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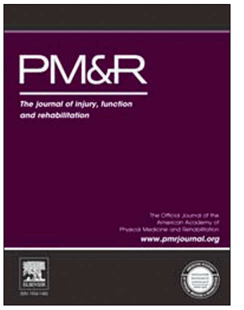

Single leg squat performance is impaired one to two years after hip arthroscopy

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ABSTRACT

Objective: 1. Evaluate single leg squat performance 1-2 years after arthroscopy for intra-articular hip pathology, compared to controls and the non-operative limb. 2. Investigate whether single leg squat performance on the operated limb was associated with hip muscle strength.

Design: Cross-sectional study

Setting: Private physiotherapy clinic and university laboratory.

Participants: Thirty-four participants (17 females, 36.7±12.6 years) 1-2 years following hip arthroscopy, and 34 sex-matched controls (17 females, 33.1±11.9 years)

Methods: Participants performed single leg squats using a standardized testing procedure. Squat performance was captured using video. Video footage was uploaded and reformatted for analyses. Hip muscle strength was measured with hand-held dynamometry using reliable methods.

Outcome measures: Frontal plane pelvic obliquity, hip adduction and knee valgus were measured. Repeated measures analysis of variance evaluated between-group differences, with limb as a within-subjects factor (operated versus non-operated) and sex as a between-subjects factor ($p<.05$).

Results: The hip arthroscopy group demonstrated significantly greater apparent hip adduction (mean difference 2.7°, 95% CI 0.7° to 4.8°) and apparent knee valgus (4.0°, 95% CI 1.0° to 7.1°) at peak squat depth, compared to controls. The operated limb also demonstrated significantly greater pelvic obliquity during single leg stance compared to the non-operated limb (1.2°, 95% CI 0.1° to 2.3°). Females had significantly greater apparent hip adduction (standing 1.6°, 95% CI 0.5° to 2.6°; peak squat depth 95% CI 2.4°, 0.3° to 4.4°) and apparent knee valgus (standing 3.3°, 95% CI 1.8° to 4.7°; peak squat depth 3.1°, 95% CI 0° to 6.1°). Significant positive correlations were found between frontal plane angles and hip flexor and extensor peak torque ($p>.05$).

Conclusion: 1-2 years after hip arthroscopy, deficits in single leg squat performance exist that have the potential to increase hip joint impingement and perpetuate post-operative symptoms. Rehabilitation post-hip arthroscopy should target retraining in functional single leg positions.

Key terms: hip arthroscopy, chondrolabral pathology, single leg squat, functional impairment

INTRODUCTION

Intra-articular hip joint pathology is a frequent source of symptoms around the hip, groin and pelvis, particularly in young active individuals.(1, 2) Associated pain, locking and catching (3, 4) can negatively affect participation in daily and occupational tasks, as well as physical activity.(5) Hip arthroscopy is often the treatment of choice to diagnose and treat intra-articular hip joint pathology.(6, 7) A systematic review by Kemp et al(8) identified positive within-subject outcomes with respect to pain and patient-reported physical function in people who have undergone hip arthroscopy.

However, compared to controls, people who have undergone hip arthroscopy demonstrate physical significant impairments at one to two years post-surgery.(9) Post-operative rehabilitation programs for people with hip pathology could be designed to target impairments observed following hip arthroscopy. While it is assumed that functional recovery is achieved at 12 months post-arthroscopy, deficits in hip flexion, extension, abduction, adduction and rotation strength, compared to controls, have been observed.(9) Furthermore, those with hip chondropathy at the time of surgery exhibited greater mediolateral and anteroposterior centre of pressure excursion during a dynamic balance task compared to controls, but no deficits in static single leg balance.(10) Although strength and balance impairments were observed following arthroscopy, movement control and its relationship with hip muscle strength is yet to be evaluated, especially using a measure of functional performance that reflects the demands of daily activities appropriate for young people at an active stage of life.

Altered movement control during daily functional tasks following hip arthroscopy may be problematic. If common tasks such as climbing stairs result in altered lower limb movement patterns (e.g. increased hip adduction and internal rotation), this could affect loading patterns on vulnerable intra-articular structures, such as the acetabular labrum and anterosuperior chondral surfaces, resulting in increased symptoms. Therefore, knowledge of movement control following hip arthroscopy is important. The single leg squat is a reliable (11) and valid (12) clinical test frequently used by sports medicine practitioners to evaluate dynamic lower limb control and hip muscle function.(11) Since single leg squat kinematics approximate three-dimensional motion observed during higher-level functional activities such as jogging,(13) the single leg squat is an appropriate tool to evaluate relevant movement control in a clinical setting. Considering known hip muscle impairments in people who have undergone hip arthroscopy, the single leg squat is likely to be a useful measure of single-leg function for this patient group.

The primary aim of this study was to determine whether people who have undergone hip arthroscopy for intra-articular hip pathology 1-2 years previously demonstrate deficits in single leg squat performance: i) compared to control participants; and ii) compared to their non-operated limb. It was hypothesized that participants would exhibit greater pelvic obliquity, frontal plane hip angle (FPHA) and frontal plane knee angle (FPKA), at peak squat depth on their operated limb, compared to controls and compared to the non-operated limb. The secondary aim was to investigate whether single leg squat performance on the operated limb was associated with hip muscle strength. It was hypothesized that those who demonstrated greater changes in pelvic obliquity, FPHA and FPKA to peak squat depth would demonstrate less hip strength on the operated limb.

