Heliyon 10 (2024) e33064

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Morphologic changes in the posterior glenoid rim is independently associated with rotator cuff impingement in baseball players

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ARTICLE INFO

Keywords:
Posterior glenohumeral distance
Rotator cuff impingement
Late cocking phase
Throwing shoulder
Magnetic resonance imaging assessment
Baseball player

ABSTRACT

Background: The morphological changes in the posterior glenoid rim are unknown in relation to the area of rotator cuff tendons pinched within the glenohumeral joint in the throwing shoulders of baseball players. Therefore, this study aimed to clarify whether these changes are associated with the area of impingement in baseball players.
Methods: Overall, 25 asymptomatic male college baseball players (average age19.8 years, 11.6 years of competing, and 50 shoulders) participated in this study. The area of impingement (AOI, mm^2) and posterior glenohumeral distance (PGHD, mm) were measured using magnetic resonance imaging to quantitatively assess the impingement area of the rotator cuff tendon within the glenohumeral joint and the morphologic change in the posterior glenoid rim. These magnetic resonance imaging assessments were measured at 90° shoulder abduction with 90° and 100° external rotation. Multiple linear regression analysis was performed to determine whether AOI is predicted by PGHD.
Findings: Multiple linear regression analysis showed that the PGHD was a predictor of the AOI at external rotation 90° (β-coefficient = 0.738, $R^2 = 0.77$, $P < 0.001$) and external rotation 100° position (β-coefficient = 0.879, $R^2 = 0.76$, $P < 0.001$).
Interpretation: This study found that the area of impingement was associated with posterior glenohumeral distance. Therefore, these findings may indicate that complex shoulder joint morphologic changes result in a disabled throwing shoulder.

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https://doi.org/10.1016/j.heliyon.2024.e33064
Received 10 July 2023; Received in revised form 12 June 2024; Accepted 13 June 2024
Available online 14 June 2024

1. Introduction

The incidence of throwing shoulder injury in baseball, from adolescent to professional baseball players, ranges from 30 % to 50 % [1–6]. This injury makes it challenging for players to participate in practices and games, resulting in difficulty in maintaining their physical and mental health [7–11]. These previous studies used different methods to collect data, such as questionnaires [1,2] and progress records [3–5]. Additionally, in each study, the degree of time-loss injury is not defined uniformly as a disabled throwing shoulder [12]. Therefore, it is important to examine the morphological changes in the glenohumeral joint caused by microtrauma from throwing in order to clarify the pathogenesis of disabled throwing shoulders [13].

Previous studies have focused on internal impingement, which is a phenomenon where the undersurface of the rotator cuff tendons is pinched between the greater tuberosity and posterior glenoid rim during shoulder abduction and external rotation of the late cocking phase [14–23]. Moreover, internal impingement syndrome is frequently observed in baseball players and is associated with throwing shoulder injuries, such as rotator cuff injury, labrum injury, and humeral head cysts [15–18]. As complex shoulder joint morphologic changes may result in throwing shoulder pain and a disabled throwing shoulder [15–17,24,25], understanding the influence of morphologic changes on the throwing shoulder is crucial. There are many factors contributing to internal impingement, such as anterior capsular laxity and posterior capsular tightness [17,19–22], rotator cuff weakness [23], glenoid retroversion [24], hyper angulation of the throwing motion [25], and scapular dyskinesis [17,26]. The most important factor is the maximum external rotation angle of the glenohumeral joint during the late cocking phase of the throwing motion [14,19,20,22].

Previous studies on rotator cuff area of impingement (AOI) have reported that throwing shoulders with greater morphological changes in the posterior glenoid rim have a greater area of rotator cuff tendon pinched within the glenohumeral joint than non-throwing shoulders [27]. However, the morphologic changes in the posterior glenoid rim have only been qualitatively assessed rather than quantitatively measured, and association with a history of throwing shoulder pain remains unclear. Examining the validity or reliability of quantitative indicators of morphological changes in the posterior glenoid rim and the relationship between quantitatively assessed morphologic changes in the posterior glenoid rim and the AOI is necessary. Therefore, it is important to determine how a higher AOI is related to shoulder morphological changes and the causes of changes in AOI.

