Abstract

Purpose: This study compares lower limb muscle strength and endurance in adults with hip osteoarthritis, to an age-matched control group. **Methods:** Thirteen adults with moderate-to-severe hip osteoarthritis (as graded by the Oxford Hip Score) and fifteen older adults participated. Maximal voluntary isometric contraction of the knee extensors, knee flexors and hip abductors and isotonic endurance of the knee extensors were measured using a dynamometer. Function was assessed using the 30-second chair stand test, the 40 metre fast-paced walk test and a stair negotiation test. Data were compared between groups using *t*-tests. **Results:** Participants with hip osteoarthritis demonstrated weakness in the affected limb when compared to the control limb during knee flexion (34%, p=0.004) and hip abduction (46%, p=0.001). Weakness was also observed in the contralateral knee flexors (31%, p=0.01). When compared to the control limb, the knee extensors of the hip osteoarthritis group were exhausted prematurely in the affected (70%, p=0.001) and contralateral limb (62%, p=0.005). The hip osteoarthritis group took twice as long to stair climb (p=0.002), walked 40% slower, (p<0.001) and had a 35% lower sit-stand performance (p<0.001). **Conclusions:** Moderate-to-severe hip osteoarthritis may be characterised by bilateral deficits in lower-limb maximal strength, markedly lower knee extensor endurance and impaired functional performance.

Keywords: hip osteoarthritis; muscular strength; muscular endurance; physiotherapy; exercise; function

Introduction

Osteoarthritis is a common musculoskeletal condition within older adults, with an estimated 33% of people aged 45 years and over having sought treatment for the disease in the United Kingdom (UK) [1]. In the UK, 10.9% of adults aged over 45 years have osteoarthritis of the hip [1], which often leads to joint pain, stiffness, reduced range of motion, slower gait speed and muscle weakness [2-6]. Exercise is an integral component of the non-pharmacological management of osteoarthritis, with local muscle strengthening and aerobic exercise recommended irrespective of age, comorbidity, pain severity or disability [7]. Likewise, when progression of the disease leads to consideration for total hip replacement surgery, preoperative physiotherapy and exercise programmes (namely 'prehabilitation') are proposed as a potential method to expedite recovery time and improve overall extent of recovery [8-10].

To develop effective physiotherapy and exercise programmes in osteoarthritis, it is crucial to understand the underlying muscular impairment, and its relationship with physical function and disease progression [11]. Whilst several research efforts have addressed maximal muscular strength deficits in the hip osteoarthritis population [3], local muscular endurance has not been studied to the same extent. Nonetheless, the physiological stimuli directed to skeletal muscle as a result of strength training and endurance training are divergent in nature [12]. Maximal strength involves exerting a maximum amount of force for a short period of time whereas muscular endurance is the ability of the muscle or muscle group to sustain repeated contractions against a load for an extended period of time [13].

Physiological studies have shown within a single muscle, motor units can vary greatly in their contractile speed, maximum force, and resistance to fatigue [14]. These varying properties are co-varying, such that the slowest units tend to be fatigue resistance but weaker (type 1 fibres), and the

strongest fibres are fast but relatively sensitive to fatigue (type II fibres) [14]. Muscle fibres can adapt to changing demands by changing size or fibre type composition, and these changes may be partially responsible for impairments and disabilities observed in patients who are deconditioned [15]. Different fibre types enable muscles to fulfill a variety of functional demands [16], and the endurance ability of the quadriceps femoris has a significant role for functional capabilities during activities of daily living, such as walking and climbing the stairs [17]. Nonetheless, in chronic disease, such as osteoarthritis, muscle fatigue may occur prematurely and persist [18]. The aim of this study is to compare lower limb maximal muscle strength and local muscular endurance in adults with hip osteoarthritis, to an age-matched control group.