METHODS

A cross-sectional study design was utilised, with 34 participants for the hip arthroscopy group, and 34 controls. Ethical approval was provided by xxxxxxxx Human Research Ethics Sub-Committee (ID xxxxxxx). All participants provided written informed consent prior to participation, and all participants rights were protected.

The hip arthroscopy cohort was recruited by a single investigator (xxx) from the database of a single orthopaedic surgeon in xxxxxx, xxxxxxx, and consisted of patients who had undergone hip arthroscopy for painful intra-articular hip pathology between January 2009 and July 2011. Consecutive patients aged 18 to 60 at the time of surgery were invited to participate one to two years post-operatively. Volunteers were deemed ineligible to participate if they had subsequently undergone total hip arthroplasty, had concurrent lower limb injuries, were unable to walk without assistance, or were unable to understand written or spoken English. All hip arthroscopies were performed using a standardised surgical procedure previously described.(14) Individual post-operative patient instructions and precautions varied depending on specific surgical procedure (e.g. labral debridement or repair, chondral debridement, microfracture, femoral osteoplasty). Patients were generally encouraged to mobilise early post-operatively (within precautions), including light cycling one week post-operatively to promote recovery of movement. Post-operative physiotherapy rehabilitation, following a standardised pathway, was offered to all patients, who could select their preferred provider. Hip arthroscopy participants were included in the single leg squat study if they were able to complete the single leg squat task, and video data were available whereby all markers were visible (n=34).

Thirty-four control participants were recruited in xxxxxxxxx, xxxxxxxxx, by a second investigator (xxx). Volunteers responded to advertisements through the university's staff and student electronic mail system. Volunteers for the control group were ineligible if they: i) were aged less than 18 or older than 60 years; ii) had a past history of hip pain, pathology or surgery; iii) had low back pain or other lower limb injuries; iv) were unable to walk without assistance; or v) were unable to read or speak English. Hip arthroscopy participants were matched with controls firstly by sex, and subsequently on age, height, hours of weekly physical activity, and nature of occupation.

All data for the hip arthroscopy group were collected between December 2010 and July 2012 by a Sports Physiotherapist with 20 years of clinical experience (xxx), at a private physiotherapy clinic in xxxxxx. Control group data were collected in August 2012 by a Sports Physiotherapist with ten years of clinical experience (xxx), at xxxxxx Department of Physiotherapy. For both groups, data pertaining to age, sex, weight, height, leg dominance (leg with which the participant would choose to kick a ball as hard as possible (15)), physical activity and nature of occupation was obtained. The Hip disability and Osteoarthritis Outcome Score (HOOS) (16) and the International Hip Outcome Tool (iHOT-33) (17) were used to characterize the cohort, and have been previously reported to have the best psychometric properties for use in this patient population.(18)

Measures of hip strength were collected from the hip arthroscopy group by a single investigator (xxx), using the testing procedure of Kemp et al.(19) Briefly, hip flexion, extension, abduction, adduction, and external and internal rotation strength were measured using a Commander Power track II hand held dynamometer (J-Tech Medical). The dynamometer was positioned at standardized landmarks on the test leg, and moment arms were calculated from the joint axis of rotation to the point of application of the dynamometer. Participants performed three isometric "make" tests, whereby the tester matched the force produced by the participant,(20) and the highest force value of the three tests was recorded. Torque was calculated for each test by multiplying the force (N) by the moment arm length (m), and normalized for body weight (kg).

For the single leg squat, a standardized testing procedure was adopted across both testing sites, based on previously described methodology.(21) Participants were barefoot, and wore shorts and a short-sleeved t-shirt to allow visualization of anatomical landmarks. Bilateral surface landmarks were marked with black ink over the anterior superior iliac spine, the midpoint between the lateral and medial femoral condyles anteriorly, and the midpoint between the lateral and medial ankle malleoli anteriorly. Participants stood in front of a height-adjustable plinth, with their foot position standardized on a template whereby the medial edge of the first metatarsophalangeal joint and the center of the posterior aspect of the heel were lined up on parallel lines 12 centimeters apart. Squat depth was standardized to 60° knee flexion, indicated when the participant's buttocks touched the top surface of the plinth. This was verified using a universal goniometer applied to the lateral aspect of the test knee.

Single leg squat performance was recorded with a digital video camera (HDR-XR150, Sony, Tokyo, Japan) fixed to a tripod. The camera was positioned at a height of 37 centimeters, perpendicular to the frontal plane, three meters in front of the participant. The selected height allowed capture of video footage from the shoulders to the feet of the participant in standing.

Each participant's unique code was filmed prior to single leg squat performance, to allow later identification.