We hypothesized that morphologic changes in the posterior glenoid rim would result in a higher AOI. To verify this hypothesis, this study aimed to clarify the relationship between the morphologic changes in the glenoid rim and AOI and to develop of an assessment tool to quantify the morphologically changed posterior glenoid rim. These findings may contribute to the evidence-based assessment and development of a new prediction model for disabled throwing shoulder in baseball players.

2. Materials and methods

2.1. Study design

This cross-sectional study commenced in 2014. The study participants' shoulder range of motion (ROM) and magnetic resonance imaging (MRI) data from 2015 to 2023 were obtained and evaluated.

2.2. Participants

The participants included 25 male baseball players (right-handed, 24; left-handed, 1; and bilateral shoulder joints, 50) without throwing-related pain, belonging to competition-level universities or adult baseball teams. The inclusion criteria were as follows: (1) adult male, (2) active baseball players (including catchers and fielders, not limited to pitchers), and exclusion criteria were as follows: (1) recreational level baseball players, (2) players who experienced pain during measurement, (3) those who had pain that prevented them from participating in practices and games, and (4) those who had a history of shoulder joint surgery.

Each participant received explanations regarding the study's purpose and underwent MRI and physical examinations. This study protocol was approved by the Ethics Committee of the Ibaraki Prefectural University of Health Sciences (protocol number 629) and the study was conducted in accordance with relevant guidelines and regulations of the Declaration of Helsinki. The participants' confidentiality and rights were protected in all cases. Finally, the participants were informed that their data would be submitted for publication, and written informed consent was obtained from all participants.

2.3. Imaging analysis

Open MRI was performed with the AIRIS Vento 0.3-T whole-body MRI machine (Hitachi, Ltd., Tokyo, Japan). One radiologist (MM1) performed the scans in this study. The MRI signals were received with a shoulder joint coil, and approximately 12 horizontal slices were obtained for each condition using the sequence of T2* images in the gradient echo method [27]. For MRI, the horizontal cross-section was determined in the sagittal plane with respect to the center of the glenohumeral joint. Finally, the imaging findings were analyzed using image analysis software (ImageJ; National Institutes of Health, Bethesda, MD, USA), and only data where the greater tuberosity was observed were used.

The MRI position was similar to the glenohumeral external rotation in the late cocking phase [28], and the MRI measurement position was 90° shoulder abduction with 90° and 100° external rotation, with the participant in the prone position [27]. Based on a previous study that reported a glenohumeral maximum external rotation angle of 106° [28], this study also considered MRI imaging in the 110° external rotation position. However, this was not performed because the non-throwing shoulder joint could not hold that limb position. Additionally, if the relationship between PGHD and AOI can be clarified even in a simplified imaging limb position without the tilt angle table, clinical application will be possible. Therefore, measurements were performed in the 90° external rotation position in this study.

2.3.1. Area of impingement: AOI

The AOI was defined as the rotator cuff tendons existing between the greater tuberosity and posterior glenoid rim (Fig. 1a and b). The area of interest (mm^2) of the AOI of the throwing shoulders was evaluated in each MRI measurement position. A high AOI indicates that the area of the rotator cuff tendons in the greater tuberosity and posterior glenoid rim is large [27]. Image analysis by the same examiner showed that the intraclass correlation coefficient (ICC) of the first and second values of the AOI was 0.925 (95 % confidence interval, 0.876–0.955) [27].

2.3.2. Posterior glenohumeral distance: PGHD

Although the specific posterior glenohumeral distance (PGHD) defined in this study has not been used in previous studies, it may be associated with morphologic changes, such as posterior labrum degeneration and a curved posterior glenoid rim. The PGHD was measured as an index showing the distance between the humeral head and the posterior glenoid rim (Fig. 2a and b). Therefore, two steps were taken to validate the PGHD. First, the presence of morphologic changes in the posterior glenoid rim was determined by an orthopedic surgeon (HM) using a qualitative assessment, where the positive and negative findings show a curved and beak-shaped posterior glenoid rim, respectively. Second, the PGHD was compared between the positive and negative morphologic changes in the posterior glenoid rim. A high PGHD indicates an expansion of the joint gap behind the glenohumeral joint.

