Skeletal Radiol (2015) 44:1727–1733
DOI 10.1007/s00256-015-2220-7

SCIENTIFIC ARTICLE

Prevalence and pattern of gluteus medius and minimus tendon pathology and muscle atrophy in older individuals using MRI

Andrew S. Chi[1] · Suzanne S. Long[2] · Adam C. Zoga[2] · Paul J. Read[2] · Diane M. Deely[2] · Laurence Parker[2] · William B. Morrison[2]

Received: 20 October 2014 / Revised: 7 June 2015 / Accepted: 20 July 2015 / Published online: 11 August 2015

Abstract
Purpose To evaluate gluteus medius and minimus tendon pathology and muscle atrophy in older individuals using MRI.
Methods A retrospective MRI study of 185 individuals was performed. The inclusion criterion was age≥50. Exclusion criteria were hip surgery, fracture, infection, tumor, or inadequate image quality. Greater trochanteric bursitis was graded none, mild, moderate, or severe. Gluteus medius, gluteus minimus, and iliopsoas tendinopathy was graded normal, tendinosis, low-grade partial tear, high-grade partial tear, or full thickness tear. Gluteus medius, gluteus minimus, tensor fascia lata, and iliopsoas muscle atrophy was scored using a standard scale. Insertion site of tendinopathy and location of muscle atrophy were assessed. Descriptive and statistical analysis was performed.
Results There was increasing greater trochanteric bursitis and gluteus medius and minimus tendinopathy and atrophy with advancing age with moderate to strong positive associations ($p<0.0001$) for age and tendinopathy, age and atrophy, bursitis and tendinopathy, and tendinopathy and atrophy for the gluteus medius and minimus. There is a weak positive association ($p<0.0001$) for age and tensor fascia lata atrophy, and no statistically significant association between age and tendinopathy or between age and atrophy for the iliopsoas. Fisher's exact tests were statistically significant ($p<0.0001$) for insertion site of tendon pathology and location of muscle atrophy for the gluteus medius.
Conclusions Gluteus medius and minimus tendon pathology and muscle atrophy increase with advancing age with progression of tendinosis to low-grade tendon tears to high-grade tendon tears. There is an associated progression in atrophy of these muscles, which may be important in fall-related hip fractures.

Keywords Gluteus medius · Gluteus minimus · Atrophy · Tendinopathy · Tendon tear · MRI

✉ Andrew S. Chi
Andrew.Chi@uphs.upenn.edu

Suzanne S. Long
Suzanne.Long@jefferson.edu

Adam C. Zoga
Adam.Zoga@jefferson.edu

Paul J. Read
Paul.Read@jefferson.edu

Diane M. Deely
Diane.Deely@jefferson.edu

Laurence Parker
Laurence.Parker@jefferson.edu

William B. Morrison
William.Morrison@jefferson.edu

[1] Department of Radiology, University of Pennsylvania, 3737 Market Street, Philadelphia, PA 19104, USA

[2] Department of Radiology, Thomas Jefferson University Hospital, 132 S. 10th Street, Philadelphia, PA 19107, USA

Introduction

The gluteus medius and minimus muscles have been referred to as the "rotator cuff of the hip" [1–4]. While pain over the greater trochanter has classically been associated with bursitis, gluteus medius and minimus tendinopathy may be a true underlying cause for greater trochanteric pain syndrome [5–12]. Rotator cuff tears of the shoulder have been described to show a progression of pathology from tendinosis to partial thickness tears to full thickness tears with subsequent muscle atrophy and secondary osteoarthritis [13–18]. Rotator cuff tears of the shoulder have been treated aggressively in the early stages in order to avoid muscle atrophy and mechanical instability

[19–23]. Similar to the shoulder, it has been anecdotally noted from our experience that degeneration and tendon tear precede atrophy of the gluteus medius and minimus muscles and that these muscles commonly have disproportionate atrophy compared to the other muscles surrounding the hip. However, unlike the rotator cuff of the shoulder, the gluteus medius and minimus tendons rarely tear completely with muscle retraction based on our anecdotal experience. Nonetheless, while rotator cuff pathology of the shoulder may interfere with daily activities, atrophy of the gluteus muscles contributes to gait disturbance and increases the risk of fall-related fractures [24–29]. While current treatment is primarily directed toward pain reduction, some surgeons have started to treat gluteus tendon tears aggressively with repair [30–34] with recent literature showing successful outcomes of repair [35].

