

## Reduced muscle radiological density, cross-sectional area, and strength of major hip and knee muscles in 22 patients with hip osteoarthritis

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**Background** Patients with hip osteoarthritis (OA) typically suffer joint pain, and often experience muscular weakness. We hypothesized that substantial atrophy would manifest in multiple muscle groups along the affected limb, resulting in severe muscle dysfunction.

**Patients and methods** We assessed 22 elderly patients with unilateral OA for maximal voluntary isometric strength of hip and knee muscles using a dynamometer that was developed for the purpose. Cross-sectional area (CSA) and radiological density (RD; in Hounsfield units: HU) of hip and knee muscles were assessed using CT. We determined SF-36, HHS, and EQ-5D.

**Results** Hip extension, flexion, adduction, abduction, and knee extension strength were reduced (11–29%;  $p < 0.01$ ) in the OA limb relative to the healthy limb. Muscle CSA of hip extensors, flexors, adductors, knee extensors and flexors, but not hip abductors, was reduced (11–19%;  $p < 0.01$ ) in the OA limb, where RD of all muscle groups except hip flexors was reduced (5–15 HU;  $p < 0.01$ ). The clinical scores confirmed impairment.

**Interpretation** Major muscles functioning around the hip and knee showed substantial loss of strength and mass, which contributes to the reduced ambulatory capacity of OA patients. Reduced muscle CSA could not fully explain the loss in strength. Infiltration with fat or other non-contractile components, as indicated by a reduced RD, in OA limb muscles was substantial.

Minimally invasive surgery (MIS) is currently emerging as a means to preserve soft tissues and speed the recovery of functional capacity when performing total hip arthroplasty (THA) for osteoarthritis (OA) (Berger et al. 2004). There is very little detailed information available on pre-operative muscle morphology and function; however, this is required in order to evaluate the benefit of any operative technique or to design specific rehabilitation training programs. Substantial hip muscle weakness and atrophy has been reported in younger OA patients (Arokoski et al. 2002), but there have been no comparisons of the changes in muscular force and mass along the limb.

One objective of our study was therefore to measure a complete set of muscle actions around the hip and knee, in order to map out muscle function of both lower limbs. A second objective was to quantify the loss of contractile muscle mass in the major muscle groups responsible for hip and knee strength. Aged and inactivated muscles are known to have increased fat content (Goodpaster et al. 2001), and thus the conventional use of muscle volume or cross-sectional area (CSA) to quantify muscle mass might overestimate the actual amount of contractile muscle. We therefore employed CT to measure both CSA and radiological density (RD) of each muscle group.

## Methods

### General design

22 patients (67 (SD 7) years old, 168 (SD 6) cm, 80 (SD 16) kg; 18 women) with unilateral hip osteoarthritis planned for total hip replacement were recruited consecutively. Measurements were taken on the day before surgery. The subjects who were accepted had had no previous surgery of the lower extremity and individuals with neurological and advanced cardiopulmonary diseases or comorbidity of the lower extremity were excluded. Clinical scores (SF-36, Harris hip score, and EQ-5D) were collected from all patients. Medical history, duration of hip symptoms, and the use of medications for pain relief were noted. Patients were instructed to maintain their normal medication on all test occasions. The subjective severity of hip pain was rated using measurements on the VAS scale (range 0–10). The experimental protocol was approved by the Ethics Committee of the Karolinska Institute.

### Computed tomography

Muscle cross-sectional area (CSA) and radiological density (RD; in Hounsfield units: HU) were assessed in multiple hip and thigh muscle groups bilaterally using transaxial CT scans (General Electric Spiral scan; GE Medical Systems, London, UK) (130kV, 200 mAs, 1.5-sec scan time). Scans were obtained after 30–60 min of bed rest to minimize the influence of postural fluid shifts on muscle CSA (Berg et al. 1993). Radiation dose was minimized by limiting scan volumes via anatomical landmarks on scout images (Figure). Thus, two scans (10-mm slice thickness) of the thigh were obtained 20 cm proximal to the joint line of the right and left knee. One 30-mm slab was obtained just proximal to the caput femoris, in order to isolate comparable images (5-mm slice thickness) of the right and left hip muscles at the top of foramen ischiadicum. One slice (10 mm) through the central part of the third lumbar vertebra was obtained to visualize the psoas muscle group. Using dedicated software (Osiris 4.0; University Hospital of Geneva, Switzerland) for computerized planimetry, areas of interest (individual muscles or groups) were manually circumscribed and automatically computed. CSA and RD for