Additionally, the percent of posterior glenohumeral distance (%PGHD) was calculated by dividing the throwing side PGHD by the non-throwing side PGHD and expressing it as a percentage (%PGHD = throwing side PGHD/non-throwing side PGHD × 100). A high value (>100) of %PGHD indicates that the joint gap of the throwing shoulder joint is enlarged compared to that of the non-throwing shoulder joint due to deformity or morphologic change of the posterior glenoid rim.

2.4. Shoulder range of motion

The examiner measured the passive maximum external rotation, internal rotation, and horizontal flexion ROM at 90° shoulder abduction with the participant in supine position. The examiner prevented the scapulothoracic joint compensatory movements, such as internal rotation, external rotation, scapular anterior and posterior tipping, by pressing the scapula [17,21,29,30]. Moreover, the external rotation gain was calculated as the angle of the throwing shoulder minus that of the non-throwing shoulder, with higher values indicating more anterior capsular laxity. The glenohumeral internal rotation and horizontal flexion deficit were calculated as the angle of the non-throwing shoulder minus that of the throwing shoulder, with higher values indicating more posterior capsular tightness [17,21,29,30]. Finally, using a joint inducer and an angle measurer, two examiners measured the shoulder ROM with an inclinometer (SLANT RULE, Shinwa Measurement Co., Japan) at a 1° interval.

2.5. History of throwing shoulder pain and grouping

Each player was interviewed and surveyed about the existing or non-existing throwing shoulder pain from college baseball plays. In addition, based on the survey results, the following groupings were made: (1) existing group: experiencing throwing shoulder pain; (2) non-existing group: no experience of throwing shoulder pain. Throwing shoulder pain was defined as throwing shoulder pain when throwing that experienced decreased performance in participation in practice or games for at least one day, and upper extremity pain, such as elbow or finger pain, was excluded from this definition.

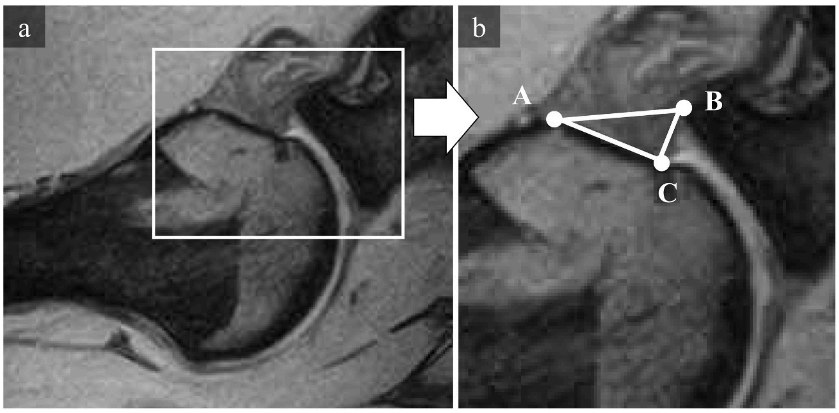

Fig. 1. Area of impingement. A: greater tuberosity, B: posterior glenoid rim, C: Depth of rotator cuff insertion. The triangle ABC indicates the area of the rotator cuff tendons (mm^2) between the greater tuberosity and posterior glenoid rim.

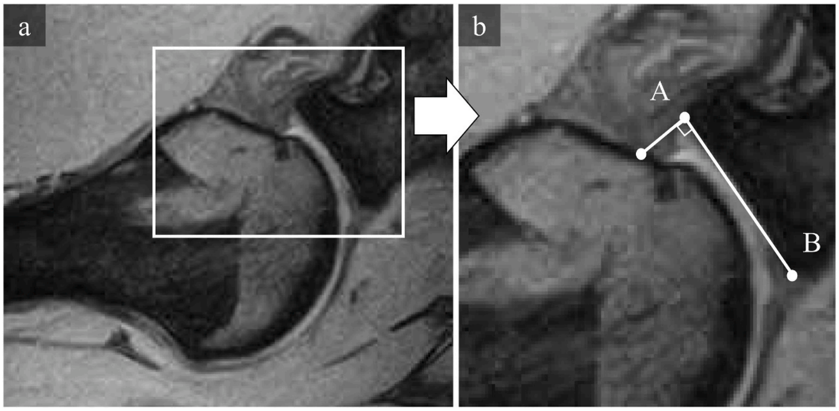

Fig. 2. Posterior glenohumeral distance. Procedure 1: A perpendicular line is drawn on the glenoid surface from the posterior glenoid rim [A] to derive the intersection [B] with the humeral head. Procedure 2: The distance between A-B is measured; the interosseous distance (mm) between the humeral head and posterior glenoid rim is derived.