Methods

Participants

This is an observational case-control study recruiting two study groups: i) adults aged over 60 years with a clinical diagnosis of unilateral or bilateral hip osteoarthritis and ii) healthy adults aged over 60 years (control group) between 12th November 2019 and 15th March 2020. The study was closed prematurely due to the COVID-19 pandemic and the Government advice to close higher education institutes. Participants were recruited from the local area through online advertisement (Twitter, Facebook) and email recruitment sent to local organisations. Sixty years was chosen as the minimum age for the control group as osteoarthritis of the hip increases between the ages of 45 and 75 [1], and the average age for total hip replacement surgery is 68.0 ± 11.4 years [19]. Participants were included in the hip osteoarthritis group if they had: i) received a clinical diagnosis of hip osteoarthritis from their general practitioner, an orthopaedic specialist or a physiotherapist; ii) presented with chronic joint pain for at least three months; iii) had an Oxford Hip score [20] of less than 40; and iv) were not on the waiting list for total hip replacement surgery. Participants

were included in the control group if they: i) were over 60 years old, ii) had no hip or lower limb pain, iii) had no significant musculoskeletal comorbidities and iv) had no neurological diseases. Exclusion criterion for both groups included: i) neurological disease affecting walking ability; ii) rheumatoid arthritis; iii) fitted with a pacemaker or other active medical implant; iv) not physically able to complete the testing protocol or v) not able to provide informed consent. The experimental protocol was approved by the institutional ethics committee on 5th September 2019. In keeping with good practice, the ethical principles for medical research outlined in the Declaration of Helsinki were followed [21]. The STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) statement for the reporting of cross-sectional studies was used to guide the reporting of this study [22].

Variables

Participants were invited to attend a laboratory-based testing session. Age, weight, height, and medical history were recorded from all participants. Affected side(s), duration of symptoms and the use of analgesia for pain relief were recorded from the participants in the hip osteoarthritis group. The subjective severity of hip pain when weight bearing was rated using the Numeric Pain Rating (NPR) scale (range 0-10 with 0 depicting minimal pain and 10 representing unbearable pain) and the severity of symptoms were quantified using the Oxford Hip Score [20]. Physical activity levels were collected using the Physical Activity Scale for the Elderly (PASE) questionnaire [23].

Maximal voluntary isometric contraction of the lower limbs

Maximal, voluntary, isometric contraction (MVIC) of the lower limbs was measured using a multimodal dynamometer (Primus RS, Baltimore Therapeutic Equipment, Hanover, USA) in line

with an experimental methodology published by our institute [24]. Muscle contractile force estimations were conducted on both legs of the participants, with one leg tested at a time.

Participants were asked to perform three repetitions of three second maximal contractions of knee extension, knee flexion and hip abduction, to encompass the muscle groups often affected by hip osteoarthritis and most relevant to functional capacity [3,4,25]. For knee flexion and extension, participants were seated on a secure chair with an 110˚ angle between the seat and the back of the chair and with their knee flexed at 90˚ [24]. Participants were secured with a Velcro strap positioned around their hips to limit contralateral compensation. The pivotal point of the lever was aligned with the rotation of the knee joint to maintain appropriate position during all testing. To perform knee flexion, the centre of the dynamometer pad was placed on the posterior part of the leg, 5cm, above the lateral malleolus. For knee extension, the dynamometer exercise head was applied to the anterior tibia, 5cm above the lateral malleolus [26]. Whilst there is much debate on whether hip abduction should be performed in standing, side lying or supine [27,28], standing has been defined as the most physiological [29] and functional [30] position for hip abduction assessment, as the majority of daily activities involves hip abduction performed in weight bearing conditions [31]. Hence, hip abduction was measured in the standing position, with the centre of the dynamometer pad located 5cm proximal to the lateral femoral condyle [31]. The participant began in the neutral position and then progressed to 10˚ abduction of the hip joint. Both arms were placed in a neutral position, and a chair was placed in front of the participant in case they required stabilisation during the test. Force was automatically adjusted by the dynamometer to account for the length of the dynamometer attachment and lower limb segments distal to the joint being tested [24].

