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Article

"Rotator Cuff" Tears of the Hip: Tear Characteristics and Concomitant Vastus Lateralis Pathology

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Abstract: Introduction. The progression patterns of hip abductor tendon tears and their association with lateral thigh pathology are poorly described. The purpose of this study was to evaluate the distribution and progression patterns of abductor tendon tears on MRI, comparing small and large tears, and to assess the prevalence of concomitant vastus lateralis pathology. Methods. Hip MRI studies obtained over a 12-month period were independently reviewed by two fellowship-trained musculoskeletal radiologists. Tear location and thickness of the gluteus medius and minimus tendons, as well as vastus lateralis origin pathology, were assessed. Results. Tears most frequently involved the posterior gluteus minimus (100%) and anterior gluteus medius (100%), while the gluteus medius posterosuperior facet was least commonly involved (19%). Interobserver agreement was moderate for full-thickness tears ($\kappa = 0.60$) and substantial for vastus lateralis pathology ($\kappa = 0.70$). Full-thickness tears were significantly more likely in the presence of gluteus medius posterosuperior involvement ($p < 0.001$). Vastus lateralis pathology was also significantly associated with abductor tendon tears ($p < 0.001$). Conclusion. This study identifies consistent patterns of abductor tendon involvement on MRI, with tears most commonly affecting the gluteus minimus posteriorly and the gluteus medius anteriorly, and larger or full-thickness tears more frequently involving the posterosuperior gluteus medius. These findings suggest a possible central-to-posterior pattern of abductor tendon tear involvement that may reflect a progression pathway; however, given the cross-sectional design, a definitive temporal sequence cannot be established. The observed associations should therefore be interpreted as hypothesis-generating, and prospective longitudinal studies are needed to confirm the natural history of abductor tendon tear progression and its clinical implications.

Keywords: vastus lateralis; MRI; hip abductors

1. Introduction

Trochanteric or lateral hip pain is a common clinical presentation resulting in MR imaging [1]. Abductor tendon tears are a well described etiology, especially when the lateral pain is correlated with concomitant abductor weakness. Classically, abductor tears have been described as "rotator cuff tears of the hip" and as such have been treated with surgical repair when full thickness tears are identified [1–5]. There are now both open abductor and endoscopic abductor repair options which have demonstrated significant pain relief as well as improved clinical

strength and function, therefore radiologists should be familiar with imaging of the abductor tendons and common tear patterns [1,6–8].

The progression that ensues in abductor tendon tear pathology has not formally been researched, but anecdotally seems to progress from anterior to posterior, similar in mechanism to Neer et al.'s description of rotator cuff tear progression in the shoulder [5,9]. Specifically, a progression from undersurface partial thickness or interstitial tears to complete tears that then propagate posteriorly has been hypothesized [10,11]. While isolated gluteus medius tears outnumber isolated minimus tears, the exact location of initial partial tearing appears to be variable and no studies have formally investigated this subject matter [11,12].

In patients with abductor tears, concomitant lateral thigh pain distal to the hip joint is a common clinical presentation. The orthopedic surgical literature has highlighted the intricate connections of the hip abductors and vastus lateralis musculature along both their insertions onto the greater trochanter and vastus tubercle [13,14]. These connections between the abductors and vastus lateralis are clinically utilized by hip preservation surgeons to aid in stability for trochanteric osteotomies secondary to its anatomic consistency which assists with compression of the fragment [14]. Hip abductor insufficiency is also a recognized sequela following total hip arthroplasty, associated with persistent lateral hip pain, gait abnormalities, and postoperative dissatisfaction, and can be reliably evaluated using MRI [15].

The purpose of this study was to examine the rates and patterns of abductor tendon tears on MRI images to differentiate between patters associated with small tears in comparison to large tears, and secondarily to examine the rates of concomitant vastus lateralis pathology in MRIs demonstrating abductor tendon tearing, We hypothesized that concomitant vastus lateralis (VL) pathology would be present and that tears of the VL would occur after gluteus minimus posterior and gluteus medius anterior tears.

2. Material and Methods

Institutional IRB review was obtained and the project determined to be exempt. An internal institutional radiology information system was queried for all MRI hip studies over a 12-month period from 3/2018 to 3/2019. MRI images were included if they contained fluid sensitive images of the hip in axial, coronal and sagittal planes, along with an axial T1 weighted sequence. All studies were performed using either 1.5T or 3T MRI with a surface coil and field of view tailored to the hip of interest. Exclusion criteria included patients with history of prior surgical procedure on the ipsilateral hip. The 100 most recent studies meeting these criteria were included.

