Skeletal Radiology (2019) 48:421–428
https://doi.org/10.1007/s00256-018-3048-8

SCIENTIFIC ARTICLE

Anatomy-based MRI assessment of the iliopsoas muscle complex after pertrochanteric femoral fracture

Malwina Kaniewska[1,2] · Matthias Schenkel[3] · Karim Eid[3] · Tobias Bühler[3] · Rahel A. Kubik-Huch[1] · Suzanne E. Anderson[1,4]

Received: 17 December 2017 / Revised: 6 August 2018 / Accepted: 14 August 2018 / Published online: 3 September 2018

Abstract

Objective To evaluate the quality of the iliopsoas muscle complex after pertrochanteric femoral fracture, using MRI; to propose an anatomy-based evaluation of the iliopsoas muscle complex; and to determine the inter-reader reliability of two classifications of fatty muscle degeneration.

Materials and methods We included adult patients with a displaced lesser trochanter following pertrochanteric femoral fracture. Muscle quality was evaluated using the Goutallier and Slabaugh classifications at three levels (L4/L5, L5/S1, and the anterior inferior iliac spine). Two radiologists independently reviewed the MRIs, and force measurement was performed on both hips. Linear mixed-effects models were used to determine the effect of fracture on muscle quality and strength, and Cohen's kappa statistic was used to assess inter-reader agreement.

Results In the 18 patients included, the iliopsoas muscle complex showed higher grades of fatty muscle degeneration on the fractured side than on the non-fractured side. The mean difference between muscle strength on the fractured vs the non-fractured side was −12 N ($p > 0.05$). Inter-reader agreement for the Goutallier and Slabaugh classifications was good and very good respectively (weighted K = 0.78 and 0.85 respectively).

Conclusion Fatty muscle degeneration of the iliopsoas muscle complex after pertrochanteric femoral fracture was evident using both classification systems; however, fatty muscle degeneration resulted in only a minimal reduction of muscle strength. To provide a thorough assessment of iliopsoas muscle complex quality, we suggest evaluating it at different anatomical levels. Regarding inter-reader agreement, the Slabaugh classification was superior to the Goutallier classification.

Keywords Hip · Hip joint · Muscle strength · Femoral fractures · Skeletal muscle · Psoas muscle · Magnetic resonance imaging · Reproducibility

Introduction

Fatty muscle degeneration (FMD) was reported in 1994 by Goutallier et al. following their examination of the quality of rotator cuff muscles after rotator cuff tears [1, 2]. FMD is a well-known finding in older patients and may be accompanied by a loss of muscle mass and function, defined as sarcopenia [3]. FMD is thought to be caused by an accumulation of adipocytes within myofibres and may occur as a result of muscle inactivity [4–6].

Fatty muscle degeneration is a very common finding after complete tears in muscle–tendon units and is an essential prognostic factor for muscle quality and function associated with loss of muscle strength and poor postsurgical findings [7, 8]. In cases of pertrochanteric femoral fracture (PFF) with avulsion of the lesser trochanter, muscle quality and

Malwina Kaniewska and Matthias Schenkel have joint authorship; these authors contributed equally to the study

✉ Malwina Kaniewska
malw.kaniewska@gmail.com

1 Institute of Radiology, Kantonsspital Baden, Baden, Switzerland

2 Chefarztsekretariat Radiologie Bea Engeli, Kantonsspital Baden, Im Ergel 4, 5404 Baden, Switzerland

3 Centre for Orthopaedic Surgery, Kantonsspital Aarau und Baden, Baden, Switzerland

4 The University of Notre Dame Australia, Sydney School of Medicine, Sydney, Australia

strength are expected to deteriorate; however, it remains unclear whether FMD following surgical repair of PFFs is also a negative prognostic sign [9]. It must be noted that a dislocated lesser trochanter, where the distal tendon of the iliopsoas muscle complex (IMC) is attached, is not routinely repaired [10–12].