We sought to investigate the prevalence of gluteus medius and minimus tendinopathy and muscle atrophy with age using MRI. We also sought to describe the pattern of involvement of the different insertion sites of the gluteus medius tendon and the distribution of fatty atrophy of both the gluteus medius and minimus muscles.

Materials and methods

Institutional review board approval was obtained prior to the performance of this study. A retrospective review of records and images without informed consent was performed in accordance with Health Insurance Portability and Accountability Act.

Study design and patient selection

We performed a database search of our institution for all pelvic MRI reports between January 2010 and December 2011. The inclusion criterion was age ≥50 years. Exclusion criteria included hip surgery, fracture, infection or tumor, or inadequate image quality. A non-interpreting researcher stratified the available patients by decade group and randomly selected the study group to meet requirements of power analysis. A group sample size of 20 was calculated to achieve 96 % power to detect a difference between group proportions of 0.60 with an alpha target of 0.05. Patient history and physical examination related to pain over the greater trochanter were not available.

MRI protocol

MR imaging of the pelvis was performed using the standard protocol on a 1.5-T scanner using a body coil. Large field of view (36–40 cm), coronal T1-weighted spin echo (TE 10–20, TR 400–800), coronal short tau inversion recovery (TE 20–40, TR >2000), axial T1-weighted spin echo (TE 10–20, TR 400–800), axial T2-weighted fast spin-echo fat-saturated (TE 30–40, TR 3000), and sagittal T2-weighted fast spin echo fat-saturated (12–16 cm FOV, TE 40–50, TR>2000) sequences were acquired. A routine bony pelvis MRI included the area from the anterosuperior iliac spine to the ischia including both hips. Images were obtained using a slice thickness of 4–5 mm with a 1-mm gap.

Evaluation of MRI examinations

Two musculoskeletal radiologists with 24 and 28 years of experience were blinded and reviewed the MR examinations in consensus on a PACS (picture archiving and communication system) workstation. Both hips were evaluated for each individual.

Greater trochanteric bursitis was graded as none, mild (slip of fluid), moderate (distended bursa with round margins), or severe (displacement of adjacent structures). Gluteus medius and gluteus minimus tendon pathology was graded as normal, tendinosis (intermediate signal, not fluid), low-grade partial thickness tear (<50 % tendon fluid signal), high-grade partial thickness tear (≥50 % tendon fluid signal), or full thickness tear (complete fluid signal). The gluteus medius and gluteus minimus were graded for fatty muscle atrophy using the classification system established by Goutallier et al. [36–38], which compares the amount of fat to the amount of muscle for rotator cuff muscle atrophy but has been applied elsewhere in the body [39]. Atrophy grading score 0 was assigned for normal muscle (no fat), score 1 for minimal atrophy (some fatty streaks), score 2 for mild atrophy (fat infiltration less than muscle), score 3 for moderate atrophy (fat infiltration equal to muscle), and score 4 for marked atrophy (fat infiltration greater than muscle). The site of insertion of tendon pathology and anterior or posterior location of muscle atrophy was also analyzed. The tensor fascia lata and iliopsoas were also scored in each patient as internal controls using the same tendon and muscle atrophy scales as above.

Descriptive and statistical analysis

Statistical analyses were performed by a statistician using SAS software. Subjects were stratified by age into decade groups. Given the number of patients, the last three decade groups were combined. Mean values and standard deviations for greater trochanteric bursitis and for tendon pathology and muscle atrophy for the gluteus medius, gluteus minimus, and iliopsoas were calculated. Spearman correlation coefficients were calculated for age and tendinopathy, age and atrophy, bursitis and tendinopathy, and tendinopathy and atrophy. Statistical significance was considered with Bonferroni correction for p-values <0.00625.