2.6. Statistical analysis

Simple linear regression analysis and multiple linear regression analysis by the stepwise method with the Akaike's Information Criteria was performed to identify the predictors of the AOI (dependent variable) among the PGHD, external rotation, internal rotation, and horizontal flexion.

Comparison of positive and negative morphologic changes in the posterior glenoid rim, and comparison of PGHD between the existing and non-existing group of throwing shoulder pain history was performed using the Shapiro–Wilk test to analyze the data distribution and subsequently using Levene's or Mann–Whitney U tests. After using Levene's test, an unpaired *t*-test or Welch's *t*-test were performed when the variances were considered unequal and equal, respectively.

We constructed receiver operating characteristic (ROC) curves from the PGHD and morphologic changes in the posterior glenoid rim and identified the cutoff points to determine the optimal combinations of sensitivities and specificities. We determined the optimal cutoff points using the Youden index (J), which is calculated as J = maximum {sensitivity + specificity −1} [31]. Furthermore, the

Table 1
Simple and multiple linear regression with the area of impingement (mm^2) as the dependent variable.

Variable	Simple linear regression			Multiple linear regression				
	Beta coefficient	SE	*P*-value	Beta coefficient	SE	*P*-value	R^2	VIF
90° ER position								
PGHD (mm)	0.860	0.02	<0.001	0.738	0.02	<0.001	0.77	1.66
ER (°)	0.542	0.10	<0.001	0.003	0.08	0.976		
IR (°)	-0.419	0.11	0.003	-0.030	0.08	0.750		
HF (°)	-0.235	0.17	0.100					
100° ER position								
PGHD (mm)	0.871	0.28	<0.001	0.879	0.35	<0.001	0.76	1.54
ER (°)	0.502	0.09	<0.001	-0.001	0.07	0.990		
IR (°)	-0.344	0.09	0.014	0.019	0.06	0.830		
HF (°)	-0.228	0.15	0.111					

PGHD: posterior glenohumeral distance, ER: external rotation, IR: internal rotation, HF: horizontal flexion, SE: standard error, VIF: Variance inflation factor.

accuracy was classified according to the size of the area under the ROC curve as follows: 0.90–1.00 (excellent), 0.80–0.89 (good), 0.70–0.79 (moderate), and <0.70 (poor) [32].

SPSS Statistics version 21 (IBM Corp, Armonk, NY, USA) was used for statistical analysis, and the significance level was set to 5 %.

3. Results

The participants' average age (19.8 ± 1.2 years), height (173.3 ± 3.2 cm), weight (71.1 ± 5.4 kg), body mass index (23.6 ± 5.4 kg/m^2), years of competing (11.6 ± 2.3 years), and position played (9 pitchers, 2 catchers, and 14 fielders) were recorded. The external rotation, internal rotation, and horizontal flexion angles for the throwing shoulder were 112.0 ± 9.2°, 31.0 ± 9.4°, and 81.8 ± 7.6°, respectively, whereas those for the non-throwing shoulder were 96.0 ± 10.1°, 47.5 ± 10.1°, and 88.0 ± 8.3°, respectively. Additionally, 9 of the 25 baseball players had a history of throwing shoulder pain.

Simple linear regression analysis showed that the PGHD (β-coefficient = 0.860, $P < 0.001$), external rotation (β-coefficient = 0.542, $P < 0.001$), and internal rotation (β-coefficient = − 0.419, $P = 0.003$) at 90° external rotation position and PGHD (β-coefficient = 0.871, $P < 0.001$), external rotation (β-coefficient = 0.502, $P < 0.001$), and internal rotation (β-coefficient = − 0.334, $P = 0.014$) at 100° external rotation position were predictors of the AOI. Moreover, multiple regression analysis showed that the PGHD was a predictor of the AOI at 90° external rotation position (β-coefficient = 0.738, $R^2 = 0.77$, $P < 0.001$) and 100° external rotation position (β-coefficient = 0.879, $R^2 = 0.76$, $P < 0.001$) (Table 1).