MRI images were reviewed on a picture archive and communications system (PACS) workstation by two fellowship trained musculoskeletal radiologists, each with 5+ years of clinical experience. The radiologists reviewed all studies independently and were blinded to clinical data; no formal pre-review calibration or training sessions were performed.

For each study, the radiologists assessed the absence or presence of a tear in the gluteus minimums, gluteus medius and vastus lateralis tendons using the three planes of fluid sensitive images. For descriptive analysis, the gluteus minimus tendon was divided into two parts and the gluteus medius tendon was divided into three parts as follows: gluteus minimus anterior (Glut Min A), gluteus minimus posterior (Glut Min P), gluteus medius anterior (Glut Med A), gluteus medius posterior (Glut med P), gluteus medius posterior superior (Glut Med PS), and vastus lateralis (VL) (Figures 1 and 2). If there was a full thickness component to the tear, the maximum sagittal diameter of the tear was measured using the best available sagittal slice (Figure 3). Vastus lateralis tears have not been previously described on MRI. For the purpose of this study, the proximal origin of the vastus lateralis was assess on coronal and axial images. A tear was defined by increased T2 signal between the tendon and the adjacent greater trochanter at its point of attachment on the anterior, lower greater trochanter (Figures 4, 5, and 6a,b). Tendinosis was defined as thickening of the proximal origin without signal abnormality between the tendon and the adjacent bone.

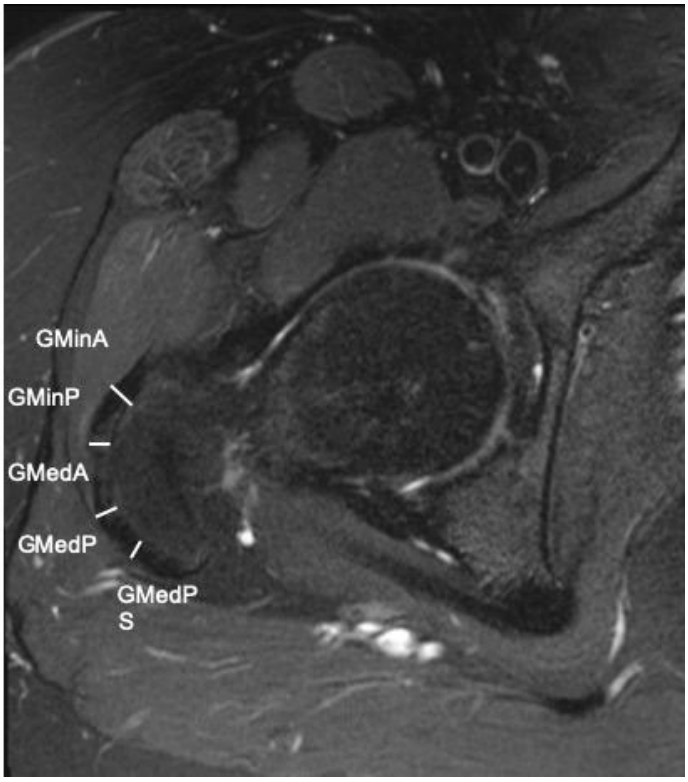


Figure 1. Axial proton density image with fat saturation through the greater trochanter showing completely intact gluteus minimus and medius tendons. The tendons were divided into gluteus minimus anterior (GMinA) and posterior (GMinP), and gluteus medius anterior (GMedA), posterior (GMedP), and posteriorsuperior (GMedPS).