Percentages of tendinosis, low-grade partial tear, high-grade partial tear, and full thickness tear for the gluteus medius and minimus tendons were calculated. For the gluteus medius,

the percentage of involvement of the different insertions of the gluteus medius tendon was calculated. The percentages of anterior or posterior distribution of the gluteus medius and minimus muscles were also calculated. Fisher's exact tests were calculated between the insertion sites of the gluteus medius tendons and location of atrophy in the stratified age groups. Statistical significance was considered with Bonferroni correction for p-values <0.025.

Results

Our initial database search yielded 2697 MRI reports of the pelvis performed at our institution between January 2010 and December 2011. Exclusion criteria were met in 213 MRI reports (18 hip surgery, 77 hip prosthesis, 92 fracture, 1 infection, 5 tumor, or 16 inadequate image quality). Of the remaining 2484 MRI reports, a non-interpreting researcher randomly selected 185 subjects 50 years old or greater (102 males, 83 females; age range, 50.3–95.7 years; mean age, 65.7 years) to serve as the study population.

Mean values (± standard deviation) for greater trochanteric bursitis, gluteus tendon pathology, and gluteus muscle atrophy increased with advancing age (Table 1, Fig. 1). There was a statistically significant moderate to strong positive correlation between age and tendinopathy and age and muscle atrophy of the gluteus medius and minimus. There was a statistically significant weak positive correlation between age and muscle atrophy for the tensor fascia lata. There was no statistically significant correlation between age and tendinopathy or between age and muscle atrophy for the iliopsoas. There was a statistically significant positive correlation between bursitis and gluteus medius and minimus tendon pathology as well as a statistically significant positive correlation between gluteus medius and minimus tendinopathy and muscle atrophy (Table 2).

There was a progression of tendon pathology with higher percentages of low- and high-grade partial tears of the gluteus medius and minimus tendons with advancing age (Table 3). There are two insertion sites of the gluteus medius tendon on the superoposterior and lateral facet of the greater trochanter of the femur routinely identified by MRI [1]. There was greater isolated involvement of the superoposterior insertion of the gluteus medius tendon in the 50–59 year group with greater involvement of both the superoposterior and lateral facet insertions in subjects greater than 60 years old. There is a statistically significant association between the gluteus medius insertion sites and location of muscle atrophy (Table 4). The majority of cases shows no muscle atrophy if there was no insertion site involved (79.5 %), isolated superoposterior insertion involvement (61.8 %), or isolated lateral insertion involvement (68.4 %) of the gluteus medius. If both gluteus medius insertions were involved, both anterior and posterior muscle atrophy was seen in 46.9 % of cases. If the superoposterior facet insertion was involved in isolation, there was greater atrophy of the anterior muscle or both anterior and posterior muscle bulk. If the lateral facet insertion was involved in isolation, there was greater atrophy in the posterior muscle or both anterior and posterior muscle bulk.

There is one insertion site of the gluteus minimus tendon on the anterior facet of the greater trochanter routinely identified by MRI [1]. There was greater isolated atrophy of the anterior gluteus minimus in the 50–59- and 60–69-year groups and greater involvement of both the anterior and posterior gluteus minimus muscle in the 70–99-year group (Table 3).

Discussion

The progression of tendon pathology from tendinosis to tears and subsequent muscle atrophy has been demonstrated in several muscle groups, including the rotator cuff of the shoulder [13–18]. While the gluteus medius and minimus have been referred to as the "rotator cuff of the hip" [1–4], the pathoetiology and natural progression of tendon pathology and subsequent muscle atrophy in these muscles are less well understood. Some tendons are prone to complete tears while others degenerate with thickening and subsequent fraying, partial thickness tearing, and thinning with associated muscle atrophy and dysfunction [40]. As the gluteus medius and minimus muscles are known to play an important role in normal gait, dysfunction of these muscles may play a significant role in increased risk of falls and subsequent fractures [24–29]. Our study aims to characterize the prevalence of tendon pathology and muscle atrophy with advancing age as

Table 1 Mean values for bursitis, tendinopathy, and muscle atrophy

			Gluteus medius		Gluteus minimus		Iliopsoas		Tensor fascia lata
Age (years)	No.	GT bursitis	Tendon	Atrophy	Tendon	Atrophy	Tendon	Atrophy	Atrophy
50–59	63	0.12±0.37	0.48±0.73	0.30±0.86	0.38±0.63	0.37±0.77	0.06±0.41	0.13±0.33	1.14±0.60
60–69	64	0.45±0.69	0.81±0.86	0.64±0.96	0.78±0.87	0.88±1.00	0.31±0.52	0.50±0.80	1.25±0.64
70–99	58	0.83±0.87	1.45±0.95	1.34±1.02	1.23±0.78	2.01±1.19	0.36±0.65	0.48±0.84	1.67±0.78

