Original Research

The Area of Impingement in the Throwing Versus Nonthrowing Shoulder of Collegiate Baseball Players

An MRI Study of the Simulated Late-Cocking Phase of Throwing

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Background: During shoulder abduction and external rotation, internal impingement can occur when compressive forces between the greater tuberosity and the posterior glenoid rim pinch the undersurface of the rotator cuff. Previous studies on internal impingement have focused on qualitative results such as pathological findings; however, few studies have quantified the area of impingement (AOI) of the rotator cuff muscles between the greater tuberosity and the posterior glenoid rim.

Purpose: To compare the AOI between the throwing and nonthrowing shoulders of baseball players.

Study Design: Controlled laboratory study.

Methods: A total of 14 asymptomatic male collegiate baseball players participated in this study. The AOI in both the throwing and the nonthrowing shoulders was calculated using magnetic resonance imaging (MRI) scans. The MRI measurements were collected with the shoulder at 90° of abduction and at 90° and 100° of external rotation. The area, width, and depth of impingement as well as cystic changes in the greater tuberosity and degeneration in the posterior labrum were compared between the throwing and nonthrowing shoulders.

Results: The AOI was significantly greater in the throwing shoulders than in the nonthrowing shoulders (90° of external rotation: 32.4 vs 19.1 mm^2, respectively; 100° of external rotation, 28.0 vs 15.6 mm^2, respectively; $P < .001$ for both). Compared with the nonthrowing shoulders, there were more positive findings in the throwing shoulders regarding greater tuberosity cystic changes (0 vs 7, respectively; $P = .006$) and posterior labral degeneration (3 vs 13, respectively; $P < .001$).

Conclusion: The AOI and the number of lesions in the greater tuberosity and posterior labrum were greater in throwing shoulders than in nonthrowing shoulders. Therefore, damage to the insertion of the rotator cuff muscles may affect internal impingement.

Clinical Relevance: Lesions in the greater tuberosity and posterior labrum in throwing shoulders may increase the AOI by expanding the joint gap behind the glenohumeral joint. Impingement of the greater tuberosity and the posterior glenoid rim may lead to rotator cuff tears.

Keywords: area of impingement; throwing shoulder; internal impingement; baseball players

Internal impingement is a phenomenon in which the undersurface of the rotator cuff is pinched and is caused by compressive forces between the greater tuberosity and the posterior glenoid rim during shoulder abduction and external rotation.[13] This impingement of the greater tuberosity and the posterior glenoid rim may cause rotator cuff abnormalities or chronic rotator cuff tears.[4,13]

Cadaveric studies have reported that anterior instability of the glenohumeral joint increases the strain and contact pressure in the posterior superior labrum.[7,11] Although these studies focused on contact of the humeral head with the posterior glenoid rim, they did not quantify impingement of the rotator cuff muscles. Furthermore, many of the periarticular muscles are removed from shoulders in cadaveric studies, and collagen fibers in the joint capsule

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have been found to be different between cadaveric shoulders and in vivo shoulders of younger patients.[14]

Magnetic resonance imaging (MRI) studies of baseball players that focused on the abnormalities of internal impingement, such as rotator cuff tears and labral injuries, have been previously published.[4,10] However, the effect of changes in the shoulder joint structure[4,10] or external rotation angles[2,6,7,11] on the rotator cuff muscles has not been clarified. Therefore, there is a need to clarify the mechanism and cause of rotator cuff injuries by quantifying internal impingement of the rotator cuff.

The area of impingement (AOI) is the area of the rotator cuff inserted in the greater tuberosity and the posterior glenoid rim during shoulder abduction with external rotation. The AOI is not an indicator of the proximity of the greater tuberosity and the posterior glenoid rim, but it does help to clarify the cause of rotator cuff tears due to impingement. The purpose of this study was to determine whether there is a difference in the AOI between the throwing and nonthrowing shoulders of baseball players. We used open MRI, in which the glenohumeral external rotation angle can be adjusted, to simulate the position of the shoulder in the late-cocking phase of baseball throwing. We hypothesized that there would be changes in the structure of the throwing shoulder that would affect the AOI and that there would be a smaller AOI in the abducted shoulder when more external rotation was present.

