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Prevalence of abnormal ultrasonography findings in the posterosuperior humeral head of asymptomatic collegiate baseball pitchers

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Background: The posterosuperior humeral head contacts the glenoid during pitching. While magnetic resonance imaging often detects abnormalities in the posterosuperior humeral head of baseball pitchers, ultrasonography may also be effective in identifying these abnormalities. However, studies on such abnormalities in asymptomatic players are limited. Thus, this study aimed to determine the prevalence of abnormal findings in the humeral head using ultrasonography in asymptomatic collegiate baseball pitchers.

Methods: We utilized ultrasonography to assess abnormal findings in the humeral head, defined as a break in continuity or an irregular surface around the infraspinatus insertion, in 33 college baseball pitchers (pitcher group) and 30 college students without experience in overhead sports (control group). For 11 of the 33 pitchers, computed tomography-like images were used to locate the abnormalities. The location was quantitatively identified in the axial plane using a clock system, with the bicipital groove designated as 12 o'clock, and qualitatively assessed in the sagittal plane. Shoulder internal and external rotation ranges of motion (IR and ER ROMs) and humeral retroversion were measured using an inclinometer. The prevalence of abnormalities among the 4 subgroups (throwing and nonthrowing shoulders of the pitcher group and dominant and nondominant shoulders of the control group) was compared using the Fisher's exact test. A paired t-test was also performed to compare the IR and ER ROMs, as well as the humeral retroversion between each group's throwing (dominant) and nonthrowing (nondominant) sides.

Results: The prevalence of abnormalities was significantly higher (76%) in the throwing shoulder of the pitcher group than in the other shoulder groups ($<.001$). The mean position of the humeral head abnormalities in the axial plane was 8:32 $\pm$ 0:21 in the clock system, with all abnormalities located at the infraspinatus insertion on the greater tuberosity in the sagittal plane according to CT-like image analysis. While ER ROM and humeral retroversion were greater in the throwing shoulder, IR ROM was less than that in the nonthrowing shoulder in the pitcher group ($<.001$).

Conclusion: Ultrasonographic assessments revealed a higher prevalence of abnormalities in humeral head for asymptomatic collegiate baseball pitchers. Repetitive throwing motions may lead not only to adaptations in the ROM of the shoulder joint but also to abnormalities in the humeral head. Thus, ultrasonography may help identify asymptomatic baseball players with physiological internal impingement.

This study was approved by Osaka University Hospital ethical review board (number: 23041).

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Throwing shoulder injuries, such as rotator cuff tears, superior labral anterior to posterior lesions, and internal impingement, result from repetitive throwing motions.[2,13,35] Previous studies have demonstrated that large forces and torques occur at the shoulder joint during maximum external rotation to the ball release in the pitching motion. These mechanical stresses are the main factors contributing to the throwing injuries.[8] Some cadaveric studies have demonstrated that maximum external rotation during the cocking phase increases contact pressure on the greater tuberosity of humerus, where the supraspinatus and infraspinatus insert, which may cause internal impingement.[22,23] Consequently, repetitive impingement forces may generate lesions in the posterosuperior part of the glenohumeral joint.

There have been several reports on the prevalence of abnormal findings in the glenohumeral joint among overhead sports athletes identified using magnetic resonance imaging (MRI).[1,15,16,34] These studies suggest that overhead motions might contribute to the development of abnormalities in the glenohumeral joint. On the glenoid side, Bennet lesions, superior labral anterior to posterior lesions, and posterior glenoid cartilage abnormalities are frequently observed in baseball players.[16,33,34] However, most of these studies on abnormal findings of glenohumeral joint for baseball players were conducted only on players experiencing pain, and only a few studies have investigated the prevalence of these findings in asymptomatic players.[1,34] Therefore, to discuss the development of injury mechanics, further studies are required to explore the prevalence of glenohumeral joint abnormal findings in healthy athletes.

Abnormal findings of humeral head around the greater tuberosity are also often present in overhead athletes, believed to result from internal impingement.[10,11,26,36] The osteochondral lesions or cystic changes are typical abnormalities of the humeral head associated with internal impingement and are most frequently observed on the humeral head around the greater tuberosity.[10] Repetitive microtrauma to the anterior soft tissues or dysfunction of the dynamic stabilizers of the glenohumeral joint can contribute to anterior translation of the humeral head on the glenoid,[10] leading to repetitive contact of the humeral head around the greater tuberosity with the posterosuperior glenoid margin. Since the contact area of the glenohumeral joint is structured around the rotator cuff insertion between the glenoid and humeral head, the rotator cuff tear may be caused by internal impingement. Thus, abnormal findings in the humeral head may be indirectly related to pathologic internal impingement.

Evaluation of abnormal findings in the humeral head may help identify athletes with physiological or pathologic internal impingement. However, previous studies that have investigated the prevalence of abnormalities in the humeral head used radiographic, arthroscopic assessment, MRI or CT.[7,16,26,36] A major limitation of these medically specific and expensive apparatuses is their limited availability for evaluating asymptomatic athletes with abnormalities in the humeral head.

The location of the abnormalities of the humeral head resembles Hill-Sachs lesions, bone defects associated with shoulder dislocation. Previous studies have demonstrated that ultrasonography (US) is highly reliable for evaluating Hill-Sachs lesions.[6,18] These results suggest the potential utility of US in identifying abnormal findings in the humeral head among baseball players. Therefore, detecting such findings during medical examinations using US could aid in identifying asymptomatic athletes experiencing mechanical stress, such as impingement force and/or traction force, on the shoulder joint due to repetitive throwing motions.