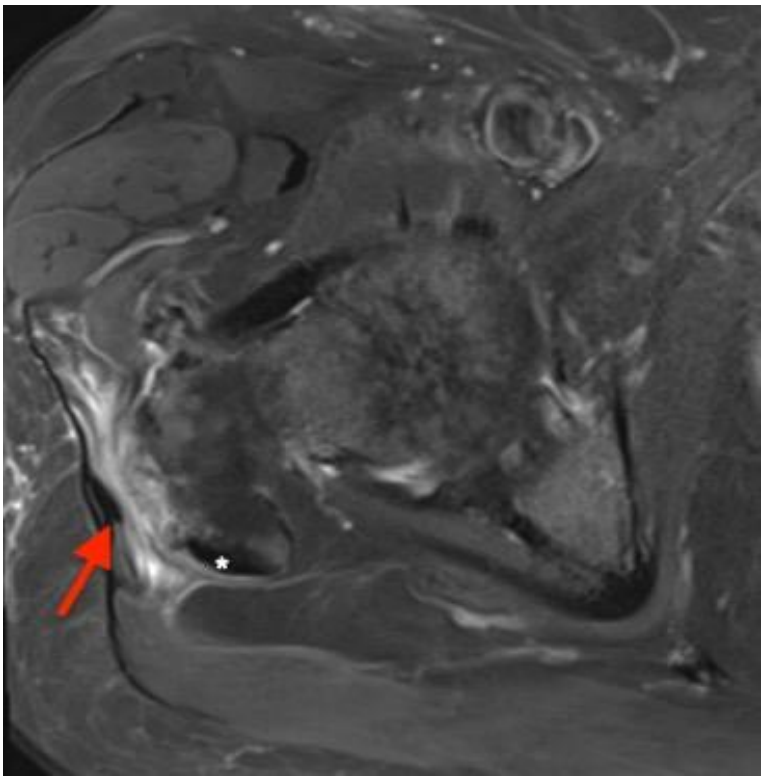


Figure 2. Axial proton density image with fat saturation through the greater trochanter showing a full thickness tear of the gluteus minimums anterior and posterior, and the gluteus medius anterior and posterior (red arrow). Only the gluteus medius posteriorsuperior portion remains intact (asterisk).

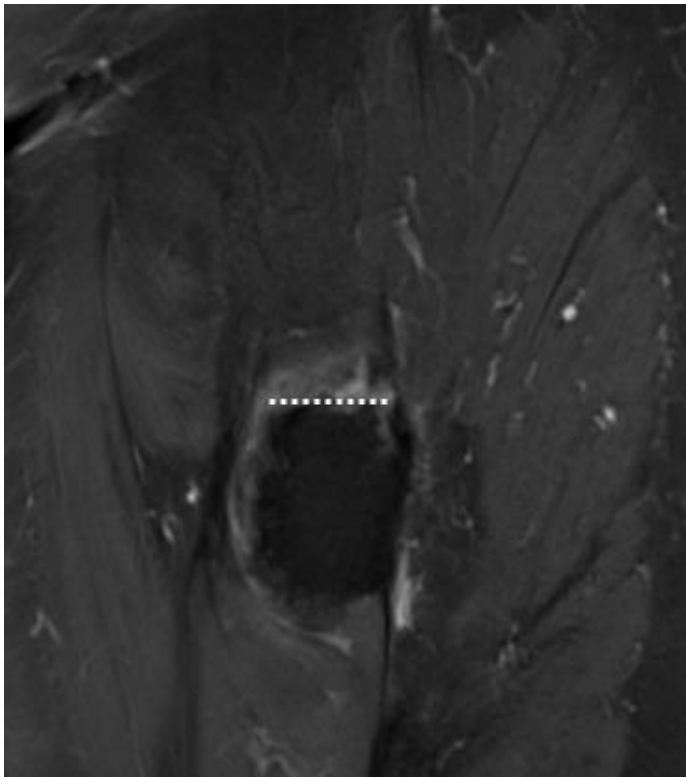


Figure 3. Sagittal proton density image with fat saturation through the greater trochanter with a full thickness tear of the anterior and posterior portions of both tendons. This image would be used to measure the widest dimension of the tear (dashed line).

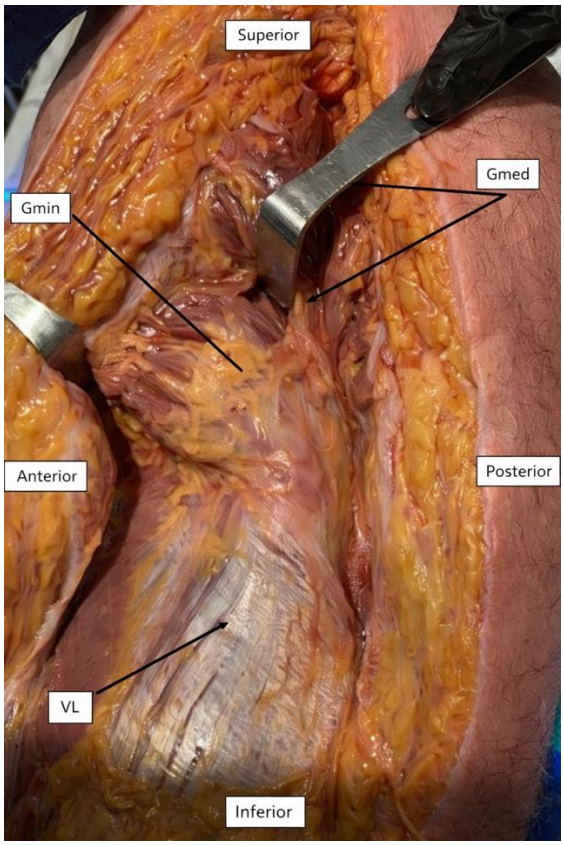


Figure 4. Gross cadaveric dissection of left hip demonstrating contiguous anatomic relationship of gluteus minimus (Gmin), medius (Gmed) and vastus lateralis (VL) insertions around the greater trochanter.