Because hip arthroscopy participants were equally as likely to have had surgery on their dominant limb as their non-dominant limb (p>.05), the order of limb testing was right followed by left to reduce order effects. Participants were instructed to stand on their right leg with the trunk upright and contralateral leg in approximately 20° of hip flexion, with the knee extended and toes off the floor (Figure 1A). This position was held for three seconds. Participants then lowered down until the buttocks contacted the plinth (Figure 1B), and returned to the starting position, taking four seconds in total. Participants were encouraged to lightly touch the plinth at the bottom of the squat, and refrain from sitting on the plinth at peak squat depth. Five consecutive squats were performed, and the procedure repeated on the left leg. Trials were deemed unsuccessful and the participant excluded from further analysis if they: i) were unable to maintain single leg balance in order to commence squatting; ii) were unable to squat to the desired depth; or iii) experienced pain during testing that affected their ability to complete testing. For the hip arthroscopy group, the investigator was blinded to the side of surgery.

Video footage was uploaded and reformatted using Format Factory (http://www.pcfreetime.com/index.html). Each video was analyzed using original digital software drawing and analysis tools created in LabVIEW software and the Vision Development Module (National Instruments, U.S.A). Frontal plane alignment of the pelvis, hip and knee was measured as pelvic obliquity angle (pelvis relative to horizontal), FPHA (femur relative to pelvis) and FPKA (femur relative to tibia) (Figure 1B). Angles were measured from single video frames at two different time points of the single leg squat. The first time point was in single leg stance, and identified as the frame prior to commencing the squat motion (determined by hip and/or knee flexion). This was measured once, prior to commencement of the first squat repetition. The second time point was at 60° knee flexion (bottom of the squat), taken as the frame where the participant's buttocks initially contacted the plinth. This was measured for each of the five squat repetitions, and the average calculated for use in subsequent analyses.

Intra-rater reliability of the alignment measures was performed on a subset of 20 hip arthroscopy participants. The investigator responsible for data processing (xxx) repeated the measures on a second occasion seven days later, blinded to the original measures. There was adequate agreement for all measures, with intraclass correlation coefficients (ICC) ranging from moderate (left FPKA in single leg stance, ICC 0.74, 95% CI 0.34 to 0.90) to excellent (right FPKA in single leg squat, ICC 0.98, 95% CI 0.96 to 0.99) (Appendix 1, supplementary file).(22)

All statistical analyses were conducted using the Statistical Package for Social Sciences (SPSS Version, 18, SPSS Science Inc., Chicago, Illinois), and significance set at .05. Normality was assessed using the Shapiro-Wilk test. Independent samples t-tests and chi square tests were used to compare baseline characteristics of the two groups. Because paired samples t-tests identified differences between the right and left limbs of the control group on the measured angles (p<.05), hip arthroscopy limbs were matched with controls according to limb dominance. If the dominant limb of the hip arthroscopy participant was their operated limb, this was matched with the dominant limb of the corresponding control participant. If the non-dominant limb of the hip arthroscopy participant was their operated limb, this was matched with the non-dominant limb of their matched control. Repeated measures analysis of variance (ANOVA) was used to evaluate differences for each outcome measure between the hip arthroscopy and control groups (between-subjects factor), between operated and non-operated limbs (within-subjects factor) and between sexes (between-subjects factor). In the event of a significant main effect or two-way interaction, post hoc comparisons of between-group effects were conducted. For the hip arthroscopy participants, Spearman's correlations were used to investigate the relationship between peak torques and the change in frontal plane angle from standing to peak squat depth. Sample size was determined based on that previously reported by Willson et al. (23) for difference in frontal plane projection angle between a control group and patellofemoral pain group of 5%, where α=.05 and β=.10.

RESULTS

There were no significant differences between the hip arthroscopy and control groups with respect to age, sex, height, hours of weekly physical activity, and occupation (p>.05, Table 1). The hip arthroscopy group had a higher body mass than the control group (mean difference 7.53kg, 95% CI 1.01 to 14.06). A significantly higher proportion of participants in the control group were right leg dominant (p=.046). Significant differences in primary physical activity were also found (p=.002). A greater proportion of hip arthroscopy participants reported no physical activity, and only 13 participants in the hip arthroscopy group had returned to their pre-operative level of sport. While walking was the primary physical activity of the hip arthroscopy group, control participants reported more vigorous primary physical activities (Table 1). Within the hip arthroscopy group, 19 participants (56%) had surgery on their dominant limb, whilst the remaining 15 had surgery on their non-dominant limb. As there was no significant effect of limb dominance on operated limb (*p*=.49), limb dominance was excluded as a within-subjects factor for all subsequent analyses. During arthroscopy, chondrolabral pathology was identified in 31 (91%) participants.

There were significant main effects for group for FPHA and FPKA at peak squat depth (Table 2). Post hoc tests revealed that, compared to the control group, the hip arthroscopy group demonstrated significantly greater hip adduction (mean difference 2.7°, 95% CI 0.7° to 4.8°) and apparent knee valgus (4.0°, 95% CI 1.0° to 7.1°) on both the operated and non-operated limbs. There was a significant main effect for limb for standing pelvic obliquity, with post hoc tests revealing that the operated limb of the hip arthroscopy group demonstrated significantly greater pelvic obliquity than the non-operated and matched control limbs (1.2°, 95% CI 0.1° to 2.3°). There were no significant group x limb interactions ($p>.05$).