There are several non-invasive diagnostic tools with which to assess muscle quality and intramuscular fat deposits; magnetic resonance imaging (MRI) and computed tomography (CT) are considered the reference standard [13]. MRI provides excellent soft-tissue contrast and is a good reproducible method for assessing muscle quality [14, 15]. A role for ultrasound has been described in the evaluation of muscle quality; however, although ultrasound and MRI without intra-articular contrast medium administration are comparable regarding the detection of rotator cuff tears, ultrasound is inferior to MRI for assessing muscle quality [16–18].

The aim of this study was to evaluate the quality of the IMC, comprising the psoas, iliacus, and iliopsoas muscle and tendon, after PFF with displacement of the lesser trochanter, using MRI. Currently, there are no classification systems or validated methods with which to assess the quality of the IMC. We propose an anatomy-based approach to evaluate the IMC at three different levels (L4/L5, L5/S1, and the anterior inferior iliac spine). We used the Goutallier and Slabaugh classification systems to assess FMD and aimed to determine inter-reader reliability between two independent radiologists.

Materials and methods

Patients/population

The patient population in this study also participated in an associated orthopaedic study [19].

Patients with a diagnosis of surgically treated PFF were retrospectively and randomly identified in our clinical information system. The inclusion criteria were:

1. Age not younger than 18 years
2. Surgical treatment of the PFF more than 6 months previously
3. Dislocation of the lesser trochanter with proximal retraction of more than 2 cm on a conventional postoperative radiograph
4. Pain-free femur
5. Freely moveable contralateral hip, without fracture of interventions

If the inclusion criteria were fulfilled, the selected patients were contacted by telephone and subsequently, if they consented, were prospectively planned for the MRI and finally included in the study. The exclusion criteria were pregnancy and MRI contraindications.

Clinical examination and hip flexion measurement

Patients underwent a clinical examination of both hips by a boarded-specialist orthopaedic hip surgeon (co-author, MS). Measurements of the hip flexion force were performed in the upright position with the Baltimore Therapeutic Equipment (BTE) Primus device (Greenwood Village, CO, USA) [20]. The BTE Primus device enables measurement of static and dynamic muscle strength and shows a high reliability for such movement as hip flexion [21]. The hip flexion strength of both hips provided mostly by the iliopsoas muscle complex was measured in a standing position in 0° and 30° flexion. All measurements were performed by a designated trained physiotherapist and are shown in Newtons [N].

MR imaging protocol

Magnetic resonance imaging of the trunk and pelvis was performed using a 1.5-Tesla system (Avanto Fit and Aera; Siemens Medical Solutions, Erlangen, Germany). Examinations were performed in the supine position using the integrated body coils of the MRI device. In the coronal plane, T1-weighted turbo-spin echo and fast-spin echo short tau inversion recovery (STIR) sequences were used to obtain an overview of the body trunk. T1-weighted turbo spin-echo images in axial planes and STIR images, including the basal lungs through the pelvis, were also obtained. Six-mm slice thickness was used for all sequences. The entire protocol is shown in Table 1.

Commercially available software for the suppression of metal artefacts was used for the pelvic region of patients with metal implants following PFF. None of the patients received contrast agents.

Analysis of MR images

Two radiologists (SEA, a MSK radiologist with 30 years of experience, and MK, a radiology resident with 2 years of experience) independently evaluated the MRI of the muscles, without knowing which hip was surgically treated. Axial T1-weighted images, where it was not apparent which side had been fractured or operated on, were used to evaluate muscle quality. An assistant prepared the axial T1-weighted images for readout and presented them separately to the radiologists.

Both right- and left-sided muscles were reviewed, with the contralateral non-fractured side being used as a control. Both investigators were blinded to any clinical data, such as hip flexion measurements, patient name, and age, and to the fracture site. We prepared anatomical slices for review with no

Table 1 Magnetic resonance imaging parameters

	TR/TE (ms)	Section thickness (mm)	FOV (mm)	Matrix size	Number of acquisitions
STIR cor	3.560/31	6	420 × 341	195 × 320	2
T1wTSE cor	526/22	6	420 × 341	250 × 512	3
T1wTSE tra 2×	759/12	6	370 × 266	221 × 512	2
T1wTSE tra 2× WARP	759/9.5	6	370 × 266	221 × 512	2
STIR tra WARP	4.200/31	6	370 × 254	165 × 320	2

TR/TE repetition time/echo time, *FOV* field of view, *TSE* turbo spin echo, *STIR* short tau inversion recovery sequence, *T1w* T1-weighted, *2×* two blocks, *tra* transverse, *cor* coronal, *WARP* metal artefact reduction sequence developed by Siemens

evidence of implants or surgical artefacts. A dedicated PACS workstation was used to evaluate the MR data.

