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Obesity and Sex Influence Fatty Infiltration of the Rotator Cuff: The ROW and MOON Cohorts

Ayush Giri[1], **Thomas H Freeman**[2], **Peter Kim**[3], **John E Kuhn**[2], **Gustavo A Garriga**[1], **Michael Khazzam**[4], **Laurence D Higgins**[5], **Elizabeth Matzkin**[6], **Keith M Baumgarten**[7], **Julie Y Bishop**[8], **Robert H Brophy**[9], **James L Carey**[10], **Warren R Dunn**[11], **Grant L Jones**[8], **C Benjamin Ma**[12], **Robert G Marx**[13], **Eric C McCarty**[14], **Sourav K Poddar**[14], **Matthew V Smith**[9], **Edwin E Spencer**[15], **Armando F Vidal**[16], **Brian R Wolf**[17], **Rick W Wright**[2], **Nitin B Jain**[18]

[1]Division of Epidemiology, Department of Medicine, Vanderbilt University Medical Center, Nashville, TN, USA; Division of Quantitative Sciences, Department of Obstetrics and Gynecology, Vanderbilt University Medical Center, Nashville, TN, USA.

[2]Department of Orthopaedic Surgery, Vanderbilt University Medical Center, Nashville, TN, USA.

[3]Department of Physical Medicine and Rehabilitation, Vanderbilt University Medical Center, Nashville, TN, USA.

[4]Department of Orthopaedics, University of Texas Southwestern, Dallas, TX, USA.

[5]King Edward Memorial Hospital, Hamilton, Bermuda.

[6]Department of Orthopaedic Surgery, Brigham and Women's Hospital and Harvard Medical School, Boston, MA, USA.

[7]Orthopedic Institute of Sioux Falls, Sioux Falls, SD, USA.

[8]Departments of Orthopaedic Surgery and Sports Medicine, Ohio State University, Columbus, OH, USA.

[9]Department of Orthopaedic Surgery, Washington University in St. Louis, St. Louis, MO, USA.

nitin.jain@utsouthwestern.edu .

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[10]Department of Orthopaedic Surgery, University of Pennsylvania and Perelman School of Medicine, Philadelphia, PA, USA.

[11]Department of Clinical Research, Fondren Orthopedic Group, Houston, TX, USA.

[12]Department of Orthopaedic Surgery, University of California San Francisco, San Francisco, CA, USA.

[13]Department of Orthopedic Surgery, Weill Medical College of Cornell University, New York, NY, USA.

[14]Department of Orthopedic Sports Medicine, University of Colorado, Denver, CO, USA.

[15]Shoulder & Elbow Division, Knoxville Orthopaedic Clinic, Knoxville, TN, USA.

[16]The Steadman Clinic and Steadman Philippon Research Institute, Vial, CO, USA.

[17]Department of Orthopedics and Rehabilitation, University of Iowa, Iowa City, IA, USA.

[18]Departments of Physical Medicine and Rehabilitation, Orthopaedics, and Population & Data Sciences, University of Texas Southwestern, Dallas, TX, USA; Department of Physical Medicine and Rehabilitation, Vanderbilt University Medical Center, Nashville, TN, USA.

Abstract

Background: Fatty infiltration (FI) is one of the most important prognostic factors for outcomes after rotator cuff surgery. Established risk factors include advancing age, larger size of tear, and increased chronicity of tear. A growing body of evidence suggests sex and obesity are associated with FI, however, data are limited.

Methods: We recruited two well-characterized multi-center cohorts of patients with rotator cuff tears (MOON cohort n=80; ROW cohort n=158). We used multivariable logistic regression to evaluate the relationship between body mass index and presence of FI while adjusting for age at MRI, participant's sex, the duration of shoulder symptoms and the cross-sectional area of tear. We analyzed the two cohorts separately and performed a meta-analysis to combine estimates.

Results: A total of 27 (33.8%) patients in the MOON cohort and 57 (36.1%) patients in the ROW cohort had FI. Using BMI < 25 kg/m^2 as the reference category, being overweight was associated with a 2.37 fold (95% CI=0.77, 7.29) increased odds of FI and being obese was associated with a 3.28 fold (95% CI = 1.16, 9.25) increased odds of FI. Women were 4.9-times (95% CI = 2.06, 11.69) as likely to have FI as men.