This study aimed to determine the prevalence of abnormal findings in the posterosuperior humeral head of the throwing shoulder among asymptomatic collegiate baseball pitchers using US. In the present study, the prevalence of abnormalities in the throwing shoulder was compared to that in the nonthrowing shoulder and in both shoulders of collegiate students without experience in overhead sports. We hypothesized that the prevalence of abnormal findings in the throwing shoulder joint would be higher among baseball pitchers than in nonthrowing shoulders or among participants without experience in overhead sports.

Materials and methods

Ethics statements

This study was conducted in accordance with the Declaration of Helsinki and approved by our institution's ethical review board (number: 23,041). Written informed consent was obtained from all participants.

Study design and participants

This cross-sectional study enrolled 37 collegiate baseball pitchers who participated in preseason medical examinations as the pitcher group, and 30 collegiate students without overhead sports experience as the control group. The pitcher group comprised pitchers from Division 1 of a university baseball league affiliated with the

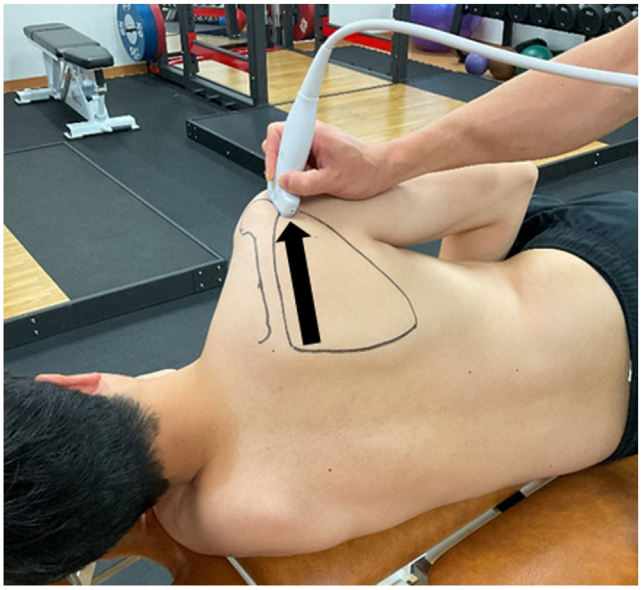

Figure 1 Participant is positioned in a side-lying posture with the palmar surface of the examination side laid on the abdomen. To detect posterosuperior abnormal findings in the humeral head, the ultrasonography probe was initially placed on the medial side of the infraspinatus and then moved onto the lateral side (*black arrow*).

Japan University Baseball Federation, boasting an average pitch speed of 142.2 ± 1.0 km/h. The exclusion criteria for both groups were as follows: difficulty in measuring joint ROM due to pain, a history of shoulder dislocation, or upper limb surgery. Pitchers experiencing shoulder discomfort during pitching at the time of measurement were also excluded from this study. Inclusion criteria for the control group encompassed individuals aged 18–25 years with no history of regular overhead sports. Both groups were recruited between February 2023 and May 2023, with measurements conducted between March and June 2023.

Assessment of abnormal findings in humeral head using ultrasonography (US assessment)

The posterior region of the humeral head was assessed using US (LOGIQ e Premium; GE HealthCare, Japan). Participants were instructed to lie on their sides with the measurement side facing upward while placing their palms on their abdomen. An examiner (T.U.) with 7 years of clinical experience in ultrasonography, positioned the US transducer along the long axis in the medial region of the infraspinatus and then laterally maneuvered it to assess the posterior humeral head[21] (Fig. 1). A break in continuity or an irregular surface of the posterolateral humeral head around the infraspinatus insertion was defined as an abnormal finding (Fig. 2B).[28] In the present study, these findings are referred to as ''abnormal findings in the humeral head.'' On the other hand, intact continuity was defined as a normal finding (Fig. 2A).

Validation of the US assessment

To validate the US assessment, 11 of the 37 participants underwent MRI following the US assessment. MRI images were acquired using a 3.0-T MRI scanner (MAGNETOM Skyra; Siemens, Erlangen, Germany) with computed tomography (CT)-like image sequences.[14] Since CT-like images can serve as a viable alternative to conventional CT scans, they were deemed suitable for evaluating the continuity of the humeral head.[7,9] This evaluation was conducted solely to assess the validity by confirming the presence or absence of continuity in the humeral head in the present study. An orthopedic surgeon (T.S.) evaluated the break in continuity of the posterolateral humeral head on MRI, and the results were compared with those from the US assessment. The evaluator of the MRI images was blinded to the results of the US assessment.

Inter-rater and intra-rater reliabilities of the US assessment

Eleven participants whose CT-like images were analyzed were examined for inter- and intra-rater reliability. For inter-rater reliability, another examiner (J.S.) who has over 10 years of the clinical experience in ultrasonography, conducted a US assessment based on the above definition. For intra-rater reliability, an examiner (T.U.) performed a reassessment at least one month after the initial assessment.