Before each maximal series, participants carried out a warm-up, followed by one trial submaximal effort of isometric knee flexion and extension and hip abduction, to become familiar with the contractions. The warm-up included five minutes of level walking in the lab at a self-selected and comfortable maximal speed, followed by a muscle warm up of both legs against a moderate resistance (approximately 25% of the participants' body weight), applied by the dynamometer. Participants with osteoarthritis completed the tests on their contralateral side first for familiarisation purposes. Participants were given consistent verbal encouragement during each contraction for attainment of maximal performance [32] and a one-minute recovery period was observed between each maximal effort [33]. If the coefficient of variation of the three tests was greater than 12.5%, the test was repeated following a period of rest to improve reliability of the study findings [34]. A mean value from the three efforts was recorded for MVIC, and later normalised to body mass (kilograms (kg)) (Nm/kg), to account for the confounding influence of body weight on dynamometric measurement [35].

Isotonic muscular endurance of the lower limbs

Following a five-minute rest period, dynamic lower limb endurance was measured on the dynamometer by calculating total energy expenditure (in joules) during repetitions of knee extension/flexion at a constant cadence under a resistance of 40% of MVIC. The knee extensor muscle group was chosen due to the significant role of the quadriceps muscle endurance for functional capabilities during activities of daily living [17], and an isotonic movement was chosen to best replicate functional activity. Participants were instructed to contract against the resistance throughout the desired arc of motion, and to complete as many repetitions as possible, at the set speed, calculated by the dynamometer as distance divided by time. Performance of each repetition was monitored through the dynamometer power output. A successful repetition consisted of

completing the entire arc of motion within 2.5 seconds. When this criterion was not achieved, the dynamometer power output would drop. A drop of ≤75% power output (as compared with the first repetition) was considered a failed repetition [36]. The test was ended after two successive failed repetitions or the participant reported exhaustion and asked to stop. Participants were seated in accordance to the positioning described for the MVIC knee extension test and secured with a Velcro strap. Endurance was tested on both legs, one at a time, with the contralateral side tested first in the osteoarthritis group, for familiarisation purposes.

Functional assessment

Functional performance was assessed through the 30-second chair stand test, the 40 metre (m) fast-paced walk test and a stair negotiation test, as recommended as the minimal core set of performance-based tests of physical function for older individuals (>40 years) diagnosed with hip osteoarthritis [37]. The 30-second chair stand test measured the number of times the participant could rise fully from chair and return to the seated position in 30 seconds. The participants' arms were crossed at the wrist and held close to the chest to avoid upper body compensation. Walk speed was measured as the time taken (in seconds) to complete a 10-metre walkway four times as quickly as possible but at a safe pace. Stair negotiation was measured as the time taken in seconds to safely ascend and descend eleven stairs (including turning around at the top) with a 20cm (8inch) step height, at a self-selected pace. A handrail was provided but not used unless necessary for safety.

Sample size and statistical methods

Since no preliminary data were available, sample size estimates were determined using data from the knee extension MVIC scores for the first eight subjects tested in each group. Using the means

and standard deviation of the MVIC scores, our effect size was 0.96. Using a type 1 error protection of 0.05, and a power of 0.80, we anticipated that 15 participants in each group to detect an outcome.

All data were analysed using IBM SPSS Statistics version 26 (SPSS Inc., Chicago, USA), with the significance level set at $p < 0.05$. Both the right and left sides of the control group were tested to observe any asymmetries, and then the right side was used as the comparison limb. The hip osteoarthritis group were analysed per affected or contralateral side. For those with bilateral hip osteoarthritis ($n = 2$), the affected or contralateral side were determined by the most and lesser affected hip. Data normality was evaluated using a Shapiro-Wilk test. If both samples passed the preliminary normality test, an independent samples or paired *t* test was conducted [39] to evaluate differences between groups and between legs, respectively. Patient demographics were assessed using an independent samples *t* test (age, BMI), a Mann Whitney U (PASE) or Fisher's exact test (gender distribution). Mean (standard deviation) and median (interquartile range (IQR)) were used to describe normally and non-normally distributed data, respectively [40]. Percentage change was also used to describe the differences between the control and osteoarthritis group. Effect sizes for differences in population means were computed using Cohen's d [41].

