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Original Research

The relationship between range of motion and muscle strength of the shoulder joint in professional baseball pitchers

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Abstract

Background and objective: This study aimed to assess the relationship between range of motion (ROM) and isometric strength of the shoulder joint, adjusted for humeral head retroversion angle (HHRA), in professional baseball pitchers.

Material and Methods: A total of 18 pitchers from a professional baseball team were included in this study. The isometric strength of internal rotation (IR) and external rotation (ER) were measured using an isokinetic device at 85° and 30° ER, and at 25° IR. A linear regression analysis was then performed.

Results: The HHRA of the dominant arm was approximately 7° greater than that of the non-dominant arm ($P < 0.001$). As the IR ROM increased by 1°, the IR isometric strength at 25° IR was significantly increased by 0.448% body weight ($P < 0.05$). However, as the ROM of IR increased, the IR isometric strength at 85° and 30° ER was not significant ($P > 0.05$), and as the ROM of ER increased, the IR and ER isometric strength were not significant ($P > 0.05$).

Conclusions: Thus, the increase of IR ROM in professional baseball pitchers was associated with an increase in isometric strength at 25° IR, after adjustments were made for HHRA.

Keywords

Humeral retroversion; Range of motion; Internal rotation; External rotation; Muscle strength; Baseball pitchers

1. Introduction

Shoulder injuries are common in professional baseball players, accounting for 17% of all injuries [1] and 35% of all upper extremity injuries [2]. Shoulder injuries in professional baseball players occur at a rate of 3.61 per 1,000 athlete-exposures [3], and this is high when compared to the rate of knee injuries in soccer players (0.91-1.19 per 1,000 athlete-exposures). Although the rate of return to sports is relatively low, the re-injury rate is nevertheless high [4]. Therefore, although treating injuries and rehabilitation exercises are essential, prevention of injuries is more important.

In baseball players, who repeatedly perform overhead activities, many factors contribute to shoulder injuries. Myers *et al.* (2006) reported that the glenohumeral internal rotation deficit (GIRD) and posterior shoulder tightness of throwing athletes might be related to internal impingement [5]. Dines *et al.* (2009) demonstrated that pathological GIRD might be related to elbow valgus instability and that prevention of GIRD is important in averting ulnar collateral ligament damage in the elbow joint [6]. Tooth *et al.* (2020) reported that the main risk factors for shoulder joint injury in athletes who repeatedly perform overhead activities include limited range of motion (ROM), weakening of the rotator cuff muscle, and training overload. Additionally, scapular dysfunction may also affect shoulder injury [7]. Among the many risk factors suggested in previous studies, shoulder joint ROM and rotator cuff muscle strength in baseball players are important factors that can be managed through interventions that prevent shoulder injuries.

In previous studies on shoulder joint ROM and the muscle strength of baseball players, Dodds *et al.* (2020) examined the shoulder joint strength and ROM in college baseball pitchers [8]. Byram *et al.* (2010) reported that weakening of the strength of the external rotators and supraspinatus muscle of professional baseball players during the preseason was associated with pitching-related damage that led to surgical interventions during the season [9]. Brown *et al.* (1988) reported on the upper extremity ROM, internal rotation (IR), and external rotation (ER) isokinetic strength of the shoulder joints of Major League Baseball (MLB) players [10]. The IR and ER ROM of the dominant arm's shoulder joint were reduced by 15° and 9°, respectively, compared to those the non-dominant arm [10]. Changes in the soft tissue and bones can decrease the IR of the dominant shoulder in baseball players [11].

In baseball players, the increase in humeral head retroversion (HHRA) is an adaptive change to the stress caused by long-term repeated pitching [12–14]. This increase in HHRA is associated with increased ER and decreased IR of the shoulder joint [14], and it allows a greater ER of the glenohumeral joint without stretching the soft tissue during the cocking phase of the pitching motion. Therefore, studies on the ROM of the dominant and the non-dominant arms and muscle strength in the shoulder joint must adjust for the changes in HHRA. As the length-tension relationship of muscles shows that the shortened muscles at rest have reduced muscle strength [15], the strength of the rotator cuff is similarly affected by its resting length. The muscle strength of the rotator cuff at specific angles increases similar to the HHRA [16]. In other words, changes in the ROM of the baseball players' shoulders are affected by both soft tissues and the HHRA. Therefore, the HHRA needs to be considered to determine whether a change in muscle strength is due to soft tissues or the HHRA.

