Original Article
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Are Rotator Muscle Performance and Posterior Shoulder Capsule Tightness Related to Glenohumeral Internal Rotation Deficit in Male College Baseball Players?

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Background: Posterior inferior capsule (PIC) tightness in the shoulder joint, a known risk factor for shoulder injury, can be assessed using shear-wave ultrasound elastography (SWE). However, to date, the correlation between PIC elasticity and shoulder rotator muscle performance in college baseball players with glenohumeral internal rotation deficit (GIRD) has not been reported. This study aimed to analyze the differences in PIC elasticity measured using SWE and shoulder rotator muscle performance between male college baseball players with and without GIRD.

Methods: Twenty-four male college baseball players participated in this study: 10 with GIRD (G group) vs. 14 without GIRD (NG group). PIC elasticity was measured using SWE in the lateral decubitus position. Shoulder rotator muscle performance tests were performed for the internal rotators (IRs) and external rotators (ERs) at an angular velocity of 180°/sec with 90° shoulder abduction using an isokinetic test device.

Results: Mean PIC elasticity was significantly greater in the throwing shoulders of the G group than in those of the NG group (4.8 ± 1.2 kPa vs. 3.7 ± 1.2 kPa, $p = 0.036$). In the throwing shoulders of the G group, compared with those of the NG-group, the ER/IR ratio was significantly lower (35.7% ± 5.0% vs. 55.5% ± 6.2%, $p < 0.001$) and IR muscle strength was significantly greater (75.0 ± 7.6 Nm kg^{-1} × 100 vs. 55.7 ± 6.4 Nm kg^{-1} × 100, $p = 0.002$). The mean elasticity of the PIC showed a significant negative correlation with the ER/IR ratio in the throwing shoulders of the G group ($r = -0.640$, $p = 0.046$).

Conclusions: Among the male college baseball players with GIRD, SWE could quantitatively assess PIC tightness, and an imbalance in shoulder rotator muscle strength was found in these baseball players. Therefore, clinicians and therapists need to focus on the restoration of shoulder rotator muscle imbalance in addition to improving internal rotation in these players.

Keywords: *Shoulder, Rotator muscle, Joint capsule, Elasticity, Shear-wave ultrasound elastography*

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Posterior inferior capsule (PIC) tightness in the shoulder joint is a known risk factor for shoulder injury,[1-3] especially during the throwing motion by baseball players.[3-5] Therefore, when treating shoulder injuries in baseball players, most clinicians and therapists focus on evaluating tightness of the PIC and the importance of stretching exercises.

Most researchers assess the glenohumeral internal rotation deficit (GIRD) to evaluate the tightness of the PIC.[6-8] However, various criteria for GIRD have been reported, such as a 15° to 20° difference in the internal rotator (IR) range of motion (ROM) between both shoulders.[3,7-11] Recently, some researchers have attempted to quantitatively assess PIC elasticity using shear-wave ultrasound elastography (SWE).[7,12,13]

The tightness of the PIC may also lead to rotator cuff muscle injury due to the obligatory translation of the humeral head during the throwing motion, in addition to labral injury.[1,9] Therefore, it might be important to evaluate rotator muscle status according to PIC elasticity. However, the relationship between PIC elasticity and shoulder rotator muscle performance remains to be elucidated. In particular, there have been no studies on PIC elasticity measured using SWE and shoulder rotator muscle performance according to the presence of GIRD. Overall, muscle performance comprises muscle strength, muscle endurance, muscle balance, and neuromuscular control. These components can be assessed using an isokinetic muscle testing system.

This study aimed to analyze the differences in PIC elasticity measured using SWE and shoulder rotator muscle performance, including muscle strength and muscle endurance, according to the existence of GIRD in college baseball players. We hypothesized that shoulder rotator muscle performance would be related to the SWE value for PIC. We also hypothesized that muscle performance would be reduced and SWE would be increased in baseball players with GIRD.

METHODS

This study complied with the Declaration of Helsinki, and was approved by the Institutional Review Board of Korea University Anam Hospital (No. 2017AN0331). All participants provided written informed consent, and their rights were protected. All participants permitted using their photos.