Position of abnormal findings in the humeral head

CT-like images of 11 participants in the pitcher group were used to locate abnormal findings in the humeral head, based on a previous study.[27] For each participant, an axial-plane image with the widest part of the abnormality was selected. Subsequently, a circumscribed circle fitting the humeral head surface was described in these axial plane images. Using the image analysis software SYNAPSE VINCENT (FUJIFILM Corp., Tokyo, Japan), the center of the circumscribed circle of the humeral head, the deepest point of the bicipital groove, and the midpoint of the defect (ie, the abnormal finding observed in the humeral head). were identified.[27] These images were then imported into Image J,[29] and the coordinates of each point were determined. As shown in Fig. 3B, the angle between the OG and OM vectors was calculated from their inner products. The position of the observed abnormal finding in the humeral head was represented by replacing the clock face with a ''G'' at the 12 o'clock position (Fig. 3B). To ensure consistency in analysis, the images of the left shoulder were inverted and adjusted to match the orientation of the right shoulder images. In the sagittal plane, the vertical position of the observed abnormal finding in the humeral head was qualitatively evaluated based on its location in relation to the supraspinatus, infraspinatus, and teres minor (Fig. 3C).

Shoulder joint range of motion: humeral retroversion and glenohumeral joint range of motion

Humeral retroversion and glenohumeral joint ROM were measured to confirm whether the throwing shoulder joints of the pitchers in this study exhibited typical functional characteristics of pitchers. US was also utilized to assess humeral retroversion.[12,24] Participants were positioned supine on a bed with the shoulder joint abducted to 90° and the elbow flexed to 90°. One examiner (T.U.) placed the US probe vertically on the anterior aspect of the shoulder

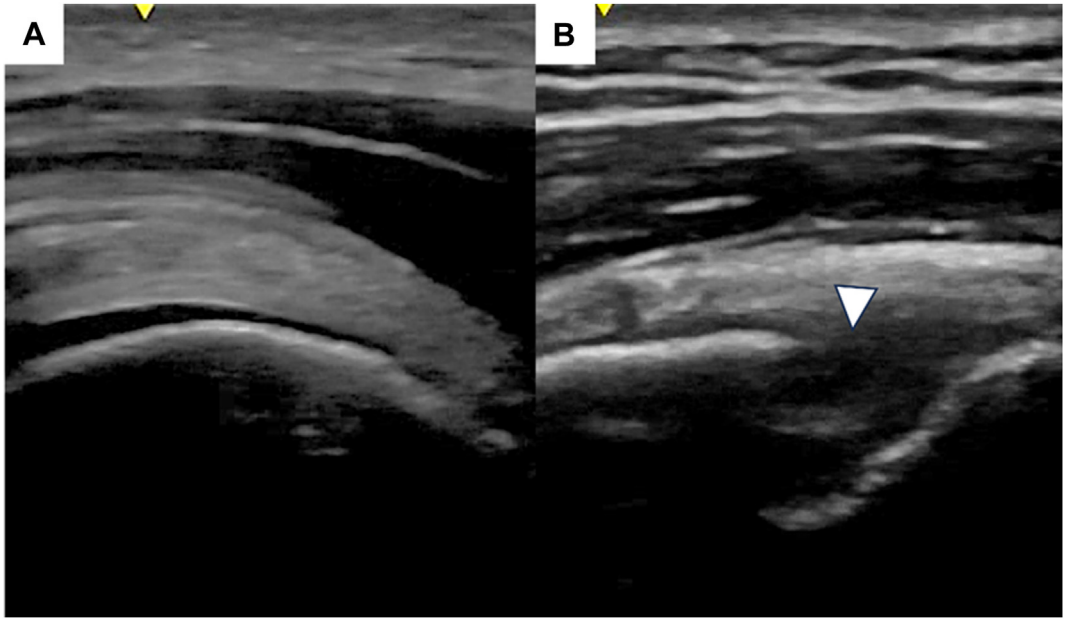

Figure 2 Definition of ultrasonography images. A *white arrowhead* indicates a break in the continuity of the humeral head ((**A**) Normal, (**B**) Abnormal).

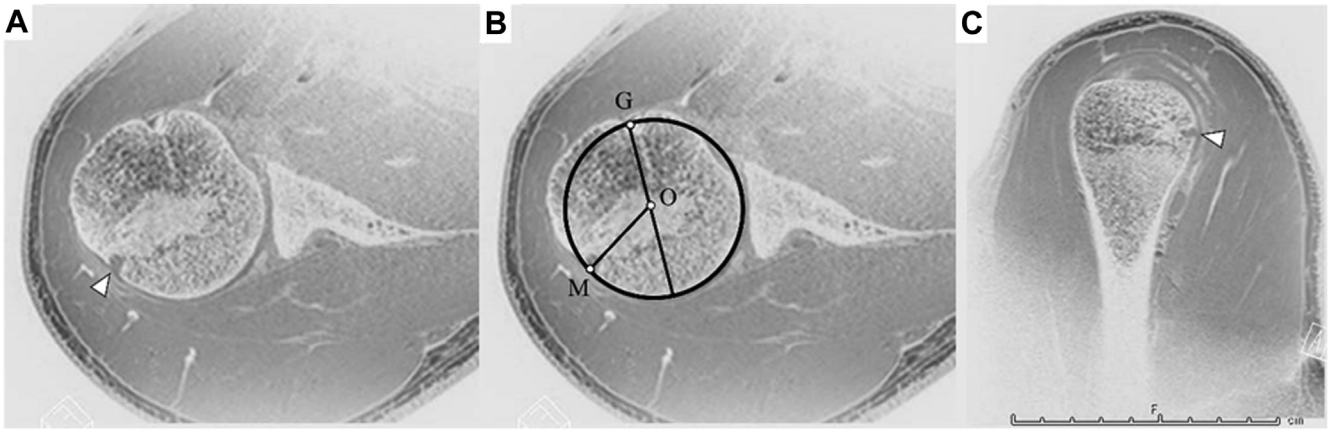

Figure 3 Location of posterosuperior abnormal findings in the humeral head in the axial and sagittal planes. The location was measured using a computed tomography (CT)-like image. (**A**) Original image of a CT-like image of the humeral head in the axial plane. (**B**) Measurement image of the location of the abnormality. (**C**) CT-like image of the humeral head in the sagittal plane. (**O**) Center of the humeral head. (**G**) The deepest point of the bicipital groove. (**M**) Midpoint of the abnormal findings. *Arrowhead*: Posterosuperior abnormal findings in the humeral head.

joint, rotated the participant's humerus, and identified the position in which the line connecting the apices of the greater and lesser tuberosities appeared parallel to the horizontal plane in the ultrasound image.[12,24] Another examiner (I.N. or H.Y.) measured the shoulder joint rotation angle along the ulna using an inclinometer, with the ulnar angle representing the humeral retroversion angle.