A significant main effect for sex was demonstrated for FPHA and FPKA in standing and at peak squat depth (Table 3). Post hoc tests revealed that females had significantly greater hip adduction in standing (mean difference 1.6°, 95% CI 0.5° to 2.6°) and at peak squat depth (2.4°, 95% CI 0.3° to 4.4°), and significantly greater apparent knee valgus in standing (3.3°, 95% CI 1.8° to 4.7°) and at peak squat depth (3.1°, 95% CI 0° to 6.1°). There were no significant interaction effects between sex and group or limb ($p>.05$).

Significant positive correlations were found between ipsilateral peak hip flexor torque, and change on pelvic obliquity angle, FPHA and FPKA from standing to peak squat depth ($p<.05$; Table 4). Those with greater hip flexor peak torque demonstrated significantly greater increases in pelvic obliquity, FPHA and FPKA when moving from standing to single leg squatting ($p<.05$). Ipsilateral peak hip extensor torque was significantly and positively correlated with change in FPHA and FPKA, where those with greater peak torque demonstrated greater increases in FPHA and FPKA from standing to single leg squatting ($p<.05$). No other significant correlations were observed.

DISCUSSION

This is the first study to evaluate single leg squat performance in people who have undergone hip arthroscopy. Compared to matched controls, those who had undergone hip arthroscopy one to two years prior demonstrated greater apparent hip adduction and apparent knee valgus at peak single leg squat depth on both the operated and non-operated limbs, irrespective of sex. Notably, mean differences were greater than the standard error of the measure (Appendix 1, supplementary file). This is of particular importance following hip arthroscopy, given that hip flexion and adduction is a position of impingement for the anterosuperior hip structures. It is plausible that this increased apparent hip adduction during single leg squatting activities may contribute to ongoing symptoms (14) and physical impairments (9) noted previously. Furthermore, considering that hip and knee kinematics during single leg squat approximate kinematics during jogging tasks,(13) this may be related to ongoing symptoms during physical activity. This may in part explain why less than 40% of our cohort reported having returned to their pre-surgery level of sporting activity, despite participants being at a post-operative time point when they are expected to have recovered and returned to sport.(24)

Findings also revealed greater pelvic obliquity on the operated limb when participants were in standing. This indicates that participants were standing with the contralateral (non-weight bearing) side of the pelvis elevated or hitched relative to the weight bearing side. However, there was no difference in pelvic obliquity when participants were at peak single leg squat depth. It is plausible that, prior to performing the single leg squat, participants activated their hip abductors on the affected (weight-bearing) hip to attempt to improve control of eccentric hip adduction during the descent phase of the single leg squat. Hip abduction peak torque is lower in female patients one to two years after hip arthroscopy, compared to controls.(9) The mean difference in pelvic obliquity (1.2°) was greater than the standard error of the measurement (0.8° to 1.17°) and minimal detectable change (0.5° to 0.72°)(Appendix 1, supplementary file). The magnitude of this difference may be small but clinically meaningful if the resultant increased hip abductor activity alters adjacent muscle activation patterns in a suboptimal manner. This requires further investigation.

Interestingly, we observed bilateral impairments in single leg squat control in those who had undergone hip arthroscopy one to two years prior, when compared to matched controls. There are a number of considerations in interpreting this finding. Firstly, neuromuscular changes may have occurred in both the operated and the non-operated limbs in response to chronic pain in the affected hip, intra-operative soft tissue disruption or post-operative pain and swelling. Joint-specific, bilateral accommodations have been noted in other lower limb conditions, such as chronic anterior cruciate ligament deficiency(25, 26) and surgical reconstruction,(25) knee osteoarthritis,(27) and chronic lateral ankle sprain.(28) Second, it is plausible that the presence of this altered movement pattern during daily activities that involve single leg stance, such as walking and stair ambulation, may have existed pre-operatively, potentially contributing to cumulative overload on the anterosuperior hip structures, and subsequently the development of intra-articular hip pathology.(29) Because the cross-sectional nature of this study precludes such conclusions being made from our findings, prospective studies should evaluate the temporal relationship between impaired single leg control and the development of hip joint pathology.

In contrast to our hypothesis, we did not find significant associations between decreased hip and trunk strength, and increased pelvic obliquity, hip adduction and apparent knee valgus excursion from standing to peak squat depth. Conversely, those who demonstrated greater increases in pelvic obliquity, hip adduction and apparent knee valgus when performing the single leg squat had greater hip flexor and extensor peak torques on isometric testing. Similar to muscle responses in low back pain (30) and chronic neck pain,(31) the deep short external rotator muscles of the hip may become inhibited in response to chronic hip pain and/or surgical disruption of hip structures.(32) Indeed, this inhibition may also be a precursor to the development of hip pathology. During functional activities, patients with intra-articular hip pathology may attempt to compensate for a lack of deep muscle control by recruiting the superficial hip flexor and extensor muscles. Increased use of these muscles may have a strengthening effect, enhancing their torque-producing capacity over time. However, the relationship between strength and movement control is imprecise and at present unclear. Further studies are needed to measure the effects of ongoing pain on deep hip muscle activation and compensatory strategies.