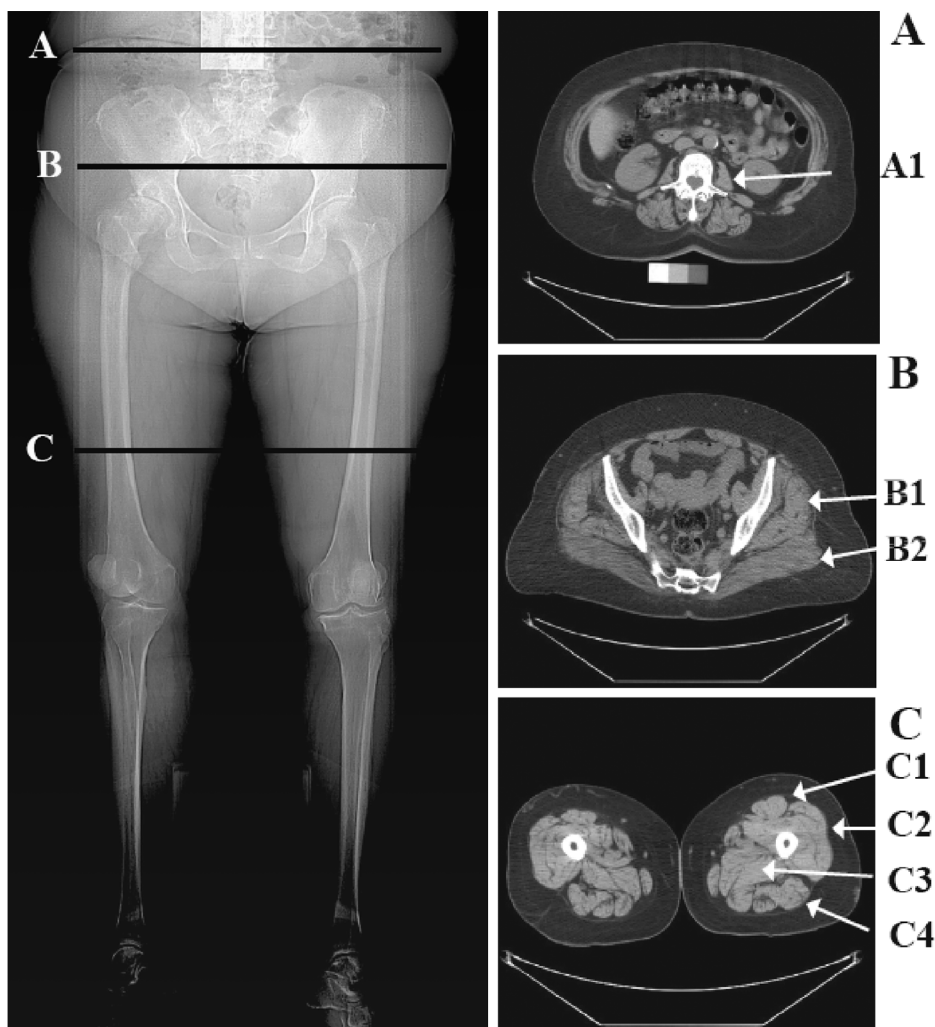
each individual muscle group were determined twice by 2 independent observers to calculate the intra- and interobserver reproducibility. The average of these measurements was used for comparison between healthy and OA limbs. The gluteal muscle group, as assessed from hip scans, comprises musculus gluteus maximus (primary extensor) and gluteus medius and minimus (abductors). Hip adductors were assessed from thigh scans, where m. adductor magnus dominates at this anatomical level. M. rectus femoris and m. psoas were used as the hip flexors. The knee extensor group comprises vastus lateralis, medialis, and intermedius. The hamstring group (m. biceps femoris brevis and longus, semimembranosus, and semitendinosus) was used as the knee flexors. RD of these muscles was averaged across each CSA.

### Assessment of muscle strength

The test apparatus and protocol for maximal voluntary isometric force measurements has been described in detail elsewhere (Rasch et al. 2005). Briefly, the subject is first seated with hip and knee positioned at right angles, and knee extension or flexion force is measured with a strain gauge. Hip forces are measured in the standing position with the upper body supported by an inclined abdominal pad and the contralateral limb partly weight bearing. The reproducibility of these measurements (i.e. coefficient of variation (CV%)) varied between 7% and 12% for a specific muscle group when tested unilaterally, where knee extension seems to show the lowest values. Variation between individual trial repetitions in one test session (3–6%) is generally lower than between sessions (7–12%).

### Statistics

Comparisons between arthritic limbs and healthy limbs were performed using paired t-tests. Absolute force divided by body weight (N/kg) was used to correct the differences related to subject size. Average knee force, hip force, or total limb force was determined by calculating the arithmetic means of individual measurements. Statistical significance was set at  $p < 0.05$ , or  $p < 0.01$  for repeated tests.