METHODS

Participants

A study group was formed in 2014 to investigate the shoulder joints of baseball players. The participants were 14 male baseball players (13 right-hand and 1 left-hand dominant; 28 shoulder joints) who did not have throwing pain and belonged to the Tokyo Metropolitan University Baseball League. Players were excluded if they experienced pain during the measurements and if they had a history of shoulder joint surgery.

Each participant received explanations of the purpose of this research, MRI examinations, and physical examinations, and we obtained informed consent from each participant. This study was conducted with approval from the local ethics committee.

MRI Examination

Open MRI was performed using a 0.3-T AIRIS Vento (Hitachi). One radiology/MRI technician (M.Monma) performed the scans in this study. A shoulder joint coil was used to receive MRI signals, and approximately 12 horizontal slices were taken for each condition using the sequence of T2* images via the gradient echo method (field of view, 220 mm; repetition time, 600 milliseconds; echo time, 11 milliseconds; slice thickness, 4 mm; slice gap, 4 mm; scan time, 3 minutes 53 seconds). For MRI positioning, the horizontal cross section was determined in the sagittal plane with reference to the center of the glenohumeral joint. The imaging findings were analyzed using image analysis software, and only data in which the greater tuberosity was clearly depicted were used.

Each participant underwent MRI in both the throwing and the nonthrowing shoulders. The participant lay prone with the shoulder arranged similar to the glenohumeral external position in the late-cocking phase of throwing[9] and underwent MRI with the shoulder at 90° of abduction and at 90° and 100° of external rotation (Figure 1).

Internal and external rotation, scapular anterior and posterior tipping of the scapulothoracic joint, and trunk rotation due to changes in the glenohumeral external rotation angle during imaging were suppressed by fixing the inferior scapular angle and the thoracic vertebrae with a belt. To determine the reliability of imaging analysis, we conducted a pilot study using T1- and T2-weighted images via the spin echo method and T2* images via the gradient echo method. T2* images were more resistant to the artifacts that occur during MRI measurements compared with T1- and T2-weighted images, and the margins of the bone and rotator cuff muscle groups, such as the rotator cuff, joint capsule, and labrum, were clearly depicted. In addition, as the slice plane might change because of glenohumeral external rotation, the slice plane in which the greater tuberosity was clearly depicted was used as the reference. However, it was possible to evaluate the AOI because external rotation of the shoulder joint did not change the depiction of the greater tuberosity. Based on this pilot study, we evaluated MRI findings under the described imaging conditions.

Imaging Analysis

Area of Impingement. The area representing the rotator cuff muscle between the greater tuberosity and the posterior glenoid rim was defined as the AOI (Figure 2).

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Ethical approval for this study was obtained from Ibaraki Prefectural University of Health Sciences (No. 629).