Consistent with previous literature in asymptomatic and patellofemoral pain cohorts,(21, 33, 34) we found that women across both groups demonstrated more hip adduction and apparent knee valgus than men, in standing and at peak squat depth. These findings suggest that the aetiology of intra-articular hip pathology may differ between men and women. With increasing female participation in sports that involve running and repetitive kicking, such as soccer and Australian Rules football, rates of intra-articular hip pathology in women may increase. This suggests the importance of screening women who may be at risk, and implementing programs to address deficits in single leg control.(35) It also highlights that, following hip arthroscopy, women may need a particular emphasis on single leg neuromuscular retraining within rehabilitation protocols.

The findings of this study have important implications in the management of those who have undergone hip arthroscopy for intra-articular hip pathology. Post-operative rehabilitation should include strategies to improve balance and motor control during single leg tasks. Such rehabilitation strategies may have implications for ongoing pain and symptoms post-arthroscopy,(14) and the development or progression of chondropathy.(10) Previous studies have shown reductions in hip adduction during running and single leg squat following a program of functional movement retraining,(36) but not with hip strengthening exercises alone.(37) Patients with chondrolabral pathology should also receive education regarding optimal alignment of the lower limb during daily activities, to avoid positions of painful hip impingement.

There are limitations associated with this study that should be considered. The cross-sectional study design means that it is unclear whether deficits in single leg squat performance were present before, or contributed to, the development of symptomatic intra-articular hip pathology, or occurred in response to symptoms and surgical sequelae. Prospective longitudinal studies of asymptomatic individuals, as well as patients with hip pathology pre- and post-operatively, will enhance understanding of this temporal relationship. In addition, we used a specific cohort with intra-articular hip pathology, who had undergone hip arthroscopy one to two years prior by a single surgeon. Thus, it is unclear whether findings are generalizable to other populations, especially those who are pre-arthroscopy or early in the post-operative period. Nevertheless, considering the length of time since surgery in our cohort, it is anticipated that any natural recovery in single leg function would have plateaued by this time. Finally, we utilized a two-dimensional measure of single leg squat performance. While this has been validated against three-dimensional measures,(38) additional information regarding femoral rotation during single leg squat could not be measured. However, the methods used in the current study were chosen due to their clinical applicability, ensuring that sports medicine practitioners working in clinical or sporting settings can utilize this test in screening or assessment.

CONCLUSION

The findings of this cross-sectional study indicate that people who have undergone hip arthroscopy for symptomatic intra-articular hip pathology one to two years previously, demonstrate deficits in single leg squat performance compared to matched controls. Importantly, the greater apparent hip adduction and apparent knee valgus observed at peak squat depth has the potential to place the hip joint in a position of painful impingement, which may perpetuate ongoing symptoms post-operatively. Evidence of greater hip flexor and extensor peak torques in those with greater apparent hip adduction and apparent knee valgus excursion during single leg squat suggests the use of a compensatory strategy to improve hip control during single leg tasks. While further prospective studies are required to understand the temporal relationship between intra-articular hip joint pathology and single leg squat control, rehabilitation following hip arthroscopy should include retraining in functional single leg positions.

KEY POINTS

Findings

- Deficits in single leg squat performance exist one to two years after hip arthroscopy for intra-articular hip joint pathology.
- Poor single leg squat performance is significantly correlated with greater strength of prime hip movers, suggesting a compensatory strategy to enhance hip control during single leg tasks.

Implications

- Findings suggest that rehabilitation after hip arthroscopy should look beyond strengthening of prime movers of the hip, and incorporate retraining in functional single leg positions.

Caution

- Cross-sectional study findings mean causative relationships cannot be determined.

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Table 1. Participant characteristics. Values are mean (SD) unless otherwise noted.

	Hip arthroscopy (n = 34)	**Control (n = 34)**	**Mean difference (95% CI)**	***P***
Age (years)	36.7 (±12.6)	33.1 (±11.9)	3.60 (-2.38 to 9.50)	.24
Height (m)	1.8 (±0.1)	1.7 (±0.1)	0.02 (-0.03 to 0.70)	.35
Weight (kg)	79.6 (±11.1)	72.0 (±15.5)	7.53 (1.01 to 14.06)	**.02***
Number (%) of males	17 (50)	17 (50)		
Number (%) of right leg dominant	28 (82)	33 (97)		**.046***
Number (%) of right hip surgery	19 (56)			
Number (%) with chondrolabral pathology	31 (91.2)			
Surgical procedure, number (%):				
arthroscopy only	2 (6)			
arthroscopy + FAI procedure	1 (3)			
arthroscopy + labral procedure	1 (3)			
arthroscopy + chondral procedure	8 (24)			
arthroscopy + 2 procedures^	9 (26)			
arthroscopy + 3 procedures^	13 (38)			
Physical activity (hours/week)	6.2 (±4.6)	5.3 (±3.3)	-0.81 (-1.11 to 2.74)	.40
Primary physical activity, number (%):				**.002***
none	6 (17.6)	1 (2.9)		
running	1 (2.9)	8 (23.5)		
swimming	0 (0.0)	3 (8.8)		
cycling	3 (8.8)	5 (14.7)		
walking	13 (38.2)	6 (17.6)		
Australian rules football	2 (5.9)	0 (0)		
gym	5 (14.7)	4 (11.8)		
other	4(11.8)	7 (20.6)		
Returned to pre-operative physical activity level, number (%):	13 (38.2)			
Occupation, number (%):				.89
not working	3 (8.8%)	2 (5.9%)		
sedentary	10 (29.4%)	10 (29.4%)		
active	21 (61.7%)	22 (64.7%)		
HOOS (100-0), median (IQR)				
Symptoms	80 (70-90)			
Pain	88.8 (75-95)			
ADL	94.9 (83.1-100)			
Sport/recreation	81.3 (62.5-89.1)			
Quality of life	68.8 (48.5-82.9)			
iHOT-33 (100-0), median (IQR)	77.8 (64.6-88.9)			
Peak torque (Nm/kg):				
Hip flexion	0.99 (0.35)			
Hip extension	1.07 (0.51)			
Hip abduction	1.46 (0.47)			
Hip adduction	1.14 (0.39)			
Hip ER (at 0° hip flexion)	0.69 (0.26)			
Hip ER (at 90° hip flexion)	0.58 (0.24)			
Hip IR (at 0° hip flexion)	0.53 (0.22)			
Hip IR (at 90° hip flexion)	0.60 (0.26)			

