

# Hip Muscle Strength and Muscle Cross Sectional Area in Men with and without Hip Osteoarthritis

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**ABSTRACT. Objective.** To study the hip muscle strength and cross sectional area (CSA) in men with hip osteoarthritis (OA) compared to age and sex matched healthy controls.

**Methods.** Based on the American College of Rheumatology criteria regarding classification of hip OA, 27 men (aged 47–64 yrs) with unilateral or bilateral hip OA and 30 age matched randomly selected healthy male controls were studied. The maximal isometric hip abductor, adductor, flexor, and extensor strength (Nm) at 0 degree of hip flexion in the supine position was determined with a dynamometer. The isokinetic hip flexion and extension strength (peak torque, Nm) was determined using angular velocities of 60°/s and 120°/s. The subjective severity of hip pain was rated by visual analog scale prior to the muscle strength test. CSA of the pelvic and thigh muscles was measured from magnetic resonance images.

**Results.** The reliability of intraclass correlation coefficients for repeated measures of muscle strength varied from 0.70 to 0.94 in controls and from 0.84 to 0.98 in subjects with OA. Hip isometric adductor and abductor strength was 25% and 31% lower ( $p < 0.001$ ) in OA subjects than in controls, respectively. The hip isometric and isokinetic flexion strength was 18–22% lower ( $p < 0.01$ ) in OA subjects than in controls, but extension strength did not differ between groups. In OA subjects, the hip flexion and extension isometric and isokinetic strength values were 13–22% lower ( $p < 0.05$ ) on the more deteriorated side compared to the better side. CSA of the pelvic and thigh muscles did not differ between the groups. However, in OA subjects, the CSA of the pelvic and thigh muscles was 6–13% less ( $p < 0.05$  to  $< 0.001$ ) on the more severely affected hip compared to the better hip.

**Conclusion.** Men with hip OA have significantly lower abduction, adduction, and flexion muscle strength than controls. The decrease of muscle size and hip pain may contribute to the decrease of muscle strength in hip OA. Other possible underlying causes of the muscle weakness need to be studied. (J Rheumatol 2002;29:2185–95)

## Key Indexing Terms:

MUSCLE  
HIP

STRENGTH  
PAIN

MAGNETIC RESONANCE IMAGING  
OSTEOARTHRITIS

Clinical studies have shown that persons with radiographic knee osteoarthritis (OA), whether symptomatic or not, have weaker quadriceps muscle strength than those without knee

OA<sup>1-4</sup>. Quadriceps weakness is one of the earliest findings reported in knee OA. It is a better determinant of pain and disability than any radiographic changes<sup>5-7</sup>. The muscle weakness has been suggested to be caused by disuse atrophy of the muscles due to joint pain<sup>3,4</sup>. The possible alterations in muscle size have not been studied in OA. In addition to pain related arthrogenous inhibition of muscle functions, reflex inhibition of muscles moving the affected joints is supposed to contribute to muscle weakness in OA<sup>3,4,8</sup>. This indicates that the reason behind the muscle weakness in OA is not clear.

Most studies on muscle performance have concerned muscles affecting the knee joint, whereas little information is available about functional properties of muscles moving the hip joint in OA. In several studies the strength of the hip muscles during isometric<sup>9-18</sup> and isokinetic<sup>14,19-23</sup> contractions of healthy subjects have been evaluated. Hip muscle strengthening after hip surgery has been prescribed to restore the strength of muscles<sup>24-30</sup>. Preoperatively, muscle groups in the diseased hips have been shown to be weaker

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(51–79% of strength observed on the healthy side) than those in the uninvolved hips<sup>29</sup>. As far as we are aware there is only one study where muscle strength in patients with hip OA has been compared with healthy controls<sup>31</sup>. Murray and Sestic showed that the maximum hip abduction and adduction forces of the patients with hip arthropathy (hip OA and aseptic necrosis) were below the range of normal variability in both the abductor and adductor muscle groups in patients with OA<sup>31</sup>. It was not reported, however, whether those patients were matched for age and sex with healthy controls.

Muscle strength measurements are useful if the measurement technique is reliable and reproducible. In general, it is agreed that any isometric assessment technique has to possess high test-retest reproducibility<sup>32</sup>. The reliability of hip muscle testing has mainly been studied in healthy subjects<sup>17–20,33–35</sup>. In general, the repeatability of hip isometric and isokinetic strength tests was high, based on intra-day or day-to-day measurements in healthy subjects. The reproducibility of isometric and isokinetic performance of muscles has not been studied in subjects with hip OA.

We investigated hip abduction, adduction, flexion, and extension muscle strength in men with hip OA and compared the results with age and sex matched healthy controls. We also assessed the day-to-day reproducibility of hip muscle strength tests. The subjective severity of hip pain was rated using a visual analog scale (VAS) prior to the muscle strength test. In addition, the cross sectional area (CSA) of the pelvic and thigh muscles was measured from magnetic resonance images (MRI). We hypothesized that patients with hip OA have lower hip muscle strength and CSA of muscles than age and sex matched controls.

## MATERIALS AND METHODS

**Subjects and selection.** A total of 27 male patients aged 47 to 64 years (mean  $\pm$  SD 56.2  $\pm$  4.9 yrs) were selected by clinical criteria for unilateral or bilateral hip OA. They were 168 to 186 cm (176.7  $\pm$  4.8) in height and 60 to 116 kg (83.9  $\pm$  11.3) in weight. Subjects had had either pain or functional impairment (e.g., limitation of hip motion or stiffness of the joint) in the hip region within the prior month as indicated in the clinical criteria of the American College of Rheumatology<sup>36</sup>. Subjects were recruited from Kuopio and nearby areas by newspaper advertisement and a few (3 subjects) were selected from those waiting for a total hip replacement in the Kuopio University Hospital. The patients with OA agreed to volunteer for the study. The exclusion criteria included a history of trauma of the hip joint or in the pelvis region, previous hip fracture or hip surgery, a hip joint infection, and a congenital or developmental disease. Further, OA subjects were excluded if they had any of the following diagnoses, symptoms, or medication: cancer, rheumatoid arthritis, endocrine disease, epilepsy, Parkinson's disease, cerebrovascular disease, polyneuropathy, neuromuscular disorder, debilitating cardiovascular disease in spite of medication, atherosclerosis of lower extremities, painful knee OA, previous back surgery, painful back, or use of corticosteroid medication. These conditions might have interfered with evaluation of pain and function of hip joints. Individuals with possible polyneuropathy and acute severe sciatica were also excluded on the basis of electromyography. All OA subjects were able to walk without physical assistance or devices.