Evaluation of IMC was performed at the following three anatomical levels:

1. L4/L5, where the psoas major muscle was visible
2. L5/S1, where the psoas major and iliacus muscles were detected
3. Anterior–inferior iliac spine, when the conjoint iliopsoas muscle and tendon were detected (Fig. 1)

This approach was used because of the complex anatomy of the IMC to determine whether IMC degeneration involves the psoas major, iliacus, or both muscles, and whether degeneration is more severe proximally or distally.

Each reader performed two separate interpretations at different time points. The Goutallier classification was used in the first reading session, and the Slabaugh classification was used in the second session after a time interval of 2 weeks. All muscle quality measurements were performed using T1-weighted axial images.

Classification systems

Goutallier classification

The Goutallier classification system consists of five elements as follows: 0—normal muscle without fatty streaks; 1—some fatty streaks; 2—less than 50% FMD; 3—equal amounts of muscle and fat; and 4—greater than 50% FMD (Table 2) [1].

Slabaugh classification

The simplified classification system proposed by Slabaugh et al. to assess FMD has only three grades: 1—normal to mild, 2—moderate, 3—fat > muscle (Table 2) [22].

Additional abdominal findings

In cases of additional findings, a separate report was made, and the coordinator of the orthopaedic part of the study (one of the co-authors with 10 years of clinical experience in hip orthopaedic surgery) was informed.

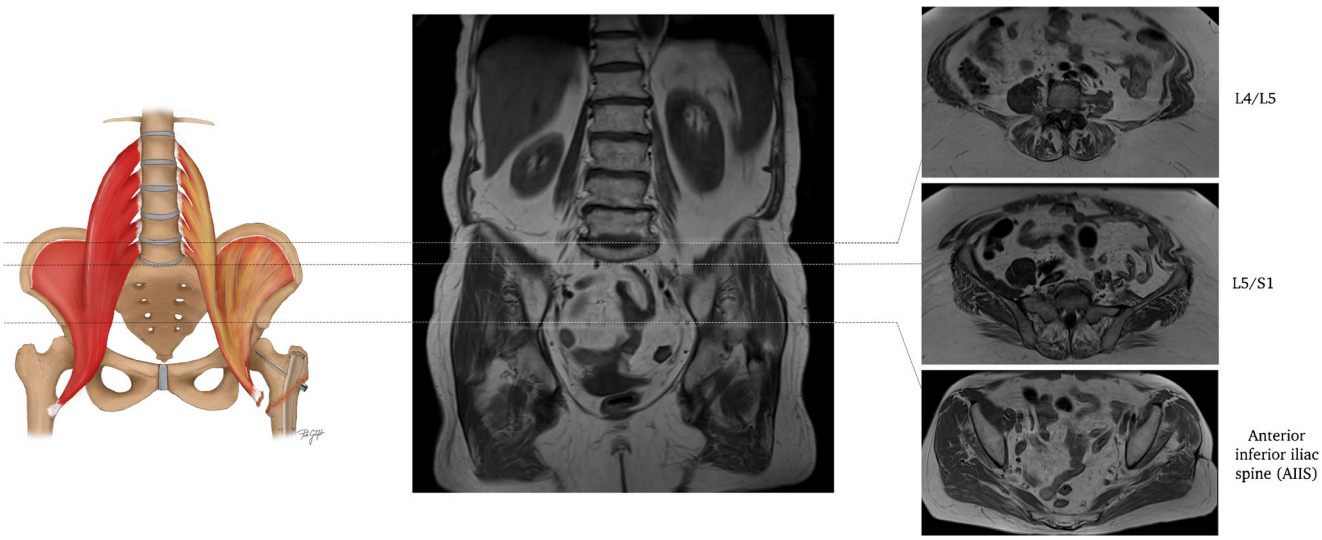

Fig. 1 An 82-year-old woman after pertrochanteric femoral fracture with displacement of the lesser trochanter on the left side. Schematic illustration of the iliopsoas muscle complex and coronal and axial T1-weighted images at three levels (L4/L5, L5/S1 and anterior inferior iliac spine). (Copyright Kantonsspital Baden, Switzerland)