HOOS: Hip disability and Osteoarthritis Outcome Score; iHOT-33: International Hip Outcome Tool; ADL: activities of daily living; CI: confidence interval; IQR: interquartile range.
^ FAI, labral or chondral procedure. ***Significant at 0.05.**

Table 2. Mean (± standard deviation) values for standing and peak squat depth angles for the hip arthroscopy and control groups, with results of repeated measures ANOVA (main effects for limb and group, and group x limb interaction effects).

Variable	**Hip Arthroscopy**		**Control**		**Limb**		**Group**		**Limb x Group**	
	Operated	**Non-operated**	**Matched operated**	**Matched non-operated**	F	*p*	F	*p*	F	*p*
Standing:										
Pelvic obliquity angle (°)	5.0 (±3.3)	3.5 (±2.7)	4.4 (±3.0)	3.6 (±2.4)	4.156	**.045***	0.229	.634	0.345	.562
FPHA (°)	83.6 (±3.4)	83.2 (±3.7)	84.2 (±3.4)	83.3 (±3.2)	3.081	.084	2.754	.102	0.081	.777
FPKA (°)	-4.0 (±4.8)	-4.6 (±4.6)	3.5 (±3.7)	-3.3 (±3.3)	0.141	.708	1.700	.120	0.464	.498
Peak squat depth:										
Pelvic obliquity angle (°)	3.4 (±4.1)	2.2 (±2.8)	3.2 (±3.2)	3.7 (±2.7)	0.373	.544	1.031	.314	3.467	.067
FPHA (°)	79.5 (±4.7)	77.2 (±5.2)	81.0 (±5.6)	81.2 (±5.4)	2.010	.161	7.523	**.008***	2.913	.093
FPKA (°)	-7.4 (±9.0)	-10.3 (±9.5)	-4.7 (±6.3)	-4.9 (±7.6)	1.596	.211	6.979	**.010***	1.097	.299

FPHA, frontal plane hip angle; FPKA, frontal plane knee angle. ***Significant at .05.**

Table 3. Mean (± standard deviation) values for standing and peak squat depth angles for males and females, for hip arthroscopy and control groups, with results of repeated measures ANOVA (main effects for sex, and group x sex and limb x sex interaction effects).

Variable	**Hip Arthroscopy Operated**		**Hip Arthroscopy Non-operated**		**Control Matched operated**		**Control Matched non-operated**		**Sex**		**Group x Sex**		**Limb x Sex**	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**F**	***p***	**F**	***p***	**F**	***p***
Standing:														
Pelvic obliquity angle (°)	3.7 (3.0)	6.2 (3.2)	3.8 (2.9)	3.1 (2.6)	4.8 (3. 8)	4.1 (1.8)	3.0 (2.4)	4.2 (2.3)	2.30	.13	0.75	.389	0.27	.602
FPHA (°)	83.6 (3.8)	83.7 (4.0)	83.7 (4.0)	80.9 (2.9)	85.5 (3.9)	83.0 (2.5)	83.7 (3.5)	82.9 (2.9)	**9.11**	**.004***	0.03	.853	0.17	.686
FPKA (°)	-1.8 (4.4)	-2.1 (3.8)	-2.6 (4.7)	-6.6 (3.6)	-2.1 (3.8)	-4.8 (3.3)	-2.3 (3.0)	-4.2 (3.5)	**20.16**	**.000***	1.84	.180	0.33	.568
Peak squat depth:														
Pelvic obliquity angle (°)	2.5 (3.9)	2.6 (4.1)	2.6 (3.0)	1.9 (2.6)	3.3 (3.6)	3.0 (2.9)	3.9 (2.8)	3.6 (2.7)	0.06	.81	0.47	.496	1.83	.181
FPHA (°)	80.5 (4.2)	78.6 (5.1)	79.0 (5.2)	75.3 (4.6)	82.1 (5.6)	80.0 (5.8)	82.0 (6.0)	80.4 (4.9)	**5.48**	**.022***	0.37	.634	0.14	.710
FPKA (°)	-4.3 (6.6)	-10.6 (10.1)	-7.7 (8.5)	-12.9 (10.0)	-4.1 (5.6)	-5.3 (7.1)	-5.2 (7.7)	-4.7 (7.8)	**4.11**	**.047***	3.18	.080	0.34	.563

