Clin Orthop Relat Res (2021) 479:2471-2479
DOI 10.1097/CORR.0000000000001798

Clinical Orthopaedics and Related Research®
A Publication of The Association of Bone and Joint Surgeons®

Clinical Research

Imbalance in Axial-plane Rotator Cuff Fatty Infiltration in Posteriorly Worn Glenoids in Primary Glenohumeral Osteoarthritis: An MRI-based Study

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Received: 20 November 2020 / Accepted: 9 April 2021 / Published online: 11 May 2021

Abstract

Background Fatty infiltration of the rotator cuff evaluated with CT has been associated with asymmetric glenoid wear and humeral head subluxation in patients with glenohumeral arthritis. The relationship between rotator cuff pathologic findings and abnormal glenoid wear plays an important role in determining the optimal surgical management of advanced glenohumeral osteoarthritis. Compared with CT, MRI has increased sensitivity for identifying rotator cuff conditions; therefore, prior studies using CT may have underestimated the association between fatty infiltration of the rotator cuff and abnormal glenoid wear.

Questions/purposes (1) Compared with Type A glenoids, which muscles in which Walch subtypes have a greater degree of fatty infiltration using Goutallier scores? (2) What glenoid type is associated with greater imbalance in fatty infiltration, as measured by comparing Goutallier scores between the posterior and anterior rotator cuff muscles? (3) What is the correlation between glenoid version and fatty infiltration of the rotator cuff muscles? (4) Comparing Type B2 and B3 glenoids with Type A glenoids, after accounting for age and sex, is there an increase in fatty infiltration of the infraspinatus muscle?

Methods A total of 129 shoulders from 129 patients undergoing anatomic total shoulder arthroplasty to treat primary glenohumeral osteoarthritis were retrospectively reviewed. Patients had an average age of 66.4 ± 9.3 years and an average BMI of 30.6 ± 6.7 kg/m^2, and 53% (69 of 129) were men. All patients underwent MRI within 12 months before total shoulder arthroplasty to assess glenoid morphology and rotator cuff pathologic findings. Three reviewers assessed the images, and glenoid morphology was assigned using the modified Walch classification system (Types A1, A2, B1, B2, B3, C, and D). Fatty infiltration of the rotator cuff was classified using Goutallier scores. The examiners demonstrated moderate-to-good reliability using these classification systems; the Walch classification system had interrater reliability kappa coefficients (κ) from 0.54 to 0.69 and intrarater reliability κ from 0.60 to 0.64. Goutallier scores using the simplified classification system had interrater reliability κ from 0.64 to 0.68 and intrarater reliability κ from 0.64 to 0.79. Thirty-six percent (46 of 129) of the shoulders had posterior wear patterns (18% [23] were Type B2 glenoids; 18% [23] were Type B3 glenoids). The average Goutallier scores for each rotator cuff muscle were determined, and the amount of fatty infiltration was compared between the various Walch subtypes using independent t-tests. Axial-plane imbalance

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All ICMJE Conflict of Interest Forms for authors and *Clinical Orthopaedics and Related Research®* editors and board members are on file with the publication and can be viewed on request.
Ethical approval for this study was obtained from Northwestern University, Chicago, IL, USA (ID: STU00209100).

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in fatty infiltration of the rotator cuff was assessed by determining the difference in the average fatty infiltration of the posterior rotator cuff muscles (infraspinatus and teres minor) and anterior rotator cuff muscles (subscapularis) and comparing the differences among the Walch subtypes using independent t-tests. The association between glenoid version and fatty infiltration was assessed using Pearson correlations. Finally, a multivariate logistic regression model was used to assess fatty infiltration of the rotator cuff among the various Walch subtypes while accounting for patient age and sex.

Results Compared with Type A1 glenoids, Type B2 and B3 glenoids had an increased amount of fatty infiltration of the infraspinatus (1.6 ± 0.7 versus 0.7 ± 0.4; mean difference 0.9 [95% CI 0.7-1.2]; $p < 0.001$ and 1.8 ± 0.4 versus 0.7 ± 0.4; mean difference 1.1 [95% CI 0.9-1.4]; $p < 0.001$, respectively) and teres minor (1.3 ± 0.7 versus 0.6 ± 0.5; mean difference 0.7 [95% CI 0.4-1.0]; $p < 0.001$ and 1.6 ± 0.6 versus 0.6 ± 0.5; mean difference 1.0 [95% CI 0.7-1.2]; $p < 0.001$, respectively). There was greater imbalance in fatty infiltration between the posterior and anterior rotator cuff muscles for Type B2 (0.5 ± 0.3) and B3 (0.6 ± 0.5) glenoids than for Type A1 (0.1 ± 0.3) and A2 (0.1 ± 0.6) glenoids ($p < 0.001$). Only the infraspinatus's fatty infiltration was strongly correlated with glenoid version ($r = 0.64$; $p < 0.001$), while fatty infiltration of the other muscles only correlated weakly or moderately. After accounting for age and sex, fatty infiltration in the infraspinatus was associated with Type B2 (OR 66.1 [95% CI 7.6-577.9]; $p < 0.001$) and Type B3 glenoids (OR 59.5 [95% CI 5.4-661.3]; $p < 0.001$) compared with Type A glenoids.