Results

Participants

Fifty-eight individuals volunteered to take part in the study (figure 1). During the initial telephone consultation, 16 volunteers did not meet the inclusion criteria due to: musculoskeletal comorbidity ($n = 6$); prior joint replacement ($n = 5$); hip pain but no clinical diagnosis of osteoarthritis ($n = 2$); cardiovascular comorbidity ($n = 1$), fitted with a pacemaker ($n = 1$); and listed for total hip replacement surgery ($n = 1$), and were excluded from the study. Six participants declined

participation due to travel or time commitments. A total of 36 were invited to attend the testing session. Two participants in the control group were excluded during the eligibility assessment due to knee pathology not previously disclosed. A further six participants were unable to attend the testing session due to the COVID-19 pandemic and the Government advice to close higher education institutes. Hence, the study was prematurely closed on 15th March 2020. This analysis includes 28 participants who were recruited prior to the pandemic (hip osteoarthritis, n = 13; control group, n = 15). Although we anticipated that 15 participants in each group to detect an outcome, a post-hoc power analysis suggested that it was only the knee extension MVIC measure that was underpowered.

There were no differences between groups in terms of age (p = 0.39) or gender distribution (p = 1.00). The osteoarthritis group were less active than the control group (median: 121.63 (IQR 70.80 to 175.13), versus 172.16 (IQR 95.07 to 209.71)), although this difference was not significant (p = 0.11). The hip osteoarthritis group had a significantly higher BMI than the control group (p = 0.03). Participants with hip osteoarthritis group had a mean Oxford Hip Score of 28 ± 8 (range: 18 – 39), suggesting moderate-to-severe hip osteoarthritis [20]. As graded by the Oxford Hip Score, one participant had severe symptoms (Oxford Hip Score of 18), six participants had moderate-to-severe symptoms (Oxford Hip Score of 20-29), and six participants had mild-to-moderate symptoms (Oxford Hip Score of 30-39). The mean duration of symptoms was 4 ± 3 years (range: 6 months – 10 years) and mean VAS pain on weight bearing was 5.31 ± 1.49 (range 3 – 8) (table 1). Eleven participants had unilateral hip osteoarthritis, and two bilateral. The two participants with bilateral osteoarthritis did not produce any anomalies in the results. Six participants were not taking any analgesics, four were taking paracetamol or ibuprofen when required, one was taking codeine

and paracetamol, one was taking the maximum dose of paracetamol, and one participant was taking diahydrocodine in addition to cod liver oil.

[Insert Table 1]

[Insert Figure 1]

Variables

Maximal voluntary isometric contraction of the lower limbs

One participant was not able to complete hip abduction MVIC on their contralateral side due to pain in their affected hip. There were no differences in maximal strength of the left and right legs of the control group (knee extension, $p = 0.67$; knee flexion, $p = 0.65$; hip abduction, $p = 0.06$) whereas some asymmetries were observed in the hip osteoarthritis group. The affected leg of the osteoarthritis group was 10% and 35% weaker when compared to the contralateral side in the knee extensors ($p < 0.001$) and hip abductors ($p = 0.003$), respectively. No asymmetry was observed in the knee flexors (table 2, figure 1).

In the osteoarthritis group, the knee extensors (quadriceps femoris) of the affected leg demonstrated weakness when compared to the control group (22%), although this was not significant ($p = 0.07$), perhaps due to this variable being underpowered. Similarly, the contralateral leg was 14% weaker during MVIC knee extension when compared to the control group, but also did not reach significance ($p = 0.23$). The knee flexors (hamstrings, gracilis, sartorius, gastrocnemius, plantaris and popliteus) of the affected leg were 34% weaker than the control group ($p = 0.004$), and the contralateral side demonstrated a 31% weakness in MVIC ($p = 0.01$), (effect sizes 1.20 and 1.07, respectively). The hip abductors (gluteus medius, gluteus minimus and tensor fasciae latae) demonstrated the most substantial weakness when compared to the control group,

with a 46% strength deficit in the affected side ($p = 0.001$, effect size 1.41), whilst the contralateral side was only 18% weaker ($p = 0.22$, effect size 0.99).