FPHA, frontal plane hip angle; FPKA, frontal plane knee angle. ***Significant at .05.**

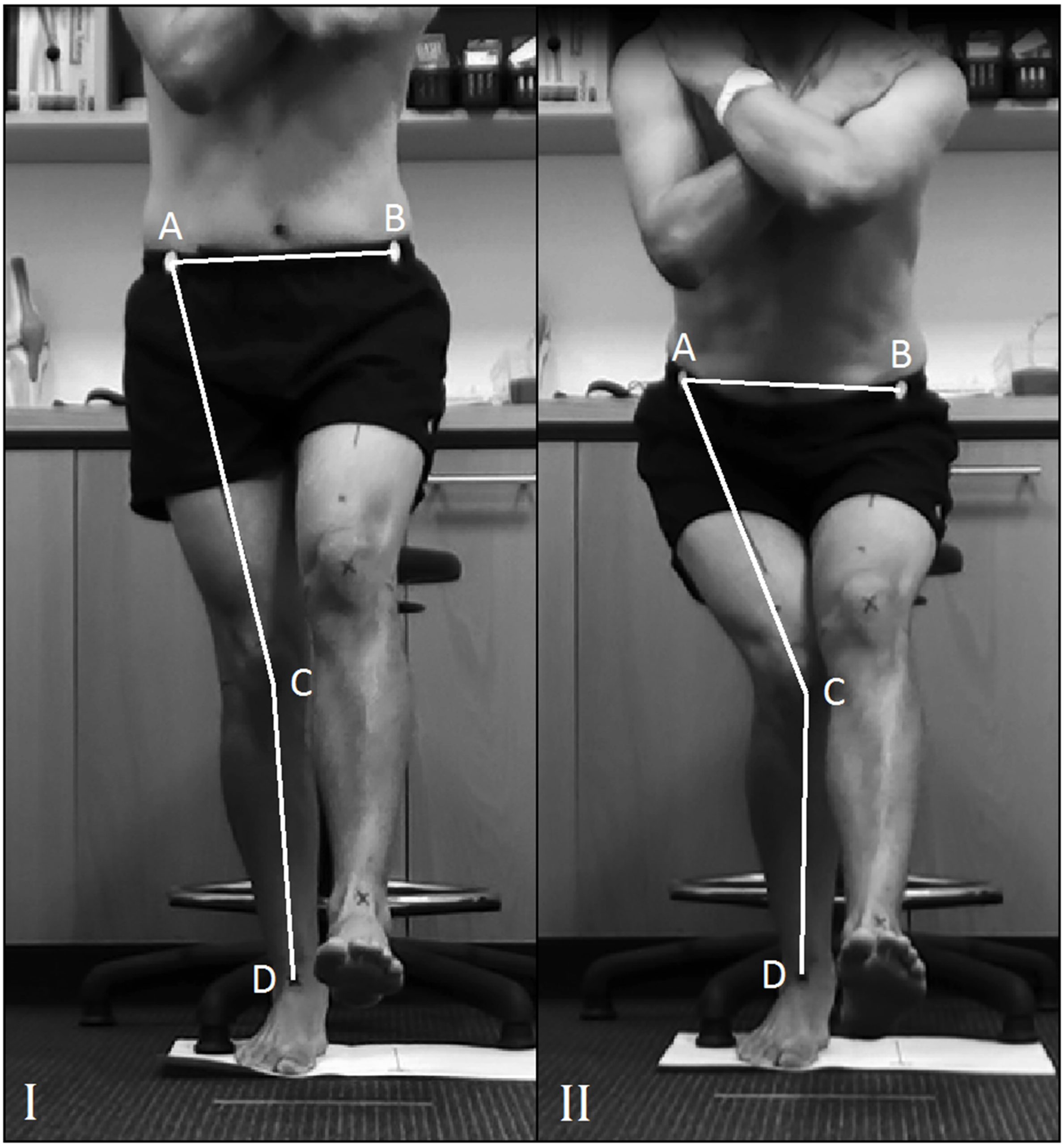
Table 4. Spearman's correlations between single leg squat variables, hip muscle peak torques (test limb) for hip arthroscopy participants.