Table 2 Goutallier and Slabaugh classification systems with descriptions for each grade

	Goutallier classification	Slabaugh classification
Grade 0	Normal muscle, without fat	
Grade 1	Some fatty streaks	Normal to mild fatty degeneration
Grade 2	Muscle > fat, less than 50% fatty muscle degeneration	Moderate fatty degeneration
Grade 3	Muscle = fat	Fat > muscle
Grade 4	Fat > muscle, more than 50% fatty muscle degeneration	

Statistical analysis

We used linear mixed effects models to compare muscle quality on the fractured and non-fractured sides. The dependent variable was the mean of the muscle quality; independent variables were fracture and landmark (anatomical levels).

The variables age and sex were also included in the linear mixed-effects models; therefore, results were adjusted for these variables, which eliminated possible confounding of the results by age and sex. Estimates are presented as differences of means for the fractured- and non-fractured sides with results expressed with 95% confidence intervals (CI) and *p*-values. Mean flexion strength on the fractured and non-fractured side in 0° and 30° hip flexion for both male and female patients was calculated. The mean difference between muscle strength on the fractured and non-fractured sides was additionally calculated. $p < 0.05$ was considered significant for all analyses.

Inter-reader agreement for evaluating muscle quality was measured using the weighted Cohen's kappa statistic. Observations of both readers (mean value) were included in the model for the statistical analysis of muscle quality. All statistical calculations were performed using the freely available statistical software R, version 3.3.2 [23].

Results

Eighteen patients were included in the study (12 women and 6 men; age range, 32–87 years; mean age, 71 years) after excluding three patients (one patient declined to have an MR examination, the other patient had a cardiac pacemaker, which precluded MRI and one patient declined to undergo muscle strength measurements). All patients had undergone surgery for PFF without fixation of the displaced lesser trochanter. The time interval between PFF and MRI ranged from 6 to 27 months.

There were equally as many fractures of the left and right hips ($n = 9$ for both). In one patient, an unexpected additional finding of a uterine mass was detected in the coronal T1-weighted and STIR sequences of the body trunk. None of the patients had a psoas minor muscle normal variant. STIR sequences were chosen to evaluate signal and structural alterations of the muscle and tendon, but these sequences provided no additional findings.

Correlation of muscle quality and muscle strength between the fractured and non-fractured sides

Box plots are shown in Fig. 2a and b. Grades 3 and 4 Goutallier and grade 3 Slabaugh classifications were assigned only on the fractured side (Table 3).

