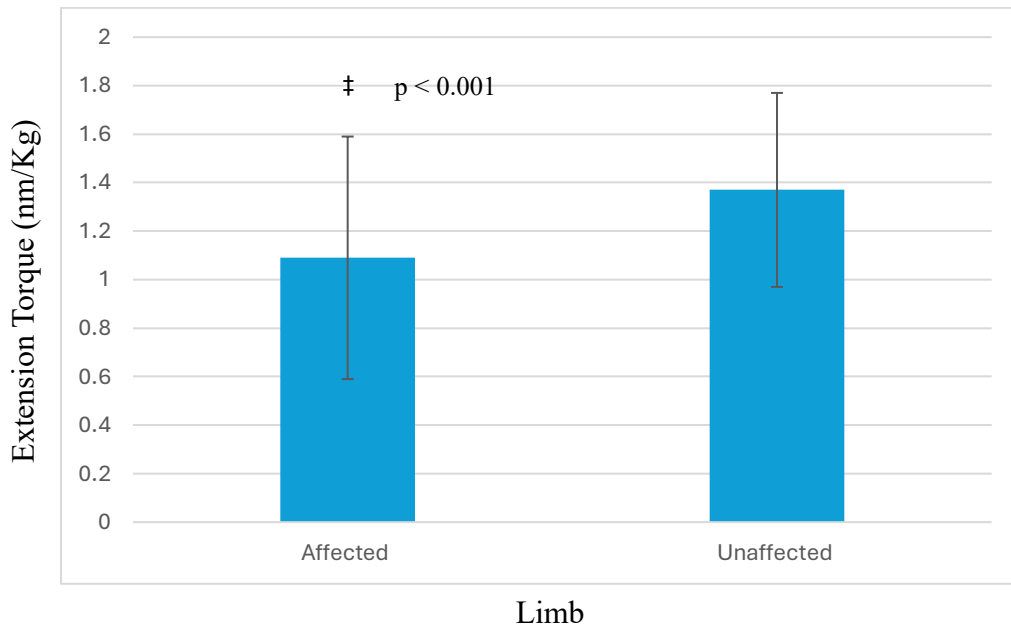


Figure 5. Isokinetic hip extension muscular strength
Mean and standard deviation of isokinetic hip extension strength for both the affected (1.09 ± 0.50 nm/kg‡) and unaffected (1.37 ± 0.45 nm/kg) limbs of 19 participants

CHAPTER V: DISCUSSION

The primary purpose of this study was to characterise active ROM, strength, and dynamic performance in participants who have elected to undergo hip arthroscopy. This cross-sectional observational study aimed to compare the affected to unaffected limb in objective measures of hip active ROM, isometric hip abduction and extension strength using a HHD and isokinetic hip flexion and extension strength to determine whether deficits exist in the affected limb. Secondary questions sought to quantify dynamic performance measures including a battery of single leg hop tests, a countermovement jump (CMJ), a SL-CMJ, and a 5-0-5 change of direction (COD) tasks.

While there were few statistically significant findings with respect to differences in ROM, strength, and dynamic performance, the results supported our hypothesis that there would be a greater difference in measures that were specific to the hip, such as ROM and strength.

Range of Motion

There is a lack of evidence to support consistent ROM deficit in FAIS. Range of motion was greater on the unaffected limb across all movements in our participants; However, the only statistically significant finding was for abduction. A restriction of abduction has been reported in previous systematic reviews (Albertoni et al., 2023; Freke et al., 2016) Our data conflicts with earlier systematic reviews that found ROM impairments in positions towards impingement (Diamond et al., 2015; Freke et al., 2016), and a more recent meta-analysis reported moderate evidence of a reduction of internal rotation (Albertoni et al., 2023).

Heterogeneity of methodology, with respect to measuring active or passive ROM, could explain the differing results amongst studies. A recent systematic review and meta-analysis by Albertoni et al. (2023) included ROM measured by visual estimation, goniometer, electromagnetic tracking system, and a 3-d CT model without specifying whether each study evaluated active or passive ROM, and recommended clinical examination could begin with passive assessment of hip ROM, especially in the absence of imaging technologies. Wörner et al. (2019) compared active and passive ROM of the affected and unaffected limbs in a postoperative setting and reported no consistent pattern of impairment except for passive hip flexion ROM. Further to reaching significance is the question of meaningful change. There is insufficient evidence for minimum detectable change (MCD) and standard error of measure (SEM) in the hip (Mosler et al., 2020), and knowledge of MCID values in this population would be valuable if we consider the ability to return to activities based on an objective change from baseline. The mean difference for active and passive flexion in postoperative vs the control group in the cross-sectional study by Wörner et al. (2019) was 5.3° and 8.9° respectively, which is comparable to our findings of an average of 6° of active flexion. The relative loss of 6° of flexion may not be relevant to activities of daily living and general physical activity, but those participants that require end ROM into flexion for their sport may consider this difference to be meaningful.