Conclusions: Obese patients had a substantially higher likelihood of FI in patients with rotator cuff tears. Further research is needed to assess whether modifying BMI can alter FI in patients with rotator cuff tears. This may have significant clinical implications for presurgical surgical management of rotator cuff tears. Sex was also significantly associated with FI, with women having higher odds of FI compared with men. Higher odds of FI in females may also explain previously reported early sub-optimal outcomes of rotator cuff surgery and higher pain in females as compared to males.

Level of Evidence: Level II; Retrospective Multivariable Design; Prognosis Study

Keywords

rotator cuff; body mass index; obesity; sex; fatty infiltration

Shoulder pain was the cause of an estimated 9.6 million annual patient visits, on average, in ambulatory settings in the United States in 2015–2016[39]. This resulted in an average estimated rate of 3.9 visits per 100 U.S. adults. Rotator cuff tears are presumed to be the leading cause of shoulder pain and disability leading to an estimated arthroscopic rotator cuff surgery rate of 11.94 to 185.35 per 100,000 persons across US states[23]. Fatty infiltration (FI) of rotator cuff muscles is critical for surgical decision-making since higher grades of FI are associated with worse outcomes[13; 14; 26; 31; 32; 36; 42; 43; 45]. However, not all patients with rotator cuff tears develop FI. In addition to established characteristics such as increasing age, larger size of tear, and increased chronicity of tear[16; 34; 35], there is limited evidence that obesity is associated with FI[8; 28; 33]. The association of obesity with FI needs to be further assessed in larger studies and will inform modifiable factors that are associated with the development of FI in patients with rotator cuff tears. Men and women, on average, differ in body fat composition throughout their lifetime and also have differential distribution of fat [12; 17; 25; 44] and data are limited on whether fat distribution in the rotator cuff also differs by sex.

We performed cross-sectional investigations on two well-characterized cohorts of patients with rotator cuff tears. The primary goal of this study was to evaluate the relationship between body mass index (BMI) and FI in men and women with rotator cuff tears.

METHODS

Patient Populations

The Rotator Cuff Outcomes Workgroup (ROW) Cohort: This cohort was recruited from three academic centers and one community center between February 2011 and June 2015. Patients 45 years and older who had symptomatic rotator cuff tears were followed. Additional details of this cohort have been previously published[7; 18; 19; 20; 21; 22]. There were a total of 158 patients with rotator cuff tears confirmed by MRI that had images to permit assessment of FI that were included in our analysis from the ROW cohort.

The Multicenter Orthopaedic Outcomes Network (MOON) Cohort: This is a well-defined cohort of patients with rotator cuff tears that was recruited from 10 sites across the United States. The cohort was recruited from January 2007 to January 2011, and patients 18 years and older were included. Additional details of this cohort have been previously published[9; 10; 15; 27]. Patients with rotator cuff tears confirmed by MRI that had images with sufficient quality to permit assessment of FI (N = 80) and information available on BMI were included in our analysis from the MOON cohort.

Structured Assessments

Patients filled out a baseline questionnaire for both cohorts where duration of symptoms was self-reported. Body mass index (BMI) was calculated from patient's height and weight primarily based on self-report from structured questionnaires administered at the time of study recruitment. If height or weight was missing, they were abstracted from the patient's electronic medical record using measures from visits prior to and inclusive of the recruitment visit.