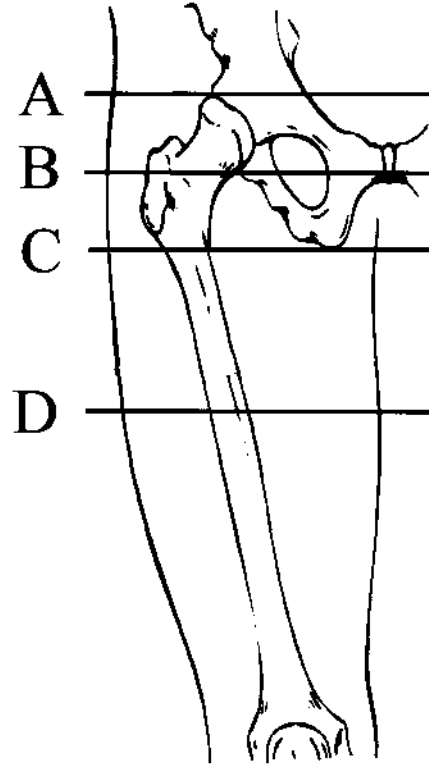
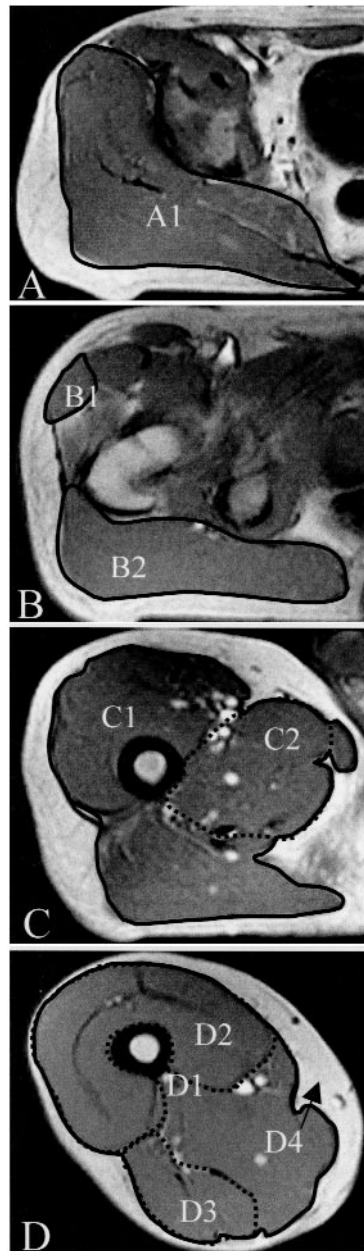
Thirty randomly selected healthy age matched men 47–64 years old (56.3  $\pm$  4.5 yrs) living in the city of Kuopio and nearby areas were used as

controls. They were sampled from the population register; they were 165 to 185 cm (173.8  $\pm$  4.8) in height and 63 to 105 kg (81.4  $\pm$  9.6) in weight. They were contacted by mail and interviewed by a physician (by M.H.A. and J.P.A.A.). Controls had neither unilateral nor bilateral hip OA according to the radiographic criteria used in this study (see below), nor any hip pain or functional impairment. Exclusion criteria were the same as for OA patients. Initially, 217 randomly selected men aged 47–64 years (n = 10,175) living in Kuopio and nearby areas were contacted. A few (12.4%) could not be reached by letter or telephone, 67.7% had health status that precluded participation, and 3.2% refused. Among those who fulfilled the inclusion criteria, 2 were excluded after electromyography due to polyneuropathy and 4 were excluded on account of a nonsymptomatic radiographic OA score of 1 in the right or left hip joint.

All subjects filled out questionnaires on medical history and hip joint symptoms. The duration of OA symptoms (years) was noted. The use of prescribed pain relief medication was determined for the previous 6 months (1 = no use, 2 = 1–9 days/6 mo, 3 = 10–59 days, 4 = 60–119 days, and 5 = 120–180 days). As well the type of pharmacological management of hip OA was recorded, i.e., analgesics, nonsteroidal antiinflammatory drugs (NSAID), other drugs. The subjective severity of hip pain was rated on the VAS (range 0–10 cm, with endpoints no pain–unbearable pain). The pain history was recorded separately for the right and left hips immediately before the muscle strength test. Subjective severity of hip pain was recorded, because impaired muscle strength in OA patients might result from joint pain rather than muscle weakness itself<sup>3,4</sup>. A 12 month leisure time physical activity (LTPA) history was recorded<sup>37,38</sup>. The total LTPA (metabolic units/year), duration of LTPA (hour/year), intensity of LTPA (mean metabolic units), and frequency of LTPA (sessions/year) were determined. Anthropometric measures were taken including height (cm) and weight (kg). Body mass index (BMI) was determined as weight divided by the square of height (kg/m<sup>2</sup>). Written consent to participate was obtained from each subject. The Ethics Committee of the Kuopio University Hospital approved the study design.

**Evaluation of plain radiographs.** Supine anteroposterior and Lauenstein radiographs were taken for both hips, as well as radiographs of the pelvis during weight-bearing. The radiographs were evaluated blind by a trained radiologist (L.N.) using the Kellgren-Lawrence grading<sup>39</sup> and Li's OA scale for the hip<sup>40</sup>, which is modified from the Council for International Organisations of Medical Sciences scale (Kellgren-Lawrence grading system) from 0 (no OA) to 4 (severe OA). The kappa value for the intraobserver (test-retest) reliability for hip radiographic grading was 0.84 (p < 0.0001).