Unless otherwise indicated, data are mean±standard deviation. GT, greater trochanteric

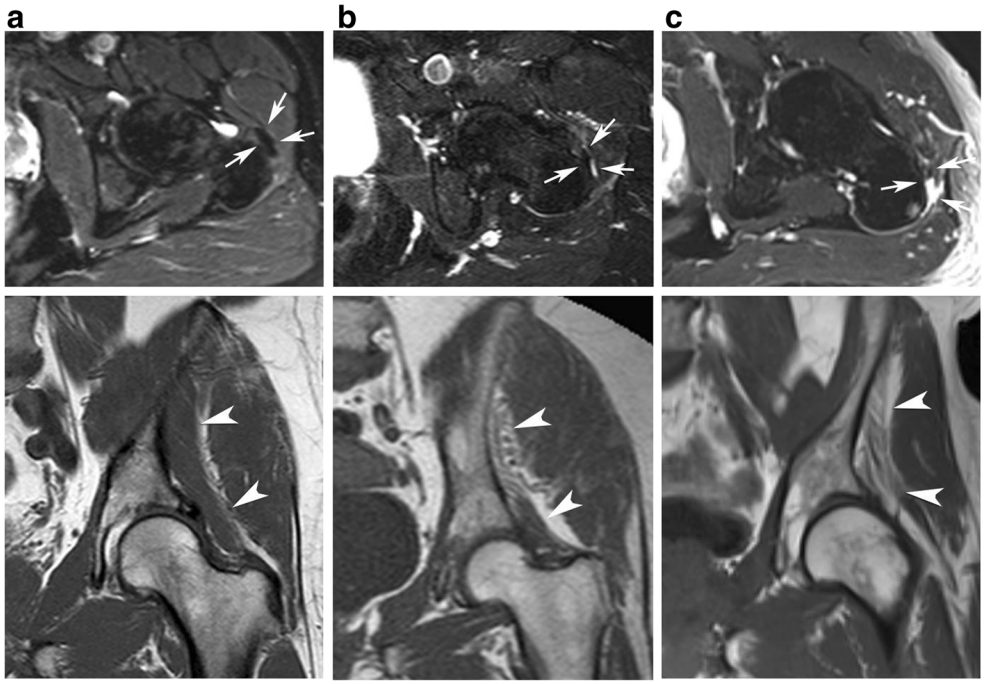

Fig. 1 **a** Axial T2-weighted fast spin echo fat-saturated MR image (top) obtained in a 59-year-old male shows gluteus minimus tendinosis (*white arrows*), and coronal T1-weighted spin echo image (bottom) shows no gluteus minimus muscle atrophy (*white arrowheads*). **b** Axial T2-weighted fast spin echo fat-saturated MR image (top) obtained in a 66-year-old female shows a low-grade partial gluteus minimus tendon tear (*white arrows*), and coronal T1-weighted spin echo image (bottom) shows grade 3 (fat=muscle) gluteus minimus muscle atrophy (*white arrowheads*). **c** Axial T2-weighted fast spin echo fat-saturated MR image (top) obtained in a 75-year-old male shows high-grade partial gluteus minimus tendon tear (*white arrows*) and coronal T1-weighted spin echo (bottom) shows grade 4 (fat > muscle) gluteus minimus muscle atrophy (*white arrowheads*)

well to investigate the distribution of the involvement of the tendon insertions and location of muscle atrophy.