FI and Tear Size of the Rotator Cuff: Shoulder experts (fellowship-trained attending physician) read shoulder MRIs for the ROW cohort. The methodology of MRI reviews for the ROW cohort has been described in a previous study, in which good inter-rater and intra-rater reliability was shown compared to readings by a musculoskeletal radiologist[20]. For the MOON cohort, shoulder MRI's were read in a standardized way by consensus between a trained senior orthopedic resident and a shoulder attending. Rotator cuff tear size was assessed in the transverse and longitudinal planes. Cross-sectional area of tear size was then calculated by taking the product of transverse and longitudinal tear sizes for the two largest tears. FI was evaluated based on fatty streaks within the muscle belly observed on a T1-weighted oblique sagittal image. It was graded as: grade 0, no fat; grade 1, thin streaks of fat; grade 2, less fat than muscle; grade 3, equal amounts of fat and muscle; and grade 4, more fat than muscle as described by Goutallier et al[14]. FI was assessed for all four rotator cuff muscles irrespective of the tendon that was torn. The highest FI grade for one of the four rotator cuff muscles was recorded for each patient. For the purposes of this analysis, the Goutallier grading was dichotomized to indicate absence of FI (grade 0) as controls, and the presence of any infiltration (grade ≥ 1) as cases.

Statistical analysis

We used multivariable logistic regression to evaluate the relationship between body mass index and presence of FI while adjusting for age at MRI, participant's sex, the duration of shoulder symptoms and the cross-sectional area of tear. BMI was assessed as a continuous variable, and as a categorical variable according to modified World Health organization categories (< 25 kg/m^2 [referent/normal BMI], 25–30 kg/m^2(overweight); ≥ 30 kg/m^2 (obese)). Each cohort was analyzed separately and resulting effect estimates were combined using inverse-variance weighted fixed effects meta-analysis to avoid confounding due to cohort assignment. As secondary analysis we also evaluated the relationship between sex and FI using the same multivariable adjusted models mentioned above and performed meta-analysis for corresponding estimates. We conducted several sensitivity analyses in the ROW cohort to evaluate the robustness of the results and to seek further insight into the relationship between BMI, sex and FI. We evaluated the association between BMI and FI with and without adjustment for covariates while varying the definition of FI from Grade 1 or higher to Grade 2 or higher in the Goutallier FI grading scale. To further evaluate how the relationship between BMI and FI is affected by presence of a tear and if the association between BMI and tear is independent of tear presence, we constructed unadjusted and multivariable models in supraspinatus, infraspinatus, subscapularis and teres minor tendons, separately. Multivariable models included FI (present/absent) in the specific tendon as the outcome (eg. FI in supraspinatus) and tear thickness of that specific tendon (no tear [reference], partial thickness tear, and full thickness tear), BMI (continuous or categorical), participant age at baseline and sex as the independent variables. These models yielded effect estimates for the association between tear thickness and FI with and without adjustment for

BMI, and for the association between BMI and FI with and without adjustment for tear. Teres minor tendons had no tears and multivariable models only include age, sex and BMI as the independent variables. Sensitivity analyses were not possible in the MOON cohort due to the small number of FI events. Odds ratios (OR) and 95% confidence intervals are presented. Analyses were conducted in R and STATA (College Station, TX, USA).

RESULTS

Approximately half the patients were female and one third of rotator cuff tears had FI of the rotator cuff in both cohorts (MOON: 27 out of 80; and ROW: 57 out of 158). In both cohorts, participants with FI were older at date of MRI than those without FI, were more likely to be female, obese and more likely to have had the tear for greater than 12 years (Table 1). A higher proportion of patients in the MOON cohort had FI in the BMI 25–30 category (33%) as compared with ≥30 category (44%). In our assessment of BMI as a continuous measure and FI, every 5 units increase in BMI was associated with a 45% increased odds of FI (OR = 1.449; 95% CI = 0.859, 2.447) in MOON and 28% increased odds in ROW (OR = 1.282; 95% CI = 0.83, 1.99), with a final meta-analysis odds ratio of 1.351 (95% CI = 0.965, 1.892) (Table 2).). Using BMI < 25 as the referent category, being overweight was associated with a 2.3 fold increased odds of FI (meta-analysis OR = 0.77, 7.29) and being obese was associated with a 3.28 fold increased odds of FI (meta-analysis OR = 3.28; 95% CI = 1.16, 9.25) (Table 2). For individual cohorts, being overweight as compared with BMI<25 was associated with a 7.13 fold increased odds of FI in the MOON cohort and 1.097 fold increase in odds of FI in the ROW cohort. This difference in OR is likely due to a smaller number of patients with FI in the MOON cohort as compared with the ROW cohort in the overweight category.