**MRI assessment of the CSA of the pelvic and thigh muscles and fat.** MRI was performed with a 1.5 T scanner (Siemens Magnetom 63SP, Erlangen, Germany). The subjects were placed supine on the imaging table. The length of the femur (LF, cm), taken as the distance from the intercondylar notch of the femur to the superior corner of the femoral head, was measured on the coronal plane. The LF was divided into 4 sections. T1 weighted axial scans of the pelvis and thigh and the CSA (cm<sup>2</sup>) of muscles were determined from the following regions (Figure 1): (1) Upper border of the acetabulum: CSA of the gluteal muscles included the gluteus minimus, gluteus medius, gluteus maximus, tensor fascia latae, and piriformis muscles; (2) lower border of the acetabulum: CSA of the tensor fascia latae and gluteus maximus muscles was determined individually; (3) upper thigh (axial scan at the lower border of the upper quarter section of LF): CSA of all thigh muscles was determined as well as separately the adductor muscle compartment including the adductor longus, brevis, and magnus muscles; and (4) middle thigh (axial scan at the middle of LF): CSA of all muscles was determined and separately CSA of the anterior muscle compartment including the vastus lateralis, medialis, intermedius, and rectus femoris muscles and the posterior muscle compartment including the biceps femoris and semitendinosus muscles (Figure 1). The CSA of thigh fat was determined from the middle LF scan. The MRI were evaluated blind (by M.V.) using the region of interest (ROI) facilities. CSA of selected muscles



- A1= Gluteal muscles
- B1= M. tensor fascia latae
- B2= M. gluteus maximus
- C1= All muscles
- C2= Adductor compartment
- D1= All muscles
- D2= Anterior compartment
- D3= Posterior compartment
- D4= Fat compartment

Figure 1. MR images of a patient showing the region of interest for muscle cross sectional area measurements. See Materials and Methods for description.

and fat was determined 3 times and the average of 3 measurements was calculated. The intraobserver reproducibility of 2 separate CSA measurements in different ROI [the coefficient of variation, CV (%)] was between 0.53% and 4.49% when assessed from 10 subjects.

**Hip abductor and adductor isometric strength assessments.** Before the muscle strength tests, subjects were informed about the test procedure and purpose. Before muscle testing a 10 min warmup phase was performed on a bicycle ergometer at a level of 1.5 W × body weight (kg), followed by a 10 min stretching phase of the lower extremities.

Isometric hip abductor and adductor strength was determined bilaterally with a computerized strain-gauge dynamometer (Digitest®, Newtest, Oulu, Finland) (by M.A.) (Figure 2). This technique has been used, e.g., to measure trunk and grip strength muscle performance and has been shown

to be valid and reliable<sup>41</sup>. Calibration of the dynamometer was carried out before the measurements. The dynamometer was connected to a data processing computer, where the force data was sampled and stored at 1000 Hz. The lower border of the belt was placed on the proximal third portion of the subject's thigh at the level just proximal to the lateral femoral condyle. The dynamometer unit was between the 2 ends of the belt attachment. The tip of the trochanter major was marked and it served as the reference for the axis of rotation. Hip abductor and adductor torque was tested with the subject positioned supine on a table. Subjects were stabilized with pelvic and chest straps. The knee of the tested leg was held in extension. Using a goniometer the subject's contralateral hip was positioned at 60° angle of flexion and the knee angle was maintained at 90° flexion.

Subjects were always tested in the following way: (1) left hip adduc-



tion, (2) right abduction, (3) right adduction, and (4) left abduction. Subjects were instructed to apply a small preload onto the dynamometer. They first performed 5 submaximal contractions to become familiar with the testing device. They were then instructed to adduct or abduct the thigh with maximal force. The isometric tests were commenced via an auditory signal after which subjects were instructed to apply maximal force for 3 s. Three maximum contractions with an intervening rest period of 15–20 s were performed. Similar verbal reinforcement was given to the subjects during the measurement. After 3 maximal contractions, a 4–5 min rest period was allowed before the next test.

The force data were analyzed using Digitest software. The mean of 3 peak force (N) measurements was calculated. Data for each subject were converted to torque values (Nm) by multiplying force values by the distance from the middle of the belt to the tip of the trochanter major. Values of mean maximal muscle torque were divided by the patient's body weight to obtain the relative muscle torque (Nm/kg).

*Hip flexor and extensor isometric and isokinetic strength assessments.* After hip abductor and adductor isometric strength assessments isometric and isokinetic hip flexor and extensor strength was determined bilaterally using a Lido® Active Isokinetic Rehabilitation System (Loredan Biomedical, West Sacramento, CA, USA) (by M.A.) (Figure 2). The Lido testing device was connected to a data processing computer (IBM compatible 486-DX PC), a monitor and a system for torque and goniometer measurement, and a data acquisition processor. The Lido dynamometer was calibrated according to the manufacturer's manual. Positioning of the subjects was as recommended by the manufacturer. Hip flexion and extension was measured in supine position. The axis of the dynamometer was

aligned with the greater trochanter. The pelvis (at the level of iliac crest), upper trunk, and contralateral thigh were stabilized with straps and a thigh pad. The lower border of the thigh cuff of the lever arm was placed just proximal to the lateral femoral condyle.

A subject was tested in flexion and extension in the following order: (1) right hip isometric, (2) right hip isokinetic, (3) left hip isometric, and (4) left hip isokinetic. Three maximal isometric flexion and extension force measurements were made at 0° of hip flexion. The subject was allowed 5 submaximal warmup movement efforts. After submaximal efforts the subject performed 3 maximum isometric flexion efforts (3 s) followed by 3 extension efforts (3 s), each separated by a rest period of about 15 s. Five isokinetic contractions (concentric and eccentric) were performed through a 60° arc of motion starting at 0° of hip flexion and ending at 60° of flexion. The 60°/s (low) and 120°/s (high) angular velocities were used. The sequencing of the angular velocity was not randomized. There was a 15–20 minute rest period between tests on the opposite side.

The mean of 3 maximal isometric hip flexion and extension force (Nm) measures was calculated including gravity compensation. Test results obtained with the isokinetic testing included the peak torque (Nm), which was the highest value of repetitions.