However, previous studies on the relationship between shoulder joint ROM and muscle strength did not adjust for HHRA [17, 18]. Therefore, in this study, we assessed the relationship between shoulder joint ROM and isometric strength after adjusting for the HHRA in professional baseball pitchers and sought a method to prevent shoulder injury and improve performance.

2. Methods

2.1 Subjects

This study was conducted on 18 male pitchers of a professional Korean baseball team. The physical characteristics of the subjects are illustrated in Table 1. The subjects of this study were professional pitchers that had no injuries during the previous six months. Prior to the experiment, the purpose of this study was fully explained, and only those who gave consent to participation in this study were included in the measurements. This study also presents the results of an additional data analysis from a previous study [19]. All examinations were performed before the commencement of the season, and this study was performed with the approval of the Institutional Review Board of Sungkyunkwan University (SKKU 2020 11 026).

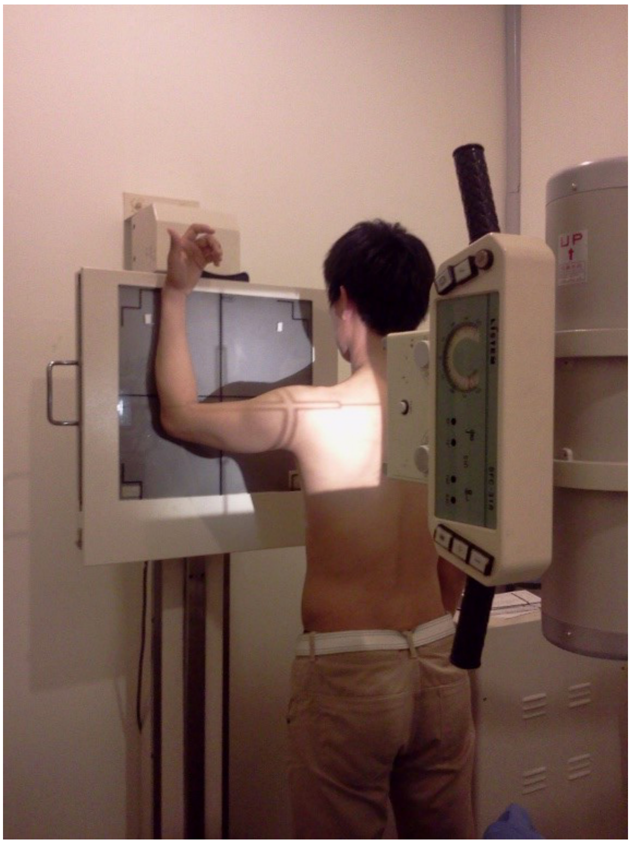

FIG. 1. The posture of the subject during X-ray examination to measure the HHRA.

TABLE 1. Participant characteristics (N = 18)

Characteristics		Mean ± S.D.	Range
Age (years)		23.56 ± 4.57	18-33
Height (cm)		183.72 ± 4.38	174-192
Weight (kg)		87.22 ± 7.84	76-108
Body mass index (kg/m^2)		25.83 ± 1.99	23.37-29.30
Career (years)		13.00 ± 3.45	8-20
Dominant arm IR (°)		37.72 ± 10.51	20-55
Dominant arm ER (°)		113.17 ± 8.08	102-130
Non-Dominant arm IR (°)		56.72 ± 15.29	34-85
Non-Dominant arm ER (°)		103.22 ± 9.25	90-120
IR isometric strength (% body weight)	ER 85°	28.67 ± 6.60	20-45
	ER 30°	32.72 ± 5.92	22-42
	IR 25°	33.56 ± 6.61	23-47
ER isometric strength (% body weight)	ER 85°	29.11 ± 5.14	18-38
	ER 30°	33.89 ± 5.42	24-44
	IR 25°	24.44 ± 8.71	8-40

ER, external rotation; IR, internal rotation; S.D., Standard deviation.