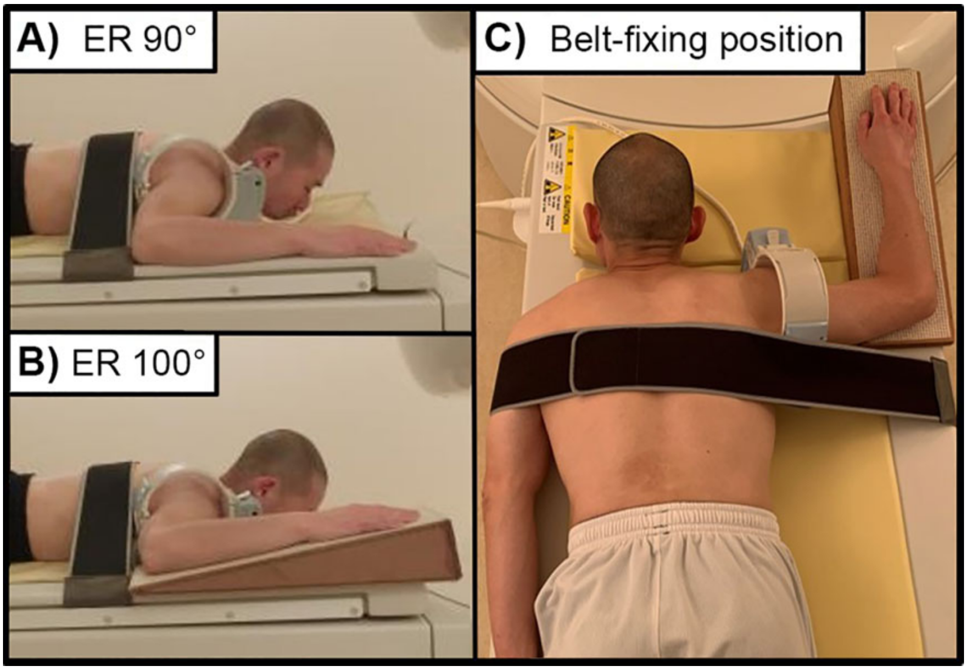

Figure 1. Measurement positioning during magnetic resonance imaging. The participant lay prone with the shoulder at 90° of abduction as well as (A) 90° and (B) 100° of external rotation (ER). (C) The inferior scapular angle and thoracic vertebrae were fixed with a belt.

Although the definition of "AOI" in this study has not been used in previous studies, it is considered to be valid as an index reflecting the rotator cuff area compressed by internal impingement.[7,11,13] A high AOI indicates that the area of the rotator cuff muscles in the greater tuberosity and the posterior glenoid rim is large.

The AOI, width of the AOI, and depth of the AOI of both the throwing and the nonthrowing shoulders were evaluated in both MRI measurement positions (90° and 100° of external rotation) for all shoulders (n = 56 images). To improve the reliability of imaging measurements, a single examiner (M.T.) performed all measurements twice. This examiner has been involved in this study since 2014 and has measured the AOI in many shoulders. Imaging analysis showed that the intraclass correlation coefficient for intraexaminer reliability was 0.925 (95% CI, 0.876-0.955), indicating high agreement.

Greater Tuberosity Cystic Changes and Posterior Labral Degeneration. MRI-based bone marrow signal alterations in the greater tuberosity are clinically significant because they indicate cystic changes in the posterior superior humeral head.[4] An orthopaedic surgeon (H.M.) who randomly assessed the imaging findings of the 28 shoulder joints evaluated cystic changes in the greater tuberosity and degeneration in the posterior labrum. Cystic changes were considered absent if there was no alternation of the bone marrow signal in the greater tuberosity (negative finding) and present if there was an alternation of the signal (positive finding) (Figure 3). Posterior labral degeneration was considered absent if the posterior glenoid rim had a beak shape (negative finding) and present if the posterior glenoid rim was curved (positive finding) (Figure 4).

Statistical Analysis

We used an online software program for power analysis (G*Power; http://www.psychologie.hhu.de/arbeitsgruppen/allgemeine-psychologie-und-arbeitspsychologie/gpower.html). A 2-way analysis of variance demonstrated effect sizes (0.6) with alpha set at .05; for our study design, 7 shoulders were necessary to achieve a statistical power of 0.814. Additionally, the chi-square test demonstrated effect sizes (0.6) with alpha set at .05; for our study design, 22 shoulders (11 throwing and 11 nonthrowing shoulders) were necessary to achieve a statistical power of 0.804.

A 2-way analysis of variance was used to compare the AOI, width of the AOI, and depth of the AOI of throwing and nonthrowing shoulders. The comparison of greater tuberosity cystic changes and posterior labral degeneration between the throwing and nonthrowing shoulders was performed as follows: The Pearson chi-square test was used when the expected frequency of <5 was $<20\%$, and the Fisher exact test was used when the expected frequency of <5 was $\geq 20\%$. SPSS Statistics Version 21 (IBM Corp) was used for statistical processing, and the significance level was set to 5%.

RESULTS

The participants' mean ± SD age, height, weight, body mass index, and years of baseball experience were 19.6 ± 0.7 years, 173.1 ± 3.5 cm, 71.1 ± 4.2 kg, 23.8 ± 1.2, and 11.9 ± 1.9 years, respectively. There were 4 pitchers, 1 catcher, and 9 fielders.