[Insert Figure 2]

Isotonic muscular endurance of the lower limbs

No asymmetries were observed between the isotonic endurance of the knee extensors of the affected and contralateral legs of the participants with hip osteoarthritis ($p = 0.26$) or left and right legs of the control group ($p = 0.12$). In the osteoarthritis group, isotonic muscular endurance of the knee extensors in the affected leg was 70% lower than the right leg of the control group ($p = 0.001$). Likewise, the knee extensors of the contralateral leg were exhausted prematurely when compared to the right leg of the control group (62%) ($p = 0.005$) (figure 3). Both comparisons yielded large effect sizes (1.41 and 1.17, respectively). One participant in the hip osteoarthritis group reported exhaustion before a drop of ≤75% power output was observed on the dynamometer, and one participant reported pain and asked to stop.

[Insert Figure 3]

[Insert Table 2]

Functional assessment

Participants with hip osteoarthritis score significantly worse than the control group in all three functional tests, yielding very large effect sizes (table 3).

[Insert Table 3]

Discussion

This study compared unilateral maximal isometric strength and muscular endurance of the affected and contralateral lower limbs in individuals with symptomatic hip osteoarthritis (graded moderate-to-severe by the Oxford Hip Score) to a healthy, age-matched control group. Individuals with hip osteoarthritis had weaker knee flexors and hip abductors than the control group in terms of MVIC in both the affected and contralateral sides. In addition, participants with hip osteoarthritis demonstrated lower isotonic muscular endurance of the knee extensors in both the affected and contralateral limbs. The knee extensors also demonstrated weakness in terms of MVIC, although this was not significant, perhaps as this outcome measure was underpowered. The deficits in strength and endurance were consistent with the results of the functional assessment; whereby participants with hip osteoarthritis performed significantly worse than their healthy counterparts in all three tests. Asymmetries were observed in the maximal isometric strength of the knee extensor and hip abductors in the affected and contralateral legs of the hip osteoarthritis group.

Comparison of the present study to the evidence-base is difficult due to differences in participant characteristics, disease progression, maximal strength testing methodologies and a paucity of evidence in the area of muscular endurance and hip osteoarthritis. In a review published in 2013 [3], thirteen studies were found to evaluate muscle strength, size, and/or inhibition in participants with hip osteoarthritis [42-54]. Individuals with hip osteoarthritis were found to exhibit generalised muscle weakness of the affected limb, which was underpinned by a combination of muscle atrophy, reduced muscle density and muscle inhibition relative to the contralateral leg and control group [3]. The greatest reductions in strength of the affected leg compared with the contralateral leg were found for the hip and knee extensors and flexors, followed by the hip abductors and adductors [3]. However, all but two articles [43,44] recruited participants from the waiting list for

a total hip replacement and included patients with advanced hip osteoarthritis. A more recent meta-analysis examined only the hip abductor muscles, and found weakness in the affected leg when compared to a control group and the unaffected limb across eight studies [55].

Few studies have investigated strength deficits at earlier stages of the disease. In the study by Zacharias et al., maximal hip abductor strength was 40% lower in the affected leg of individuals with moderate-to-severe hip osteoarthritis, when compared to a control group [25], similar to the 46% deficits observed in the present study. In a study by Loureiro et al., mild-to-moderate hip osteoarthritis was characterised by 22% less knee extensor strength [2], and Rydevik et al. reported 15% less strength in patients with mild-to-moderate pain, when compared to controls [56], comparable to the 22% weakness observed here. No evidence of between-limb asymmetries in muscle strength or volume were found in individuals with mild-to-moderate hip osteoarthritis [2], whereas in the present study, asymmetries were observed in the hip osteoarthritis group. In line with previous investigations, these findings suggest strength asymmetries are a characteristic of advanced hip osteoarthritis [3].