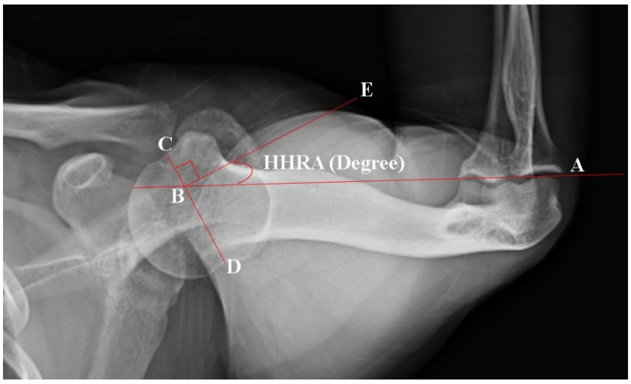

FIG. 2. Radiographic measurement of the HHRA. The A-B line is the distal axis. The C-D line is the proximal axis. A vertical line (B-E) was drawn to connect the point where the distal and proximal axes met the proximal axis.

2.2 Measurement tools and methods

Two athlete trainers with 10 and 7 years of experience, respectively, performed the measurements in this study.

2.2.1 HHRA

Measurement of the HHRA in the semi-axial view in radiological examinations has a high accuracy [18, 20]. The HHRA was measured using plain radiography; images were obtained in the posterior view (Fig. 1). The subject flexed the shoulder and elbow joints at 90° while standing upright and 20° horizontal abduction; the forearm was maintained at a neutral position. The HHRA was measured using the following method (Fig. 2): First, a line was drawn on the radiograph connecting the capitello-trochlear joint surfaces to determine the distal axis (A-B). Next, a line was drawn to connect the two points where the humeral head became flat in an elliptical shape to determine the proximal axis (C-D). A vertical line was then drawn from the proximal axis to the point where the distal and proximal axes met (B-E). The HHRA was determined as the angle between the vertical line and the distal axis [21].

2.2.2 IR and ER ROM of the shoulder joint

An inclinometer (Ever Prosperous Instruments Inc., Taiwan) was used to measure the ROM of the shoulder joint, and two examiners passively measured the IR and ER ROM of the shoulder joint. The subject was asked to maintain 90° abduction of the shoulder joint and 90° flexion of the elbow in the supine position. Examiner 1 internally rotated the humerus of the subject with one hand and compressed the anterior part of the acromion to stabilize the scapula. The IR ROM was measured until a firm end-feel was observed with passive movements [21]. Examiner 2 observed compensatory movements of the subject while measuring the ROM of the shoulder joint using an inclinometer that was fixed to the dorsal surface of the forearm after the elbow joint of the subject was flexed at 90°. Shoulder joint ER ROM was measured in the same way as measuring the IR ROM by externally rotating the shoulder joint. The total ROM was calculated as the sum of IR and ER ROM [22–24].

2.2.3 IR and ER isometric strength of the shoulder joint

The subject was restrained from pitching and training the upper body for two days before the test. The subjects performed light shoulder stretching as a warm-up exercise before isometric strength was measured. While maintaining the same posture as the measurement posture, 50%, 70%, and 100% of the maximum strength were exerted for 3 seconds each to familiarize the subjects with the measurement procedure. Measurements were performed after a 2-minute break following the warm-up exercises. The IR and ER isometric strength tests were measured using an isokinetic device, CSMi (Humac Co., USA). These tests were performed in the supine position, with the shoulder joint and the elbow joint abducted and flexed at 90°, respectively. The axis of the dynamometer was aligned with the long axis of the humerus to pass through the central part of the glenoid. During the measurement, the trunk and forearm of the subject were fixed with a belt to prevent the action of other parts of the body other than the shoulder joint. We investigated muscle function during the stressful phases of the pitching motion in the shoulder by examining angles that were similar to the late cocking, arm acceleration, and arm deceleration stages [25]. The isometric muscle strength was measured for five seconds at 85° and 30° ER, and 25° IR (Fig. 3). A 20-second break was provided between each test, and the dominant arm was examined before the non-dominant arm. The subjects were also instructed to stabilize the pelvis and the scapulae on the table in order to increase the reliability of the test.