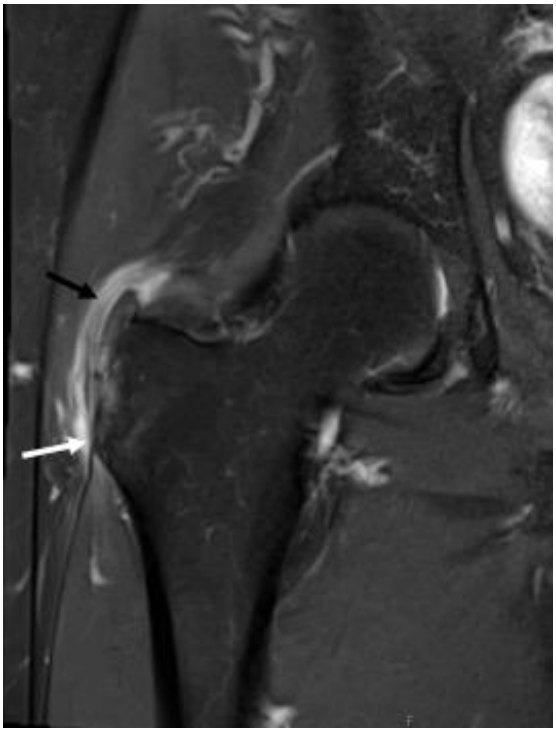
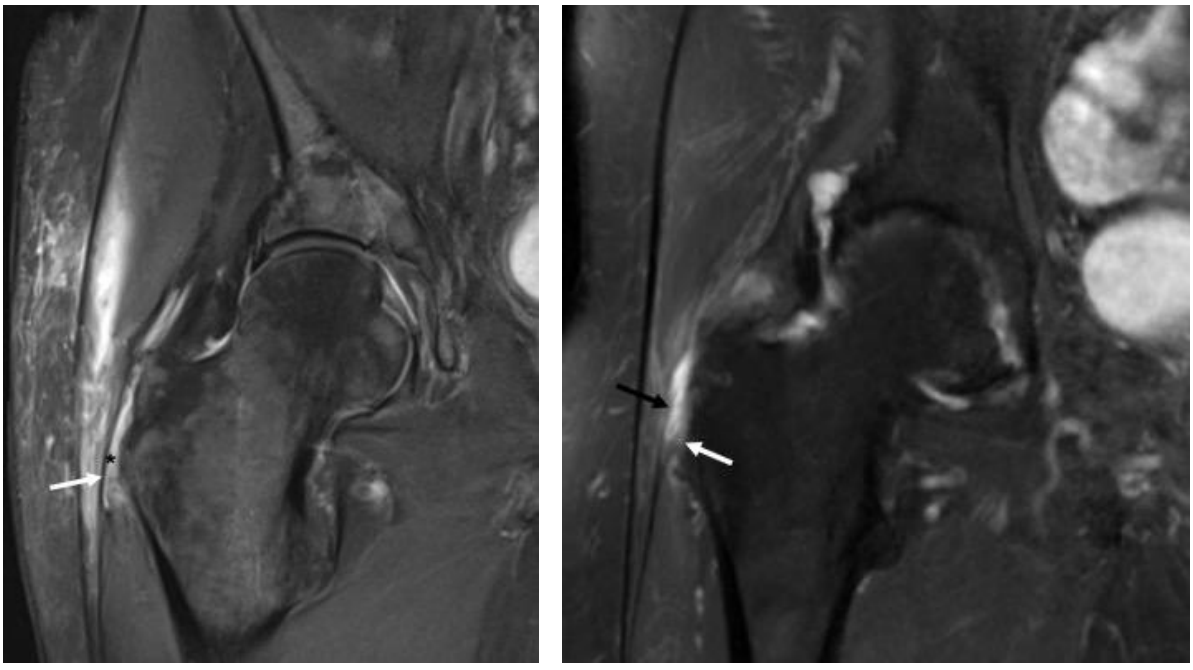


Figure 5. Coronal proton density image with fat saturation through the greater trochanter. There is a full thickness tear of the gluteus medius tendon (black arrow) with an intact vastus lateralis tendon origin (white arrow).



(**a**) (**b**)

Figure 6. (**a**) Coronal proton density image with fat saturation through the greater trochanter. There is hyperintense signal (black asterisk) between the vastus lateralis tendon (white arrow) and the greater trochanter consistent with a tear. (**b**) Coronal proton density image with fat saturation through the greater trochanter. There is moderate thickening of the vastus lateralis tendon origin with hyperintense signal between portions of the tendon and the greater trochanter consistent with a tear (black arrow). A small portion of the tendon origin remains intact distally (white arrow).