The main and novel finding of this study is that endurance of the knee extensors was markedly lower in both the affected and contralateral sides of the hip osteoarthritis group when compared to the left and right sides of the control group. These findings are perhaps not surprising, given that muscle atrophy in osteoarthritis is homogeneous among both fibre types [57], and the relationship between maximal isometric strength and relative muscular endurance [58,59]. These findings may also be explained by changes in muscle fibre composition, whereby muscle fibres adapt to changing demands [15]. For example, muscle disuse, prominent in the osteoarthritis population, can lead to slow switch muscle fibres changing to a fast-twitch, fatigable fibre type [15]. Nonetheless, knee extensor endurance has important clinical implications due to the significant

role of the quadriceps femoris endurance for functional capabilities during activities of daily living, such as walking, rising from a chair, and climbing stairs [17]. Findings from the functional assessment further highlight the need to train endurance in the lower limbs of individuals with hip osteoarthritis, given that it took this group twice as long to complete the stair negotiation test, 40% longer to complete the 40m walk test and they had a 35% lower sit-stand performance. These findings may be a result of deconditioning of the participants with osteoarthritis, secondary to their pain. Activity levels in the osteoarthritis group were lower than in the control group, and inactivity can lead to deconditioning of the muscular, cardiovascular, and respiratory systems [60]. Furthermore, as both the affected and contralateral limbs fatigued sooner than the control limb, deconditioning combined with pain are likely to be causing factors.

Endurance training induces central and peripheral adaptations that improve cardiovascular function and the capacity of skeletal muscles to generate energy through oxidative metabolism [61]. In both hip and knee osteoarthritis, knee extensor exercises are commonly prescribed, however not always with the training principles required to promote endurance benefits [62]. Training with low repetitions and high resistance favours adaptions for strength, power and hypertrophy, whereas training with high repetitions and low resistance increases muscular endurance and appears more suitable for submaximal, prolonged contractions [63]. Given the concern that high-intensity or high-load strength training may increase pain and joint stress for those with osteoarthritis [64], in addition to the function and endurance deficits observed in the present study, endurance training may be the most suitable training modality in the hip osteoarthritis population. For example, research has shown benefits of indoor cycling classes [65] and circuit-based weight training for adults with hip osteoarthritis [66]. Clinically, our

findings are important to inform specific exercise prescription in physiotherapy and exercise programmes for the hip osteoarthritis population.

A clear limitation of this study is the failure to meet the sample size estimates calculated due to a global pandemic and the premature completion of data collection. The ongoing pandemic and closure of higher education institutes prevented us from re-opening the study and recruiting any additional participants. However, a post-hoc power analysis suggested that it was only knee extension MVIC that was underpowered. More females were recruited to the study than males which may be a source of experimental bias. However, as approximately 60% of the osteoarthritic population are female, and 40% male [1], the participants in this study offer a reliable representation of the wider population. Similarly, whilst the participants with hip osteoarthritis had significantly higher BMI than the control group, obesity is widely acknowledged as a risk factor for both the incidence and progression of osteoarthritis [67]. In addition, obesity can be a consequence of osteoarthritis due to reduced physical activity due to joint pain, and hence, the sample may offer a true representation of the population. Nonetheless, strength measurements were normalised to body mass, to account for the confounding influence of body weight on dynamometric measurement. Finally, the cross-sectional design of this study does not allow us to evaluate whether muscle weakness is a cause or consequence of hip osteoarthritis.

Conclusion

In addition to bilateral deficits in maximal strength of the hip and knee muscles, moderate-to-severe hip osteoarthritis may be characterised by markedly lower muscular endurance of the knee extensors and impaired functional performance. The endurance capacity of the knee extensors can

play an important role in daily function, and thus it is important to consider endurance training principles when prescribing exercise in hip osteoarthritis.

Declaration of Interest Statement

The authors report no conflicts of interest.