Conclusion Compared with concentric wear, posteriorly worn glenoids had an imbalance in axial-plane rotator cuff fatty infiltration and an increased amount of fatty infiltration of the infraspinatus and teres minor compared with the subscapularis. These imbalances may contribute to the higher rates of failure after anatomic total shoulder arthroplasty in patients with posterior wear compared with those with concentric wear. Future research should be directed toward investigating the temporal relationship of these findings, as well as understanding the clinical outcomes for patients undergoing anatomic total shoulder arthroplasty who have posteriorly worn glenoids with a high degree of fatty infiltration of the posterior rotator cuff musculature.

Clinical Relevance Providers should consider the increased likelihood of higher-grade fatty infiltration of the posterior rotator cuff in the setting of posteriorly worn glenoids, particularly when treating patients without using MRI. These patients have higher rates of failure postoperatively and may benefit from closer monitoring and altered postoperative rehabilitation protocols that target the posterior rotator cuff.

Introduction

Consideration of the glenoid morphology is critical in the success of anatomic total shoulder arthroplasty for primary glenohumeral osteoarthritis [15, 24]. Failure to accommodate for the variations in glenoid morphology can result in component loosening and early failure of total shoulder arthroplasty and subsequent revision [12, 15]. Posteriorly worn glenoids are particularly challenging and have been associated with posterior humeral-head subluxation as the joint degenerates over time [9, 20-22]. The rotator cuff plays an integral role in the success of anatomic total shoulder arthroplasty, and is therefore an important structure to understand and consider in the optimization of total shoulder arthroplasty.

Recent CT-based studies have investigated the association between pathologic patterns of glenoid wear and rotator cuff conditions [1, 4]. Some authors have identified more high-grade fatty infiltration of the posterior rotator cuff muscles (the infraspinatus and teres minor) in B3-type glenoids [4], whereas others have found an increase in the ratio of posterior rotator cuff muscle bulk to anterior rotator cuff bulk as being associated with B2-type glenoids [1]. The amount of glenoid retroversion has also been correlated with an increasing amount of fatty infiltration of the posterior rotator cuff [4]. The two previously mentioned studies used CT to assess the rotator cuff, although CT has been demonstrated to underestimate the severity of fatty infiltration of the rotator cuff in patients with glenohumeral osteoarthritis compared with MRI [5]. MRI has an improved ability to distinguish between healthy muscle and pathologic fibrous tissue and has been shown to be largely comparable to CT for evaluating glenoid morphology and version [11, 18]. Additionally, the quality of MRI has continued to improve with time, and surgeons are increasingly able to proceed with surgical planning for total shoulder arthroplasty, particularly in the setting of pathologic glenoid morphology, without the need for CT. Finally, age and sex have been associated with the muscle area of the rotator cuff, but they have not been controlled for in prior studies investigating the association between fatty infiltration of the rotator cuff and glenoid morphology [1].

Therefore, we sought to answer the following questions: (1) Compared with Type A glenoids, which muscles in which Walch subtypes have a greater degree of fatty infiltration using Goutallier scores? (2) What glenoid type is associated with greater imbalance in fatty infiltration, as measured by comparing Goutallier scores between the posterior and anterior rotator cuff muscles? (3) What is the correlation between glenoid version and fatty infiltration of the rotator cuff muscles? (4) Comparing Type B2 and B3 glenoids with Type A glenoids, after accounting for age and sex, is there an increase in fatty infiltration of the infraspinatus muscle?

Patients and Methods

We retrospectively reviewed patients undergoing surgery at our institution, and the electronic medical record was reviewed to collect patient demographic information. We identified 312 patients treated with anatomic total shoulder arthroplasty for glenohumeral osteoarthritis between 2009 and 2018. Of these, we considered those who had an MRI performed before their procedure as potentially eligible. Based on this criterion, 51% (160 of 312) were eligible; further exclusions included 6% (20 of 312) for having MRI performed greater than 12 months from the time of surgery, 1% (4 of 312) for a history of avascular necrosis, 1% (3 of 312) for having a bilateral procedure, 1% (2 of 312) for having a history of rheumatoid arthritis, and 1% (2 of 312) for having revision procedures. All MRIs had high-quality resolution (minimum 1.5 T) and had adequate imaging sequences in the axial and sagittal planes that allowed for a full assessment of glenoid morphology and fatty infiltration of the rotator cuff muscles.

Patient Demographics

One hundred twenty-nine shoulders in 129 patients with primary glenohumeral osteoarthritis who were scheduled to undergo anatomic total shoulder arthroplasty and had an MRI of the shoulder were identified and included in this study (Table 1). Patients had an average age of 66.4 ± 9.3 years and an average BMI of 30.6 ± 6.7 kg/m^2, and 53% (69 of 129) were men.