*Reproducibility of muscle strength measurements.* Six healthy controls, 11 healthy young men, and 9 subjects with hip OA were used to study the repeatability of the muscle strength measurements. Eleven men aged 19 to 24 years ( $22.8 \pm 1.7$ ) were recruited from university students to study the repeatability of the muscle strength measurements. The heights of these subjects ranged from 169 to 193 cm ( $181.7 \pm 8.4$ ) and their weights from 57 to 85 kg ( $74.9 \pm 8.4$ ). There were no significant anthropometric differ-

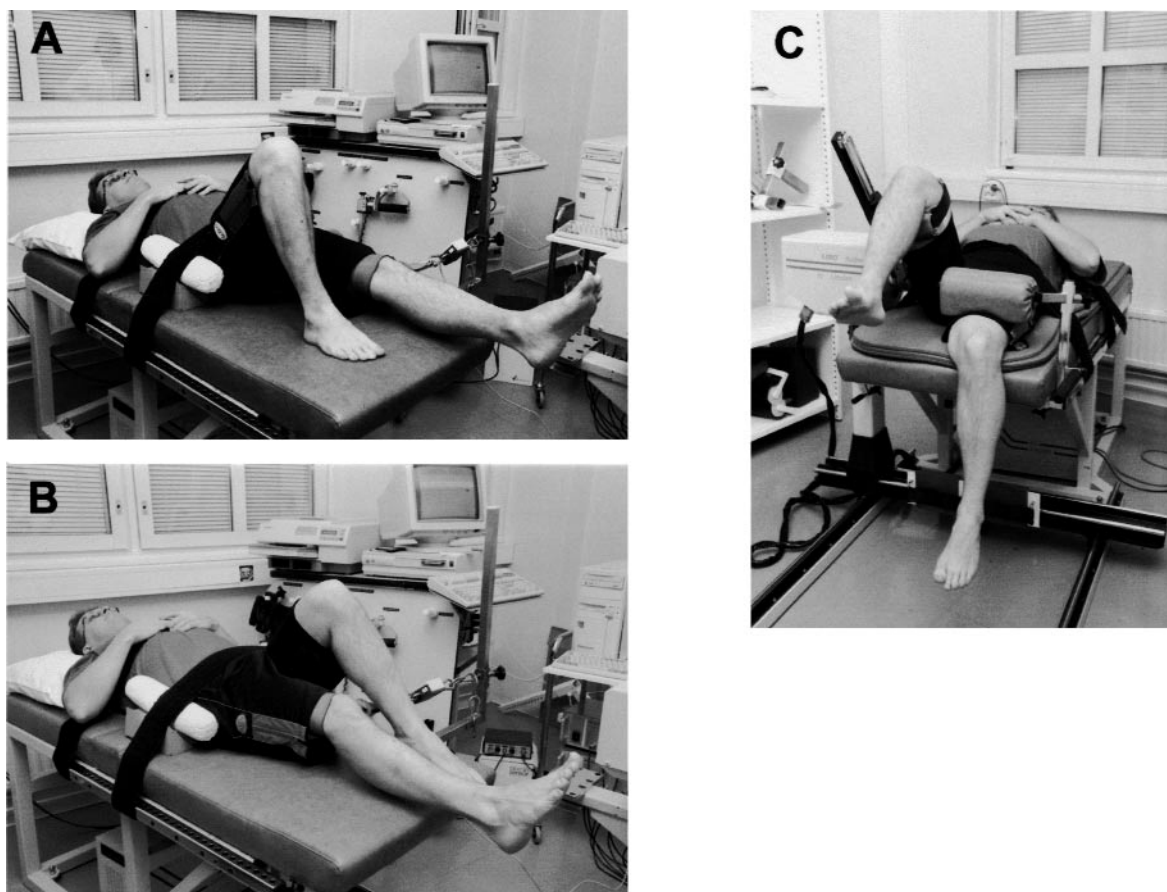


Figure 2. Positions of a subject during testing of (A) hip adduction, (B) hip abduction, and (C) hip flexion and extension torque. See Materials and Methods for details.

ences between these younger and the older controls. There were no limitations in their hip movements, no pain in the hip region, and none had had surgery of the lower extremity nor had known hip pathology. None of these subjects had previously exercised on an isometric or isokinetic device.

The left hip of each healthy subject and the more severe side (based on plain radiographs) of OA subjects were tested on 2 separate days at an interval of 2 to 6 weeks, with the evaluator blind to the initial results. Attempts were made to test each subject at about the same time of day.

**Statistical analysis.** All values were expressed as mean  $\pm$  SD. Normality of distribution was assessed using the Kolmogorov-Smirnov test with significance level set at 0.05. Pearson's correlation coefficient was used to quantify correlation between normally distributed continuous variables. Spearman's rank correlation coefficient was used to assess the reliability of variables that did not follow a normal distribution. Another measure for reproducibility was the intraclass correlation coefficient (ICC). The CV (%) reflected the variability of the measurements<sup>42</sup>. Wilcoxon's matched-pairs signed-rank test or paired Student t test was used to study the possible systematic variation of whether muscle strength was significantly different between the first and second tests. Student t test was used to test the significance of the difference between the control and OA subjects. The hip with the highest radiographic OA score and clinical symptoms of a patient were used for the analysis. The differences were compared with the hip on the same side of an age matched control subject. Side-to-side comparisons were by paired t test or Wilcoxon's matched-pairs signed-ranks test. The correlation between muscle strength and subjective severity of hip pain (VAS) was by Spearman's rank correlation coefficient. Differences in hip pain (VAS) between the radiographic OA subgroups (grades 1–3) were determined separately by the nonparametric Kruskal-Wallis test. Results were regarded as significant if  $p < 0.05$ .