Combined Flexion/Adduction/Internal rotation (FADIR) is a position of impingement and categorized as a symptom provocation test. There is little scientific evidence for most clinical tests; However, the FADIR test continues to be supported by consensus as an appropriate diagnostic screening tool for FAIS (Griffin et al., 2016). While a positive FADIR test is not necessary, nor sufficient, for the diagnosis of FAIS, 74% of affected limbs in our study had a

positive FADIR test. ~~which supports its use in the clinical assessment for FAIS in our cohort.~~
Despite the statistically significant findings in our study, the low specificity (0.43) and high sensitivity (0.75) (Eneski et al.; 2014) of the FADIR test suggests it may not be appropriate to either rule in or rule out a diagnosis of FAIS.

The popular narrative that cam morphology leads to ROM restrictions, particularly into positions of impingement, is not equivocally supported by the evidence (Albertoni et al., 2023; Freke et al., 2016). Early systematic reviews (Diamond et al., 2015; Freke et al., 2016) that included pre- and post-arthroscopy comparisons reported that ROM was not restored with cam resection (Kubiak-Langer et al., 2007). This supports the rationale that morphology alone cannot predict ROM restrictions. A counter argument in support of morphology precipitating symptoms can be made based on Audenaert et al. (2012) where their conclusion was those with symptomatic and asymptomatic morphological changes had reduced internal rotation compared to those without morphological findings; However, it was a combination of cam size, acetabular coverage, and femoral version that accounted for 75% of the variance. Our study provided further evidence of a lack of predictable consistent findings for single plane ROM deficits in FAIS, while supporting the overall view that ROM may be reduced in the affected limb and combined ROM into positions of impingement (FADIR) are present in a high proportion of the preoperative population.

Muscle Strength

Strength was assessed by two methods to compare both between limb differences in all measures, and to determine the difference of isometric HHD and isokinetic testing for hip extension. The only observed difference between limbs was found for isokinetic hip flexion and

extension. This is consistent with previous studies that reported hip flexor deficits with isokinetic dynamometry (Casartelli et al., 2011, 2012, 2014; Kierkegaard et al., 2017), and a study that reported affected limb deficits of extension (Kierkegaard et al., 2017).

Hip extension was the only strength measure overlapping both methods of assessment. Larger, statistically significant differences were found using isokinetic testing. The methodology used for HHD in our study may have been a factor in our results due to the lack of external fixation (Thorborg, Bandholm, & Hölmich, 2013). Hand-held dynamometry measures isometric peak force at a fixed joint angle and is therefore not a comparable measure to isokinetic dynamometry which measures peak torque. Given that FAIS is a motion-related syndrome, there is an argument to be made that strength may best be evaluated through isokinetic testing as this requires muscle strength through motion. The ability to generate force in a muscle is dependent on the joint angle and perhaps if the angle at which HHD evaluated peak force was compared to the same angle within the force curves of the isokinetic peak torque we may be able to provide more information on how the use of HHD in various joint angles could serve as a proxy for isokinetic dynamometry in a clinical setting.

Dynamic Performance

The evaluation of dynamic performance in FAIS is an emerging area of study. Our results did not find dynamic performance-based deficits in our preoperative FAIS cohort. Our hypothesis considered the possibility of this finding by suggesting measures specific to the hip, such as ROM and strength, would be lower in the affected limb. Dynamic performance-based measures are not isolated to the hip, and it is possible that intra-limb compensatory strategies shield limitations at any one specific joint. This is supported in part by findings in the ACL RTS

literature where protective adaptations occur to shield the postoperative limb (Orishimo et al., 2010).

The single limb countermovement jump (SL-CMJ) was found to be statistically significant in our cohort, yet with an LSI value of 89.66%, this is unlikely to be meaningful. Limited studies have found similar results for hop testing in postoperative cohorts (Tijssen et al., 2016; Wörner et al., 2019). There is an argument to be made that hop testing should continue to be investigated to determine whether there is a relationship between symptoms, strength, and performance at the hip in RTS testing. Evaluation of hop testing, not solely to measure distance but rather incorporating peak force and rate of force development, may strengthen the value of hop testing as a proxy.