Patient images were de-identified and reviewed by three orthopaedic surgeons (MJH, REH, and PTS). Fatty infiltration of the rotator cuff was evaluated using T1 sagittal oblique sequences and the Goutallier classification, with scores ranging from 0 to 4 [8]. This system was originally created using CT to determine the degree of fatty infiltration on a single slice immediately medial to the spinoglenoid notch, Y-view [7, 8, 13]. MR images were reviewed in a similar fashion in order to assign Goutallier grades using the sagittal sequences. Goutallier assignments were made with the examiners blinded to the Walch classification, and the three scores for each patient were averaged. Goutallier scores for the supraspinatus were assessed using a previously described, simplified classification system [17]. The examiners in this study demonstrated good interrater reliability, established with kappa coefficients (κ) of 0.64 to 0.68 (Pair 1: κ = 0.65 [95% CI 0.52-0.77]; Pair 2: κ = 0.68 [95% CI 0.56-0.80]; Pair 3: κ = 0.64 [95% CI 0.51-0.77]) and good intrarater reliability with κ of 0.64 to 0.79 (Reviewer 1: κ = 0.79 [95% CI 0.69-0.89]; Reviewer 2: κ = 0.73 [95% CI 0.61-0.85]; Reviewer 3: κ = 0.64 [95% CI 0.51-0.77]). These values are consistent with reported values that range from 0.43 to 0.82 for interrater reliability and 0.70 to 0.83 for intrarater reliability [16, 17].

Blinded to Goutallier grade results, the same three examiners (MJH, REH, and PTS) independently evaluated glenoid morphology on axial-plane sequences according to the modified Walch classification, and a final consensus was obtained for all shoulders [19, 21]. Glenoid version was assessed using MR images and was determined by measuring the angle between a line drawn from the anterior and posterior rims of the glenoid and a line down the scapular plane, as previously described [6]. Posterior humeral-head subluxation was defined as the location of the center of the humeral head with reference to the scapular plane. Glenoid types consisted of Types A1, A2, B1, B2, B3, C, and D. Type B1 glenoids were defined as posterior humeral-head subluxation greater than 55% with minimal glenoid erosion. Type B2 glenoids similarly had posterior humeral-head subluxation but had a clear biconcave appearance. Type B3 glenoids were defined as having a monoconcave appearance with greater than 15° of retroversion or greater than 70% of posterior humeral-head subluxation, as defined in an updated definition of the Type B3 glenoid [2]. The Walch classification demonstrated moderate-to-good interrater reliability, with κ of 0.54 to 0.69 (Pair 1: κ = 0.54 [95% CI 0.44-0.65]; Pair 2: κ = 0.60 [95% CI 0.50-0.70]; Pair 3: κ = 0.69 [95% CI 0.60-0.79]) and good intrarater reliability with κ of 0.60 to 0.64 (Reviewer 1: κ = 0.62 [95% CI 0.52-0.72]; Reviewer 2:

Table 1. Descriptive statistics and comparisons by Walch subtype (n = 129 patients)

Patient characteristics	All patients	A1	A2	B1	B2	B3	Significance
Percentage (n) of all patients		28 (36)	25 (32)	12 (15)	18 (23)	18 (23)	
BMI in kg/m^2, mean ± SD[a]	30.6 ± 6.7	30.9 ± 5.7	31.5 ± 7.2	30.9 ± 9.2	28.7 ± 5.0	30.6 ± 7.1	0.64
Age in years, mean ± SD[a]	66.4 ± 9.3	62.5 ± 7.5	71.3 ± 8.8	64.3 ± 11.4	65.8 ± 9.4	67.6 ± 8.7	< 0.001
Percentage (n) men[b]	53 (69)	42 (15)	53 (17)	40 (6)	61 (14)	74 (17)	0.13
Glenoid retroversion in degrees, mean ± SD[a]	11.9 ± 8.1	6.0 ± 5.9	8.1 ± 4.1	10.3 ± 4.8	16.7 ± 6.0	22.8 ± 5.5	< 0.001

[a]p values were calculated using one-way analysis of variance between all Walch subtypes.
[b]p values were calculated using a chi-squared test between all Walch subtypes.

κ = 0.60 [95% CI 0.50-0.71]; Reviewer 3: κ = 0.64 [95% CI 0.53-0.74]). These values were consistent with or higher than reported values ranging from 0.51 to 0.60 for interrater reliability and 0.61 for intrarater reliability [10, 14].

Ethical Approval

Ethical approval for this study was obtained from the institutional review board at Northwestern University.