The internal and external rotational ranges of shoulder motion were measured using an inclinomete.[12,20,31] Participants were positioned in the same manner as during the humeral retroversion assessment. The examiner (T.U.) rotated the shoulder joint internally and externally to the maximum ROM. Another examiner (I.N. or H.Y.) positioned the inclinometer as described earlier and recorded it as the shoulder internal and external rotation angle (Overall IR and Overall ER, respectively).[3] The shoulder joint IR and ER rotation angles, adjusted for the humeral retroversion angle, were then calculated as the soft tissue-related IR and ER angles (STR IR and STR ER, respectively).[12]

Statistical analysis

Categorical data (throwing and nonthrowing) and numerical demographic data (age, height, and weight) were compared between the pitcher and control groups using chi-square and independent t-tests, respectively.

Table I Demographic data of pitcher and control groups

Variable	Pitcher group	Control group	*P* value*
Number of participants	33	30	
Dominant side, right/left	23/13	27/3	n.s.
Age, mean ± SD, yrs	20.1 ± 0.9	20.7 ± 2.8	n.s.
Height, mean ± SD, m	1.77 ± 0.05	1.72 ± 0.08	n.s.
Weight, mean ± SD, kg	78.6 ± 7.0	62.2 ± 13.1	<.001

n.s., not significant; *SD*, standard deviation.
* Statistical significance level was adjusted using Bonferroni correction.

Inter- and intra-rater agreement for the US assessment was assessed using Cohen's Kappa Coefficient and classified according to Landis and Koch[19]: values < 0 were considered poor, 0.00-0.20 slight, 0.21-0.40 fair, 0.41-0.60 moderate, 0.61-0.80 good and 0.81-1.00 excellent agreement.

Fisher's exact test was employed to compare the prevalence of abnormal findings in the humeral head between the throwing and non-throwing shoulders in the pitcher group, and between dominant and non-dominant shoulders in the control group. Humeral retroversion, Overall IR and ER, and STR IR and ER within each group were compared using a dependent t-test. The statistical significance level was adjusted using Bonferroni correction with JMP Pro16 (SAS Institute Inc., Cary, NC, USA).

Results

Four participants were excluded from the pitcher group due to pain during pitching at the time of the US assessment. A priori power analysis ($\alpha = 0.05$, $1\text{-}\beta = 0.80$) was performed using G Power[5] (Version 3.1.9.4 Kiel University, Germany) to determine the sample size. The sample size, calculated from a prior power analysis, was 44 participants, based on a large effect size of Cohen's w = 0.5. The total number of participants in both groups was 63 (33 in the pitcher group and 30 in the control group), which was adequate to calculate the differences between the groups. The demographic data showed a significant difference between the pitcher and control groups in terms of weight, while no significant differences were observed in the other variables (Table I).

Cohen's Kappa coefficients for the inter- and intra-rater reproducibility of the US assessment were both 0.744, indicating substantial agreement.[19]

The prevalence of abnormal findings in the humeral head detected via US assessment significantly differed between the groups ($P < .001$, Cramer's V = 0.58; Table II). Specifically, the prevalence on the throwing side in the pitcher group was 76%, whereas it was <20% in the other groups.

Findings from MRI images for 11 pitchers showed that 2 were evaluated as having continuity of the posterosuperior humeral head, while 9 exhibited a break in continuity. The US assessment and CT-like images were in complete agreement regarding the presence of a break in the continuity of the humeral head (Fig. 4). The average location of the abnormal findings in the humeral head, based on CT-like images, was 8:32 ± 0:21 according to the clock system in axial plane analysis. In the sagittal plane, the abnormal findings in the humeral head were consistently located at the infraspinatus insertion in the humeral greater tuberosity across all participants.

Humeral retroversion and overall ER in the throwing shoulder were significantly greater than those in the non-throwing shoulder (Table III). Additionally, the overall IR of the throwing shoulder was significantly lower than that of the non-throwing shoulder in the pitcher group (Table III). However, the STR IR and ER showed no significant differences between the shoulders. In the control group, for the dominant and nondominant shoulders, humeral retroversion was 70 ± 7 and 69 ± 9° ($P = .776$, Cohen's d (E.S.) = 0.13), overall ER was 109 ± 12 and 105 ± 10° ($P = .883$, E.S. = 0.31), overall IR was 38 ± 9 and 42 ± 8° ($P = .021$, E.S. = 0.53), STR ER was 128 ± 9 and 126 ± 12° ($P = .738$, E.S. = 0.17), and STR IR was 18 ± 6 and 22 ± 8° ($P = .045$, E.S. = 0.44), respectively. No variables showed significant differences in the control group.