Based on the diagnosis of one orthopedic surgeon (HM), 27 positive cases (throwing shoulder, 24; non-throwing shoulder, 3) and 23 negative cases (throwing shoulder, 1; non-throwing shoulder, 22) of morphologic changes were found in the posterior glenoid rim, and the presence of morphologic changes in the posterior glenoid rim was found in 24 participants out of 25. The PGHD at 90° external rotation position for positive and negative morphologic changes in the posterior glenoid rim was 7.8 ± 1.9 mm and 4.5 ± 2.2 mm, respectively, and the PGHD at 100° external rotation position for positive and negative morphologic changes in the posterior glenoid rim was 6.9 ± 1.7 mm and 3.6 ± 1.4 mm, respectively, with the positive group showing significantly higher values than the negative group (Table 2). Additionally, in comparison of any history of throwing shoulder pain, %PGHD at 100° external rotation position in the existing group (247 ± 82) was significantly higher than in the non-existing group (177 ± 49). There were no significant differences in age, height, weight, years of competition, body mass index, external rotation gain, glenohumeral internal rotation deficit, horizontal flexion test, or %PGHD in 90° external rotation position between the existing and non-existing groups (Table 3).

In the receiver operating characteristic curve of the PGHD for the morphologic changes in the posterior glenoid rim (Fig. 3), the area under the curve (AUC) at 90° external rotation position was 0.90. When the cutoff point was 5.9 mm, the model showed a sensitivity and specificity of 88.9 % and 87.0 %, respectively. Additionally, the AUC at 100° external rotation position was 0.95. When the cutoff point was 4.6 mm, the model showed a sensitivity and specificity of 96.3 % and 87.0 %, respectively. In the intra-observer examination (MT), the ICC was 0.942 (95 % confidence interval: 0.912–0.962), and the standard error of the mean was 0.62 mm for the PGHD (Table 4).

4. Discussion

In this study, multiple linear regression analysis results showed that the PGHD was associated with AOI, which reflected the rotator cuff tendons existing between the greater tuberosity and posterior glenoid rim. Takahashi et al. [27] reported that the AOI of the throwing shoulder with morphologic change in the posterior glenoid rim was higher than that of the non-throwing shoulder, indicating an increase in the area of the rotator cuff tendons between the humeral head and posterior glenoid rim. Morphologic changes in the posterior glenoid rim diminish the bumper effect of the posterior glenoid rim and impair its protective role as a "wall." Our results suggest that the humeral head was pushed forward under condition of negative intra-articular pressure [33], and the rotator cuff tendons entered the gap behind the glenohumeral joint. Regarding the morphologic changes in the posterior glenoid rim, Harbrecht et al. [18] reported that the throwing shoulders of college baseball players showed more posterior labrum degeneration than the non-throwing shoulders. Morphologic changes in the posterior glenoid rim theoretically result from a collision between the humeral head and posterior glenoid rim caused by internal impingement while throwing. Therefore, morphological changes in the posterior glenoid rim may result in an increased likelihood of the rotator cuff tendons being pinched within the glenohumeral joint and thus an elevated occurrence of rotator cuff tendons being affected by internal impingement. Additionally, simple linear regression analysis also showed that external rotation and internal rotation were predictors of AOI. Changes in range of motion, specifically increased external

Table 2
Comparison of the posterior glenohumeral distance (positive vs. negative) for the morphologic changes in the posterior glenoid rim.

Variable	Morphologically changed posterior glenoid rim		*P*-value	Effect size (r)
	Positive[a] (n = 27)	Negative[b] (n = 23)		
PGHD (mm)				
90° ER position	7.8 ± 1.9	4.5 ± 2.2	<0.001	0.637
100° ER position	6.9 ± 1.7	3.6 ± 1.4	<0.001	0.723

MRI measurement position was 90° shoulder abduction with 90° and 100° external rotation.
[a] 24 throwing and three non-throwing shoulders.
[b] one throwing and 22 non-throwing shoulders. PGHD: posterior glenohumeral distance, ER: external rotation, MRI: magnetic resonance imaging.

Table 3
Comparison of posterior glenohumeral distance between the existing and non-existing groups of throwing shoulder pain history.