Statistical Analysis

Patient characteristics including age, gender, and laterality (left vs. right hip) were summarized. The distributions of abductor tendon tear ratings were summarized for each of the two MRI reviewers separately. Categorical measures and ordinal scale measures were summarized by response frequencies and percentages.

Continuous measures were summarized by mean, standard deviation, and range. Agreement between the two MRI reviewers was assessed for each of the measures. Percent agreement was computed for each of the categorical and ordinal measures. Additionally, Cohen's Kappa, and Cohen's Weighted Kappa were computed for the categorical and ordinal measures respectively with 95 percent confidence intervals. Among patients who were rated as having full thickness by both reviewers, agreement of maximum sagittal diameter was assess via an intraclass correlation (ICC) with a 95 percent confidence interval. For interpretation purposes, we followed the recommendations of Altman (1991) [16]. and considered ICC and kappa values less than 0.20 as poor agreement; values 0.21–0.40 were considered fair agreement; values 0.41–0.60 were considered moderate agreement; values 0.61–0.80 were considered good agreement; and values 0.81–1.00 were considered very good agreement. Differences in sagittal thickness by the presence of gluteus medius posterosuperior location was also assessed stratified by each reviewer. The difference in presence of full thickness tears was assessed via Pearson's chi-square test. Differences in maximum sagittal diameter were assessed via Student's *t*-test. Differences in measurement patterns for patients with and without vastus lateralis pathology were also assessed stratified by reviewer. Differences in binary variables were assessed via Pearson's chi-square test, and differences in ordinal variables were assessed via the Wilcoxon Ranks Sum Test. Test with *p*-values less than 0.05 were considered statistically significant. All analyses were conducted using R version 3.6.

3. Results

Mean patients age in this study was 58 years old with a slight female predominance of 64% (Table 1). 55% of the MRIs in the study were of the right hip with the remaining 45% the left hip. A total of 26 full thickness tears were reported by reviewer #1 and 18 by reviewer #2 (Table 2).

Table 1. Demographics of study population.

N	**100**
Age (mean, range)	58.28 (14–91)
Gender	
Female	36
Male	54
Laterality (L/R%)	
Left	45
Right	55

Note: Subject demographics for age, gender, and laterality.

Table 2. MRI pathology findings by individual reviewer.

	#1	**#2**
Vastus Lateralis	14 (14.0%)	8 (8.0%)
Gluteus Minimus Anterior	45 (45.0%)	21 (21.0%)
Gluteus Minimus Posterior	63 (63.0%)	27 (27.0%)
Gluteus Medius Anterior	65 (65.0%)	34 (34.0%)
Gluteus Medius Posterior	28 (28.0%)	15 (15.0%)
Gluteus Medius Posterosuperior	5 (5.0%)	4 (4.0%)
Full Thickness Tears	26 (26.0%)	18 (18.0%)
Max sag diameter (mm)		
N-Miss	74	82
Mean (SD)	27.5 (7.8)	29.4 (11.5)
Range	14.0–37.0	7.0–47.0

Note: Agreement between abductor and vastus lateralis pathology identification.

Agreement between the two reviewers was assessed using weighted Cohen's Kappa. Good agreement for gluteus medius posterior tears (87%, kappa 0.62), good agreement for full thickness tears (86%, kappa 0.60), and moderate agreement for gluteus minimus anterior tears (76%, kappa 0.49), gluteus medius anterior tears (69%, kappa 0.43), and maximum sagittal tear diameter (ICC 0.41) were observed. The kappa value for gluteus medius posterior superior was poor (0.19) despite 93% agreement (Table 3) [16].

Table 3. Agreement statistics between measurements of reviewers 1 & 2.

	% Agreement	Cohen's Kappa
Vastus Lateralis	94	0.70 (0.47, 0.92)
Gluteus Minimus Anterior	76	0.49 (0.34, 0.64)
Gluteus Minimus Posterior	64	0.36 (0.23, 0.49)
Gluteus Medius Anterior	69	0.43 (0.3, 0.57)
Gluteus Medius Posterior	87	0.62 (0.45, 0.8)
Gluteus Medius Posterosuperior	93	0.19 (−0.19, 0.56)
Full Thickness (Y/N)	86	0.60 (0.41, 0.78)
Maximal Sagittal Diameter (mm)		0.41 (0.24, 0.56) *

Note: Agreement between radiologists displayed in terms of percent agreement and Cohen's Kappa Coefficient. * Agreement for "Maximal Sagittal Diameter" was measured by Interclass Correlation Coefficient (ICC) among the 15 subjects rated as full thickness by both raters.