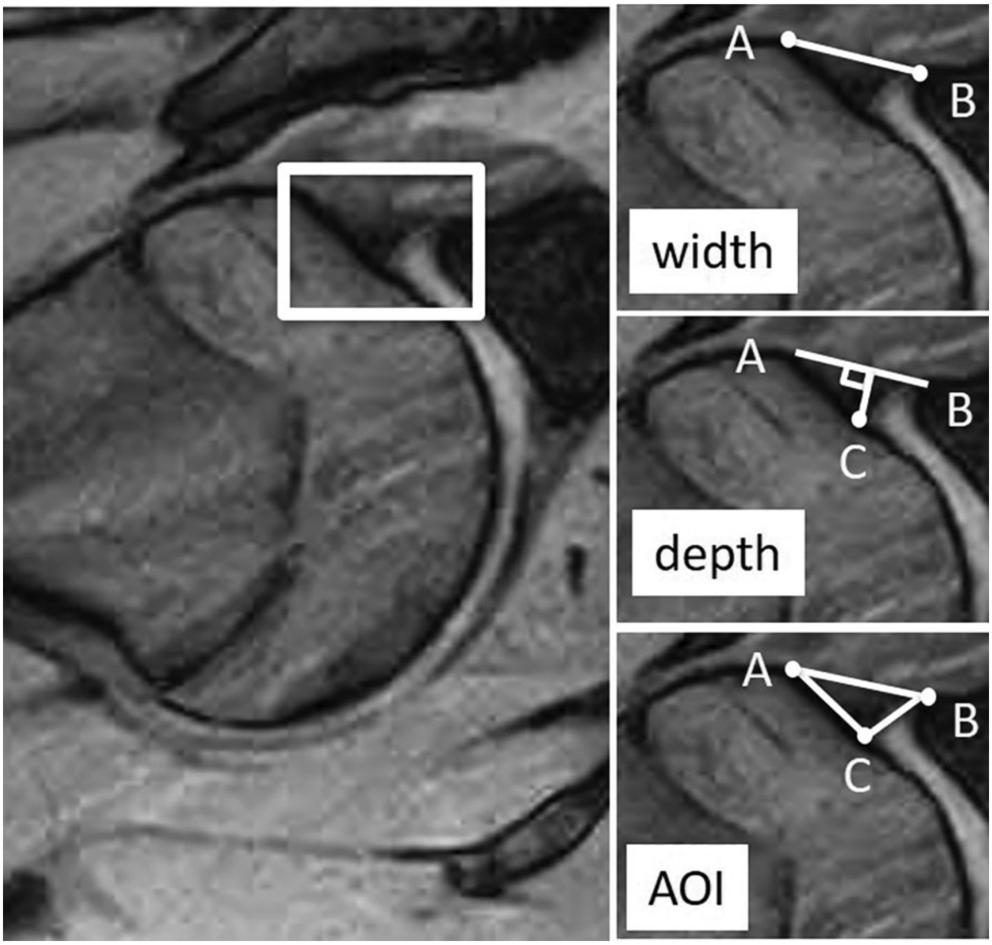

Figure 2. Area of impingement (AOI) on magnetic resonance imaging scans. The rectangle in the left panel indicates the AOI. The width of the soft tissue was measured as the distance between points *A* and *B*. The depth was measured as the distance from line *AB* to point *C*. The area of the rotator cuff muscle between the greater tuberosity and the posterior glenoid rim (AOI) is indicated by triangle *ABC*.