Compared to men, women were 4.9-fold as likely to have FI (meta-analysis OR = 4.91; 95% CI = 2.06, 11.69), with a consistently positive direction of association in both cohorts (Table 2).

Sensitivity analyses

In sensitivity analyses performed in the ROW cohort, changing the definition of FI to only include individuals with grade 2 or higher FI in the Goutallier scale showed associations between BMI and FI were stronger with the magnitudes of odds ratios larger in the new definition (Table 3). However, the substantial drop in FI cases (from 44 to 31) with the more stringent definition led to further loss of power and decreased precision in our estimates. Unadjusted and multivariable adjusted results were similar. In contrast to this, the association between sex and FI was starkly different with no evidence of increased association between females and FI (0 vs. Grade 1 or higher) in unadjusted model (OR = 0.95; 95% CI = 0.51, 1.82) and a strong association in multivariable adjusted model (OR = 3.59; 95% CI = 1.15, 11.25) (Table 3). This reversal in association compared to the unadjusted model was contributed by adjustment for tear size (cross sectional area of the tear). Similar reversal of association was seen when this association was assessed in FI grade 2 or higher as the outcome (Table 3).

In addition to evaluating FI as a composite and binary variable with FI defined as presence of fatty infiltration in any one or more of the four tendons, we assessed FI in each tendon separately (Tables 4 and 5). Irrespective of tear, FI was present in 30% of supraspinatus, 27% of infraspinatus, 16% of subscapularis and 10% of teres minor tendons evaluated (Table 4). Tears were present in 92% of the supraspinatus muscles evaluated, and fewer in infraspinatus (32%), subscapularis (14%) and none in the teres minor tendons evaluated. Compared to not having a tear, having a full thickness tear was associated with higher odds of FI in all three of the muscles in tears: supraspinatus (OR = 3.93; 95% CI = 0.78, 19.84), infraspinatus (OR = 27.22; 95% CI = 9.32, 79.53), and subscapularis (OR = 5.64; 95% CI = 1.59, 20.04) after adjustment for age, sex and BMI (Table 4). Similar results were observed for unadjusted and multivariable models (Table 4). Understanding the positive correlation between tear and FI in each tendon, we assessed whether BMI is associated with FI in each tendon with and without adjustment for tear in the specific tendon (Table 5). BMI was positively associated with FI with or without adjustment for tear thickness; multivariable adjusted OR for each unit increase in BMI (continuous) showing consistent associations in all four tendons: supraspinatus (OR = 1.04; 0.98, 1.11), infraspinatus (OR = 1.09; 95% CI = 1.01, 1.19); subscapularis (OR = 1.12; 95% CI = 1.03, 1.21); and teres minor (OR = 1.11; 95% CI = 1.02, 1.21) (Table 5). Similar associations were observed in unadjusted models (Table 5).

DISCUSSION

Considering limited evidence about the relationship between obesity and FI in the literature[8; 28; 33], we performed a cross-sectional evaluation of the relationship between BMI and FI in individuals with rotator cuff tears from two independent cohorts. We found obesity was associated with substantially higher odds of having FI in both cohorts after adjusting for age, sex and tear characteristics including size of tear and duration of tear. The association between BMI and FI was similar when we changed the definition of FI to a more clinically relevant threshold of Grade 2 or higher in the Goutallier grading scale. Women had substantially higher odds of FI as compared with males after adjusting for confounding and mediating variables.