When comparing the presence of full thickness tearing to the location of the tear, both reviewers found that a full thickness tear was significantly more likely if there was a tear present at the posterosuperior portion of the gluteus medius (p-value < 0.001) (Table 4). Specifically, reviewer #1 reported 5 posterosuperior tears of which 100% were full thickness, and reviewer #2 reported 4 posterosuperior tears, 3 of which (75%) were full thickness (Tables 2 and 4). Additionally, for both reviewers the maximal sagittal diameter of the tear was larger in the presence of gluteus medius posterosuperior tear although this was only statistically significant for reviewer #1 (25.6 mm vs. 35.8 mm, p-value 0.005 for reviewer #1; 28.9 mm vs. 31.7 mm, p-value 0.719 for reviewer #2).

Table 4. Cross-tabulation of full thickness tears by presence of gluteus medius posterosuperior tear; separated by reviewer.

Reviewer	Gluteus Medius Posterosuperior Tears = No (N = 191)	Gluteus Medius Posterosuperior Tears = Yes (N = 9)	Total (N = 200)	p-Value
#1				
Full Thickness				<0.001 [1]
No	74 (77.9%)	0 (0.0%)	74 (74.0%)	
Yes	21 (22.1%; 95% CI 7.3–16.2)	5 (100.0%; 95% CI: 56.6–100%)	26 (26.0%)	
Max sag diameter (mm)				0.005 [2]
N-Miss	74	0	74	
Mean (SD)	25.6 (7.3)	35.8 (1.3)	27.5 (7.8)	
Range	14.0–37.0	34.0–37.0	14.0–37.0	
#2				
Full Thickness				0.002 [1]
No	81 (84.4%)	1 (25.0%)	82 (82.0%)	
Yes	15 (15.6%; 95% CI: 9.7–24.2%)	3 (75.0%; 95% CI: 30.1–95.4%)	18 (18.0%)	
Max sag diameter (mm)				0.719 [2]
N-Miss	81	1	82	
Mean (SD)	28.9 (11.4)	31.7 (14.4)	29.4 (11.5)	
Range	7.0–47.0	15.0–40.0	7.0–47.0	

Note: Full thickness tear location frequency as recorded by reviewer #1 and #2. [1] Pearson's Chi-squared test; [2] Linear Model ANOVA.

In terms of concomitant vastus lateralis pathology, reviewer #1 reported a prevalence of 14% vs. 8% for reviewer #2 with substantial agreement (94%, kappa 0.70) (Tables 2 and 3). For reviewer #1 vastus lateralis pathology was significantly associated with anterior and posterior gluteus minimus pathology as well as anterior and posterior gluteus medius pathology (p-values < 0.001). For reviewer #2 the results were similar with vastus lateralis pathology significantly associated with anterior and posterior gluteus minimus pathology as well as anterior and posterior gluteus medius pathology (p-values < 0.001) (Table 5).

Table 5. Association of concomitant vastus lateralis pathology with abductor pathology.

Reviewer	Vastus Lateralis Tear = No (*N* = 178)	Vastus Lateralis Tear = Yes (*N* = 22)	Total (*N* = 200)	*p*-Value
#1				
Gluteus Minimus Posterior				<0.001 [1]
No	34 (66.7%)	3 (6.1%)	37 (37.0%)	
Yes	17 (33.3%)	46 (93.9%)	63 (63.0%)	
Gluteus Medius Anterior				<0.001 [1]
No	30 (58.8%)	5 (10.2%)	35 (35.0%)	
Yes	21 (41.2%)	44 (89.8%)	65 (65.0%)	
Gluteus Minimus Anterior				<0.001 [1]
No	43 (84.3%)	12 (24.5%)	55 (55.0%)	
Yes	8 (15.7%)	37 (75.5%)	45 (45.0%)	
Gluteus Medius Posterior				<0.001 [1]
No	48 (94.1%)	24 (49.0%)	72 (72.0%)	
Yes	3 (5.9%)	25 (51.0%)	28 (28.0%)	
Full Thickness Tears				<0.001 [1]
No	48 (94.1%)	26 (53.1%)	74 (74.0%)	
Yes	3 (5.9%)	23 (46.9%)	26 (26.0%)	
#2				
Gluteus Minimus Posterior				<0.001 [1]
No	73 (79.3%)	0 (0.0%)	73 (73.0%)	
Yes	19 (20.7%)	8 (100.0%)	27 (27.0%)	
Gluteus Medius Anterior				<0.001 [1]
No	66 (71.7%)	0 (0.0%)	66 (66.0%)	
Yes	26 (28.3%)	8 (100.0%)	34 (34.0%)	
Gluteus Minimus Anterior				<0.001 [1]
No	78 (84.8%)	1 (12.5%)	79 (79.0%)	
Yes	14 (15.2%)	7 (87.5%)	21 (21.0%)	
Gluteus Medius Posterior				<0.001 [1]
No	82 (89.1%)	3 (37.5%)	85 (85.0%)	
Yes	10 (10.9%)	5 (62.5%)	15 (15.0%)	
Full Thickness Tears				<0.001 [1]
No	82 (89.1%)	0 (0.0%)	82 (82.0%)	
Yes	10 (10.9%)	8 (100.0%)	18 (18.0%)	