Statistical Analysis

Descriptive statistics were evaluated for demographic factors across Walch classification groups. Analysis of variance was used to identify differences between Walch subtypes for the various patient characteristics. For variables with statistical significance, a post hoc Tukey test was used to identify specific differences between Walch subtypes. Average Goutallier scores were then determined for each rotator cuff and compared between various Walch subtypes using independent t-tests. Axial-plane imbalance in fatty infiltration of the rotator cuff was assessed by determining the difference in the average fatty infiltration of the posterior rotator cuff muscles (infraspinatus and teres minor) and the anterior rotator cuff muscles (subscapularis). These values were then compared among the various Walch subtypes using independent t-tests. The association between glenoid version and fatty infiltration was assessed using Pearson correlation. Finally, a multinominal multivariate logistic regression model was used to assess fatty infiltration of the rotator cuff among the various Walch subtypes. Patient characteristics that were significantly different ($p < 0.1$) among the Walch subtypes in the post hoc Tukey test were included in the final analysis. All statistical analyses were performed using SPSS Version 23 (IBM Corp.), with α set at 0.05.

Results

Goutallier Scores by Walch Subtype

Compared with Type A1 glenoids, Type B2 and B3 glenoids had an increased amount of fatty infiltration of the infraspinatus (1.6 ± 0.7 versus 0.7 ± 0.4; mean difference 0.9 [95% CI 0.7-1.2]; $p < 0.001$ and 1.8 ± 0.4 versus 0.7 ± 0.4; mean difference 1.1 [95% CI 0.9-1.4]; $p < 0.001$, respectively) and teres minor (1.3 ± 0.7 versus 0.6 ± 0.5; mean difference 0.7 [95% CI 0.4-1.0]; $p < 0.001$ and 1.6 ± 0.6 versus 0.6 ± 0.5; mean difference 1.0 [95% CI 0.7-1.2]; $p < 0.001$, respectively) (Table 2). There was no difference in the amount of fatty infiltration of any of the rotator cuff muscles between Type B2 and B3 glenoids (1.6 ± 0.7 versus 1.8 ± 0.4; mean difference 0.2 [95% CI -0.1 to 0.5]; p = 0.15 for the infraspinatus; 1.3 ± 0.7 versus 1.6 ± 0.6; mean difference 0.3 [95% CI -0.1 to 0.6]; p = 0.08 for the teres minor, and 0.9 ± 0.6 versus 1.1 ± 0.5; mean difference 0.2 [95% CI -0.1 to 0.5]; p = 0.12 for the subscapularis) (Table 3). The infraspinatus and teres minor had higher-grade fatty infiltration than the subscapularis in Type B2 and B3 glenoids but were no different from the subscapularis in A1, A2, and B1 glenoids (Fig. 1).

Imbalance in Fatty Infiltration of the Posterior and Anterior Rotator Cuff

There was greater imbalance in fatty infiltration between the posterior and anterior rotator cuff muscles for Type B2 (0.5 ± 0.3) and B3 (0.6 ± 0.5) glenoids than for Type A1 (0.1 ± 0.3) and A2 (0.1 ± 0.6) ($p < 0.001$) glenoids (Table 2). There was no difference in axial-plane imbalance between Type A1 and A2 glenoids and Type B2 and B3 glenoids (Fig. 2).

Correlations of Fatty Infiltration of the Rotator Cuff with Glenoid Version and BMI

The infraspinatus was the only rotator cuff muscle with a strong correlation with glenoid version ($r = 0.64$; $p < 0.001$) (Table 4). Fatty infiltration of the other rotator cuff muscles was only weakly or moderately correlated with glenoid version. There were no correlations between any of the rotator cuff muscles and BMI.

Fatty Infiltration by Walch Classification After Accounting for Age and Sex

After accounting for age and sex, compared with Type A glenoids, fatty infiltration of the infraspinatus was associated with Type B2 (OR 66.1 [95% CI 7.55-577.88]; $p < 0.001$) and Type B3 glenoids (OR 59.53 [95% CI 5.36-661.31]; $p < 0.001$) (Table 5). Men were also more likely to have Type B2 (OR 4.47 [95% CI 1.11-18.01]; p = 0.04) and Type B3 (OR 12.17 [95% CI 2.40-61.65]; p = 0.003) glenoids than women were.

Discussion

Glenoid morphology and rotator cuff integrity play an integral role in the success of anatomic total shoulder arthroplasty, and failure to account for pathologic findings in either of these structures can result in component

Table 2. The mean Goutallier scores by Walch classification subtypes

	A1	A2	B1	B2	B3
Infraspinatus, mean ± SD	0.7 ± 0.4	1.1 ± 0.4	0.9 ± 0.5	1.6 ± 0.7	1.8 ± 0.4
Teres minor, mean ± SD	0.6 ± 0.5	0.9 ± 0.3	0.6 ± 0.5	1.3 ± 0.7	1.6 ± 0.6
Subscapularis, mean ± SD	0.5 ± 0.4	0.9 ± 0.6	0.7 ± 0.5	0.9 ± 0.6	1.1 ± 0.5
Axial-plane imbalance[a], mean ± SD	0.1 ± 0.3	0.1 ± 0.6	0.1 ± 0.2	0.5 ± 0.3	0.6 ± 0.5