Gluteus medius and minimus tendon pathology and muscle atrophy increase with age above 50 years. There appears to be progression of the gluteus medius and minimus pathology from tendinosis to tendon tears with advancing age with associated progression in muscle atrophy. There is a positive association between greater trochanteric bursitis and tendon pathology with advancing age, suggesting that tendon pathology may often be the true underlying cause of greater trochanteric pain syndrome. Of note, no full thickness tears of either the gluteus medius or minimus tendons were observed in our study, indicating that these tendons may undergo a gradual process of degeneration with repetitive injury and repair leading to dysfunction and atrophy rather than rupture. The tensor fascia lata was selected as an internal control for nerve-related atrophy given that the superior

Table 2 Quantitative analysis of age, tendinopathy, atrophy, and greater trochanteric bursitis

Muscle	Age and tendinopathy		Age and atrophy		GT bursitis and tendinopathy		Tendinopathy and atrophy	
	Spearman correlation coefficient	*p* value	Spearman correlation coefficient	*p* value	Spearman correlation coefficient	*p* value	Spearman correlation coefficient	*p* value
Left gluteus medius	0.37	<0.0001*	0.47	<0.0001*	0.40	<0.0001*	0.39	<0.0001*
Right gluteus medius	0.36	<0.0001*	0.49	<0.0001*	0.53	<0.0001*	0.32	<0.0001*
Left gluteus minimus	0.38	<0.0001*	0.56	<0.0001*	0.38	<0.0001*	0.50	<0.0001*
Right gluteus minimus	0.41	<0.0001*	0.50	<0.0001*	0.44	<0.0001*	0.46	<0.0001*
Left iliopsoas	0.22	0.0029	0.15	0.0394	–	–	–	–
Right iliopsoas	0.17	0.0184	0.15	0.0488	–	–	–	–
Left tensor fascia lata	–	–	0.36	<0.0001	–	–	–	–
Right tensor fascia lata	–	–	0.37	<0.0001	–	–	–	–

* The difference between the groups was significant with Bonferroni correction ($p<0.00625$)

Table 3 Percentages of gluteus medius and minimus tendon pathology, insertion site involvement, and atrophy location

	Age				Age		
Gluteus medius	50–59 years	60–69 years	70–99 years	Gluteus minimus	50–59 years	60–69 years	70–99 years
No. of tendons	126	128	116	No. of tendons	126	128	116
Tendinopathy	44 (34.9 %)	69 (53.9 %)	94 (81.0 %)	Tendinopathy	38 (30.2 %)	64 (50.0 %)	99 (85.3 %)
Tendinosis	30 (68.2 %)	37 (53.6 %)	36 (38.3 %)	Tendinosis	28 (73.7 %)	29 (45.3 %)	63 (63.6 %)
Low-grade partial tear	12 (27.3 %)	29 (42.0 %)	42 (44.7 %)	Low-grade partial tear	10 (26.3 %)	34 (53.1 %)	28 (28.3 %)
High-grade partial tear	2 (4.5 %)	3 (4.3 %)	16 (17.0 %)	High-grade partial tear	0 (0.0 %)	1 (1.6 %)	8 (8.1 %)
Full-thickness tear	0 (0 %)	0 (0 %)	0 (0 %)	Full-thickness tear	0 (0 %)	0 (0 %)	0 (0 %)
Insertion site involvement	44	69	94	Insertion site involvement	38	64	99
Superoposterior facet	29 (65.9 %)	18 (23.7 %)	8 (8.1 %)	Anterior facet	38 (100 %)	64 (100 %)	99 (100 %)
Lateral facet	6 (13.6 %)	3 (3.9 %)	10 (10.1 %)				
Both facets	9 (20.5 %)	55 (72.4 %)	81 (81.8 %)				
Muscle atrophy	18	54	93	Muscle atrophy	25	62	94
Anterior location	4 (22.2 %)	11 (20.4 %)	26 (28.0 %)	Anterior location	15 (60.0 %)	38 (61.3 %)	39 (41.5 %)
Posterior location	4 (22.2 %)	14 (25.9 %)	12 (12.9 %)	Posterior location	4 (16.0 %)	2 (3.2 %)	1 (1.1 %)
Both locations	10 (55.6 %)	29 (53.7 %)	55 (59.1 %)	Both locations	6 (24.0 %)	22 (35.5 %)	54 (57.4 %)

Unless otherwise indicated, data are no. (percentage)

gluteal nerve innervates the gluteus medius, gluteus minimus, and tensor fascia lata. The iliopsoas was selected as an internal control for generalized muscle atrophy as it rarely atrophies in isolation and is innervated by a separate nerve supply from the gluteus medius and minimus. Disproportionate tendon pathology and atrophy of the gluteus medius and minimus muscles about the hip suggest that atrophy of the gluteus medius and minimus is more strongly associated with tendon pathology than generalized atrophy or denervation/nerve impingement. Anatomic compression of the tendons as they drape over the greater trochanter may cause gradual wear of the tendons with age and explain the disproportionate atrophy of these muscles about the hip in addition to age-related changes related to generalized neuropathy, denervation, or nerve impingement.