Note: Percentage and association of concomitant vastus lateralis pathology with abductor pathology. [1] Trend test for ordinal variables.

4. Discussion

This study demonstrates the variable prevalence of vastus lateralis tears in patients undergoing hip MR imaging and a significant association of vastus tears, when present, with other gluteal pathology. Prior literature has suggested a biomechanical mechanism to hip abductor tears similar to the progression of rotator cuff tears in the shoulder [1,5,9]. However reports of this process in the hip previously are anecdotal. This study attempts to record the prevalence of tears in specific anatomic locations and to quantify tear progression by comparing the location of small tears and large tears. Gluteus minimus posterior and gluteus medius anterior tears were both the most prominent tears overall, as well as the highest associations with concomitant vastus lateralis pathology (Tables 2 and 5). This study supports a central gluteus minimums and medius junction initiation of the tears with a posterior progression [10]. Additionally, both reviewers in this study found larger maximal sagittal diameters for full thickness tears that involved the posterosuperior portion of the gluteus medius suggesting that these posterior tears occur later in the progression as they are larger (Table 4). While the primary blood supply of the abductors is well known, this common tear pattern warrants further research to examine potential watershed zones of perfusion placing this central portion at higher risk for tear initiation.

Clinically establishing an order of progression may be important as rotator cuff tears in the shoulder have been shown to progress from tendinopathy, to partial thickness, to full thickness tears and subsequent advanced arthritis [17–19]. Such a progression for abductor tears in the elderly population could compromise hip mechanics and increases the risk for a fall [20,21]. Many surgeons have started to aggressively repair partial or full thickness tears with the primary goal of symptom relief along with improvement in gait mechanics [22]. As such, it is important for radiologists to be able to identify abductor tendon tear patterns and to be aware of concomitant vastus lateralis pathology. Anecdotally, many of these partial tears begin deep, similar to an articular sided partial cuff tear, and progress outwards to full thickness. This makes it difficult to endoscopically identify symptomatic partial

hip abductor tears and increases the need to pre-operatively identify common tear patterns, initiation sites, and progression to assist the surgeon is which tears should be taken down and repaired. Detailed MRI assessment of abductor tendon pathology has gained increased attention in recent years, with newer imaging studies highlighting the spectrum of tear patterns and their clinical correlates. For example, recent work by Browning et al. [23]. demonstrates improved MRI-based characterization of abductor tendon tearing and supports nuanced evaluation beyond traditional descriptions.

In addition to quantifying most common tear types (gluteus minimus posterior and gluteus medius anterior) and progression (central to posterior), this study also evaluated the prevalence of ipsilateral vastus lateralis pathology. When present, vastus lateralis tears were highly associated with abductor pathology and to our knowledge no study exists discussing repair of this commonly injured structure. While not part of most routine advanced imaging assessments of the abductors, the intimate anatomic connection of the vastus to the abductors and the prevalence of variable vastus pathology in this study should prompt more research to better understand the role this associated injury may play in lateral thigh pain. Future studies quantifying pain relief and patient reported outcomes with abductor and vastus tear repairs are warranted.

Vastus lateralis pathology has been relatively underreported in prior studies of hip abductor tears, likely because imaging and clinical attention has traditionally focused on the gluteus medius and minimus tendons as the primary pain generators in lateral hip pathology [24]. Additionally, the vastus lateralis origin is often incompletely evaluated on routine hip MRI protocols or considered outside the primary field of interest, which may contribute to under-recognition. Our findings suggest that more systematic evaluation of the vastus lateralis origin may be warranted. A standardized MRI assessment approach could include routine inspection of the vastus lateralis origin on fluid-sensitive sequences for signal abnormality, fiber disruption, or reactive changes, particularly in patients with full-thickness or posteriorly extending abductor tendon tears.