[a]Comparison of differences in Goutallier scores between the posterior rotator cuff muscles (infraspinatus and teres minor) and anterior rotator cuff muscles (subscapularis).

loosening and early failure [12, 15, 24]. CT-based studies have investigated the association between pathologic patterns of glenoid wear and rotator cuff pathology but have had conflicting results [1, 4]. Some authors found that fatty infiltration of the posterior rotator cuff was associated with patterns of posterior glenoid wear [4], while others have found that hypertrophy of the posterior rotator cuff musculature is associated with patterns of posterior glenoid wear [1]. CT, however, substantially underestimates the severity of fatty infiltration of the rotator cuff compared with MRI [5]. We therefore investigated the relationship between glenoid wear and rotator cuff pathologic findings using MRI, while also performing analyses that account for patient characteristics known to have an association with pathologic glenoid morphology and fatty infiltration of the rotator cuff. We found that compared with concentrically worn glenoids, posteriorly worn glenoids have an imbalance in axial-plane rotator cuff fatty infiltration, with an increased amount of fatty infiltration in the infraspinatus and teres minor compared with the subscapularis. Providers should consider the increased likelihood of higher-grade fatty infiltration of the posterior rotator cuff in the setting of posteriorly worn glenoids, particularly when treating patients without the use of MRI. These patients are known to have higher proportions of failure postoperatively and may benefit from closer monitoring and altered postoperative rehabilitation protocols that target the posterior rotator cuff.

Limitations

This study has several limitations. The patients in this study had primary glenohumeral osteoarthritis; therefore, these results do not apply to patients with other conditions such as rheumatologic conditions, those with a history of avascular necrosis, or those with prior humerus fractures. Additionally, all patients in this study had an MRI available for review; MRIs are not a routine part of the treating surgeons' workup for total shoulder arthroplasty, but patients may have had the MRI ordered by providers before evaluation by the surgeon performing the total shoulder arthroplasty. Next, the sample size in the current study was small and limited our ability to identify additional potential risk factors for either glenoid findings or fatty infiltration of the rotator cuff, such as hyperlipidemia. Therefore, providers should understand that this study does not rule out other factors that are associated with these findings. Providers should also be aware that the Goutallier classification has a wide range of reliability from moderate to good agreement when used by orthopaedic surgeons [18]; the present study found good interrater and intrarater reliability. Next, some

Table 3. The mean Goutallier scores by Walch classification subtypes

	Infraspinatus		Teres minor		Subscapularis		Axial-plane imbalance[a]	
	Mean difference (95% CI)	p value	Mean difference (95% CI)	p value	Mean difference (95% CI)	p value	Mean difference (95% CI)	p value
A1:A2	0.4 (0.1-0.6)	0.002	0.3 (0.1-0.6)	0.01	0.4 (0.1-0.6)	0.003	0.0 (-0.2 to 0.2)	0.90
B2:A1	0.9 (0.7-1.2)	< 0.001	0.7 (0.4-1.0)	< 0.001	0.4 (0.1-0.7)	0.004	0.4 (0.2-0.6)	< 0.001
B2:A2	0.5 (0.3-0.8)	< 0.001	0.4 (0.1-0.6)	0.01	0.0 (-0.2 to 0.3)	0.87	0.4 (0.2-0.6)	< 0.001
B2:B1	0.7 (0.4-1.0)	< 0.001	0.7 (0.3-1.0)	< 0.001	0.2 (-0.1 to 0.6)	0.15	0.4 (0.2-0.7)	0.001
B2:B3	0.2 (-0.1 to 0.5)	0.15	0.3 (-0.1 to 0.6)	0.08	0.2 (-0.1 to 0.5)	0.12	0.1 (-0.2 to 0.9)	0.90
B3:A1	1.1 (0.9-1.4)	< 0.001	1.0 (0.7-1.2)	< 0.001	0.6 (0.4-0.9)	< 0.001	0.5 (0.2-0.6)	< 0.001
B3:A2	0.7 (0.5-1.0)	< 0.001	0.7 (0.4-0.9)	< 0.001	0.2 (-0.1 to 0.5)	0.07	0.5 (0.2-0.6)	< 0.001
B3:B1	0.9 (0.6, 1.2)	< 0.001	1.0 (0.6-1.3)	< 0.001	0.4 (0.1-0.8)	0.006	0.5 (0.2-0.7)	< 0.001

[a]Comparison of differences in Goutallier scores between the posterior rotator cuff muscles (infraspinatus and teres minor) and anterior rotator cuff muscles (subscapularis).