Of the abductors, tendinopathy and atrophy of the gluteus medius may have more clinical significance in symptomatic patients [40]. In our study, isolated involvement of the superoposterior facet insertion of the gluteus medius was demonstrated in a higher proportion in younger patients with involvement of both insertions in the older patients, suggesting that the superoposterior insertion is the first to degenerate. For isolated involvement of the superoposterior facet insertion, there was greater atrophy in the anterior muscle bulk or in both anterior and posterior muscle bulk compared to isolated posterior muscle bulk atrophy. However, the majority of cases with isolated superoposterior or lateral facet tendon involvement demonstrated no muscle atrophy, suggesting that one tendon attachment may be sufficient to prevent atrophy of the overall muscle bulk. Degeneration of the both insertion sites demonstrated both anterior and posterior muscle atrophy in the highest proportion of cases. For the gluteus minimus, atrophy of the posterior portion of the gluteus minimus may have more clinical significance in symptomatic patients [41]. In our study, the atrophy of the anterior portion of the gluteus minimus muscle was more frequent in patients less than 70 years old with greater involvement of both the anterior and posterior minimus in patients greater than

Table 4 Gluteus medius insertion involvement and muscle atrophy location

Tendon insertion involvement	Muscle atrophy location				
	None	Anterior	Posterior	Both anterior and posterior	Total
None	120 (79.5 %)	11 (7.3 %)	6 (4.0 %)	14 (9.2 %)	151
Superoposterior facet	34 (61.8 %)	10 (18.2 %)	1 (1.8 %)	10 (18.2 %)	55
Lateral Facet	13 (68.4 %)	2 (10.5 %)	2 (10.5 %)	2 (10.5 %)	19
Both facets	38 (26.2 %)	18 (12.4 %)	21 (14.5 %)	68 (46.9 %)	145

Unless otherwise indicated, data are no. (percentage). Fisher's exact tests for gluteus medius insertion site and muscle atrophy location were $p<0.0001$ for both the right and left sides

70 years old. The etiology of the distribution of gluteus minimus atrophy is unclear as only one insertion of the gluteus minimus is visible by MRI.

There are certain limitations to our study methodology. Our study was a retrospective review of gluteus tendon pathology and muscle atrophy, limiting our ability to demonstrate direct causality between tendon tears and muscle atrophy. An attempt was made to perform a subgroup analysis in patients with multiple studies over time to evaluate the progression of tendinopathy and atrophy in individuals over time; however, there was not an adequate number of patients with repeat studies in the timeframe of our approved IRB to provide useful analysis. Our study was also limited by the number of patients in the older groups above age 70 years. No correlation could be made with the grading of tendon and muscle pathology to histological or pathological specimens as these data were not available. Interobserver variability in the assessment of tendon pathology and muscle atrophy was not included in our study; previous literature has demonstrated the reliability of the Goutallier staging system by MRI [37–39]. Lastly, MR imaging in this study did not include 3.0-T systems as this was not a routine protocol at our institution.

Conclusion

In conclusion, gluteus medius and minimus tendon pathology appears to progress from tendinosis to low-grade partial tears to high-grade partial tears with corresponding progression in muscle atrophy with advancing age. Given the important function of the gluteus medius and minimus in normal gait and the association of muscle atrophy with fall-related hip fractures, more aggressive therapy of tendon tears to prevent atrophy and subsequent falls could be beneficial.