To our knowledge, only three[8; 28; 33] other studies have reported on the association between measures of obesity and FI. Lee et al[28] measured fat fraction in the supraspinatus, infraspinatus, subscapularis and teres minor muscle groups in 182 men and women presenting with shoulder problems including rotator cuff tears. They reported a positive association between BMI and fat fraction in multivariable adjusted linear regression models for each of the four muscle groups evaluated. Although the study adjusted for presence of tears, inclusion of individuals with and without tears could have potentially biased effect estimates between BMI and fat fraction because FI is far more prevalent in patients with tears than without tears. In agreement with Lee et al, our study finds that the positive associations between tear size and fatty infiltration and BMI and fatty infiltration are independent of each other as shown by persistence of associations after mutually adjusting for each other. These associations were consistent across all four tendons evaluated separately. Similar to Lee et al, we did not find any tears in the Teres minor tendon and observed a positive association between BMI and FI. Yet, we are not able to state if this is independent of tears as the influence of a tear on an adjacent or nearby tendon on fatty infiltration of the tendon in question cannot be discounted fully. A limitation for the study by Lee et al and the present study is the cross-sectional design where information on BMI and FI are abstracted simultaneously making it difficult to draw inferences regarding temporality. It is not clear whether elevated BMI leads to FI in individuals with tears, or if the observation between BMI and FI is coincidental, due to the presence of tears.

The two other studies that evaluated this association between BMI and FI were in individuals without rotator cuff tears. The observation of a positive association between BMI and FI by both studies suggests the relationship between obesity and FI may be independent of tears.

FI is histologically associated with increased interstitial connective tissue that is vascular with high macrophage density. Fat accumulation occurs at the surface of the muscle and within the sarcoplasm of muscle fibers. Obesity-induced alterations may promote FI through mechanisms that remain not fully understood. Matson et al[33] postulated that alterations in signaling pathways of proteins involved in rotator cuff muscle homeostasis such as protein kinase B (Akt) and mammalian target of rapamycin (mTOR)[40] may result in activation of genes that enhance protein breakdown and activate adipogenic changes mediated by sterol regulating element-binding protein 1 (SREBP1) and fibrotic changes mediated by transforming growth factor beta (TGF-b)[30]. This may promote differentiation of pre-adipocytes into adipocytes[29] via peroxisome proliferator-activated receptor gamma (PPARg)[24], which is linked to obesity[11; 41].

It is well-understood that functional outcomes of individuals who undergo surgical repair for rotator cuff tear are better in the absence of FI[13; 14; 26; 31; 32; 36; 42; 43; 45]. It is not known if weight reduction can reduce FI. If obesity is causally associated with FI, then understanding if FI can be reversed in part by losing body weight (through fat loss) has potential implications for patient care where a weight loss regimen prior to surgery may be used to reduce FI. Our study does not have data on this issue that needs further research.

We also evaluated the relationship between sex and FI and found that females were more likely to have FI than men after adjusting for age, BMI, tear size and duration of tear. This association was present in both cohorts, ROW and MOON. Lee et al[28] reported higher fat fraction in the supraspinatus, infraspinatus, and subscapularis in females as compared with males after adjusting for confounders. To find potential explanations for this observed association, we assessed the relationship between sex and FI with and without adjustment for covariates in the ROW cohort. We only observe a statistically significant increased odds of FI in women compared to men when we evaluate this association in a multivariable model. This association is absent in a model that only included sex and FI suggesting one or more of the variables that we adjusted for were strongly correlated with sex and FI. With the exception of aging, all other factors that we adjusted for are potential mediators of the association between sex and FI rather than confounders. Further evaluation of data showed women in our study on average had smaller tear size (cross section mean [SD] = 7.88 [14.9]) than men (cross section mean [SD] = 13.24 [20.96]). Because women were less likely to have larger tears and larger tears are associated with higher degree of FI, adjusting for this mediating variable necessarily generates a positive association between sex and FI. Therefore, results should be carefully interpreted, where females are more likely to have FI than men only when size of the tear is held constant on average. Barry et al[1] reported a 1.7 times increased odds of having higher grades of FI for women than for men. Sex differences in body fat composition are established with women having approximately 10% higher body fat compared to men for the same body mass index[12; 17; 25; 44]. Women have lower intra-abdominal fat mass than men on average and higher subcutaneous white adipose tissue in the abdominal and the gluteofemoral area than men[2; 5; 6; 38]. Whether women are more likely to have background FI than men, independent of tears, and whether this association is mediated by differences in fat composition and distribution are questions better addressed in a larger sample of men and women who do not have rotator cuff tears, than our present study which only assessed FI in men and women with tears. Although the mechanism is not entirely clear, it is possible that body fat composition differences and hormonal differences among males and females contribute towards a higher presence of FI of the rotator cuff in females. This may also be relevant for shoulder pain and functional outcomes after rotator cuff surgery where sex differences were reported in early postoperative recovery period. Women reported greater pain[3; 4] and lower ASES scores[4; 37] than men. If women have a higher propensity towards FI, a well-established factor for poor post-surgical outcomes, this may in part explain sub-optimal outcomes in women as compared with men that have been previously attributed to differences in pain perception and societal expectations.