Discussion

This study highlights a higher prevalence of abnormal findings in the humeral head, characterized by a break in the continuity of the posterosuperior humeral head as determined by US, in the throwing shoulder compared to the nonthrowing shoulder in the pitcher group and both shoulders in the control group. Previous studies using MRI to determine the prevalence of cystic changes in the posterosuperior humeral head among overhead sports athletes reported a prevalence of 70% in athletes diagnosed with throwing shoulder injuries and 60% in handball players.[15,16] In this study, US was employed to evaluate the continuity of the humeral head in asymptomatic baseball pitchers, revealing a prevalence of 76% for abnormal findings in the humeral head. Both handball throwing and baseball pitching involve the cocking phase, which includes shoulder joint abduction and external rotation, accompanied by higher internal rotation torque and anterior force

Table II Prevalence of abnormal findings in the humeral head*

	Throwing shoulder of pitcher group	Nonthrowing shoulder of pitcher group	Dominant shoulder of control group	Nondominant shoulder of control group
Normal, n (%)	8 (24)	27 (82)	28 (93)	24 (80)
Abnormal, n (%)	25 (76)	6 (18)	2 (7)	6 (20)

* Significant difference between groups ($P < .001$).

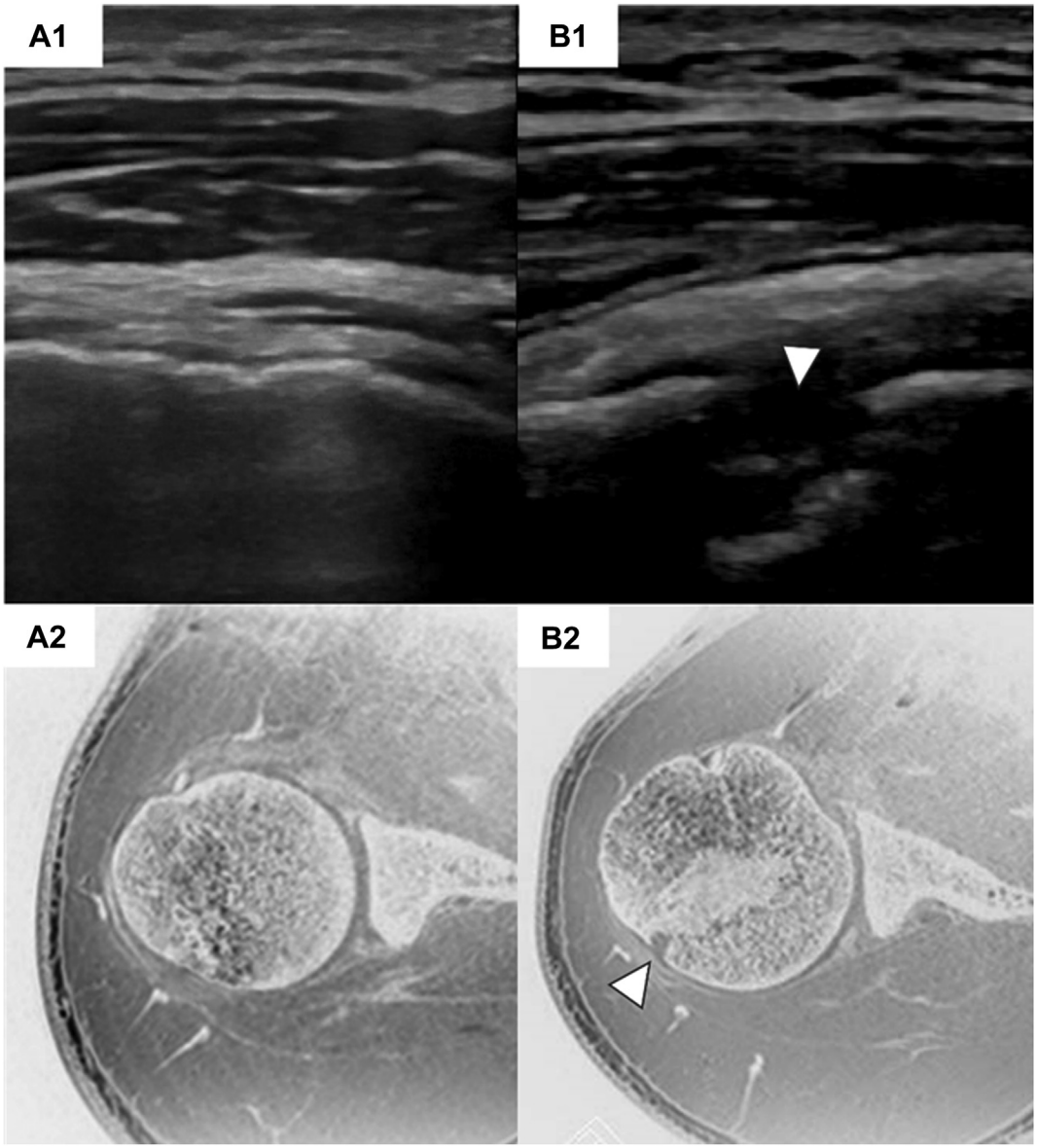

Figure 4 Ultrasonography and CT-like images used in the evaluation of the posterosuperior humeral head. *White arrowheads* indicate the break in the continuity of the humeral head. (**A-1**) The continuity of the humeral head by ultrasonography evaluation. (**A-2**) The continuity of the humeral head by computed tomography (CT)-like image (the same participants as **A-1**). (**B-1**) Abnormal findings in the humeral head by ultrasonography evaluation. (**B-2**) Abnormal findings in the humeral head by CT-like image (the same participants as (**B-1**)).