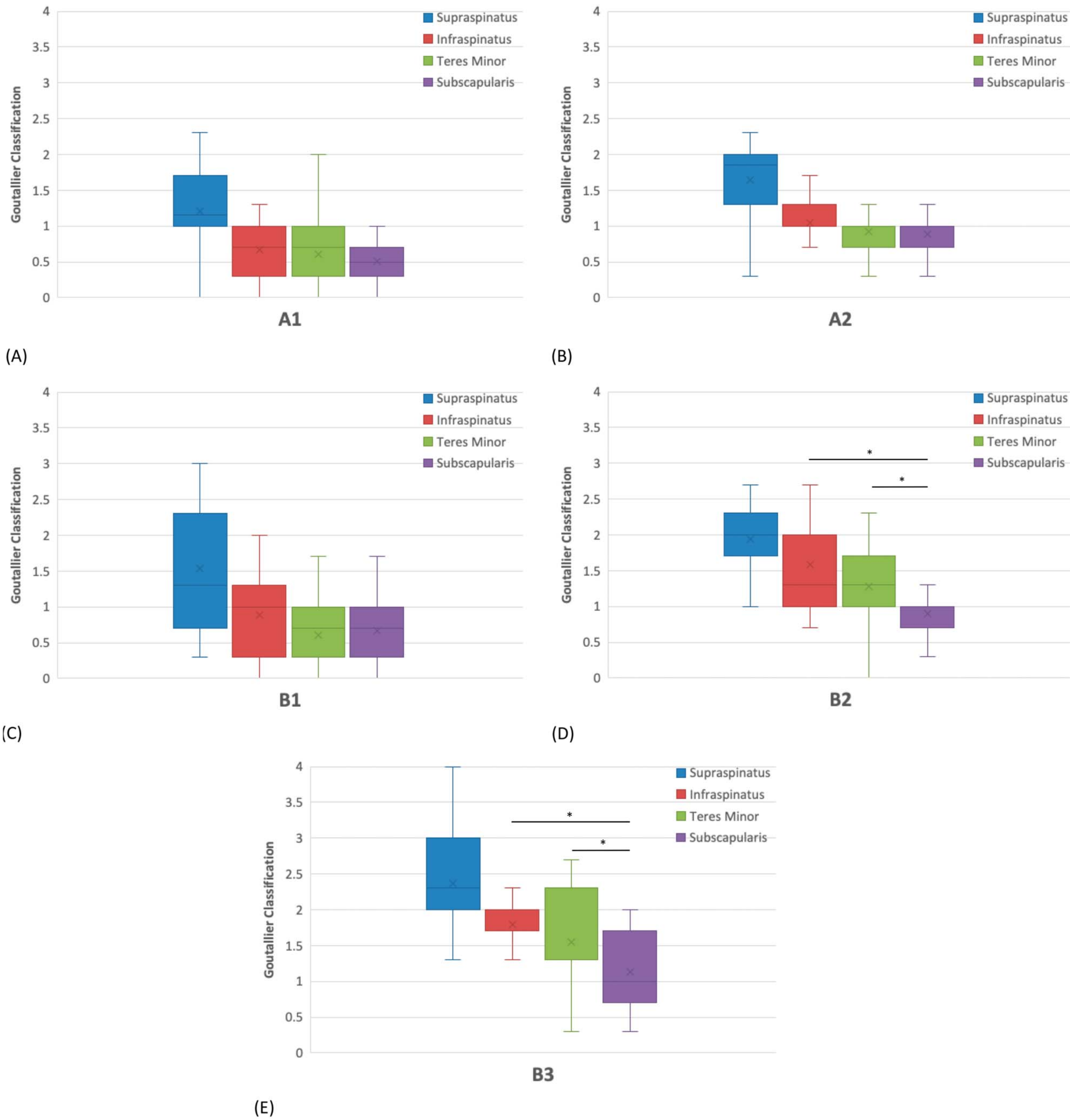

Fig. 1 These box-and-whisker plots demonstrate the mean ± SD Goutallier score of all four rotator cuff muscles by Walch classification subtype: (**A**) A1, (**B**) A2, (**C**) B1, (**D**) B2, and (**E**) B3. The horizontal lines in each figure represent direct comparisons between the means of the designated rotator cuff muscles (* = $p < 0.05$).

authors have suggested that MRI under-identifies Type B2 glenoids and over-identifies Type C glenoids, which have very similar characteristics to Type B2 glenoids [11]. However, that study [11] did not evaluate for Type B3 glenoids, as we did in the present study, which limits the ability to generalize their findings with respect to characterizing posterior glenoid wear with MRI. Further, a more recent systematic review of imaging modalities used to assess the glenoid found that both CT and MRI can accurately measure glenoid bone loss [23]. Lastly, we did not account for joint-line medialization, a factor that has been associated with fatty infiltration of the rotator cuff [7]. However, Type B3 glenoids have more fatty infiltration of the rotator cuff after controlling for joint-line medialization [7]; therefore, although joint-line medialization has an association with Type B3 glenoids, this association is not as