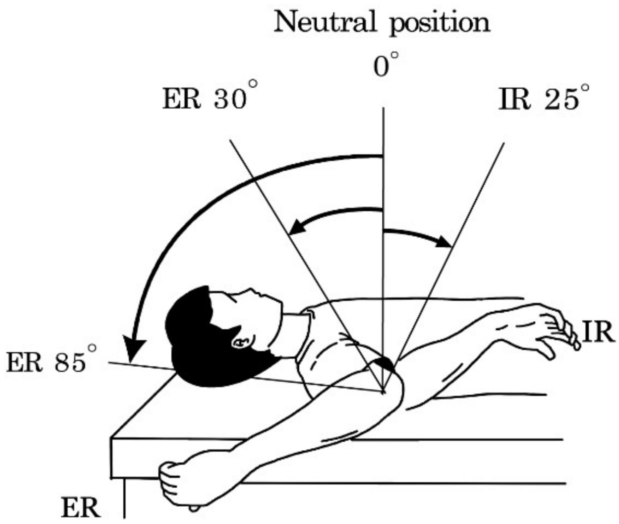

FIG. 3. IR and ER ROM angle point for isometric strength measurement in the shoulder joint.

2.2.4 Statistical Analysis

The mean and standard deviation of all measured variables were calculated using the STATA 15 statistical program. A paired *t*-test was performed to compare the differences in the

HHRA of the dominant and the non-dominant arm. Linear regression analysis was performed to analyze the relationship between shoulder joint IR and ER ROM and isometric strength, after adjustments were made for HHRA. The level of statistical significance was set at α = 0.05.

3. Results

TABLE 2. Difference between the HHRA of the dominant and non-dominant arm

Variables	Dominant arm	Non-dominant arm	T	P
HHRA	37.74 ± 3.93	30.58 ± 3.91	7.94	< 0.001***

*** $P < 0.001$.
HHRA, humeral head retroversion angle.

The HHRAs of the dominant and non-dominant arms of 18 professional baseball pitchers are shown in Table 2. We found that the HHRA of the dominant arm was approximately 7° greater than that of the non-dominant arm ($P <$ 0.001).

The relationship between the IR ROM, and IR and ER isometric strength of the dominant arm was assessed after adjusting for the HHRA (Table 3, Fig. 4). As the IR ROM increased by 1°, the IR isometric strength at 25° IR increased significantly by 0.448% body weight ($P < 0.05$); however, as IR ROM increased by 1°, the IR isometric strength at 85° and 30° ER were not significant correlated ($P > 0.05$). The ER isometric strength at 85° and 30° ER and 25° IR were not significant correlated, respectively ($P > 0.05$). There was a non-significant tendency of ER isometric strength measured at the IR ROM and 25° IR (P = 0.057).

TABLE 3. The relationship between IR ROM and isometric strength in the shoulder joint (dominant arm)

Variables	Shoulder Position	Coef.	SE	95% CI	T	P
IR isometric strength	ER 85°	0.032	0.178	-0.758	0.18	0.861
	ER 30°	0.235	0.149	-0.636	1.57	0.136
	IR 25°	0.448	0.135	0.161-0.735	3.33	0.005*
ER isometric strength	ER 85°	0.055	0.136	-0.579	0.4	0.694
	ER 30°	0.148	0.130	-0.554	1.14	0.273
	IR 25°	0.164	0.232	-0.99	0.71	0.491

*$P < 0.05$. Adjusted for humeral head retroversion. ER, external rotation; IR, internal rotation; SE, standard error.