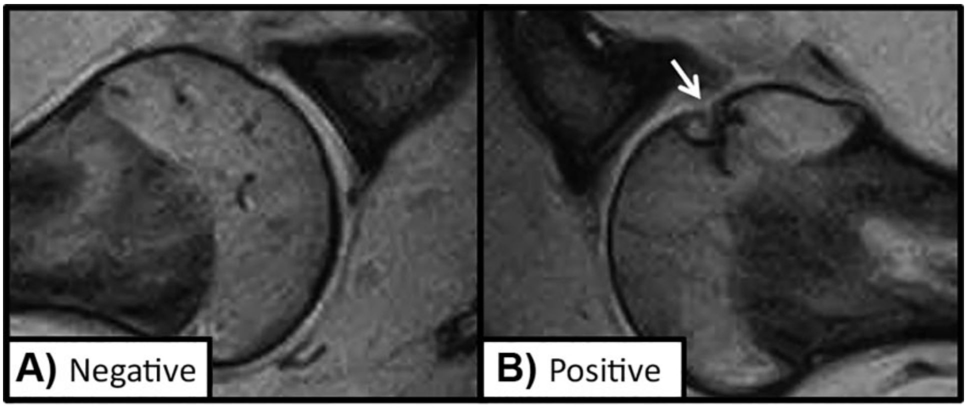

Figure 3. Cystic changes in the greater tuberosity on magnetic resonance imaging scans. (A) A negative finding in a left (nonthrowing) shoulder shows no alteration of the bone marrow signal in the greater tuberosity. (B) A positive finding in a right (throwing) shoulder shows an alteration of the bone marrow signal in the greater tuberosity (arrow).

Results of the MRI evaluation indicated that the AOI, width of the AOI, and depth of the AOI were significantly greater in the throwing shoulders than the nonthrowing shoulders ($P \leq .001$ for all). In addition, the AOI was significantly less at 100° of external rotation than 90° of external rotation (Table 1). Positive findings of cystic changes in

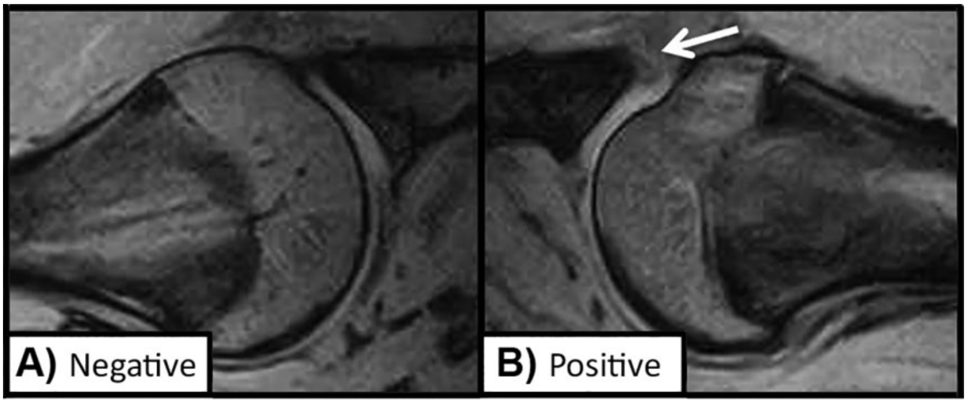

Figure 4. Posterior labral degeneration on magnetic resonance imaging scans. (A) A negative finding is shown in a left (nonthrowing) shoulder in which the posterior glenoid rim has a beak shape. (B) A positive finding is shown in a right (throwing) shoulder in which the posterior glenoid rim is curved (arrow).

TABLE 1
AOI, Width of the AOI, and Depth of the AOI[a]

			P Value for Main Effect		
	Throwing Shoulder (n = 14)	Nonthrowing Shoulder (n = 14)	Throwing vs Nonthrowing Shoulder	90° vs 100° of ER	*P* Value for Interaction
AOI, mm^2			**<.001**	**.045**	.811
90° of ER	32.4 ± 7.7	19.1 ± 7.2			
100° of ER	28.0 ± 5.8	15.6 ± 6.6			
AOI width, mm^2			**.001**	.415	.954
90° of ER	11.6 ± 2.0	9.5 ± 2.5			
100° of ER	11.1 ± 1.4	9.1 ± 2.6			
AOI depth, mm			**<.001**	.058	.950
90° of ER	5.6 ± 1.1	4.0 ± 1.1			
100° of ER	5.0 ± 0.7	3.5 ± 1.1			

[a]Data are presented as mean ± SD. Bolded *P* values indicate statistical significance ($P < .05$). AOI, area of impingement; ER, external rotation.

the greater tuberosity and degeneration in the posterior labrum were both significantly higher in the throwing shoulders compared with the nonthrowing shoulders ($P = .006$ and $P < .001$, respectively) (Table 2).