Table III Shoulder function assessment comparing throwing and non-throwing shoulders in the pitcher group

Variable (°)	Throwing shoulder	Nonthrowing shoulder	*P* value*	Effect size†
	Mean ± SD	Mean ± SD		
Humeral retroversion	83 ± 8	70 ± 8	<.001	1.60
Overall ER	127 ± 10	117 ± 9	<.001	1.02
STR ER	134 ± 11	137 ± 12	.141	0.26
Overall IR	26 ± 11	43 ± 11	<.001	1.57
STR IR	19 ± 8	23 ± 8	.013	0.54

ER, external rotation; *IR*, internal rotation; *STR*, soft tissue related.
* Statistical significance level was adjusted using Bonferroni correction.
† Cohen's d effect size.

applied to the shoulder joint.[8,30,32] Despite differences in evaluation methods, findings (cystic change vs. break in continuity or an irregular surface), and sports, abnormal findings in the humeral head occurred at similar positions and rates. This suggests that such findings may result from the complex shoulder joint movement during the throwing motion, involving large mechanical forces such as the impact force due to internal impingement and traction force due to infraspinatus contraction.

The results of the positional analysis of the abnormal findings in the humeral head using CT-like images showed that they were located in the posterolateral part of the humeral head, with their height aligned with the level of the infraspinatus insertion. In shoulder abduction movements, the path of contact between the glenoid and the humeral head is called the "glenoid track."[37] Omori et al[25] investigated the glenoid track while maintaining the arm at maximum external rotation and horizontal abduction. Their study demonstrated that the glenoid track shifts from the bottom to the top of the humeral head as shoulder abduction increases. Specifically, at 90° shoulder abduction, which corresponds to the typical shoulder angle at maximum external rotation during baseball pitching, the posterosuperior humeral head comes into contact with the posterior part of the glenoid. Additionally, a cadaveric study simulating a late cocking posture indicated that the insertion from the supraspinatus to the infraspinatus contacted the posterosuperior side of the glenoid.[22] Moreover, it was noted that the degree of overlap of these insertions with the glenoid and the resulting contact pressure increased with excessive horizontal abduction.[23] Excessive horizontal abduction during the pitching motion, termed hyperangulation,[4] is recognized as a risk factor for throwing shoulder injuries.[2,38] Notably, excessive horizontal abduction during the early cocking and acceleration phases may increase the contact pressure between the posterosuperior humeral head and glenoid.[2,38] This increased pressure may cause internal impingement and subsequently lead to some abnormal findings of glenohumeral joint. Thus, mechanical stress resulting from improper pitching mechanics could potentially contribute to microtrauma around the posterosuperior region of the humeral head, particularly induced by external shoulder rotation combined with excessive horizontal abduction. This increased stress might ultimately lead to the development of abnormal findings in the humeral head.

The presence of abnormal findings in the humeral head may provide evidence that physiological internal impingement of the posterosuperior part of the humeral head occurred during the pitching motion. Recent analyses of pitching motion, including scapular models, have suggested that poor coordination of scapular movement with the shoulder joint complex during pitching may increase the risk of developing internal impingement.[38] Therefore, a comparison of the differences in glenohumeral joint motion during pitching with and without abnormal findings in the humeral head would help clarify the assumption that improper scapular motion contributes to the development of abnormalities.

Takahashi et al[34] indicated that abnormal findings in the humeral head are a factor involved in the enlargement of the area of impingement (AOI). The AOI, comprising the greater tuberosity at the rotator cuff attachment and posterior glenoid fossa, is larger in the throwing shoulder compared to the nonthrowing shoulder. Furthermore, the prevalence of abnormal findings in the shoulder joint (such as greater tuberosity cystic changes and posterior labrum degeneration) was significantly higher in the throwing shoulder than in the non-throwing shoulder, suggesting that these abnormal findings may contribute to a larger AOI and increase the risk of rotator cuff injury.[34] Therefore, detecting abnormal findings in the humeral head using ultrasonography may assist in identifying the risk of physiological internal impingement related to the rotator cuff tear.

In our study, the pitcher group displayed characteristic shoulder joint functions characteristic, such as greater humeral retroversion, increased external rotation of the glenohumeral joint, and reduced internal rotation. These results are consistent with findings from previous studies[12,20,24] and indicate the frequent occurrence of abnormal findings in the humeral head of the throwing shoulder among collegiate baseball pitchers. Considering these results alongside the findings of the current study, it is suggested that repetitive mechanical stress from the

pitching motion not only contributes to the adaptations in the shoulder joint ROM and humeral retroversion but also morphological changes in the humeral head, such as the observed abnormal findings in the humeral head.

This study has a few limitations. First, the US assessment evaluated only breaks in the continuity or irregular surfaces of the humeral head. Its association with other abnormal findings in the humeral head, such as osseous edema or cysts, is unknown. However, the purpose of this study was to focus on abnormal findings in the humeral head that can be assessed using ultrasound. These associations call for further studies. Second, the results cannot be generalized to other age groups because only college students participated in this study. Future studies involving participants from different age groups are warranted. Third, a causal relationship between abnormal findings in the humeral head and throwing shoulder injuries could not be established. Therefore, the relationship between abnormal findings in the humeral head and shoulder pain remains unclear. There is currently no consensus on the appropriate course of action following early detection, as the findings have shown limited correlation with clinical symptoms.[29] After early detection, further investigation using a prospective approach is needed. Finally, in this study, STR IR and ER are calculated, but glenoid retroversion was not included. Glenoid retroversion, like humeral retroversion, may be a protective adaptive change and could have affected STR IR and ER.[17,33] However, a previous study investigating the overall IR, overall ER, STR IR, and STR ER in baseball players with pathological internal impingement also only used humeral retroversion.[12] In that study, the functional characteristics of the throwing shoulders of baseball pitchers were represented without measuring glenoid retroversion. Following this methodology, we employed the same approach. Thus, our results indicating that our pitcher group exhibited typical functional characteristics of baseball pitchers were not affected by the absence of glenoid retroversion measurement.[12]