CONCLUSION

FI is one of the most important prognostic factors for outcomes after rotator cuff surgery. However, data on the relationship between FI, and obesity and sex are limited. We found that obese patients had a significantly higher likelihood of FI in patients with rotator cuff tears. Sex was also significantly associated with FI, with females having substantially higher odds of FI as compared with males. The impact of modifying BMI in patients with rotator cuff tears on FI needs to be further studied. If women are more likely to have FI of the rotator cuff than men, as our results suggest, this may also explain the suboptimal outcomes of rotator cuff surgery and higher pain in females as compared to males. Supported by further investigations, these findings may lead to personalize care for rotator cuff tear patients before and after surgery and to improve surgical outcomes.

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Table 1.

Characteristics of participants in the MOON and ROW cohorts with MRI images of the rotator cuff.

		MOON			ROW	
Fatty Infiltration	**N**	**No**	**Yes**	**N**	**No**	**Yes**
		N=53	***N=27***		***N=106***	***N=60***
Body Mass index (kg/m^2)	80					
Q1, Q2, Q3		23, 25, 30	25, 29, 34		25, 28, 32	26, 29, 33
Mean (SD)		27.5 (5)	30 (6)		29 (6)	30 (5)
BMI (Category)	80			158		
<25		42% (22)	22% (6)		23% (24)	15% (9)
25–30		32% (17)	33% (9)		30% (31)	39% (23)
≥30		26% (14)	44% (12)		38% (41)	43% (26)
Missing		.	.		10% (10)	3% (2)
Age (years)	80					
Q1, Q2, Q3		55, 61, 69	59, 61, 69		53, 60, 67	60, 64, 69
Mean (SD)		62 (10)	65 (9)		61 (9)	64 (7)
Cross-sectional area (cm^2)	80			149		
Q1, Q2, Q3		1, 2, 4	4, 5, 7		0, 0.4, 2.3	3.1, 13.3, 39.8
Mean (SD)		3 (3)	5 (3)		2.4 (4.6)	23.6 (24.0)
Gender	80			158		
Female		38% (20)	74% (20)		44% (47)	46% (26)
Male		62% (33)	26% (7)		56% (59)	54% (34)
Duration of Shoulder Symptoms (years) *	80			158		
< 3		32% (17)	15% (4)		20% (21)	23% (14)
4–6		17% (9)	18% (5)		35% (37)	12% (7)
7–11		15% (8)	18% (5)		20% (21)	17% (10)
≥12		36% (19)	48% (13)		22% (24)	35% (21)
Missing		.	.		3% (3)	13% (8)

* prior to presentation

Table 2.

Associations evaluating body mass index and sex in relation to fatty infiltration in the MOON and ROW cohorts.

	MOON		ROW		Meta-analysis	
Variable	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**
Body mass index (BMI)						
BMI (continuous)	1.077	(0.970, 1.196)	1.051	(0.963, 1.148)	1.062	(0.993, 1.136)
BMI <25	1.000	(Ref)	1.000	(Ref)	1.000	(Ref)
BMI 25–30	7.132	(1.236, 41.156)	1.097	(0.254, 4.748)	2.369	(0.770, 7.291)
BMI > 30	3.498	(0.743, 16.465)	3.116	(0.773, 12.558)	3.281	(1.164, 9.248)
Sex (Female vs. Male [ref])	7.533	(1.981, 28.652)	3.592	(1.148, 11.245)	4.910	(2.062, 11.691)

Odds ratios (OR) and 95% Confidence interval (95% CI) were estimated using logistic regression using BMI (continuous) or BMI (categorical) and sex, while adjusting for age at MRI, cross sectional area of tear, and duration of tear. Meta-analysis OR (95% CI) were estimated using inverse variance-weighted fixed-effects meta-analysis across the two studies.