## RESULTS

According to the side of the highest radiographic score from the patients with clinical hip OA, 29.6% had grade 1, 29.6% grade 2, and 40.8% grade 3 OA. Fifteen OA subjects had a unilateral clinical OA and 12 had bilateral disease. The mean ( $\pm$  SD) duration of hip symptoms was  $6.4 \pm 5.2$  years. The use of pain relief medication on a daily basis was as follows: 9 subjects (33.3%) no use within 6 mo, 6 subjects (22.2%) 1–9 days/6 mo, 8 subjects (29.7%) 10–59 days/6 mo, one subject (3.7%) 60–119 days/6 mo, and 3 subjects (11.1%) 120–180 days/6 mo. Among the OA subjects who used pain relief medication only one had used analgesics (acetaminophen), whereas they all had used NSAID and 2 had also used glucosamine sulfate. There were no differences in body weight or BMI between the groups. Height in the group with OA was 1.7% greater ( $p < 0.05$ ) than in the control group, but length of the femoral bone did not differ between the OA and age and sex matched control groups. The subjective severity of hip pain on VAS was  $2.1 \pm 2.3$  cm (range 0–6.6) in the OA group and 0 cm in the healthy group immediately prior to the muscle strength test. In the subjects with unilateral clinical hip OA, 6 had pain on the right side (VAS  $2.8 \pm 2.2$  cm, range 0.1–6.4) and 4 on the left side (VAS  $2.5 \pm 2.4$  cm, range 0.1–6.4) immediately prior to the muscle strength test. There were no significant differences in subjective severity of the hip pain (VAS) between the radiographic OA subgroups (Kruskal-Wallis test; data not shown). However, the subjective severity of hip pain was significantly ( $p < 0.001$ ) higher on the more severe side,  $2.2$

$\pm 2.4$  cm, compared to the better hip side,  $0.9 \pm 2.1$  cm ( $n = 20$ ). There were no significant differences in LTPA measures between the OA and control groups (data not shown).

**Reproducibility of muscle strength measurements.** The mean isometric and isokinetic hip muscle strength values (Nm) from the first and second measurements, the correlation coefficients, ICC, and CV are presented in Table 1. In general, the mean differences between the first and second measurements were not statistically significant between controls and subjects with OA (Table 1). Only the peak torque in extension ( $120^\circ/s$ ) was significantly higher on the second test occasion.

Correlation coefficients between the first and second measurements varied between 0.881 ( $p < 0.001$ ) and 0.902 ( $p < 0.001$ ) for isometric adduction and between 0.569 ( $p < 0.05$ ) and 0.746 ( $p < 0.01$ ) for isometric abduction strength values in controls (Table 1). In the OA group, correlation coefficients between first and second measurements on the more severe side were 0.786 ( $p < 0.05$ ) for isometric abduction and 0.750 ( $p < 0.05$ ) for adduction (Table 1). Correlation coefficients between first and second measurements varied between 0.529 ( $p < 0.05$ ) and 0.839 ( $p < 0.001$ ) for isometric and isokinetic flexion and between 0.710 ( $p < 0.01$ ) and 0.824 ( $p < 0.001$ ) for isometric and isokinetic extension strength values in controls (Table 1). In the OA group, correlation coefficients between first and second measurements at the more severe side were between 0.883 ( $p < 0.01$ ) and 0.926 ( $p < 0.001$ ) for flexion and between 0.750 ( $p < 0.05$ ) and 0.964 ( $p < 0.001$ ) for extension (Table 1). In the controls, ICC for hip strength measurements ranged from 0.70 to 0.94 (Table 1). ICC was highest for isometric adduction measurements and lowest for isometric flexion and flexion peak torque at  $60^\circ/s$  measurements in controls. In OA subjects, ICC for hip strength measurements ranged from 0.84 to 0.98 (Table 1). In controls, CV of hip muscle strength measurements ranged from 8.4% to 24.0% (Table 1). In the OA group, CV of strength measurements on the more severe side ranged from 7.5% to 20.3% (Table 1). The CV of the extension peak torque at  $120^\circ/s$  was higher than at  $60^\circ/s$  (Table 1).

**Muscle strength between groups and within the OA group.** In general, isometric and isokinetic muscle strength values did not reveal any significant difference between the sides in controls (data not shown). Only isometric extension strength was higher, by 15.8% ( $p < 0.05$ ), in the right side than in the left side in the controls.

The mean value of hip isometric adduction strength was 25% lower ( $p < 0.001$ ) in subjects with OA than in controls (Table 2). Similarly, hip isometric abduction strength was 31% lower ( $p < 0.001$ ) in OA subjects than in controls (Table 2). However, in OA subjects, when the radiographic scoring difference was  $\geq 1$  grade between the right and left hips, the adduction and abduction strength values did not differ from each other (Table 3). Neither did the adduction

Table 1. Reproducibility of hip adduction, abduction, flexion, and extension strength (Nm) measurements (mean ± SD) with a computerized strain gauge dynamometer (Digitest®) and a Lido® Active Isokinetic Rehabilitation System in healthy men (n = 14–17) and men with hip OA (n = 7–9).

Hip Function	Measurement		d <sup>1</sup>	p <sup>2</sup>	Correlation Coefficient <sup>3</sup>	ICC <sup>4</sup>	CV (%) <sup>5</sup>
	1st	2nd					
Isometric adduction							
Control	124 ± 32	129 ± 27	5	NS	0.902***	0.94	10.3
Hip OA	99 ± 34	102 ± 27	3	NS	0.750*	0.84	15.0
Isometric abduction							
Control	128 ± 27	126 ± 21	−2	NS	0.746**	0.84	8.7
Hip OA	95 ± 25	94 ± 31	1	NS	0.786*	0.90	13.9
Isometric flexion							
Control	142 ± 30	145 ± 31	3	NS	0.529*	0.71	14.1
Hip OA	133 ± 27	130 ± 29	−3	NS	0.926***	0.98	7.5
Isometric extension							
Control	130 ± 36	132 ± 39	2	NS	0.824***	0.90	11.6
Hip OA	108 ± 36	116 ± 35	8	NS	0.964***	0.98	11.6
Isokinetic flexion and extension							
Control							
Flexion peak torque 60°/s	129 ± 29	131 ± 24	2	NS	0.538*	0.70	15.2
Flexion peak torque 120°/s	118 ± 27	120 ± 20	2	NS	0.839***	0.89	8.4
Extension peak torque 60°/s	225 ± 57	225 ± 47	0	NS	0.707**	0.90	13.8
Extension peak torque 120°/s	191 ± 56	196 ± 35	5	NS	0.710**	0.84	24.0
Hip OA							
Flexion peak torque 60°/s	119 ± 17	129 ± 31	11	NS	0.893**	0.84	10.1
Flexion peak torque 120°/s	107 ± 19	123 ± 25	17	NS	0.883**	0.89	12.5
Extension peak torque 60°/s	178 ± 53	193 ± 51	16	NS	0.750*	0.87	15.3
Extension peak torque 120°/s	146 ± 51	182 ± 50	36	*	0.929**	0.86	20.3