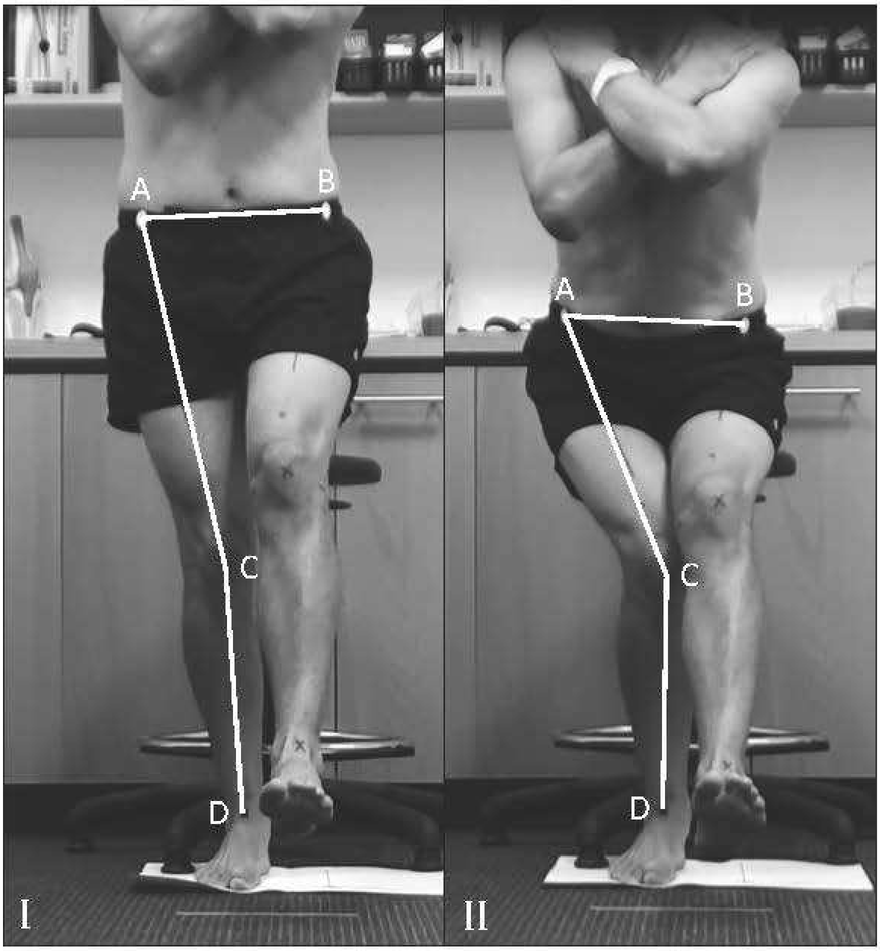
	Pelvic obliquity angle	FPHA	FPKA
Peak torque: hip flexion	**0.341***	**0.496***	**0.391***
Peak torque: hip extension	0.307	**0.482***	**0.417***
Peak torque: hip abduction	-0.009	0.020	0.081
Peak torque: hip adduction	0.203	0.203	0.154
Peak torque: hip ER (at 0° hip flexion)	0.183	0.190	0.169
Peak torque: hip ER (at 90° hip flexion)	0.135	0.068	0.007
Peak torque: hip IR (at 0° hip flexion)	0.171	0.243	0.230
Peak torque: hip IR (at 90° hip flexion)	0.173	0.161	0.066

FPHA, frontal plane hip angle; FPKA, frontal plane knee angle; ER, external rotation; IR, internal rotation. ***Significant at .05.**

FIGURE LEGENDS

Figure 1. Starting position (I) and bottom (60° knee flexion on test leg) (II) of the single leg squat test. Pelvic obliquity angle represented as the angle of the pelvis (A-B), relative to horizontal. Frontal plane hip angle represented as the angle between the pelvis (A-B) and femur (A-C). Frontal plane knee angle represented as the angle between the femur (A-C) and tibia (C-D).




A
B
C
D
I
A
B
C
D
II

Appendix 1. Test-retest (intra-rater) reliability of lower limb alignment angles, in 20 hip arthroscopy participants. Angles were measured from the same video trial on two separate occasions, by one investigator (PCC).

Measurement		Measure 1 Mean (SD)	Measure 2 Mean (SD)	ICC (95% CI)	SEM	MDC
Pelvic obliquity angle (standing)	Left	4.35 (3.26)	3.88 (2.97)	0.86 (0.65 to 0.95)	1.17	0.72
	Right	4.65 (3.50)	4.42 (3.70)	0.95 (0.88 to 0.98)	0.80	0.50
Pelvic obliquity angle (peak squat depth)	Left	2.74 (3.80)	2.78 (3.53)	0.97 (0.92 to 0.99)	0.63	0.39
	Right	2.94 (4.09)	2.90 (3.96)	0.87 (0.68 to 0.95)	1.45	0.90
FPHA (standing) (n=18)	Left	84.02 (3.82)	84.48 (3.43)	0.92 (0.78 to 0.97)	1.03	0.67
	Right	82.49 (3.71)	82.53 (3.55)	0.95 (0.87 to 0.98)	0.81	0.50
FPHA (peak squat depth)	Left	80.73 (6.30)	80.09 (5.41)	0.89 (0.73 to 0.96)	1.94	1.20
	Right	76.84 (4.88)	76.62 (4.62)	0.78 (0.43 to 0.91)	2.23	1.38
FPKA (standing)	Left	-1.88 (4.79)	-2.07 (5.91)	0.74 (0.34 to 0.90)	2.73	1.69
	Right	-5.77 (3.97)	-5.38 (4.03)	0.89 (0.73 to 0.96)	1.33	0.82
FPKA (peak squat depth)	Left	-4.31 (9.25)	-5.57 (8.87)	0.90 (0.75 to 0.96)	2.87	1.78
	Right	-12.27 (9.68)	-12.32 (10.03)	0.98 (0.96 to 0.99)	1.39	0.86

FPHA, frontal plane hip angle; FPKA, frontal plane knee angle; ICC, intraclass correlation coefficient; CI, confidence interval; SEM, standard error of the measure, SEM = pooled SD x √1-ICC; MDC, minimal detectable change, MDC = 1.96 x √2 x (SEM/√n).