A scout image (left) indicates the anatomical level of the three transaxial CT scans (see Methods). In scans A–C, arrows indicate muscle groups on the healthy left side, which were compared to the smaller and less signal-intense muscles of the atrophied right OA hip side. The lumbar scan (A) shows the psoas muscle (A1; hip flexor). The transgluteal scan (B) shows mm. gluteus minimus et medius (B1; hip abductors) and m. gluteus maximus (B2; hip extensor). The mid-thigh scan (C) shows the m. rectus femoris (C1; hip flexor/knee extensor) and mm. vastii (C2; knee extensors), mm. adductor magnus et longus (C3; hip adductors), and the hamstring muscle compartment (C4; knee flexors).

## Results

Hip extension, flexion, abduction, adduction, and knee extension strength were reduced (11–29%;  $p < 0.01$ ) in the OA limb relative to the healthy limb (Table 1). Muscle CSA of hip extensors, flexors, adductors, and knee extensors and flexors, but not hip abductors, was reduced by 11–19% ( $p < 0.01$ ) in the OA limb, whereas RD of all muscle groups except hip flexors was reduced by 5–15 HU ( $p < 0.01$ ) relative to the healthy limb

(Table 2). Intraobserver reproducibility (CV%) for 2 separate CSA measurements varied between 0.4% and 4.1% and interobserver reproducibility varied between 1.4% and 6.2%. For RD measurements, intraobserver reproducibility was 0.3–2.0% and interobserver reproducibility was 0.9–2.1%. Mean duration of hip symptoms before surgery was 4.3 (SD 3) years and that of hip pain was 5.2 (SD 2.5) on the visual analog scale (VAS). The clinical scoring was similar to that in other studies: mean

**Table 1.** Mean values (SD), percentage differences, and p-values for maximal voluntary isometric muscle action in healthy limbs compared to hip osteoarthritic (OA) limbs in 22 patients with unilateral OA

Exercise	Healthy (N)	OA (N)	Difference (%)	P-value
Knee extension	394 (91)	286 (117)	-29	< 0.001
Knee flexion	152 (48)	142 (42)	-5	0.06
Knee total <sup>a</sup>	273 (61)	214 (69)	-22	< 0.001
Hip extension	264 (111)	213 (93)	-19	< 0.001
Hip flexion	271 (69)	198 (65)	-27	< 0.001
Abduction	157 (57)	137 (60)	-14	0.004
Adduction	247 (69)	215 (70)	-11	0.004
Hip total <sup>b</sup>	235 (65)	191 (63)	-19	< 0.001
Total <sup>c</sup>	247 (62)	198 (63)	-21	< 0.001

<sup>a</sup> values averaged for knee extension and flexion;  
<sup>b</sup> values averaged for hip extension, flexion, abduction, and adduction;  
<sup>c</sup> values averaged for all 6 knee and hip muscle actions.

**Table 2.** Mean values (SD), percentage differences, and p-values for cross-sectional area and radiological density in healthy compared to hip osteoarthritic (OA) limbs in 22 patients with unilateral OA

Muscle	Healthy	OA	Difference	P-value
<b>Cross-sectional area (mm<sup>2</sup>)</b>				
Gluteus maximus	3,699 (830)	3,218 (787)	-13%	< 0.001
Gluteus medius/minimus	4,613 (943)	4,546 (920)	-1%	0.2
Gluteus total <sup>a</sup>	8,698 (1647)	8,156 (1571)	-6%	< 0.001
Psoas	826 (191)	666 (180)	-19%	< 0.001
Rectus femoris	484 (119)	414 (101)	-13%	< 0.001
Vastii	4,509 (1045)	3,914 (1119)	-14%	< 0.001
Hamstring	2,707 (478)	2,402 (416)	-11%	< 0.001
Adductor	2,213 (643)	1,865 (620)	-16%	< 0.001
<b>Radiological density (HU) <sup>b</sup></b>				
Gluteus maximus	29 (12)	16 (17)	-13 HU	< 0.001
Gluteus medius/minimus	34 (11)	20 (14)	-15 HU	< 0.001
Gluteus total <sup>a</sup>	29 (11)	15 (15)	-14 HU	< 0.001
Psoas	37 (9)	35 (9)	-2 HU	0.1
Rectus femoris	53 (5)	52 (8)	-1 HU	0.4
Vastii	53 (6)	48 (8)	-5 HU	< 0.001
Hamstring	38 (8)	32 (10)	-6 HU	< 0.001
Adductor	43 (6)	36 (10)	-7 HU	< 0.001

<sup>a</sup> Gluteus maximus + medius/minimus;  
<sup>b</sup> HU, hounsfield units.