<sup>1</sup> Difference (Nm) between 1st and 2nd measurement. <sup>2</sup> Statistical significance between 1st and 2nd measurement (paired t test or Wilcoxon matched pairs signed-ranks test). <sup>3</sup> Spearman or Pearson correlation coefficient between 1st and 2nd measurement; \* p < 0.05, \*\* p < 0.01, \*\*\* p < 0.001. <sup>4</sup> ICC between the 1st and 2nd measurement. <sup>5</sup> Coefficient of variation between 1st and 2nd measurement.

and abduction strength values differ between the diseased (radiographic scoring grade ≥ 1) and nondiseased (grade 0) side when compared in OA subjects (n = 12; data not shown). The differences between the groups and within the OA group were similar when the isometric hip adduction

and adduction measures were expressed as relative muscle torque values (Nm/kg) (data not shown).

The hip isometric and isokinetic flexion strength was 18–22% lower (p < 0.01) in OA subjects than in controls

Table 3. Differences in muscle strength (Nm) (mean ± SD) within the hip OA group.

Hip Functions	Better Hip	Worse Hip	Ratio (%) Between Sides (RSD ≥ 1) <sup>1</sup>
Isometric adduction	121 ± 23	115 ± 30	95
Isometric abduction	106 ± 21	106 ± 29	100
Flexion			
Isometric	105 ± 23	83 ± 25	79*
Isokinetic			
Peak torque			
60°/s	120 ± 23	103 ± 31	86*
120°/s	111 ± 27	92 ± 34	83*
Extension			
Isometric	85 ± 23	66 ± 21	78**
Isokinetic			
Peak torque			
60°/s	179 ± 47	155 ± 53	87*
120°/s	160 ± 45	137 ± 61	86*

<sup>1</sup> The ratio between the hip with higher OA grade and the hip with lower OA grade when the radiographic scoring difference (RSD) is ≥ 1 grade (n = 15–20). Radiographic grading was according to Li, *et al*<sup>40</sup>. \* p < 0.05, \*\* p < 0.01, paired t test or Wilcoxon matched-pairs signed-ranks test.

Table 2. Hip muscle adduction, abduction, flexion, and extension strength (Nm) (mean ± SD) in controls and men with hip OA.

Hip Functions	Controls	OA Group	Ratio (%) Between OA and Controls
Isometric adduction	157 ± 35	118 ± 29	75***
Isometric abduction	154 ± 35	106 ± 28	69***
Flexion			
Isometric	102 ± 21	84 ± 25	82**
Isokinetic			
Peak torque			
60°/s	130 ± 29	106 ± 31	82**
120°/s	121 ± 24	94 ± 34	78**
Extension			
Isometric	85 ± 29	71 ± 22	84
Isokinetic			
Peak torque			
60°/s	186 ± 40	161 ± 51	87
120°/s	165 ± 35	140 ± 58	85

\*\*p < 0.01, \*\*\*p < 0.001, Student t test or Mann-Whitney U test.

(Table 2). Hip isometric and isokinetic extension strength values did not differ between groups (Table 2). In OA subjects, hip flexion and extension isometric and isokinetic strength values were 13–22% lower ( $p < 0.05$  and  $p < 0.01$ ) in the more severely affected hip compared to the better hip (Table 3).

In the OA group, there were significant differences in the hip muscle isometric extension and abduction strength values between the radiographic OA subgroups ( $p < 0.05$ ; Kruskal-Wallis test), but not in other muscle strength measures (data not shown). Muscle strength did not correlate with the subjective severity of hip pain (by VAS) in the OA group (data not shown). However, there were significant negative correlations in the isokinetic flexion peak torque at 120°/s ( $r = -0.383$ ,  $p < 0.01$ ) and abduction ( $r = -0.302$ ,  $p < 0.05$ ) strength values with the subjective severity of the hip pain in the total study population. Other muscle strength measures did not correlate significantly with the subjective severity of hip pain in the total study population (data not shown).

*CSA of pelvic and thigh muscles and fat.* The CSA of muscles did not differ between the OA and control groups (Table 4). However, in OA subjects, the CSA of muscles in the pelvis and thigh was significantly lower (6–13%) in the more severely affected hip compared to the better hip (Table 5). The CSA of fat did not differ between the groups (Table 5).

Correlation coefficients between the CSA of pelvic and thigh muscles and the muscle strength measures are shown in Table 6. The isometric abduction and isokinetic flexion and extension strength were significantly correlated with the CSA of gluteal muscles (Table 6). The CSA of the gluteus maximus muscle was highly correlated with all muscle strength variables (Table 6). The CSA of the middle thigh and of the posterior compartment of the middle thigh were

significantly correlated with isokinetic peak torque (60°/s) values (Table 6).

## DISCUSSION

Patients with hip OA showed reduced isometric and isokinetic muscle strength in comparison with the healthy age matched controls. Muscle strength of the OA subjects was 68–87% of that in the controls. The CSA of the pelvic and thigh muscles did not differ between groups. To our knowledge, this is the first study to compare performance of the hip muscles with simultaneous muscle CSA measurements in patients with hip OA and age and sex matched controls.

In patients with knee OA, isometric and isokinetic measurements have demonstrated muscle strength deficits<sup>1,2,43–47</sup>. Quadriceps strength was reduced by about 15–45% compared to age and sex matched healthy controls<sup>1,44,47</sup>. In this respect our results are comparable to those in knee OA. Quadriceps weakness is more apparent than hamstring weakness<sup>47</sup>. On the other hand, the quadriceps and hamstring strength ratio appears not to change with knee OA<sup>48,49</sup>. In our study, the decrease of muscle strength was about equal in the agonist and antagonist muscles, even though the observed strength deficits were different in the abduction-adduction movements from those in flexion-extension movements. The decrease in abduction and adduction muscle strength was more distinct than the difference in flexion and extension strength when the men with hip OA were compared to controls.