TABLE 2
Greater Tuberosity Cystic Changes and Posterior Labral Degeneration[a]

	Throwing Shoulder (n = 14)	Nonthrowing Shoulder (n = 14)	*P* Value
Greater tuberosity cystic changes			**.006**
Positive findings	7	0	
Negative findings	7	14	
Posterior labral degeneration			**<.001**
Positive findings	13	3	
Negative findings	1	11	

[a]Data are presented as No. Bolded *P* values indicate statistical significance ($P < .05$).

DISCUSSION

This study's results indicated that cystic changes in the greater tuberosity and degeneration in the posterior labrum were more frequently observed in throwing shoulders than in nonthrowing shoulders. This result was similar to that in a previous study in which they were considered to be caused by friction between the greater tuberosity and the posterior glenoid rim as a result of shoulder abduction and external rotation during throwing.[4] The presence of greater tuberosity cystic changes and posterior labral degeneration may affect expansion of the joint space behind the glenohumeral joint.

The AOI and depth of the AOI were greater in throwing shoulders than in nonthrowing shoulders. A previous study reported that the internal joint pressure was negative when the shoulder was elevated to 90°.[5] Therefore, it is possible that expansion of the joint gap behind the glenohumeral joint caused by the presence of greater tuberosity cystic changes and posterior labral degeneration in throwing shoulders may have led to an increase in the AOI. The insertion of the rotator cuff muscles caused by internal impingement may be large. This impingement of the greater tuberosity and the posterior glenoid rim may cause a rotator cuff tear. Furthermore, greater tuberosity cystic changes and posterior labral degeneration in throwing shoulders may increase the AOI by expanding the joint gap behind the glenohumeral joint.

Our results showed that the AOI was significantly less during 100° of external rotation than 90° of external rotation. However, cadaveric studies have reported that the contact pressure and strain between the humeral head and the posterior glenoid rim increase as shoulder external rotation increases.[7,11] Therefore, the decrease in the AOI with increasing shoulder external rotation was considered to be caused by compression of the rotator cuff to the humeral head and the posterior glenoid rim.

It has been pointed out that the disabled throwing shoulder becomes a complicated and complex pathological conditions, such as the examples given, cause or develop in the disabled throwing shoulder in baseball players at higher levels or over time.[1,12] It will be necessary to perform a cohort study to clarify whether the presence of greater tuberosity cystic changes and posterior labral degeneration as well as an increased AOI in throwing shoulders, which were observed in our study, are involved in the developmental mechanism of the disabled throwing shoulder.

This study has some limitations. Although the participants of this research were mostly pitchers and fielders, there may have been differences in the AOI, greater tuberosity cystic changes, and posterior labral degeneration depending on the position, so it is necessary to investigate these parameters by position in the future. Because we performed a static evaluation via open MRI, it is necessary to devise a measurement method that more closely resembles a throw in consideration of dynamic evaluations and joint force. In addition, the AOI for each shoulder's external rotation angle obtained on MRI scans may be a measurement that includes not only the glenohumeral joint but also posterior tilt of the scapulothoracic joint. However, the examiner was able to confirm by visual inspection and palpation that there was no compensatory movement of the scapulothoracic joint (the participant's arm slipped off the slope, and 90° of shoulder abduction and elbow flexion did not change) and that the shoulder external rotation range was appropriate for MRI. Therefore, it is considered that the AOI could be measured by suppressing the compensatory movement of the scapulothoracic joint. Finally, internal impingement is caused not only by the shoulder external rotation angle but also by the horizontal extension angle.[8] It has been pointed out that internal impingement caused by an increase in the horizontal extension angle is an anatomic factor.[8] However, the external rotation angle may be affected not only by anatomic factors but also by soft tissue, and there are still many unknown factors.[2,3,6,7,11] Therefore, this study focused on the external rotation angle of the shoulder joint and investigated the AOI. In the future, it will be necessary to investigate the relationship between the AOI used in this study and the horizontal extension angle.

CONCLUSION

Cystic changes in the greater tuberosity and degeneration of the posterior labrum were more frequently observed in throwing shoulders than in nonthrowing shoulders. Additionally, the AOI was greater in throwing shoulders than in nonthrowing shoulders. Therefore, the insertion of the rotator cuff muscles caused by internal impingement may be large. This impingement of the greater tuberosity and the posterior glenoid rim may cause a rotator cuff tear.

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