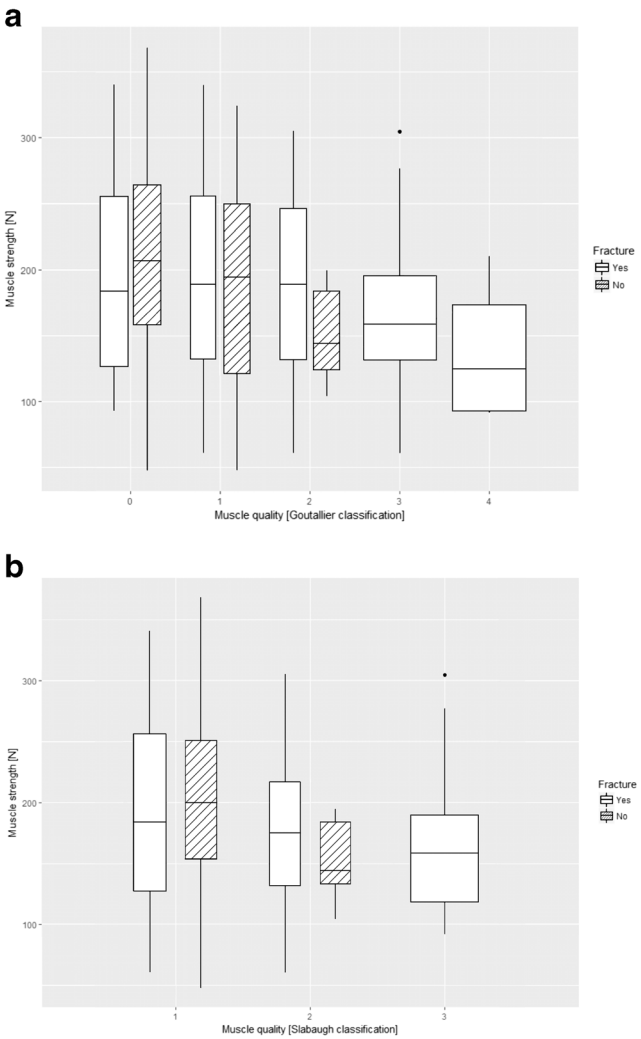

Fig. 2 Box plots depicting the correlation between muscle strength and muscle quality evaluated using **a** the Goutallier and **b** Slabaugh classification systems for the fractured and non-fractured sides in flexion at 0° and 30°. The mean difference between muscle strength on the fractured- and non-fractured sides was −12 N (−26.8–2.7 N, $p > 0.05$). The line in the middle of the boxes corresponds to the median, and the lower and upper borders of the boxes correspond to the first and third quartiles respectively

Table 3 Summary of the number of findings on the non-fractured and fractured sides with the related grade of fatty muscle degeneration according to both classification systems

Fracture	No (%)	Yes (%)
Goutallier		
0	110 (62.5)	29 (16.5)
1	61 (34.7)	53 (30.1)
2	5 (2.84)	39 (22.2)
3	0 (0.00)	33 (18.8)
4	0 (0.00)	22 (12.5)
Slabaugh		
1	172 (95.6)	76 (42.2)
2	6 (3.33)	66 (36.7)
3	2 (1.11)	38 (21.1)

Correlation of muscle strength between the fractured and non-fractured sides

There was only a minimal difference in muscle strength between the fractured and non-fractured sides; therefore, FMD did not correlate with muscle strength. The mean difference between muscle strength on the fractured and non-fractured sides was −12 N (95% CI: −27.8–2.7 N, $p > 0.05$). Male patients showed higher muscle strength values than female patients with a mean difference of approximately 84.2 N (95% CI: 20.2–148.2 N, $p > 0.05$). On the fractured side at 0° flexion mean muscle strength was 195.21 and 150.98 N in male and female patients respectively, whereas at 30° flexion it was 202.62 and 114.17 N respectively. Flexion strength on the non-fractured side was higher in both males and females (240.53 N and 167.40 at 0° flexion and 208.05 and 135.83 N at 30° flexion respectively).

IMC muscle quality on the fractured side at three different levels

In both classification systems, higher FMD grades were assigned to lower anatomical levels, with the highest grades at the level of the anterior inferior iliac spine (Fig. 3a and b, Table 4).

Inter-reader agreement

Inter-reader agreement was good for the Goutallier classification and very good for the Slabaugh classification (weighted $\kappa = 0.78$ [0.74–0.82] and 0.85 [0.81–0.89] respectively; Table 5).

Discussion

Our study describes an anatomy-based MR evaluation of the IMC with two different classification systems used to assess muscle quality. We also performed functional flexion testing of both hips, on the fractured and non-fractured sides.