An isometric test situation does not closely resemble the dynamic nature of joint movements. Neither the movement nor the loading patterns of isokinetic assessments bear close resemblance to human movements<sup>32</sup>. Even though the measurements have disadvantages, these are the main methods to investigate whether the static or dynamic prop-

Table 4. Cross sectional area (CSA, cm<sup>2</sup>) (mean ± SD) of pelvic and thigh muscles and fat in controls and men with hip OA.

Site of CSA Measurements and Muscle Compartments <sup>1</sup>	Controls	OA Group	Ratio (%) Between OA and Controls
Upper border of the acetabulum			
Gluteal muscles	112.8 ± 12.9	109.4 ± 12.1	97
Lower border of the acetabulum			
M. tensor fasciae latae	9.4 ± 2.0	8.9 ± 1.8	94
M. gluteus maximus	58.3 ± 10.3	56.3 ± 9.6	97
Upper thigh			
All muscles	179.1 ± 51.1	184.6 ± 28.1	103
Adductor compartment	51.4 ± 8.9	49.0 ± 6.4	95
Middle thigh			
All muscles	161.2 ± 32.9	159.2 ± 20.5	99
Anterior compartment	81.2 ± 17.3	80.7 ± 11.1	99
Posterior compartment	25.0 ± 3.5	24.7 ± 4.9	99
Fat compartment	50.6 ± 32.2	50.7 ± 22.2	100

<sup>1</sup> See Figure 1 and Materials and Methods for definition of sites of cross sections. There were no significant differences in muscle cross sectional areas between the groups (Student t test or Mann-Whitney U test).



Table 5. Cross sectional area (CSA, cm<sup>2</sup>) (mean ± SD) of pelvic and thigh muscles and fat within the hip OA group.

Site of CSA Measurements and Muscle Compartments <sup>1</sup>	Better Hip	Worse Hip	Ratio (%) Between Sides (RSD ≥ 1) <sup>2</sup>
Upper border of the acetabulum			
Gluteal muscles	115.7 ± 19.0	108.3 ± 12.3	94*
Lower border of the acetabulum			
M. tensor fascia latae	10.2 ± 2.7	8.9 ± 2.1	87*
M. gluteus maximus	61.9 ± 11.3	56.5 ± 9.9	91*
Upper thigh			
All muscles	198.9 ± 34.2	187.1 ± 32.2	94*
Adductor compartment	53.5 ± 7.6	48.9 ± 6.9	92***
Middle thigh			
All muscles	169.8 ± 28.2	158.5 ± 20.7	93*
Anterior compartment	88.1 ± 16.7	79.8 ± 10.8	91**
Posterior compartment	25.4 ± 6.5	24.8 ± 5.3	97
Fat compartment	50.2 ± 26.3	51.5 ± 25.8	103

<sup>1</sup> See Figure 1 and Materials and Methods for definition of sites of cross sections. <sup>2</sup> The ratio between the hip with higher OA grade and the hip with lower OA grade when the radiographic scoring difference (RSD) is ≥ 1 grade (n = 17–19). Radiographic grading was according to Li, *et al*<sup>40</sup>. \* p < 0.05, \*\* p < 0.01, \*\*\* p < 0.001, Student t test or Wilcoxon matched pairs signed ranks test.

Table 6. Correlation coefficients between cross sectional area (cm<sup>2</sup>) of the pelvic and thigh muscles<sup>1</sup> and muscle strength (Nm).

Hip Muscle Strength Measurements	Gluteal Muscles	M. gluteus maximus	M. tensor fascia latae	Upper Thigh		Middle Thigh		
				All Muscles	Adductor Muscles	All Muscles	Anterior Compartment	Posterior Compartment
Isometric								
Adduction	0.162	0.223	0.057	0.109	0.064	0.036	0.095	-0.034
Abduction	0.388**	0.423**	0.093	0.177	0.183	0.122	0.165	-0.035
Flexion								
Isometric	0.204	0.422**	0.047	0.129	0.100	0.078	0.066	-0.054
Isokinetic								
Peak torque								
60°/s	0.344*	0.396**	0.210	0.189	0.203	0.271*	0.215	0.287*
120°/s	0.352*	0.420**	0.070	0.159	0.156	0.231	0.101	0.094
Extension								
Isometric	0.277	0.384**	0.157	0.151	0.252	0.066	0.039	0.078
Isokinetic								
Peak torque								
60°/s	0.274*	0.393**	0.169	0.125	0.116	0.222	0.191	0.255
120°/s	0.262	0.404**	0.033	0.187	0.055	0.162	0.060	0.096

<sup>1</sup> See Figure 1 and Materials and Methods for definitions of the sites of cross sections. \* p < 0.05, \*\* p < 0.01, Pearson correlation.

erties of muscles are altered in OA. In knee OA, isokinetic strength was markedly reduced compared to isometric strength, and was a more important predictor of pain and pain disability than isometric strength<sup>7</sup>. Our study shows that both isometric and isokinetic muscle strength are equally reduced in patients with hip OA.

Quadriceps muscle weakness has generally been ascribed to disuse atrophy, which is presumed to develop because the patient minimizes use of the painful limb<sup>3,4,8</sup>. We found slightly, but significantly, lower CSA values for muscle when the more severely affected hip was compared to the

better hip in the OA group. We also noted significant reduction in the CSA of abductor and adductor muscles, i.e., the gluteal muscles and adductor longus, brevis, and magnus muscles, even though no simultaneous abductor and adductor muscle strength deficit was observed. We concluded that although the CSA of the gluteal muscles significantly correlates with the hip muscle strength, the reduction in muscle CSA of patients with hip OA is not a direct indicator of decreased hip muscle strength.

As well, qualitative changes in muscles may contribute to the loss of hip muscle strength. In hip OA, selected atrophy



of type II muscle fibers has been shown to be increased compared to controls<sup>50</sup>. This atrophy was independent of age. The atrophy was interpreted as a consequence of decreased muscle activity. It has been suggested that the relative increase in type I fibers may increase the stiffness of muscles and may render the joint more susceptible to OA by altering its shock-absorbing capacity<sup>3</sup>. However, quantitative documentation in support of this hypothesis is scarce.