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Figure captions

Figure 1. Participant recruitment through study

Figure 2. Maximal voluntary isometric contraction (Nm/kg) and endurance (joules) in adults with hip osteoarthritis compared to controls (mean ± standard error)

**indicates significance when compared to the mean of the affected limb ($p < 0.05$)*

Figure 3. Knee extensor isotonic endurance, expressed as total work (joules) before two consecutive contractions power were ≤75% of the first repetition, in adults with hip osteoarthritis compared to healthy controls (mean ± standard error)

**indicates significance when compared to the mean of the affected limb ($p < 0.05$)*

Tables

Characteristic	Unilateral hip OA *n* = 11	Bilateral hip OA *n* = 2	All hip OA *n* = 13	Control group *n* = 15
Age (years)	75 ± 7.69	72 ± 4.95	75 ± 7.30	72 ± 6.42
Males, n (%)	4 (36%)	1 (50%)	5 (38%)	5 (33%)
Height (m)	1.68 ± 0.08	1.70 ± 9.90	1.68 ± 0.08	1.68 ± 0.12
Weight (kg)	83.0 ± 18.29	91.00 ± 4.24	84.23 ± 17.01	71.85 ± 14.89
BMI (kg/m^2)	29 ± 6	32 ± 2	30 ± 6	25 ± 4
Oxford Hip Score	27 ± 7	34 ± 5	28 ± 7	N/A
Pain (VAS)	5.79 ± 1.62	5.5 ± 0.71	5.31 ± 1.49	N/A
Duration of symptoms (years)	3.68 ± 2.82	6.0 ± 5.66	4.04 ± 3.17	N/A

Table 1. Sample characteristics

Measure	Affected limb Mean ± SD	Contralateral limb Mean ± SD	Difference between affected limb and contralateral limb (95% CI)	*p*	Effect size	Control limb (right) Mean ± SD	Difference between affected limb and control limb (95% CI)	*p*	Effect size	Difference between contralateral limb and control limb (95% CI)	*p*	Effect size
MVIC knee extension	2.56 ± 1.18	2.83 ± 1.13	0.27 (0.16, 0.37)	<0.001*	0.23	3.28 ± 0.72	0.71 (-0.07, 1.50)	0.07	0.74	0.45 (-0.31, 1.21)	0.23	0.47
MVIC knee flexion	1.14 ± 0.43	1.19 ± 0.46	0.05 (-0.09, 0.19)	0.49	0.11	1.73 ± 0.55	0.59 (0.20, 0.98)	0.004*	1.20	0.54 (0.14, 0.94)	0.01*	1.07
MVIC hip abduction	0.30 ± 0.14	0.46 ± 0.18	0.16 (0.07, 0.25)	0.003*	0.99	0.56 ± 0.22	0.27 (0.12, 0.41)	0.001*	1.41	0.10 (-0.06, 0.27)	0.22	0.50
Isotonic knee extensor endurance	659 ± 402	829 ± 721	170 (-140, 480)	0.26	0.29	2204 ± 1494	1544 (695, 2394)	0.001*	1.41	1375 (471, 2278)	0.005*	1.17

Table 2. Maximal voluntary isometric contraction (Nm/kg) and endurance (joules) in adults with hip osteoarthritis compared to controls

**indicates significant difference when compared to osteoarthritis (affected) leg ($p < 0.05$)*

Measure	All hip OA *n* = 13	Control group *n* = 15	Difference in means (95% CI)	*p*	Effect size
30s chair stand (n)	7.92 ± 1.44	12.13 ± 2.77	4.21 (2.45, 5.97)	< 0.001*	1.91
40m fast-paced walk (s)	45.92 ± 9.85	32.80 ± 4.86	13.12 (7.22, 19.03)	< 0.001*	1.69
Stair negotiation (s)	23.77 ± 11.04	11.80 ± 2.46	11.97 (5.22, 18.72)	0.002*	1.50

Table 3. Functional assessment scores for adults with hip osteoarthritis, compared to healthy

`controls (mean ± SD)

**indicates significant difference between study groups ($p < 0.05$)*