Sample Size Estimation and Participant Enrollment

For comparison of college baseball players with and without GIRD, we considered a 10% difference as clinically significant based on previous results on the strength of the shoulder rotator muscle in patients with shoulder injuries.[14,15] To determine the sample size, we conducted an a priori power analysis with a significance level of 0.05 and power of 0.8. Effect size (Cohen's d, 1.553) was calculated from the results of a pilot study involving 5 shoulders in each group. This indicated that a sample of 8 shoulders in each group was required to determine a clinically meaningful difference in the muscle strength (> 10%) between the groups. The power required to detect differences in the muscle strength was 0.823.

This prospective comparative study consecutively enrolled 29 male college baseball players (10 pitchers and 19 field players) during the pre-season period. We excluded 5 participants for the following reasons: recent shoulder or elbow injury and a history of shoulder or elbow surgery within previous 1 year. A total of 24 players (10 pitchers and 14 field players) were evaluated, including 10 with GIRD (G group: 4 pitchers and 6 field players)

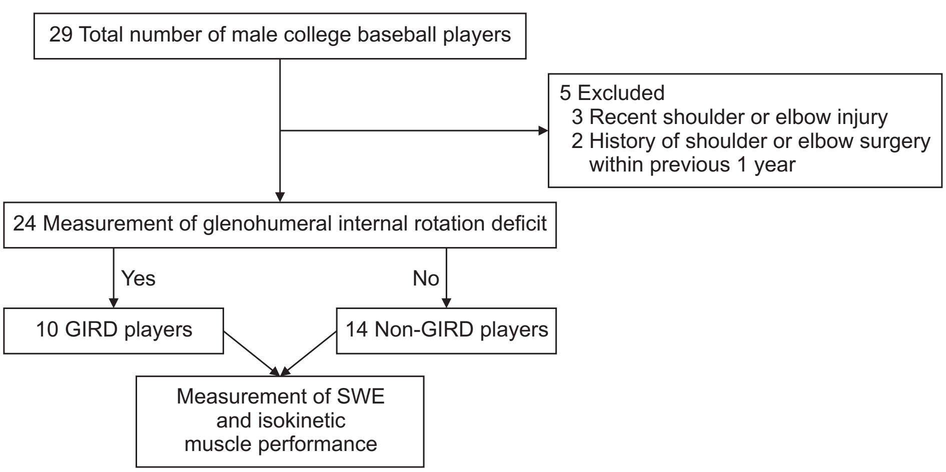

Fig. 1. Study flowchart. GIRD: glenohumeral internal rotation deficit, SWE: shear-wave ultrasound elastography.

and 14 without GIRD (NG group: 6 pitchers and 8 field players) (Fig. 1). There were 22 right-dominant and 2 left-dominant arms. The shoulders of the dominant arms were regarded as throwing shoulders.

Outcome Measures

GIRD measurement

Shoulder IR and external rotator (ER) ROM were measured by two orthopedic surgeons (WKJ, HJP) using a digital goniometer with players in the supine position with 90° abduction and 90° elbow flexion[16] for both throwing and non-throwing shoulders (Fig. 2). Based on previous GIRD assessment,[7,11] we defined GIRD as a limitation of more than 15° for the IR ROM and a limitation of more than 10° for the total rotation ROM when comparing the throwing shoulders with the non-throwing shoulders; intra-class correlation coefficients (ICCs) ranged between 0.90 and 0.97.[7]

SWE assessment

SWE for the PIC involved the shear-wave velocities and was performed using Aplio i700 (Canon Medical Systems, Otawara, Japan) with a convex array probe (1–10 MHz, PVI-574BX), which indicated the tension in the PIC. All ultrasound evaluations were performed in the lateral decubitus position with cross-body adduction (Fig. 3A), which was measured by a single orthopedic surgeon (WKJ) with extensive experience in musculoskeletal ultrasonography. In a previous study,[17] cross-body adduction in the supine position was found to be reliable for PIC evaluation (ICC, 0.83). Additionally, based on a previous study on the use of shear-wave elasticity for PIC assessment,[8] a convex transducer was placed on the posterior aspect of the shoulder joint for a longitudinal scan of the PIC. This was followed by shear-wave elasticity measurement at a location 5 mm lateral from the edge of the labrum (Fig. 3B and C). Greater elasticity of the PIC indicated greater PIC stiffness.