Table 3.

Sensitivity analyses evaluating body mass index and sex in relation to fatty infiltration in the ROW cohort.

	Unadjusted					
	N-cases/N-controls	FI (Grade 1 or higher)		N-cases/N-controls	FI (Grade 2 or higher)	
Variable		**OR**	**95% CI**		**OR**	**95% CI**
Body mass index (BMI)						
BMI (continuous)	58/96	1.02	(0.97, 1.08)	42/96	1.03	(0.97, 1.10)
BMI <25	9/24	1.00	(Ref)	4/24	1.000	(Ref)
BMI 25–30	23/31	1.98	(0.78, 5.05)	20/31	3.87	(1.17, 12.83)
BMI > 30	26/41	1.69	(0.68, 4.20)	18/41	2.63	(0.80, 8.70)
Sex (Female vs. Male [ref])	58/96	0.95	(0.51, 1.82)	42/96	0.70	(0.33, 1.46)

	Multivariable Adjusted					
	N-cases/N-controls	FI (Grade 1 or higher)		N-cases/N-controls	FI (Grade 2 or higher)	
Variable		**OR**	**95% CI**		**OR**	**95% CI**
Body mass index (BMI)						
BMI (continuous)	44/82	1.051	(0.963, 1.148)	31/82	1.08	(0.98, 1.21)
BMI <25	7/22	1.000	(Ref)	2/22	1.00	(Ref)
BMI 25–30	19/27	1.097	(0.254, 4.748)	16/27	2.52	(0.25, 25.76)
BMI > 30	18/33	3.116	(0.773, 12.558)	13/33	7.81	(0.84, 72.28)
Sex (Female vs. Male [ref])	44/82	3.592	(1.148, 11.245)	31/82	2.38	(0.59, 9.58)

FI = fatty infiltration defined either as grade 1 or higher level of fatty infiltration in the Goutallier scale; or as grade 2 or higher level of fatty infiltration in the Goutallier scale; Odds ratios (OR) and 95% Confidence interval (95% CI) were estimated using logistic regression using BMI (continuous) or BMI (categorical) and sex, while adjusting for age at MRI, cross sectional area of tear, and duration of tear for multivariable model. Unadjusted model only included BMI (continuous or categorical) or sex with FI.

Table 4.

Evaluating relationship between tear thickness and fatty infiltration by rotator cuff tendon location in the ROW cohort.

Tear location	Tear thickness	N (%)	Goutallier Fatty Infiltration Grade - N (%)					Unadjusted	Adjusted
			0	1	2	3	4	OR (95% CI)	OR (95% CI)
Supraspinatus	No tear	13 (8%)	11 (84.6%)	0 (0.0%)	1 (7.7%)	1 (7.7%)	0 (0.0%)	1.0 (Ref)	1.00 (Ref)
	Partial	53 (35%)	48 (90.6%)	4 (7.5%)	0 (0.0%)	1 (1.9%)	0 (0.0%)	0.57 (0.10, 3.35)	0.51 (0.08, 3.17)
	Full	100 (65%)	57 (57.0%)	15 (15.0%)	11 (11.0%)	4 (4.0%)	13 (13.0%)	4.15 (0.87, 19.70)	3.93 (0.78, 19.84)
	All	166 (100%)	116 (69.9%)	19 (11.5%)	12 (7.2%)	6 (3.6%)	13 (7.8%)	-	-
Infraspinatus	No tear	112 (68%)	100 (89.3%)	9 (8.0%)	2 (1.8%)	1 (0.9%)	0 (0.0%)	1.00 (Ref)	1.00 (Ref)
	Partial	12 (7%)	10 (83.34%)	1 (8.3%)	0 (0.0%)	1 (8.3%)	0 (0.0%)	1.67 (0.33, 8.52)	0.73 (0.11, 4.87)
	Full	41 (25%)	11 (26.8%)	6 (14.6%)	9 (22.0%)	3 (7.3%)	12 (29.3%)	22.73 (9.11, 56.70)	27.22 (9.32, 79.53)
	All	165 (100%)	121 (73.3%)	16 (9.7%)	11 (6.7%)	5 (3.0%)	12 (7.3%)	-	-
Subscapularis	No tear	141 (86%)	124 (87.9%)	8 (5.7%)	2 (1.4%)	2 (1.4%)	5 (3.6%)	1.00 (Ref)	1.00 (Ref)
	Partial	8 (5%)	6 (75.0%)	1 (12.5%)	1 (12.5%)	0 (0%)	0 (0%)	2.43 (0.45, 13.03)	4.19 (0.60, 29.18)
	Full	15 (9%)	8 (53.3%)	1 (6.7%)	1 (6.7%)	4 (26.6%)	1 (6.7%)	6.38 (2.05, 19.84)	5.64 (1.59, 20.04)
	All	164 (100%)	138 (84.1%)	10 (6.1%)	4 (2.4%)	6 (3.7%)	6 (3.7%)	-	-
Teres Minor	No tear	164 (100%)	148 (90.2%)	9 (5.5%)	1 (0.6%)	1 (0.6%)	5 (3.1%)	-	-