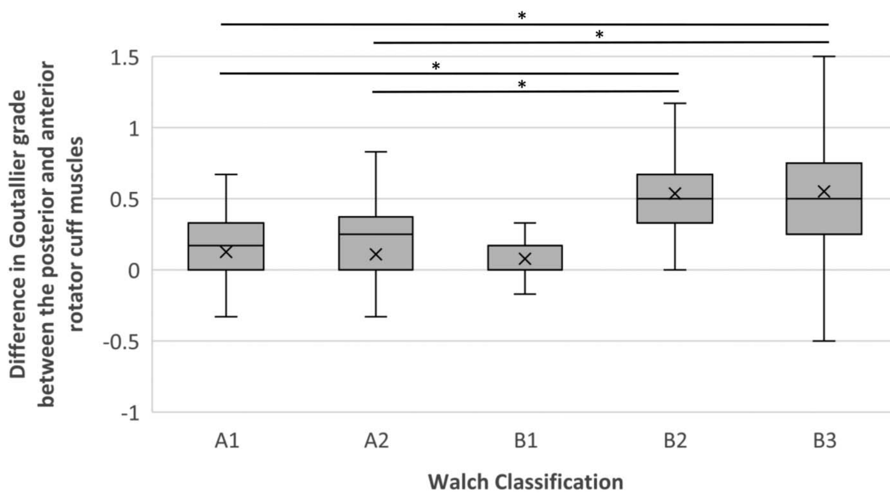

Fig. 2 This box-and-whisker plot demonstrates imbalance in fatty infiltration of the posterior rotator cuff muscles (infraspinatus and teres minor) compared with that of the anterior rotator cuff muscles (subscapularis) by Walch subtype. Imbalance was calculated by subtracting the mean Goutallier score of the subscapularis from the mean score of the infraspinatus and teres minor. The horizontal lines above the plots represent direct comparisons between the designated rotator cuff muscles (* $p < 0.05$).

strong as the association with fatty infiltration. Nonetheless, providers should be aware that joint-line medialization may contribute to fatty infiltration of the rotator cuff.

Goutallier Scores by Walch Subtype

Patients with Type B2 and B3 glenoids had a greater degree of fatty infiltration, primarily in the posterior rotator cuff. One study investigated 190 CT images from patients undergoing total shoulder arthroplasty and assigned Goutallier classifications to each, which were simplified to a three-score system as previously described [7]. The authors found that higher-grade fatty infiltration of the rotator cuff was associated with Type B3 glenoids, increased pathologic glenoid retroversion, and joint-line medialization. They also found less fatty infiltration in Type B2 glenoids (16%) than in Type B3 glenoids (55%). In contrast, our current MRI-based study found higher-grade fatty infiltration in both B2- and B3-type glenoids but did not find any differences in the degree of fatty infiltration between the two. Importantly, our study also controlled for age and sex in a multivariate analysis and found increased fatty infiltration in both the infraspinatus and teres minor in patients with Types B2 and B3 glenoids compared with those with Type A glenoids after accounting for these confounding variables. These variations in methods may account for the different findings between studies. Surgeons should therefore consider that patients with both B2- and B3-type glenoids are likely to have higher-grade fatty infiltration of the posterior rotator cuff musculature. Additionally, researchers should consider this information to support the use MRI in future studies that investigate the temporal relationship between fatty infiltration of the rotator cuff and patterns of posterior glenoid wear.

Imbalance in Fatty Infiltration of the Posterior and Anterior Rotator Cuff

Type B2 and B3 glenoids had more imbalance in fatty infiltration between the posterior and anterior rotator cuff muscles than Type A glenoids did. We did not, however,

Table 4. Relationship between fatty infiltration in each rotator cuff muscle and glenoid version or BMI

	Supraspinatus		Infraspinatus		Teres minor		Subscapularis	
Variable	r	p value	r	p value	r	p value	r	p value
Glenoid version	0.39	< 0.001	0.64	< 0.001	0.56	< 0.001	0.34	< 0.001
BMI	-0.07	0.40	-0.009	0.92	0.11	0.24	0.06	0.49

Calculated using Pearson correlations.

Table 5. Multivariate logistic regression model by glenoid type based on Walch classification[a]

	B1		B2		B3	
Variable	OR (95% CI)	p value	OR (95% CI)	p value	OR (95% CI)	p value
Age[b]	0.96 (0.90-1.03)	0.27	0.93 (0.86-1.01)	0.08	0.93 (0.86-1.02)	0.12
Sex (men)	0.83 (0.23-3.01)	0.78	4.47 (1.11-18.01)	0.04	12.17 (2.40-61.65)	0.003
Fatty infiltration[c]						
Supraspinatus	1.62 (0.44-5.78)	0.47	1.20 (0.32-4.58)	0.79	2.47 (0.53-11.44)	0.25
Infraspinatus	3.31 (0.33-33.37)	0.31	66.1 (7.55-577.88)	< 0.001	59.53 (5.36-661.31)	< 0.001
Teres minor	0.08 (0.01-1.00)	0.05	2.04 (0.35-11.80)	0.42	2.96 (0.46-19.23)	0.26
Subscapularis	2.18 (0.23-17.07)	0.46	0.17 (0.02-1.61)	0.12	0.20 (0.02-2.24)	0.19