Isokinetic shoulder muscle performance test

The shoulder rotator muscle performance test (concentric/concentric mode) was performed to assess muscle strength ratio, muscle strength, and muscle endurance using the isokinetic Biodex Multijoint System 4 (Biodex Medical Systems, Shirley, NY, USA). The IRs and ERs of the throwing and non-throwing shoulders were performed in a sitting position with shoulder abduction at 90°

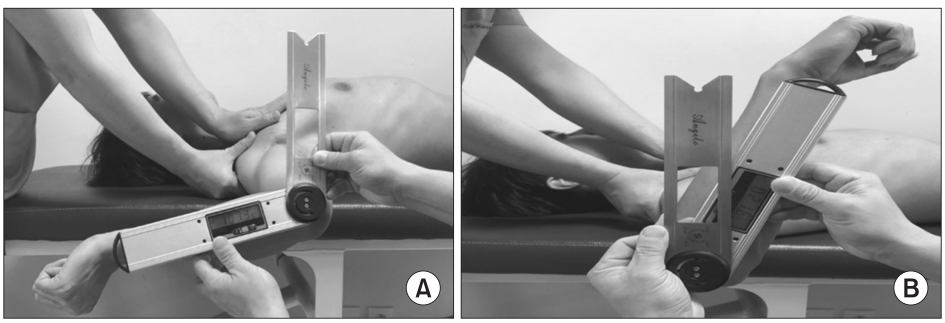

Fig. 2. (A, B) Test position for the assessment of glenohumeral internal rotation deficit.

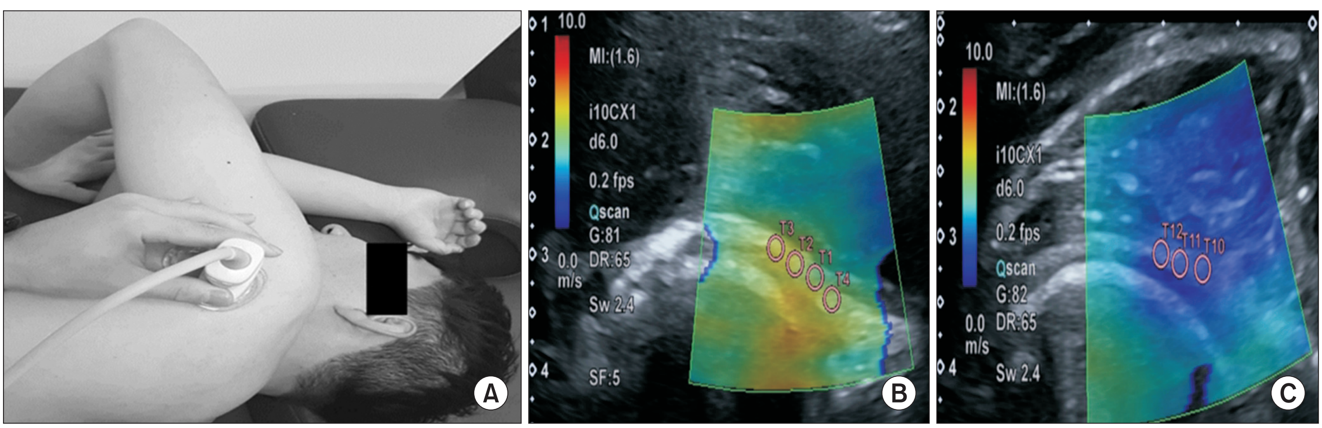

Fig. 3. (A) Test position on ultrasound to assess tightness of the posterior inferior capsule (PIC). The shear-wave elasticity images of the PIC in the throwing (B) and non-throwing (C) shoulders.

and a rest time of 1 min between the tests. The ER/IR ratio (%), peak torque per body weight (PT/BW, Nm $kg^{-1} \times 100$), and total work (TW, J) were regarded as the muscle strength ratio, muscle strength, and muscle endurance, respectively.[14,15] Similar to previous studies,[14,15] the ER/IR ratio was defined as the muscle strength balance of agonist and antagonist muscles during muscle contraction, PT/BW was defined as the normalized maximum torque for body weight, and TW was defined as the sum of the total torque curve during the 15 repetitions for IR and ER. The shoulder rotator muscle performance test involved 15 IR and ER repetitions at an angular velocity of 180°/sec.