The tear distribution patterns identified in this study may have important clinical implications for both diagnosis and surgical planning. Recognition that abductor tendon tears frequently involve the gluteus minimus posteriorly and gluteus medius anteriorly, with larger and full-thickness tears more often extending to the posterosuperior gluteus medius, may prompt heightened suspicion for advanced pathology when posterior involvement is identified on MRI. For surgeons, these findings may aid in preoperative counseling, surgical approach selection, and intraoperative planning, as posterior extension of tearing may necessitate more extensive mobilization or repair strategies. Additionally, the strong association between abductor tears and concomitant vastus lateralis pathology suggests that careful evaluation of the lateral thigh structures on preoperative imaging may be warranted, particularly in patients with persistent lateral hip pain or incomplete symptom resolution following abductor repair. Recent literature supports the clinical relevance of detailed preoperative imaging in guiding surgical decision-making for abductor tendon pathology. A systematic review and meta-analysis by Looney et al. [25]. demonstrated that greater fatty infiltration of the hip abductor musculature is associated with inferior clinical outcomes following repair, underscoring the importance of accurately characterizing tear severity and muscle quality on MRI. Additionally, contemporary surgical series, such as that reported by Ebert et al. [26], have shown favorable functional outcomes and acceptable reoperation rates following modern hip abductor tendon repair techniques, highlighting the potential impact of appropriate patient selection and operative planning. While these implications remain hypothesis-generating, they highlight how detailed MRI characterization of tear patterns may contribute to more informed clinical decision-making.

This study also highlights the challenges in diagnosing vastus lateralis pathology near the greater trochanter on MRI. The vastus lateralis origin in this region is markedly thinner than the gluteus minimus and medius tendons [27–29]. Pathology in this area has not been previously well described in the radiology literature. Further description and focus on VL pathology will promote a better understanding of this across the literature.

Limitations

There are several notable limitations to this study. In addition to the retrospective nature of the study, a small sample size limits our confidence interval in terms of quantifying tear locations and the presence or absence of vastus pathology. The study included all patients with hip MRI images, regardless of the clinical presentation. Additionally, there is some subjectivity to assessing low grade tears versus the diagnostic category “tendinosis” which may explain the variable agreement among smaller partial thickness tears and higher agreement among full thickness tears. Inter-reader agreement was lower for partial-thickness abductor tendon tears compared with full-thickness tears. This likely reflects the inherent subjectivity in distinguishing low-grade partial tearing from tendinosis on MRI, particularly given the thin morphology of the abductor tendons and the lack of established imaging criteria for grading partial-thickness tears at the hip. In contrast, agreement was higher for full-thickness

tears and vastus lateralis pathology, which are more clearly defined radiographically. These findings underscore the need for standardized MRI-based classification systems and correlation with surgical findings in future studies. Another limitation is the lack of surgical follow up for all of these patients which limits our ability to correlate imaging with intraoperative findings. Despite these limitations we feel this study adds to the existing literature in terms of helping better define common tear patterns and drawing attention to the little mentioned concomitant vastus pathology for further study.

5. Conclusions

This study identifies consistent patterns of abductor tendon involvement on MRI, with tears most commonly affecting the gluteus minimus posteriorly and the gluteus medius anteriorly, and larger or full-thickness tears more frequently involving the posterosuperior gluteus medius. These findings suggest a possible central-to-posterior pattern of abductor tendon tear involvement that may reflect a progression pathway; however, given the cross-sectional design, a definitive temporal sequence cannot be established. The observed associations should therefore be interpreted as hypothesis-generating, and prospective longitudinal studies are needed to confirm the natural history of abductor tendon tear progression and its clinical implications.

Author Contributions

J.D.H., J.A.F., J.R.L., J.L.M.: design, data acquisition, analysis and interpretation of data; L.D.M.: data acquisition, analysis and interpretation of data; J.C.B.: data acquisition, analysis and interpretation of data; D.E.H.: design, data acquisition, analysis and interpretation of data. All authors have read and agreed to the published version of the manuscript.

Institutional Review Board Statement

Ethical review and approval were waived for this study because it was a retrospective review of previously obtained, clinically indicated MRI examinations. The study involved no direct patient contact or intervention, posed minimal risk to participants, and all data were de-identified prior to analysis. Given the retrospective nature of the study and use of existing imaging data, the Institutional Review Board determined that formal ethical review and approval were not required.

Informed Consent Statement

Informed consent was waived for this project because this study was a retrospective review of previously obtained clinically indicated MRI examinations. The study involved no direct patient contact, no intervention, and posed minimal risk to participants. All data were de-identified prior to analysis, and the research could not practicably be carried out without the waiver of informed consent.

Data Availability Statement

Data is available upon request.

Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

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