OR = odds ratios; 95% CI = 95% Confidence Interval; ORs were computed from logistic regression models for association between tear thickness (no tear as reference group) and fatty infiltration (Grade >= 1); Unadjusted ORs represent models with only tear thickness as independent variable: Adjusted ORs represent models that were additionally adjusted for BMI, sex, and participant age at baseline

Table 5.

Evaluating the relationship between BMI and fatty infiltration by rotator cuff tendon location in the ROW cohort.

Tear location	Body mass index	FI/No FI	Unadjusted	Adjusted
			OR (95% CI)	**OR (95% CI)**
Supraspinatus	BMI (continuous)	49/105	1.02 (0.96, 1.08)	OR (95% CI)1.04 (0.98, 1.11)
	BMI <25	7/26	1.00 (Ref)	1.00 (Ref)
	BMI 25–30	22/32	2.55 (0.94, 6.91)	5.26 (1.60, 17.33)
	BMI > 30	20/47	1.58 (0.59, 4.23)	3.06 (0.98, 9.55)
Infraspinatus	BMI (continuous)	44/109	1.06 (1.00, 1.12)	1.09 (1.01, 1.19)
	BMI <25	4/29	1.00 (Ref)	1.00 (Ref)
	BMI 25–30	18/36	3.63 (1.10, 11.90)	3.20 (0.66, 15.66)
	BMI > 30	22/44	3.63 (1.13, 11.61)	7.10 (1.41, 35.85)
Subscapularis	BMI (continuous)	55/127	1.08 (1.01, 1.16)	1.12 (1.03, 1.21)
	BMI <25	1/32	1.00 (Ref)	1.00 (Ref)
	BMI 25–30	11/42	8.38 (1.03, 68.31)	5.90 (0.64, 53.95)
	BMI > 30	13/53	7.85 (0.98, 62.87)	8.99 (1.07, 75.69)
Teres Minor	BMI (continuous)	16/136	1.08 (1.00, 1.17)	1.11 (1.02, 1.21)
	BMI <25	2/31	1.00 (Ref)	1.00 (Ref)
	BMI 25–30	4/49	1.27 (0.22, 7.32)	1.70 (0.28, 10.52)
	BMI > 30	10/56	2.77 (0.57, 13.44)	3.94 (0.76, 20.60)

FI = fatty infiltration defined as absence (0 on Goutallier scale) and presence (Goutallier grades 1 – 4 as infiltration). Odds ratios computed for BMI measures and FI with and without multivariable adjustment by tendon location. For supraspinatus, infraspinatus and subscapularis multivariable models were adjusted for age at MRI, sex, and tear thickness at the corresponding tendon (none, partial tear, or no-tear). Multivariable model for teres minor did not adjust for tear as there were no tears.