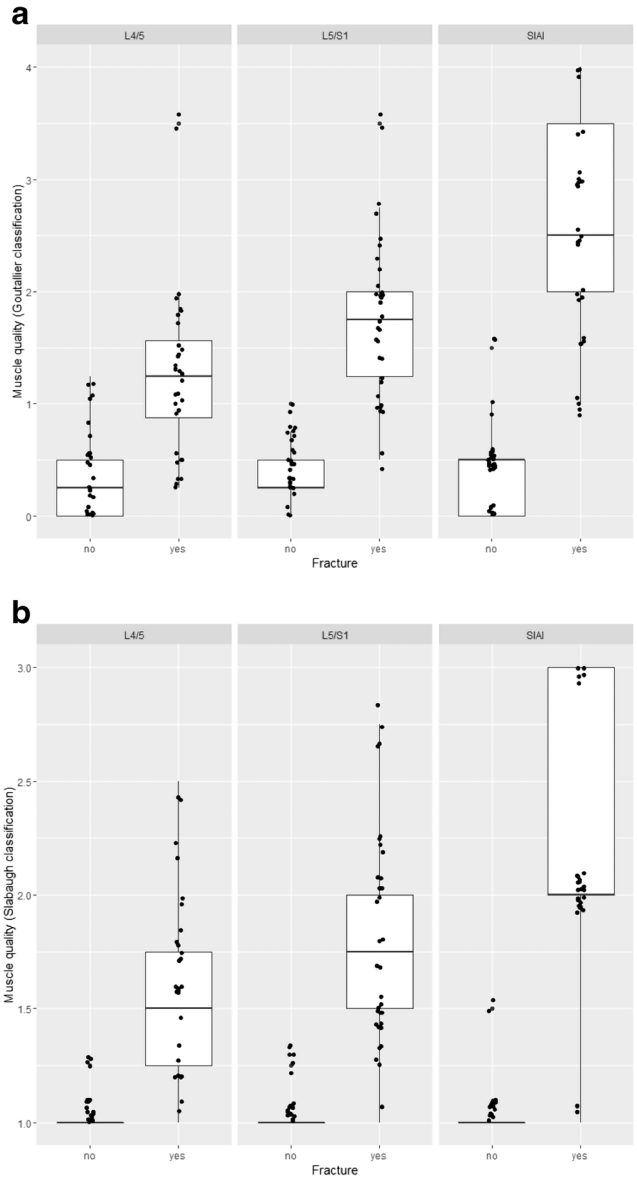

Fig. 3 Box plots depicting muscle quality at three different anatomical levels for **a** Goutallier and **b** Slabaugh classifications. The highest levels of fatty muscle degeneration (FMD) are observed at the level of the anterior inferior iliac spine. See also Table 4

Aprato et al. assessed muscle strength in patients with a consolidated intertrochanteric femoral fracture or PFF and found that lesser trochanter displacement correlates directly with flexion strength [9]; however, the results of our study do not confirm this. One of the reasons for this discrepancy may be the different methodologies used. In the study by Aprato et al., hip flexion was measured in three positions (neutral, 90°, and "figure four" position), whereas we assessed hip strength in 0° and 30° flexion. Normal walking requires hip flexion of approximately 30°, whereas hip flexion of 90° is required predominantly in sports activities. We chose two hip positions usually required for normal daily activity. Different evaluation methods of hip strength, such as the spring gauge

Table 4 Difference in grading of fatty muscle degeneration (FMD) on the non-fractured and fractured sides (overall for all anatomical levels and separately for L4/L5, L5/S1 and the anterior inferior iliac spine)

Fracture		Estimate	Lower	Upper	*p* value
Goutallier classification					
Overall					
No—yes		−1.404	−1.781	−1.027	< 0.0001
Anatomical levels					
No—yes	L4/L5	−0.9375	−1.172	−0.7032	< 0.0001
No—yes	L5/S1	−1.397	−1.624	−1.17	< 0.0001
No—yes	AIIS	−2.206	−2.433	−1.979	< 0.0001
Slabaugh classification					
Overall					
No—yes		−0.7588	−0.901	−0.6166	0.0001
Anatomical levels					
No—yes	L4/L5	−0.5156	−0.6669	−0.3644	0.0001
No—yes	L5/S1	−0.75	−0.8967	−0.6033	0.0001
No—yes	AIIS	−1.147	−1.294	−1	0.0001

We saw an overall difference in FMDf grading between the non-fractured and fractured sides of 1.4 and 0.75 in the Goutallier and Slabaugh classifications respectively, resulting in higher FMD grades on the fractured side ($p < 0.05$ for both). When evaluating FMD at our proposed anatomical levels, the highest difference in grading of the muscle quality was at the level of the anterior inferior iliac spine, resulting in higher FMD grades on the fractured side of 2.2 and 1.14 in the Goutallier and Slabaugh classifications respectively ($p < 0.05$ for both)

AIIS anterior inferior iliac spine

used by Aprato et al., versus the isokinetic physical strength analysis system, BTE Primus, used in our study, may have led to discordant results. There is an ongoing discussion on the most appropriate technique and approach to strength measurement. Patient populations in Aprato et al.'s study and ours were similar: our study included 18 patients, and theirs included 15 patients.