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Pfirrmann CW, Chung CB, Theumann NH, et al. Greater trochanter of the hip: attachment of the abductor mechanism and a complex of three bursae—MR imaging and MR bursography in cadavers and MR imaging in asymptomatic volunteers. Radiology. 2001;221(2):469–77.
2. Bunker TD, Esler CN, Leach WJ. Rotator-cuff tear of the hip. J Bone Joint Surg (Br). 1997;79(4):618–20.
3. Kagan II A. Rotator-cuff tear of the hip. J Bone Joint Surg (Br). 1998;80(1):182–3.
4. Kagan II A. Rotator cuff tears of the hip. Clin Orthop. 1999;368:135–40.
5. Cvitanic O, Henzie G, Skezas N, et al. MRI diagnosis of tears of the hip abductor tendons (gluteus medius and gluteus minimus). AJR Am J Roentgenol. 2004;182(1):137–43.
6. Dwek J, Pfirrman C, Stanley A, Pathria M, Chung CB. MR imaging of the Hip abductors: normal anatomy and commonly encountered pathology at the greater trochanter. Magn Reson Imaging Clin N Am. 2005;13(4):691–704.
7. Kingzett-Taylor A, Tirman PF, Feller J, et al. Tendinosis and tears of gluteus medius and minimus muscles as a cause of hip pain: MR imaging findings. AJR Am J Roentgenol. 1999;173(4):1123–6.
8. Lonner JH, Van Kleunen JP. Spontaneous rupture of the gluteus medius and minimus tendons. Am J Orthop. 2002;31(10):579–81.
9. Chung CB, Robertson JE, Cho GJ, Vaughan LM, Copp SN, Resnick D. Gluteus medius tendon tears and avulsive injuries in elderly women: imaging findings in six patients. AJR Am J Roentgenol. 1999;173(2):351–3.
10. LaBan MM, Weir SK, Taylor RS. 'Bald trochanter' spontaneous rupture of the conjoined tendons of the gluteus medius and minimus presenting as a trochanteric bursitis. Am J Phys Med Rehabil. 2004;83(10):806–9.
11. Howell GE, Biggs RE, Bourne RB. Prevalence of abductor mechanism tears of the hips in patients with osteoarthritis. J Arthroplasty. 2001;16(1):121–3.
12. Long SS, Surrey DE, Nazarian LN. Sonography of greater trochanteric pain syndrome and the rarity of primary bursitis. AJR Am J Roentgenol. 2013;201(5):1083–6.
13. Nakagaki K, Ozaki J, Tomita Y, Tamai S. Fatty degeneration in the supraspinatus muscle after rotator cuff tear. J Shoulder Elb Surg. 1996;5:194–200.
14. Thomazeau H, Rolland Y, Lucas C, Duval JM, Langlais F. Atrophy of the supraspinatus belly: assessment by MRI in 55 patients with rotator cuff pathology. Acta Orthop Scand. 1996;67:264–8.
15. Farley TE, Neumann CH, Steinbach LS, Jahnke AJ, Petersen SS. Full-thickness tears of the rotator cuff of the shoulder: diagnosis with MR imaging. AJR Am J Roentgenol. 1992;158:347–51.
16. Moosmayer S, Tariq R, Stiris M, Smith HJ. The natural history of asymptomatic rotator cuff tears: a three-year follow-up of fifty cases. J Bone Joint Surg Am. 2013;95(14):1249–55.
17. Tashjian RZ. Epidemiology, natural history, and indications for treatment of rotator cuff tears. Clin Sports Med. 2012;31(4):589–604.
18. Tempelhof S, Rupp S, Seil R. Age-related prevalence of rotator cuff tears in asymptomatic shoulders. J Shoulder Elb Surg. 1999;8(4):296–9.
19. Mellado JM, Calmet J, Olona M, et al. Surgically repaired massive rotator cuff tears: MRI of tendon integrity, muscle fatty degeneration, and muscle atrophy correlated with intraoperative and clinical findings. AJR Am J Roentgenol. 2005;184(5):1456–63.
20. Bigliani LU, Cordasco FA, McIlveen SJ, Musso ES. Operative repair of massive rotator cuff tears: long-term results. J Shoulder Elb Surg. 1992;1:120–30.
21. Rokito AS, Cuomo F, Gallagher MA, Zuckerman JD. Long-term functional outcome of repair of large and massive chronic tears of the rotator cuff. J Bone Joint Surg Am. 1999;81:991–7.
22. Harryman DT, Mack LA, Wang KY, Jackins SE, Richardson ML, Matsen FA. Repairs of the rotator cuff: correlation of functional results with integrity of the cuff. J Bone Joint Surg Am. 1991;73:982–9.
23. Goutallier D, Postel JM, Gleyze P, Leguilloux P, Van Driessche S. Influence of cuff muscle fatty degeneration on anatomic and functional outcomes after simple suture of full-thickness tears. J Shoulder Elb Surg. 2003;12(6):550–4.
24. Beck M, Sledge JB, Gautier E, et al. The anatomy and function of the gluteus minimus muscle. J Bone Joint Surg (Br). 2000;82(3):358–63.
25. Anderson FC, Pandy MG. Individual muscle contributions to support in normal walking. Gait Posture. 2003;17(2):159–69.
26. Maquet PGJ. Biomechanics of the Hip. Berlin: Springer; 1985.