Conclusion

Abnormal findings in the humeral head were successfully identified using US. A higher prevalence of these findings was observed in the throwing shoulder compared to the nonthrowing shoulder and control groups, with a prevalence of 76% even in asymptomatic players. Therefore, morphologic changes due to physiological internal impingement may have already begun, potentially progressing to pathological internal impingement. The study found morphologic changes that might represent the transition from physiological to pathologic internal impingement. This suggests that ultrasonographic assessment may help identify the potential risk of internal impingement in asymptomatic baseball players.

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References

1. Beitzel K, Zandt JF, Buchmann S, Beitzel KI, Schwirtz A, Imhoff AB, et al. Structural and biomechanical changes in shoulders of junior javelin throwers: a comprehensive evaluation as a proof of concept for a preventive exercise protocol. Knee Surg Sports Traumatol Arthrosc 2016;24:1931-42. https://doi.org/10.1007/s00167-014-3223-y
2. Burkhart SS, Morgan CD, Ben Kibler W. The disabled throwing shoulder: spectrum of pathology Part I: Pathoanatomy and biomechanics. Arthroscopy 2003;19:404-20. https://doi.org/10.1053/jars.2003.50128
3. Cools AM, De Wilde L, van Tongel A, Ceyssens C, Ryckewaert R, Cambier DC. Measuring shoulder external and internal rotation strength and range of motion: comprehensive intra-rater and inter-rater reliability study of several testing protocols. J Shoulder Elbow Surg 2014;23:1454-61. https://doi.org/10.1016/j.jse.2014.01.006
4. Davidson PA, Elattrache NS, Jobe CM, Jobe FW. Rotator cuff and posterior-superior glenoid labrum injury associated with increased glenohumeral motion: a new site of impingement. J Shoulder Elbow Surg 1995;4:384-90.
5. Erdfelder E, FAul F, Buchner A, Lang AG. Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. Behav Res Methods 2009;41:1149-60. https://doi.org/10.3758/BRM.41.4.1149
6. Farin PU, Kaukaneno E, Jaroma H, Harju A, Väätäinen U. Hill-Sachs lesion: sonographic detection. Skeletal Radiol 1996;25:559-62.
7. Feuerriegel GC, Kronthaler S, Weiss K, Haller B, Leonhardt Y, Neumann J, et al. Assessment of glenoid bone loss and other osseous shoulder pathologies comparing MR-based CT-like images with conventional CT. Eur Radiol 2023;33:8617-26. https://doi.org/10.1007/s00330-023-09939-9
8. Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. Kinetics of baseball pitching with Implications about injury Mechanisms. Am J Sports Med 1995;23:233-9.