Hain et al. described atrophy of the iliacus and psoas muscles in patients after iliopsoas tenotomy performed for "snapping hip". This finding was regarded as an expected imaging appearance following iliopsoas tendon release [24]. Our results suggest that PFF with dislocation of the lesser trochanter leads to reduced quality and FMD of the IMC on the fractured side. However, FMD did not correlate with muscle strength, contrary to the results of Aprato et al. [9]. We believe that the muscle strength measurements in our study may have been influenced by several factors, including muscle plasty with a change in the muscle volume and structure, the compensation of other muscles at the time of measurements or variable time intervals after surgery, and hypertrophy of other muscles in the long term. All of these elements may have resulted in different outcomes from those of Aprato et al. [9].

The highest FMD grades were assigned to the fractured side, whereas lower grades were given to the non-fractured side. PFF with displacement of the lesser trochanter resulted in minimally lower muscle strength on the fractured- versus the non-fractured side, with a mean difference of −12 N. This difference appears clinically unnoticeable, as hip strength normally ranges from 200 to 300 N, depending on patient's age and sex.

Goutallier's classification was initially proposed for unenhanced CT examinations of the rotator cuff muscles and has been adapted for MRI over time [1]. Fuchs et al. suggested a modification of Goutallier's classification for use with MRI, wherein grades 3 and 4 from Goutallier's classification are combined, and T1-weighted turbo spin-echo sequences are used to evaluate muscle quality [25]. Based on clinical and statistical outcomes, Slabaugh et al. proposed combining grades 2 and 3 from the Goutallier classification and showed higher reliability compared with that of the original Goutallier classification [22]. The Warner classification can also be used to define the rotator cuff atrophy on preoperative MRI examinations; however, this classification shows only a moderate inter-observer agreement and therefore has not been selected for our study [26, 27].

We sought to define the optimal classification system for assessing IMC quality; therefore, we used both the Goutallier and Slabaugh classifications [1, 22]. Two independent readers evaluated the quality of the psoas, iliacus, and iliopsoas muscles. The Slabaugh classification showed slightly higher inter-reader agreement than the Goutallier classification (weighted K = 0.78 and 0.85 respectively), indicating that the three-element scale proposed by Slabaugh appears to be superior to the Goutallier classification. However, the Slabaugh classification is not as clear and does not provide the exact percentage of FMD involvement; therefore, it remains unclear which of these classifications may be more helpful. Also, only 18 patients were included in our study, resulting in only a slight difference in inter-reader agreement between the two classifications. To validate the superiority of the Slabaugh over the Goutallier

Table 5 Inter-reader agreement for both classification systems

	Lower	Estimate	Upper
Goutallier			
Weighted kappa	0.74	0.78	0.82
Slabaugh			
Weighted kappa	0.81	0.85	0.89

Results are correlation coefficients and confidence boundaries (95% confidence intervals)

classification, implementation of both classification systems should be considered in future studies with greater numbers of patients.

The IMC consists of the iliacus and psoas major muscles, in addition to the psoas minor muscle in some cases. The psoas major muscle has its proximal insertion at the transverse processes and vertebral margins of T12 to L5 and inserts distally on the lesser trochanter. The iliacus muscle extends from the iliac wing to the lesser trochanter. The iliopsoas muscle begins at the level of L5–S2 where the iliacus and psoas muscles merge and form a conjoint tendon [28–30]. The psoas minor muscle normal variant is absent in approximately 40% of patients and was not detected in any patients included in this study.