EQ-5D score was 0.45 (SD 0.25) and HHS was 51.6 (SD 9.2). Domains reported in SF-36 were physical function: 29 (SD 15); role physical: 9 (SD 23); body pain: 28 (SD 10); general health: 65 (SD 21); vitality: 47 (SD 20); social function: 63 (SD 24); role emotional: 36 (SD 44); and mental health: 69 (SD 18).

## Discussion

Our most important finding was the general deficit in muscular strength along the affected limb as compared to the contralateral (healthy) side in patients with unilateral hip OA, and that related muscles showed marked atrophy as evidenced by reduced CSA and an infiltration of non-contractile

components. This muscular dysfunction is likely to contribute to the reduced ambulatory capacity of OA patients, as loss of lower-limb muscle strength has been shown to predict the onset of ADL dependence in the elderly (Rantanen et al. 2002). These baseline data will help in our understanding of the mechanisms of muscular dysfunction in hip OA, and they can be used to evaluate the potential need for specific training programs or altered surgical technique. Self-scored function and quality of life was similar to that previously reported by OA patients (Ostendorf et al. 2004).

Maximal voluntary isometric strength was on average 21% lower in the OA limb than in the healthy limb. Based on previous findings in inactivated healthy subjects (Berg et al. 1991, 1997), the greatest loss of strength was expected in the weight-bearing extensor muscles. This appears to have been confirmed around the knee; extension strength was severely reduced while knee flexion strength was not reduced to any significant extent. In contrast, hip muscle strength was substantially compromised in all 4 test modalities (Table 1), confirming data from a small number of previous studies in younger patients with OA of the hip (Shih et al. 1994, Arokoski et al. 2002). Actually, there are currently no data available to support the idea that hip abductors or extensors (which are supposedly important for gait and weight bearing) are more compromised than other hip muscles in response to OA. There may be several mechanisms contributing to the reduced voluntary force output of the OA limb, including a reduced muscular mass, a diminished ability to recruit existing muscle, and possibly pain and apprehension on the test occasion.

Substantial muscle atrophy of the OA limb, compared to the healthy one, was found to accompany the loss of strength. Interestingly, the reduction in cross-sectional muscle area (CSA) was similar in all thigh compartments—including knee extensors and flexors and hip adductors, and in hip extensors (m. gluteus maximus) and flexors (m. psoas and rectus femoris; Table 2). Surprisingly, the primary hip abductors (m. gluteus medius et minimus) did not show any decrease in CSA. Arokoski et al. (2002) showed similar or somewhat smaller reductions in a younger group of hip OA patients, although they did not report on individual hip muscles.

In contrast to previous OA studies, our study adds the measurement of radiological density (in Hounsfield units; HU) for all muscle groups, and we found a marked decline in density in most muscles of the OA-affected limb (Table 2). Goodpaster et al. (2001) reported a low methodological error in such muscle density assessment. They concluded that the fat content of muscle could be readily assessed using CT, and that each per cent increase in tissue fat corresponded to a reduction in density of 0.75–1 HU. In the gluteal muscles, a reverse calculation would infer that fat content had increased by approximately 10%, indicating a similar relative loss of contractile muscle in the OA limb. Consequently, the total atrophic response of the gluteal muscles would be about two-fold compared to the estimation from the reduced CSA alone. The absence of a reduction in CSA in the hip abductors on the OA side was an unexpected finding, but it is interesting to note that the prominent reduction in RD indicates a substantial net loss in contractile muscle—and even larger in the hip extensors.

Studies using tomographic techniques (i.e. MRI, CT) to quantify muscle atrophy due to inactivity, trauma, or disease by CSA or volume only may lead to an underestimation of changes due to undetected alterations in extra- or intramuscular fat or other non-contractile components. Reduced muscle CSA could not fully explain the loss of strength, confirming what is typically shown after unloaded inactivity (Berg et al. 1991, 1997). After compensating for non-contractile components in hip extensor muscles using the decreased RD, however, there seems to be no obvious mismatch between weakness and atrophy in the OA limb. In knee extensors, however, the small increase in non-contractile components does not seem to compensate for the gap between the relative muscular atrophy and loss of strength. When gauging the relative decrements in these generally inactive patients, we should bear in mind that the contralateral healthy limb might also be weakened, and thus partly obscure some of the losses in the OA limb (Neander et al. 1999).

#### *Contributions of authors*

AR: performed all strength measurements, collected and analyzed CT materials, performed data- and statistical analyses, and prepared the manuscript. HEB: designed the study, assisted with some strength and CT measurements,

and prepared the manuscript. AHB: analyzed CT materials. ND: assisted in study design and manuscript revision.

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