The relationship between the ER ROM and isometric IR and ER isometric strength in the dominant arms of professional baseball pitchers was assessed after adjusting for the HHRA, and the results are shown in Table 4. The ER ROM and IR and ER isometric strength at 85° and 30° ER, and 25° IR ($P > 0.05$) were not significant, respectively ($P > 0.05$).

4. Discussion

Pitching motion is a continuous motion that can be divided into six stages, namely wind-up, early cocking, late cocking, arm acceleration, arm deceleration, and follow-through [26]. Among these pitching motions, the late cocking, arm acceleration, and arm deceleration stages lead to maximized activities of muscles involved in the movement of the shoulder joint and induce great stress. During the late cocking stage, an IR torque of 67 Nm is generated in the shoulder joint, and a force of 310 N is applied to the anterior part of the shoulder joint [27]. In the arm acceleration phase, the shoulder joint is rapidly rotated internally, and the maximal IR angular velocity reaches a maximum of 8,000 degrees/sec [28]. These rapid movements are controlled by eccentric contraction of the muscles around the shoulder joint during the arm deceleration and follow-through phases. Therefore, the muscles around the shoulder joint experience great stress. Long-term exposure to such stress causes adaptive bone changes and soft tissue changes that affect ROM and muscle strength. Evaluation of the shoulder joint's ROM and the muscle strength of professional baseball players is very important and is required to prevent damage and improve performance. To better assess the effects of soft tissues during the evaluation of shoulder joint ROM of baseball players, adaptive changes in the humerus must be considered.

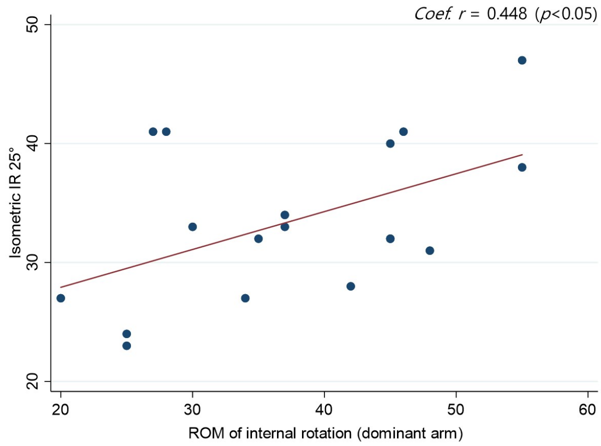

FIG. 4. The relationship between IR ROM and the internal isometric strength at 25° in the shoulder joint (dominant arm).

TABLE 4. The relationship between EX ROM and isometric strength in the shoulder joint (dominant arm)

Variables	Shoulder Position	Coef.	SE	95% CI	T	P
IR isometric strength	ER 85°	-0.045	0.209	-0.892	-0.22	0.833
	ER 30°	0.036	0.189	-0.806	0.19	0.852
	IR 25°	-0.38	0.184	-0.785	-2.06	0.057
ER isometric strength	ER 85°	0.070	0.160	-0.681	0.44	0.669
	ER 30°	-0.072	0.158	-0.675	-0.45	0.657
	IR 25°	-0.394	0.259	-1.101	-1.52	0.148

Adjusted for humeral head retroversion. ER, external rotation; IR, internal rotation; SE, standard error.

Therefore, in this study, we measured the HHRA of the shoulder joint of professional baseball pitchers. The HHRA of professional baseball players was 37.74° and 30.58° in the dominant and non-dominant arm, respectively, where the angle in the dominant arm was 7° greater than that of the non-dominant arm. Similarly, Chant *et al.* (2007) reported that the HHRA of the dominant arm and non-dominant arm was 44.9° and 34.3°, respectively, where the HHRA of the dominant arm was 10.6° greater than that of the non-dominant arm [29]. In a study on MLB players by Tokish *et al.* (2008) it was reported that the HHRA of the dominant arm was 29.7°, which was 11.2° greater than that of the non-dominant arm which was 18.5° [30]. Although the HHRA differed depending on the method of measurement, these results consistently showed that the HHRA of the dominant arm was greater than that of the non-dominant arm. Moreover, the mean age of the subjects in our study was 23.56 years, and the mean duration of experience in playing baseball was 13.00 years. Therefore, in addition to the findings of previous studies, it is thought that the increase in the dominant arm's HHRA was caused by adaptive changes in pitching during the growth phase.