Statistical Analysis

Student *t*-test was used to compare PIC elasticity measured using SWE and shoulder rotator muscle performance, including muscle strength ratio, muscle strength, and muscle endurance in the IRs and ERs of both shoulders between the male college baseball players with and without GIRD. The paired *t*-test was used to compare all parameters between the throwing and non-throwing shoulders of the G group. Correlations between GIRD, PIC elasticity, and shoulder rotator muscle performance were assessed using the Pearson's coefficient of correlation. Fisher's exact test was performed to identify any significant changes in the categorical variables. Statistical analysis was performed using IBM SPSS ver. 21.0 (IBM Corp., Armonk, NY, USA) at a confidence level of $p = 0.05$.

RESULTS

Overall, 24 college baseball players (10 in the G group vs. 14 in the NG group) were analyzed. There were no significant differences in age, height, weight, or BMI between the G group and the NG group. Differences were noted only in the GIRD and total rotation ROM deficits (Table 1).

Shear-Wave Ultrasound Elastography

The mean elasticity of the PIC was significantly greater in the throwing shoulders of the G group than in the throwing shoulders of the NG-group (4.8 ± 1.2 kPa vs. 3.7 ± 1.2 kPa; 95% confidence interval [CI], 0–2.1; effect size: 0.916; $p = 0.036$) but not in the non-throwing shoulders ($p > 0.05$) (Table 2).

Isokinetic Shoulder Rotator Muscle Performance

The ER/IR ratio was significantly lower for the throwing shoulders of the G group than for those of the NG group (35.7% ± 5.0% vs. 55.5% ± 6.2%; 95% CI, −24.7 to −14.7; effect size: −3.515; $p < 0.001$) but not for the non-throwing shoulders ($p > 0.05$) (Table 2). There was a difference in the muscle strength of the IRs for the throwing shoulders between the two groups (75.0 ± 7.6 Nm $kg^{-1} \times 100$ vs. 55.7 ± 16.4 Nm $kg^{-1} \times 100$; 95% CI, 7.7–30.9; effect size: 1.510; $p = 0.002$) (Table 2) but not the muscle strength of the ERs and non-throwing shoulders ($p > 0.05$) (Table 2). The muscle endurance of the ERs and IRs was not significantly different between the two groups for both the throwing and non-throwing shoulders ($p > 0.05$) (Table 2).

Comparison of SWE and Shoulder Rotator Muscle Performance between the Throwing and Non-throwing Shoulders of the G Group

The mean elasticity of the PIC was significantly greater in the throwing shoulders than in the non-throwing shoulders (4.8 ± 1.2 kPa vs. 3.5 ± 0.9 kPa, $p = 0.005$). The ER/IR ratio was significantly lower (35.7 ± 5.0 vs. 52.0 ± 9.9, $p = 0.008$) and IR muscle strength (75.0 ± 7.6 Nm $kg^{-1} \times 100$ vs. 62.0 ± 8.9 Nm $kg^{-1} \times 100$, $p = 0.007$) was significantly greater in the throwing shoulders than in the non-throwing shoulders but not the muscle strength of the ERs and muscle endurance of ERs and IRs ($p > 0.05$) (Fig. 4).