Because of the complex IMC anatomy, it appears necessary to evaluate its muscle quality at different levels. Hain et al. evaluated the quality of the IMC and tendon in patients after iliopsoas tenotomy as a treatment for "snapping hip". The assessment was performed above, at, and below the iliopectineal eminence [24]. We chose specific anatomical landmarks that would allow reproducible assessment and proposed assessment at the following levels:

1. L4/L5, where the psoas major muscle was visible
2. L5/S1, where the psoas major and iliacus muscles were evaluated
1. The anterior–inferior iliac spine, where the conjoined iliopsoas muscle and tendon were detected and assessed

There was a significant difference in FMD between the proposed anatomical levels, with the highest degrees of FMD at the level of the anterior–inferior iliac spine. This difference may be caused by the near location of the distal insertion of the IMC to the lesser trochanter and as a result of FMD beginning distally.

In this study, the entire IMC was evaluated as one muscle consisting of the psoas, iliacus, and iliopsoas. Muscle quality may be assessed separately for each muscle using a global fatty degeneration index, as proposed by Goutallier et al. [31]. This approach appears to be preferred in the orthopaedic literature. Because all muscles were affected by FMD, which resulted in higher grades in both classification systems, we evaluated the IMC as a complex muscle encompassing the psoas, iliacus, and iliopsoas, and did not use the global fatty degeneration index.

Certain essential considerations underlie our study. For example, although rotator cuff muscle quality would normally be assessed in sagittal MRI planes using the Goutallier classification, no specific landmarks or classification systems are considered a reference standard for evaluating the IMC.

A time-efficient MR protocol (approximately 20 min) was designed for this study and was used to evaluate FMD of the psoas, iliacus, and iliopsoas muscles. To shorten the examination protocol, the addition of Dixon techniques should be considered in future studies.

Our study has several limitations. First, this was a pilot study with only 18 patients. The examined patient group was relatively heterogeneous, with patient ages ranging from 32 to 87 years, and FMD pattern and its speed of development may differ between younger and older patients.

Second, muscle quality was evaluated in the MRI examinations only after PFF and not before PFF, comparing the fractured- with the non-fractured side as a control. It may be of value to assess the muscle before and after trauma; however, this assessment appears difficult with a prospective human study design.

Next, we evaluated only patients after PFF with displacement of the lesser trochanter in this study, and we compared the IMC on the fractured side with that on the contralateral side. There was no control group in which fixation of the lesser trochanter was performed. Currently, international standard surgical treatment for PFF does not include lesser trochanter fracture fragment fixation [10–12]. The addition of such a control group in future studies may be valuable.

Finally, MRI examinations were performed at heterogeneous time intervals after PFF, varying between 6 and 27 months. Consequently, different manifestations of FMD and related changes in muscle strength may be expected.

In conclusion, the FMD can be evaluated using T1-weighted axial plane MRI sequences and it is more conspicuous on the fractured side. The FMD is more prominent in the distal part of the iliopsoas muscle complex (at the level of the anterior–inferior iliac spine); however, this finding does not seem to have any impact on the clinical outcome of the subjects included in this pilot study of 18 patients. Regarding inter-reader agreement, the Slabaugh classification appears superior to the Goutallier classification; however, to validate this finding, implementation of both classification systems should be considered in future studies with greater numbers of patients.

Acknowledgements We would like to thank the statistician, Andreas Schötzau Dipl.-Math. (info@eudox.ch) and the medical illustrator, Dr Piotr Golofit (piotrgolofit@gmail.com) for their contributions to this study. We also thank Jane Charbonneau, DVM, from Edanz Group (www.edanzediting.com/ac) for editing a draft of this manuscript.

Funding This radiology research was partially funded by a Young Researchers Grant awarded by the European Society of Musculoskeletal Radiology (ESSR) during the ESSR Annual Meeting in Bari, Italy, June 2017. This project has been accepted for the European Congress of Radiology 2018 ("Anatomy-based MR classification of the iliopsoas muscle complex after pertrochanteric femur fracture", Control #: 1786, Session Date/Time: 3/1/2018 10:30:00 AM – 3/1/2018 12:00:00 PM).

Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflicts of interest.

Ethical approval This radiological study is part of a prospective orthopaedic study that was approved by the Ethical Review Committee (EKNZ BASEC 2016-00612) of our institution.

Informed consent Informed consent was obtained from all individual participants included in the study.

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