9. Hesse N, Feuerriegel GC, Erber B, Reidler P, Gottfried V, Stohldreier Y, et al. CT-like images based on T1-weighted gradient echo MRI sequences for the assessment of fractures of the hand and wrist compared to CT. Skeletal Radiol 2024;53:2607-15. https://doi.org/10.1007/s00256-024-04683-7
10. Heyworth BE, Williams RJ. Internal impingement of the shoulder. Am J Sports Med 2009;37:1024-37. https://doi.org/10.1177/0363546508324966
11. Ishikawa H, Henninger HB, Kawakami J, Zitnay JL, Yamamoto N, Tashjian RZ, et al. A stabilizing role of the glenoid labrum: the suction cup effect. J Shoulder Elbow Surg 2023;32:1095-104. https://doi.org/10.1016/j.jse.2022.12.002
12. Ishikawa H, Kurokawa D, Muraki T, Nagamoto H, Takahashi H, Yamamoto N, et al. Increased external rotation related to the soft tissues is associated with pathologic internal impingement in high-school baseball players. J Shoulder Elbow Surg 2022;31:1823-30. https://doi.org/10.1016/j.jse.2022.02.021
13. Jobe CM, Jobe M. Posterior superior glenoid impingement: expanded spectrum. Arthroscopy 1995;11:530-6.
14. Johnson B, Alizai H, Dempsey M. Fast field echo resembling a CT using restricted echo-spacing (FRACTURE): a novel MRI technique with superior bone contrast. Skeletal Radiol 2021;50:1705-13. https://doi.org/10.1007/s00256-020-03659-7/Published
15. Jost B, Zumstein M, Pfirrmann CWA, Zanetti M, Gerber C. MRI findings in throwing shoulders: abnormalities in professional handball players. Clin Orthop Relat Res 2005;434:130-7. https://doi.org/10.1097/01.blo.0000154009.43568.8d
16. Karcich J, Kazam JK, Rasiej MJ, Wong TT. Bennett lesions in overhead athletes and associated shoulder abnormalities on MRI. Skeletal Radiol 2019;48:1233-40. https://doi.org/10.1007/s00256-019-03176-2
17. Kuhn JE. Adaptive pathology: new insights into the physical examination and imaging of the thrower's shoulder and elbow. J Shoulder Elbow Surg 2024;33:474-93. https://doi.org/10.1016/j.jse.2023.07.031
18. van Lancker HP, Martineau PA, Khoury V. Sonography as a tool for identifying engaging hill-sachs lesions preliminary experience. J Ultrasound Med 2013;32:1653-7. https://doi.org/10.7863/ultra.32.9.1653
19. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977;33:159-74.
20. McHugh MP, Tyler TF, Mullaney MJ, Mirabella MR, Nicholas SJ. The effect of a high pitch volume on musculoskeletal adaptations in high school baseball pitchers. Am J Sports Med 2016;44:2246-54. https://doi.org/10.1177/0363546516650183
21. Michelin P, Kasprzak K, Dacher JN, Lefebvre V, Duparc F. Ultrasound and anatomical assessment of the infraspinatus tendon through anterosuperolateral approach. Eur Radiol 2015;25:2240-5. https://doi.org/10.1007/s00330-015-3614-6
22. Mihata T, Gates J, McGarry MH, Neo M, Lee TQ. Effect of posterior shoulder tightness on internal impingement in a cadaveric model of throwing. Knee Surg Sports Traumato Arthrosc 2015;23:548-54. https://doi.org/10.1007/s00167-013-2381-7
23. Mihata T, McGarry MH, Kinoshita M, Lee TQ. Excessive glenohumeral horizontal abduction as occurs during the late cocking phase of the throwing motion can be critical for internal impingement. Am J Sports Med 2010;38:369-74. https://doi.org/10.1177/0363546509346408
24. Nakase C, Mihata T, Itami Y, Takeda A, Neo M. Relationship between humeral retroversion and length of baseball career before the age of 16 years. Am J Sports Med 2016;44:2220-4. https://doi.org/10.1177/0363546516651864
25. Omori Y, Yamamoto N, Koishi H, Futai K, Goto A, Sugamoto K, et al. Measurement of the glenoid track in vivo as investigated by 3-dimensional motion analysis using open MRI. Am J Sports Med 2014;42:1290-5. https://doi.org/10.1177/0363546514527406
26. Paley KJ, Jobe FW, Pink MM, Kvitne RS, Elattrache NS. Arthroscopic Findings in the overhand throwing athlete: evidence for posterior internal impingement of the rotator cuff. Arthroscopy 2000;16:35-40.
27. Saito H, Itoi E, Minagawa H, Yamamoto N, Tuoheti Y, Seki N. Location of the Hill-Sachs lesion in shoulders with recurrent anterior dislocation. Arch Orthop Trauma Surg 2009;129:1327-34. https://doi.org/10.1007/s00402-009-0854-4
28. Sakata J, Ishikawa H, Inoue R, Urata D, Ohinata J, Kimoto T, et al. Physical functions, to be or not to be a risk factor for osteochondritis dissecans of the humeral capitellum? JSES Int 2022;6:1072-7. https://doi.org/10.1016/j.jseint.2022.07.001
29. Schär MO, Dellenbach S, Pfirrmann CW, Raniga S, Jost B, Zumstein MA. Many shoulder MRI findings in elite professional throwing athletes resolve after retirement: a clinical and radiographic study. Clin Orthop Relat Res 2018;476:620-31. https://doi.org/10.1007/S11999.0000000000000042
30. Serrien B, Baeyens JP. Systematic review and meta-analysis on proximal-to-distal sequencing in team handball: prospects for talent detection? J Hum Kinet 2018;63:9-21. https://doi.org/10.2478/hukin-2018-0002
31. Shanley E, Rauh MJ, Michener LA, Ellenbecker TS, Garrison JC, Thigpen CA. Shoulder range of motion measures as risk factors for shoulder and elbow injuries in high school softball and baseball players. Am J Sports Med 2011;39:1997-2006. https://doi.org/10.1177/0363546511408876
32. Skejø SD, Møller M, Bencke J, Sørensen H. Shoulder kinematics and kinetics of team handball throwing: a scoping review. Hum Mov Sci 2019;64:203-12. https://doi.org/10.1016/j.humov.2019.02.006
33. Sweitzer BA, Thigpen CA, Shanley E, Stranges G, Wienke JR, Storey T, et al. A comparison of glenoid morphology and glenohumeral range of motion between professional baseball pitchers with and without a history of SLAP repair. Arthroscopy 2012;28:1206-13. https://doi.org/10.1016/j.arthro.2012.02.023
34. Takahashi M, Iwamoto K, Monma M, Mutsuzaki H, Mizukami M. 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. Orthop J Sports Med 2021;9. https://doi.org/10.1177/2325967121992133
35. Walch G, Boileau P, Noel E, Donell ST. Impingement of the deep surface of the supraspinatus tendon on the posterosuperior glenoid rim: an arthroscopic study. J Shoulder Elbow Surg 1992;1:238-45.
36. Wright RW, Steger-May K, Klein SE. Radiographic findings in the shoulder and elbow of major league baseball pitchers. Am J Sports Med 2007;35:1839-43. https://doi.org/10.1177/0363546507304493
37. Yamamoto N, Itoi E, Abe H, Minagawa H, Seki N, Shimada Y, et al. Contact between the glenoid and the humeral head in abduction, external rotation, and horizontal extension: a new concept of glenoid track. J Shoulder Elbow Surg 2007;16:649-56. https://doi.org/10.1016/j.jse.2006.12.012
38. Yanai T, Crotin R, Du T. Proximal to distal sequencing impacts on maximum shoulder joint angles and the risk of impingement in baseball pitching involving a scapular independent thoracohumeral model. Scand J Med Sci Sports 2023;33:1322-34. https://doi.org/10.1111/sms.14374