Correlations between GIRD, SWE, and Shoulder Rotator Muscle Performance

Correlations between GIRD, SWE, and shoulder rotator muscle performance are shown in Table 3. For the throw-

Table 1. Demographic Data of the Male College Baseball Players with and without GIRD

Variable	GIRD player (n = 10)	Healthy player (n = 14)	*p*-value
Sex (male : female)	10 : 0	14 : 0	-
Pitcher : field player	4 : 6	6 : 8	0.729
Age (yr)	21.5 ± 0.5	21.6 ± 0.6	0.566
Height (cm)	179.6 ± 3.5	177.9 ± 6.5	0.447
Weight (kg)	81.5 ± 9.5	85.5 ± 9.8	0.328
Body mass index (kg/m^2)	25.2 ± 2.6	26.9 ± 2.4	0.107
Right-dominant or left-dominant shoulders	10 : 0	12 : 2	-
GIRD	20.7 ± 4.0	10.6 ± 7.9	0.001*
Total rotation ROM deficit	15.8 ± 5.5	9.8 ± 8.3	0.044*

Values are presented as mean ± standard deviation.
GIRD: glenohumeral internal rotation deficit, ROM: range of motion.
*Statistically significant.

Table 2. SWE, ER/IR Ratio, Muscle Strength, and Muscle Endurance in the Male College Baseball Players with and without GIRD

Variable	Throwing shoulder		*p*-value	Non-throwing shoulder		*p*-value
	GIRD player	Healthy player		GIRD player	Healthy player	
SWE (kPa)	4.8 ± 1.2	3.7 ± 1.2	0.036*	3.5 ± 0.9	3.3 ± 1.2	0.571
MD (95% CI)	1.1 (0 to 2.1)			1.2 (0 to 2.2)		
Effect size	0.916			0.188		
ER/IR ratio (%)	35.7 ± 5.0	55.5 ± 6.2	0.000*	52.0 ± 9.9	53.0 ± 9.6	0.683
MD (95% CI)	–19.7 (–24.7 to –14.7)			–1.0 (–9.9 to 6.7)		
Effect size	–3.515			–0.102		
IR strength (Nm/kg × 100)	75.0 ± 7.6	55.7 ± 16.4	0.002*	62.0 ± 8.9	56.0 ± 16.3	0.268
MD (95% CI)	19.3 (7.7 to 30.9)			6.0 (–5.3 to 18.3)		
Effect size	1.510			0.456		
ER strength (Nm/kg × 100)	26.0 ± 3.9	30.0 ± 6.8	0.142	32.0 ± 3.3	29.0 ± 7.9	0.165
MD (95% CI)	–3.6 (–8.6 to 1.3)			3.8 (–1.7 to 9.3)		
Effect size	–0.721			0.495		
IR endurance (J)	762.0 ± 169.9	718.0 ± 207.3	0.589	773.0 ± 209.2	686.0 ± 149.8	0.247
MD (95% CI)	43.8 (–121.8 to 209.4)			86.9 (–64.6 to 238.5)		
Effect size	0.232			0.478		
ER endurance (J)	346.0 ± 92.9	307.0 ± 95.4	0.339	344.0 ± 87.4	328.0 ± 65	0.634
MD (95% CI)	38.2 (–42.8 to 119.2)			15 (–49.4 to 79.4)		
Effect size	0.414			0.207		

Values are presented as mean ± standard deviation at 180°/sec. Throwing shoulder was regarded as the dominant shoulder.
SWE: shear-wave ultrasound elastography, ER: external rotator, IR: internal rotator, GIRD: glenohumeral internal rotation deficit, MD: mean difference, CI: confidence interval.
*Statistically significant.