Several other mechanisms may account for the loss of muscle strength in OA. Possible mechanisms involve motivational factors, pain, or fear of pain during muscle strength measurement<sup>3,4,8</sup>. It was supposed that pain in the more severely diseased hip may reduce daily activities and this can also lead to decreased muscle strength in the opposite hip. However, we found no significant differences in LTPA measures between groups. In knee OA, quadriceps strength seems to be strongly associated with knee pain, even when activation and psychological factors are taken into account<sup>8</sup>. In our study, there was significant negative correlation in the hip muscle isokinetic flexion peak torque at 120°/s and isometric abduction strength values with the severity of the hip pain in the total study population. On the other hand, the muscle strength values did not correlate with hip pain severity in the OA group, although the VAS scores for pain immediately prior to muscle strength testing were higher for the more severely affected hip compared to the better side. Thus, it is possible that hip muscle weakness may be present in patients who have OA, but the patients need not have hip pain or muscle atrophy; a similar finding was reported in knee OA<sup>47</sup>.

However, because the reduction in muscle CSA values was much less than in hip muscle strength values, it is possible that pain or fear of pain in strength measurements is also associated with muscle weakness as well as with reduced muscle mass as suggested earlier<sup>51</sup>. Thus, it is possible that a muscle strength test of the patients with hip pain also measures the pain threshold and ability to bear pain. It may have been appropriate to have a VAS post-testing to evaluate the influence of pain on muscle strength results. Unfortunately this was not done, which is a limitation of this study. The contribution of arthrogenic inhibition cannot be overlooked in hip OA, as reported in the community in subjects with knee OA<sup>8</sup>. To overcome the pain problem the actual muscle strength could be utilized via the technique of twitch superimposition<sup>52</sup>.

In the OA group, there were no significant differences in the subjective severity of hip pain prior to the muscle strength testing between the radiographic OA subgroups. As well, studies indicate that there is a discordance between the hip joint symptoms and radiographic findings, because the patients with severe radiographic changes can be asymptomatic<sup>53</sup>. Since joint pain is subjective and variable and because pain can derive from many joint structures, pain seems to be a nonspecific and subjective marker for OA<sup>53,54</sup>.

The loss of hip muscle strength seems to be a better marker than subjective pain for severe OA, because in our study the hip muscle isometric extension and abduction strength values were associated with radiographic changes in the OA group.

It has been suggested that Pearson correlation and ICC values are accepted as clinically meaningful if  $r \geq 0.70$  and  $ICC \geq 0.80$ , respectively<sup>55</sup>. Although most of the Pearson correlation and ICC values were acceptable, some were indicative of a moderate degree of reliability between the test and retest conditions. Thus, the low reliability in isometric and isokinetic hip flexion test conditions ( $ICC = 0.70-0.71$ ) in this study is a limitation. However, the mean strength values did not vary significantly between the 2 test occasions. The results are in agreement with those reported previously from healthy subjects<sup>17,19,20,22,56</sup>. Although no significant change occurred in muscle strength between the test and retest measurements, the CV were higher in isokinetic measurements using angular velocity 120°/s. Thus, variability of muscle strength test results is higher during dynamic movements than in the static supine position, as reported<sup>32</sup>. In this study, variability of the flexion and extension isokinetic measurements ranged from 8.4% to 24.0%, which is similar to that reported in the hip joint in patients with rheumatoid arthritis<sup>56</sup>. Even though the large CV somewhat limit the use of muscle strength measurements in the individual subject, the technique appears to be applicable when comparing groups. Small changes in muscle strength cannot be viewed with certainty as a real change in individual measurements, since it can be within the range of measuring error of the method. This must be taken into account when monitoring individual patients during an individual training program.

It is not possible to identify which of the confounding factors has the greatest influence on the CV. In particular, the CV for hip extension measurements appeared to be higher than for the other measurements. The pain could not account for variable results, because CV values were also similar in healthy controls. Isokinetic measurements are technically more difficult in the hip than in the knee. The high CV are due to the greater freedom of movement of the hip and thus there is the possibility that the subject performs a movement differently on separate occasions. The high CV of isokinetic measurements may have been due to insufficient familiarization with the measurement procedure prior to being tested. Also, inadequate stabilization of the trunk and the pelvis during the measurement can cause errors. The importance of fixation of trunk and pelvis has been emphasized by Jensen, *et al*<sup>14</sup>. In our study, the pelvis and upper trunk were fixed firmly against the table. However, it is possible that small alterations in rotation (internal and external) can occur.

We used the same order of muscle strength tests to ensure that we tested the reliability of paired measurements, and for

practical reasons. Using a constant testing pattern, there is a possibility that results may be influenced by an ordering effect. The possible fatigue of the musculature was supposed to be similar between opposed hips and between study groups, because right and left hips were tested alternately and the order of the tests was identical in both control and OA groups. We think that a time interval between each repetition and between each muscle test may provide an adequate recovery period. Also, the most demanding isokinetic test of the day was executed last.

We found a rather wide variability of hip muscle strength values among the healthy controls, as noted by others<sup>12,14,21,31</sup>. Murray, *et al* found the mean isometric adduction torque value was 153 Nm in healthy men<sup>31</sup>, quite similar to our results. Minns, *et al* reported mean torque of 77 Nm for abduction and 65 Nm for adduction<sup>25</sup>. The differences can be due to different testing positions and study design. There is one study where normal values for hip isometric muscle strength have been given. Andrews, *et al* obtained the values for hip isometric flexion and abduction force using a hand-held dynamometer with subjects in supine position<sup>57</sup>. The mean hip abduction force was between 240 and 294 N in men aged 50–79 years. Since the values were expressed in Newtons, direct comparison cannot be made with our results.

It has been suggested that a strong muscular system may prevent the initiation and progression of OA, because it has been shown that reduced quadriceps strength relative to body weight may be a risk factor for knee OA in women<sup>47,58</sup>. Thus, in the future assessment of muscle, strength may prove to be an important diagnostic indicator of OA. The cross sectional design of this study does not answer the question whether the muscle strength difference occurred before or after the development of hip OA. However, our results show that men with hip OA have significantly lower hip muscle strength than age and sex matched controls. Both the decrease of muscle size and pain may contribute to the decrease of muscle strength in hip OA. The underlying causes behind the muscle weakness in hip OA need further study.

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