27. Gottschalk F, Kourosh S, Leveau B. The functional anatomy of tensor fasciae latae and gluteus medius and minimus. J Anat. 1989;166:179–89.
28. Lang T, Koyama A, Li C, et al. Pelvic body composition measurements by quantitative computed tomography: association with recent hip fracture. Bone. 2008;42(4):798–805.
29. Lang T, Cauley JA, Tylavsky F, Bauer D, Cummings S, Harris TB. Computed tomographic measurements of thigh muscle cross-sectional area and attenuation coefficient predict hip fracture: the health, aging, and body composition study. J Bone Miner Res. 2010;25:513–9.
30. Domb BG, Botser I, Giordano BD. Outcomes of endoscopic gluteus medius repair with minimum 2-year follow-up. Am J Sports Med. 2013;41(5):988–97.
31. Domb BG, Nasser RM, Botser IB. Partial-thickness tears of the gluteus medius: rationale and technique for trans-tendinous endoscopic repair. Arthroscopy. 2010;26(12):1697–705.
32. Yanke AB, Hart MA, McCormick F, Nho SJ. Endoscopic repair of a gluteus medius tear at the musculotendinous junction. Arthrosc Tech. 2013;2(2):e69–72.
33. Fisher DA, Almand JD, Watts MR. Operative repair of bilateral spontaneous gluteus medius and minimus tendon ruptures. A case report. J Bone Joint Surg Am. 2007;89(5):1103–7.
34. Voos JE, Shindle MK, Pruett A, Asnis PD, Kelly BT. Endoscopic repair of gluteus medius tendon tears of the hip. Am J Sports Med. 2009;37(4):743–7.
35. Makridis KG, Lequesne M, Bard H, Djian P. Clinical and MRI results in 67 patients operated for gluteus medius and minimus tendon tears with a median follow-up of 4.6 years. Orthop Traumatol Surg Res. 2014;100(8):849–53.
36. Goutallier D, Postel JM, Bernageau J, Lavau L, Voisin MC. Fatty muscle degeneration in cuff ruptures. Pre- and postoperative evaluation by CT scan. Clin Orthop. 1994;304:78–83.
37. Fuchs B, Weishaupt D, Zanetti M, Hodler J, Gerber C. Fatty degeneration of the muscles of the rotator cuff: assessment by computed tomography versus magnetic resonance imaging. J Shoulder Elb Surg. 1999;8:599–605.
38. Mitsiopoulos N, Baumgartner RN, Heymsfield SB, Lyons W, Gallagher D, Ross R. Cadaver validation of skeletal muscle measurement by magnetic resonance imaging and computerized tomography. J Appl Physiol. 1998;85:115–22.
39. Engelken F, Wassilew GI, Köhlitz T, et al. Assessment of fatty degeneration of the gluteal muscles in patients with THA using MRI: reliability and accuracy of the goutallier and quartile classification systems. J Arthroplasty. 2014;29(1):149–53.
40. Khan KM, Cook JL, Bonar F, Harcourt P, Astrom M. Histopathology of common tendinopathies. Update and implications for clinical management. Sports Med. 1999;27(6):393–408.
41. Pfirrmann CW, Notzli HP, Dora C, Hodler J, Zanetti M. Abductor tendons and muscles assessed at MR imaging after total hip arthroplasty in asymptomatic and symptomatic patients. Radiology. 2005;235(3):969–76.