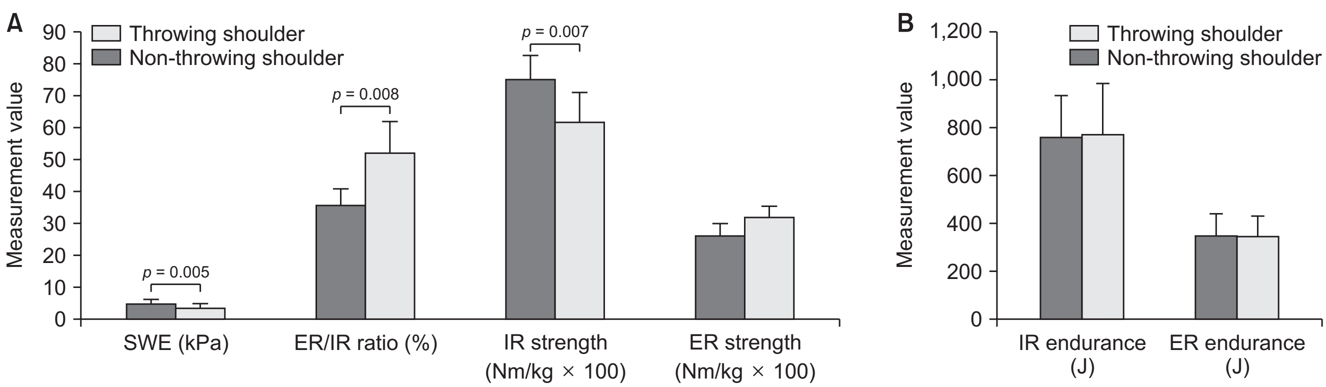

Fig. 4. Comparison of shear-wave ultrasound elastography (SWE) and shoulder rotator muscle strength and ratio (A) and comparison of shoulder rotator muscle endurance (B) between the throwing and non-throwing shoulders of the glenohumeral internal rotation deficit group. ER: external rotator, IR: internal rotator.

Table 3. Correlations between GIRD, SWE, ER/IR Ratio, Muscle Strength, and Muscle Endurance

Variable	Throwing shoulder		Non-throwing shoulder	
SWE	GIRD		GIRD	
PCC (*r*)	0.697		0.423	
p-value	0.025*		0.224	
	GIRD	SWE	GIRD	SWE
ER/IR ratio				
PCC (*r*)	–0.674	–0.640	0.137	0.092
p-value	0.033*	0.046*	0.707	0.801
IR strength				
PCC (*r*)	–0.283	–0.510	–0.173	0.137
p-value	0.429	0.132	0.633	0.706
ER strength				
PCC (*r*)	0.370	0.277	–0.030	0.558
p-value	0.293	0.439	0.936	0.093
IR endurance				
PCC (*r*)	0.323	0.143	0.371	0.165
p-value	0.363	0.694	0.291	0.649
ER endurance				
PCC (*r*)	0.471	0.308	0.384	0.191
p-value	0.170	0.387	0.273	0.596

Throwing shoulder was regarded as the dominant shoulder.
GIRD: glenohumeral internal rotation deficit, SWE: shear-wave ultrasound elastography, ER: external rotator, IR: internal rotator, PCC: Pearson's correlation coefficient.
*Statistically significant.

ing shoulders of the G group, there was a significant positive correlation between GIRD and SWE ($r = 0.697$, $p = 0.025$) but not for the non-throwing shoulders ($p > 0.05$). For the throwing shoulders of the G group, GIRD and SWE showed a significant negative correlation with the ER/IR ratio ($r = –0.674$, $p = 0.033$ and $r = –0.640$, $p = 0.046$, respectively), but not with muscle strength and muscle endurance ($p > 0.05$). No significant correlations were observed for the non-throwing shoulders ($p > 0.05$).

DISCUSSION

The present study assessed differences in PIC, measured using SWE and shoulder rotator muscle performance, between the male college baseball players with and without GIRD. The most important result of the present study was that PIC elasticity was significantly greater in the throwing shoulders of the G group than in those of the NG group. Furthermore, the ER/IR ratio was significantly lower, and the muscle strength of the IRs was significantly greater in the throwing shoulders of the G group than in those of the NG group. GIRD and PIC elasticity showed a significant negative correlation with the ER/IR ratio for the throwing shoulders of the G group.

In recent studies,[8,18,19] SWE has been used as a quantitative tool to evaluate PIC stiffness, and it is regarded as one of the most reliable methods for such an assessment. A recent study investigated GIRD using SWE in 45 healthy male college baseball players.[8] Here, PIC elasticity was significantly greater in the throwing shoulders with GIRD than in the non-throwing shoulders. Additionally, PIC elasticity was negatively correlated with the IR ROM of the glenohumeral joint. Our results are consistent with these findings. However, to the best of our knowledge, no study has investigated the correlation between GIRD, SWE, and shoulder rotator muscle performance in male college baseball players with GIRD. We found that GIRD and PIC elasticity, measured using SWE, showed a significant negative correlation with the ER/IR ratio in the throwing shoulders of baseball players with GIRD. Recent studies have reported that the ER/IR ratio is significantly lower in overhead athletes with GIRD than in those without GIRD.[9,20] Additionally, Labriola et al.[21] reported that proper balance of the IRs and ERs plays an important role in dynamic glenohumeral stability and that GIRD may disrupt this balance.[1,22] In particular, balanced shoulder rotator muscle strength is an important factor for optimal performance in overhead athletes[23] because muscle strength imbalance can be a risk factor for serious shoulder injuries.[24]