Variable	History of throwing shoulder pain		*P*-value	Effect size (r)
	Existing group (n = 9)	Non-existing group (n = 16)		
Age (year)	19.8 (1.2)	19.8 (1.1)	0.902	0.024
Height (cm)	174.2 (4.0)	172.8 (2.4)	0.386	0.261
Weight (kg)	72.1 (6.9)	70.6 (4.2)	0.508	0.139
Competing years	12.3 (2.1)	11.1 (2.3)	0.227	0.250
BMI (kg/m^2)	23.7 (1.6)	23.6 (0.6)	0.924	0.020
ERG (°)	15.2 (9.6)	16.4 (10.9)	0.727	0.068
GIRD (°)	14.8 (7.2)	17.5 (8.7)	0.172	0.272
HF deficit (°)	3.6 (8.5)	7.7 (5.3)	0.175	0.280
%PGHD				
90° ER position	280.9 (206.5)	184.3 (72.3)	0.152	0.289
100° ER position	247.2 (81.9)	177.2 (48.8)	0.031	0.425

BMI: body mass index, ERG: external rotation gain, GIRD: glenohumeral internal rotation deficit, HF: horizontal flexion, PGHD: posterior glenohumeral distance, ER: external rotation.

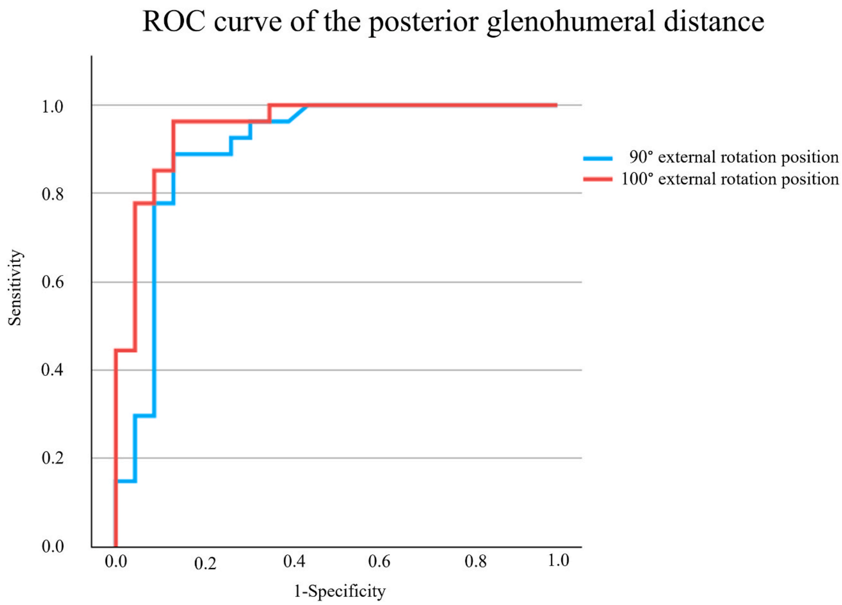

Fig. 3. ROC curve of the posterior glenohumeral distance for the morphologic changes in the posterior glenoid rim. PGHD at 90° external rotation position: The AUC, sensitivity, and specificity were 0.90, 88.9 %, and 87.0 %, respectively, when the cutoff point was set at 5.9 mm; n = 50. PGHD at 100° external rotation position: The AUC, sensitivity, and specificity were 0.95, 96.3 %, and 87.0 %, respectively, when the cutoff point was set at 4.6 mm; n = 50. ROC, receiver operating characteristic; PGHD, posterior glenohumeral distance; AUC, area under the curve.

Table 4
Reliability of the posterior glenohumeral distance.

ICC (1,2)	95 % CI		SEM (mm)
	Low	Upper	
0.942	0.912	0.962	0.62

ICC: Intraclass correlation coefficient, CI: Confidence interval, SEM: Standard error of the mean.

rotation and decreased internal rotation, are specific to overhead sports, including baseball players [34]. These changes can be influenced by factors such as glenoid retroversion [24], humeral torsion [4], anterior capsular laxity, and posterior capsular tightness [17,19–22]. The results of this study revealed that morphologic changes in the posterior glenoid rim and pinched rotator cuff tendons are contributing factors in range of motion changes of throwing shoulders.