The 5-0-5 change of direction (COD) test is considered to have good discriminative validity with the range of time to complete the test across a variety of age, level, and sport of 1.5-3.0 seconds (Ryan et al., 2022). While our results for the 5-0-5 COD reached an LSI of 99.3%, the time to complete the test was above the 3.0 second threshold on both the affected and unaffected limbs. Our medial and lateral hop testing procedure required a single hop rather than a triple hop test which has been reported in the literature (Kivlan et al., 2013). The rationale behind converting the medial and lateral triple hop to a single hop was made based on observations in the lab when it became apparent that the challenge of completing a triple hop was not being met. We did have participants complete a Hip Sports Activity Scale (HSAS) which provided a self-report of activity level pre and post development of symptoms. The median value pre-symptom development was 5 compared to a 3 post-symptomatology which suggests our cohort spent less time participating in high level sport leading up to electing to undergo hip arthroscopy. Considering the findings for the 5-0-5 COD, hop testing, and our HSAS scores, our cohort may

represent a less multidirectional athletically skilled group at the time of evaluation, leaving room to consider that both limbs may have been undertrained and the use of LSI values in this context may underestimate performance deficits. This concept is supported in the ACL RTS literature where athletes demonstrated bilateral deficits on hop tests compared to age and sex matched normative data in healthy controls (Gokeler et al., 2017), and in another study where landing symmetry can be achieved by shortening the contralateral limb (Wren et al., 2018).

We cannot discount the ability to perform at a high level while experiencing symptoms as a potential long-term issue. Evaluating performance in symptomatic FAI compared to healthy controls, squat depth showed no difference in ROM but did result in symptom provocation, and sprint speed and agility, while lower than controls, had high reports of anterior groin pain (Mullins et al., 2018). We did include a Numeric Pain Rating Scale (NPRS) on the day of the clinical assessment; However, we did not evaluate pain intensity associated with each of our performance-based tests and thus cannot suggest that performance is equal yet symptomatic for any individual tests. In consideration of the range of activity levels of people electing to undergo hip arthroscopy for FAIS, it is likely that a tiered evaluation of physically demanding performance-based measures matches the level of the individual to the activities they plan to return to rather than evaluate sport related performance based on high level demands.

Limitations

Our sample size was small, may not have represented a multidirectional skilled active adult, and came from a single surgeon. We did not meet the total of 20 participants due to a pause in recruitment which may have led to our study being underpowered. Our results may not be generalizable past our local population, or adequate to compare to larger multisite studies.

We measured active ROM, and including a passive ROM assessment may have provided more insight as to differences in ROM between the affected and unaffected limbs. Our participants all met the diagnostic criteria for FAIS set by the Warwick Agreement (Griffin et al., 2016), but there was no subgroup analysis considered with respect to type of FAIS and relative features of femoral or acetabular version which may play a role in the overall variance of internal rotation ROM (Audenaert et al., 2012). Our methodology for HHD may have contributed to a less accurate measure of strength given that we did not use an externally fixed protocol which is considered a more reliable method (Thorborg, Bandholm, & Hölmich, 2013; Waiteman et al., 2023). We based our choice of dynamic performance measures on a typical battery of tests found in the ACL RTS literature and included medial and lateral hop testing. The literature for RTS testing at the hip, although limited, has suggested the use of medial and lateral triple hop tests, and our study used a single medial and lateral hop test due to level of ability of our participants.

CHAPTER VI: CONCLUSION

There is vast heterogeneity of self-reported physical limitations and symptoms within the FAIS population. The size and location of cam or pincer morphology, the unique spectrum of femoral and acetabular version, and potential involvement of soft tissue irritability are all likely contributors to symptoms associated with ROM in this population. Moving forward, the evaluation of hip muscle strength with HHD must be standardized with respect to position of the participant, joint angle, and use of external fixation. With limited availability of isokinetic devices, expanding the body of evidence using HHD in a variety of joint angles and continuing to assess its reliability and validity, clinicians may be provided the opportunity to appropriately measure and detect changes in muscle strength over time. Returning to a desired activity level is a goal of people electing to undergo hip arthroscopy. To date, we are unable to provide support for a battery of dynamic performance-based measures that adequately objectively detects the subjective reports of performance impairments in the FAIS population. Future research in this area should consider symptoms associated with both active and passive ROM, standardized testing procedures for measurement of muscle strength that provide meaningful detection of change over time, and a testing protocol for dynamic performance throughout the rehabilitation phases to address the individual level and demands of activities.

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