Isokinetic tests have been widely used to assess muscle performance and injury risk in overhead sports. Previous studies have reported that the strength of the ERs was significantly lower in shoulders with GIRD than in shoulders without GIRD among overhead athletes.[2,20] However, we found that the strength of the ERs did not differ between male college baseball players with and without GIRD. A possible explanation for this finding may be the difference in test positions. The test position used in our study was shoulder abduction at 90°, whereas that used in previous studies was the scapular plane position. In Hinton's study on baseball players,[25] there was a greater mechanical advantage for reproducing efficiently the strength of the ERs in the 90° shoulder abduction position than in the scapular plane position. Furthermore, we found that the strength of the IRs was significantly greater in the throwing shoulders of male college baseball players with GIRD than in those without GIRD. A possible reason for the greater IR strength may be the increased humeral retroversion in players with GIRD. Takenaga et al,[8] Osbahr et al,[26] and Reagan et al.[27] reported that humeral retroversion in baseball players can affect GIRD, which can increase the external rotation moment,[28] resulting in the production of sufficient IR torque in the 90° shoulder abduction position.[29] Hurd and Kaufman[29] reported a positive correlation between greater strength of the IRs and external rotation moment in the 90° shoulder abduction position in baseball players. The same cannot be said regarding the strength of the ERs. Tonin et al.[30] found that the strength of the IRs was greater in overhead athletes with GIRD. This finding was consistent with our results. In this study, muscle endurance did not differ between the two groups. Therefore, further studies are needed to investigate muscle strength and endurance after specific rehabilitation,[31,32] such as sleeper and cross-adduction stretches to recover IR ROM in overhead athletes with GIRD.

This study has several limitations. First, we enrolled a relatively small number of athletes in each group. However, we performed a power analysis to determine the sample size and enrolled more than the least necessary number of athletes. Second, pitchers and field players who may have different shoulder performances were evaluated together. However, the differences may not be significant in influencing the result because most players performed as both field players and pitchers until high school. Third, this study did not include measurements of humeral retroversion. GIRD can be affected by humeral retroversion,[8,26,27] which may affect ROM and shoulder muscle performance of the shoulder joint.[29] Fourth, muscle performance in our study was measured in the isokinetic concentric-contraction mode. Previous studies have reported that eccentric strength of the ERs was weak in overhead athletes with GIRD.[9,20] In particular, eccentric ERs to concentric IRs muscle strength ratio (functional ER/IR ratio) play an important role in the prevention of injury and dynamic stability of the shoulder joint in overhead athletes with GIRD.[9,20,23] Fifth, the measured value of SWE may vary, depending on the posture, the degree of stretching, and the situation in which the probe was applied. Therefore, the authors attempted to test similar scan positions and postures of the baseball players. During SWE scanning, the authors selected the capture point when the shear wave was most stable by the propagation map, as recommended by investors. Finally, we did not investigate the elasticity of the ERs, including the infraspinatus and teres minor, using SWE. Previous studies have reported that muscle stiffness of the ERs can directly affect GIRD.[7,33-35] Therefore, investigating the impact of eccentric strengthening exercises and SWE assessment for ERs in overhead athletes with GIRD should be included in a future study. Despite these limitations, to our knowledge, this is the first study to determine the differences in PIC elasticity measured using SWE and shoulder rotator muscle performance between male college baseball players with and without GIRD.

In conclusion, SWE can quantitatively assess PIC tightness in college baseball players with GIRD, and an imbalance in shoulder rotator muscle strength was found in these baseball players. Therefore, clinicians and therapists need to focus on the restoration of shoulder rotator muscle imbalance in addition to improving internal rotation in these players.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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