PGHD in this study had high reliability (ICC: 0.94): the discrimination AUC for the 90° external rotation position was 0.90, with a sensitivity and specificity of 88.9 % and 87.0 %, respectively, when the cutoff point was set at 5.9 mm, and the AUC for the 100° external rotation position was 0.95, with a sensitivity and specificity of 96.3 % and 87.0 %, respectively, when the cutoff point was set at 4.6 mm. These results suggest that our developed PGHD model can be used to effectively identify a morphologic change in the posterior glenoid rim among baseball players. Therefore, the PGHD, which represents morphologic changes in the glenohumeral joint, may be used as a variable in future epidemiological studies of throwing shoulder injuries and their pathology. Additionally, the present study devised a %PGHD to evaluate the degree of morphologic changes of the posterior glenoid rim of the throwing shoulder by normalizing the PGHD of the non-throwing shoulder. Furthermore, when the %PGHD was compared between the groups with and without existing conditions, the %PGHD of the existing group was significantly higher than that of the non-existing group. Although there are limitations in verifying the relationship between symptoms and imaging findings because the grouping was defined by a previous history of throwing shoulder pain, and the definition of throwing shoulder pain history compared to previous studies [12] was mild that results in decreased performance, it is suspected that the accumulation of microtrauma from pitching caused structural and functional changes in the glenohumeral joint, including changes in alignment and instability, which contributed to throwing shoulder pain [13].

There are several limitations to this study that should be taken into consideration. First, although PGHD assessment can provide quantitative results for morphologic changes, this study used open MRI, which has a lower resolution than closed MRI, and the imaging findings were analyzed using image analysis software, which may introduce some measurement error. Second, although this study clarified the relationship between the AOI and PGHD, due to the cross-sectional nature of this study, it cannot establish causality between the area of impingement and posterior glenoid rim morphology. Third, this study only included baseball players; therefore, the applicability of the findings to other populations may be limited. Forth, the throwing motion is a dynamic action, so it does require further dynamical analysis, either while in motion or under load. Finally, this study did not investigate the effects of other factors such as training techniques, equipment, and individual differences in anatomy and biomechanics on rotator cuff injuries.

5. Conclusions

Multiple regression analysis showed that the AOI was associated with PGHD. Therefore, we suggest that the morphologically changed posterior glenoid rim, which is the joint gap behind the expanded glenohumeral joint, contributes to an increased AOI. Additionally, PGHD was a valid assessment method for quantifying the morphologically altered posterior glenoid rim and was also associated with a history of throwing shoulder pain. These results suggest that our developed PGHD model can be used to effectively identify a morphologic change in the posterior glenoid rim among baseball players.

Funding

None.

Data availability statement

The datasets generated and analyzed during the current study are not publicly available due to the protection of the study participants' personal information, but are available from the corresponding author (MT) on reasonable request.

Ethics statement

This study protocol was approved by the Ibaraki Prefectural University Ethics Committee (protocol number 629) and followed the relevant guidelines and regulations of the Declaration of Helsinki. The privacy and rights of the participants were protected in all cases, and the participants were notified that their data would be submitted for publication. Written informed consent was obtained from all participants.

CRediT authorship contribution statement

Makoto Takahashi: Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Hirotaka Mutsuzaki:** Writing – review & editing, Supervision, Methodology, Formal analysis, Data curation. **Koji Iwamoto:** Writing – review & editing, Supervision, Resources, Investigation, Formal analysis, Data curation, Conceptualization. **Masahiko Monma:** Visualization, Methodology, Formal analysis, Data curation. **Kazuhide Tomita:** Writing – review & editing, Visualization, Supervision. **Masafumi Mizukami:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Makoto Takahashi reports was provided by Japan University of Health Sciences.

Hirotaka Mutsuzaki reports was provided by Ibaraki Prefectural University of Health Sciences.

Koji Iwamoto reports was provided by Tokyo Professional University of Health Sciences.

Masahiko Monma reports was provided by Ibaraki Prefectural University of Health Sciences.

Kazuhide Tomita reports was provided by Ibaraki Prefectural University of Health Sciences.

Masafumi Mizukami reports was provided by Ibaraki Prefectural University of Health Sciences.

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