[a]Walch Type B glenoids were compared with Type A glenoids as the reference group.
[b]Age was analyzed as a continuous variable, with presented odds ratios representing the change in odds per year.
[c]For each of the four rotator cuff muscles, odds ratios represent the increase in odds for the specified Walch type with each increasing grade of fatty infiltration according to the Goutallier classification.

find a difference in imbalance between B2- and B3-type glenoids. The etiology of Type B2 and B3 glenoids has been debated, and while it may seem intuitive for Type B3 glenoids to be a progression from Type B2 glenoids, contradictory evidence has demonstrated that these may be two separate patterns of wear that have no temporal relation to one another [3, 22]. The results from the present study do not allow for speculation on the temporal relationship between fatty infiltration of the rotator cuff and patterns of posterior glenoid wear, given the cross-sectional design of the study. However, we were able to demonstrate that similar muscle imbalance forces exist in both B2- and B3-type glenoids. Further temporal studies using MRI are needed to better characterize the potential effect of fatty infiltration of the rotator cuff on the progression of pathologic glenoid morphology.

Correlations of Fatty Infiltration of the Rotator Cuff with Glenoid Version and BMI

Increased glenoid version strongly correlated with greater fatty infiltration of the infraspinatus; there were no correlations between glenoid version and BMI. This finding is similar to that reported in a CT-based study that investigated the association between fatty infiltration of the rotator cuff and glenoid morphology [4]. The current MRI-based study evaluated bony morphology of the glenoid and found a similar correlation between glenoid retroversion and fatty infiltration, as seen with a CT-based study. Surgeons should therefore consider that when treating patients without an MRI to better characterize the health of the rotator cuff muscles, patients with higher degrees of glenoid retroversion are more likely to have an increased amount of fatty infiltration of the posterior rotator cuff, which has been demonstrated to influence clinical outcomes after anatomic total shoulder arthroplasty [24].

Fatty Infiltration by Walch Classification After Accounting for Age and Sex

Types B2 and B3 glenoids were associated with fatty infiltration, primarily in the infraspinatus, even after accounting for age and sex. Another study attempted to define the relationship between pathologic conditions of the rotator cuff and glenoid morphology [1]. In contrast to the current study, the authors used CT scans and assessed the rotator cuff in terms of the cross-sectional area of the muscles instead of by the degree of fatty infiltration, as done in the current study. They reviewed 370 CT images to measure the muscle area of the rotator cuff and calculated ratios of the posterior rotator cuff to the subscapularis. Age and sex were similarly accounted for in a multivariate analysis and, similar to the present study, being a man was associated with Type B2 and B3 glenoids. Interestingly, they found an imbalance in the axial-plane musculature with posteriorly worn glenoids; however, in contrast to our findings, the authors found that an increase in the ratio of the posterior rotator cuff muscle area was associated with Type B2 glenoids. They attributed the change in the ratio of axial-plane musculature to a relative decrease in subscapularis size, whereas we found an increase in fatty infiltration of the posterior rotator cuff compared with the subscapularis. The clinical importance of the rotator cuff muscle's volume with respect to shoulder function has not been established; however, this would be a contradictory finding to that of the current study if the muscle cross-sectional area is assumed to be a surrogate for overall muscle health. The finding of an increased posterior rotator cuff muscle cross-sectional area to subscapularis area ratio was also limited to Type B2 glenoids, whereas we found an equally increased imbalance in fatty infiltration of the posterior-to-anterior rotator cuff in both B2- and B3-type glenoids compared with Type A glenoids. The differences in these findings may be attributed to the differing associations that fatty infiltration of the rotator cuff muscle and muscle size have with glenoid morphology. Importantly, the Goutallier classification has well-described associations with shoulder function [18]. Surgeons should be aware that patients with Type B2 and B3 glenoids, regardless of age or sex, are likely to have an increased amount of fatty infiltration of the posterior rotator cuff, which may influence clinical outcomes after anatomic total shoulder arthroplasty. Future research should elucidate the clinical and radiographic outcomes of patients with Type B2 and B3 glenoids with high grades of fatty infiltration of the posterior rotator cuff at the time of surgery.

Conclusion

Compared with concentric wear, posteriorly worn glenoids had an imbalance in axial-plane rotator cuff fatty infiltration, with an increased amount of fatty infiltration of the infraspinatus and teres minor compared with the subscapularis. These imbalances may contribute to the higher proportions of failure after anatomic total shoulder arthroplasty in patients with posterior wear compared with those with concentric wear. Providers should consider the increased likelihood of higher-grade fatty infiltration of the posterior rotator cuff in the setting of posteriorly worn glenoids, particularly when treating patients without the use of MRI. These patients are known to have higher proportions of failure postoperatively and may benefit from closer monitoring and altered postoperative rehabilitation protocols that target the posterior rotator cuff. Future research should be directed toward investigating the temporal relationship of these findings, as well as understanding the clinical outcomes for patients undergoing anatomic total shoulder arthroplasty who have posteriorly worn glenoids with a high degree of fatty infiltration of the posterior rotator cuff musculature.

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