There have been previous studies on HHRA and ROM of the shoulder joint in baseball players. Astolfi *et al.* (2015) reported that the HHRA showed a correlation of r = -0.413 (P = 0.01) and r = 0.448 (P = 0.007) with the IR and ER of the glenohumeral joint, respectively [11]. Hibbered *et al.* (2015) showed that the HHRA had a 13.3% effect on GIRD [31]. Moreover, Bailey *et al.* (2015) reported that the IR ROM showed a correlation of r = -0.35 with the HHRA in baseball players [32]. Greenberg *et al.* (2017) suggested that the increase in HHRA of baseball players was caused by participation in baseball games in childhood [33]. Reuther *et al.* (2018) reported that reduced IR and increased ER ROM of the shoulder joint can help to accurately evaluate the effects of soft tissues when the HHRA was adjusted [34]. It is impossible to analyze the separate effects of soft tissues on the relationship between the ROM and muscle strength without adjusting for HHRA. Therefore, in this study, the ROM was evaluated after adjusting for the HHRA in pitchers, and the relationship between the ROM, after adjusting for HHRA, and isometric strength were analyzed.

In this study, the angle for isometric strength was chosen as described in a previous study [25]. The IR and ER isometric strength of the shoulder joint was measured at 85° ER, which is similar to the shoulder joint ER angle of the cocking and arm acceleration phases. An angle of 30° ER is similar to the shoulder joint position during ball release, and 25° IR corresponds to the arm deceleration phase that are pitching positions with increased stress on the shoulder. The relationships between shoulder joint IR ROM and isometric strength at 85° and 30° ER and 25° IR were analyzed in this study, and it was observed that IR muscle strength at 25° IR was increased by 0.448% body weight as the IR ROM increased. However, there was no correlation between IR ROM and IR muscle strength at 85° and 30° ER, and the ER isometric strength at 85° and 30° ER and 25° IR. Moreover, ER ROM, IR, and ER muscle strength of the shoulder joint did not show a correlation.

These findings were partially different from what we expected. According to the length-tension relationship of muscles, a shorter or extended muscle length at rest decreases muscle strength relative to that of the normal muscle [15]. Reciprocal inhibition refers to the inhibition of antagonizing motor neuron by afferent impulse when the motor neuron of an agonist receives an excitatory impulse from the afferent nerve [35]. Based on this concept, we predicted that the reduced shoulder joint IR ROM of the dominant arm in professional baseball players would lead to decreased ER muscle strength. Additionally, we expected that the IR muscle strength would also be reduced by shortening the external rotators through reciprocal inhibition. However, the only finding that was consistent with our expectations was that IR muscle strength measured at 25°IR correlated with IR ROM. The findings of our study could not clearly explain the cause of these results.

Astolfi *et al.* (2015) reported that the dominant arm shoulder joint posterior capsule was thickened in baseball players with 8-12 years of experience [11]. Bailey *et al.* (2015) reported that the decreased IR ROM in baseball players correlated with rotator cuff stiffness (r = 0.35) and that stretching and soft tissue mobilization of the shoulder joint increased IR ROM and total ROM by 5° and 8°, respectively [32]. Additionally, Kay *et al.* (2018) observed a thickened and stiff posterior capsule of the dominant arm in overhead throwing athletes [36]. In our study, the IR muscle strength at 25° IR increased by 0.448% body weight as the IR ROM increased. If normal ROM is not restored, muscle function and efficient movement may also not be restored [37]. Therefore, to successfully recover the function and mobility of the shoulder muscles of a baseball player, soft tissue mobilization and stretching must first be performed. It is recommended to perform stabilization exercises after the mobility of the shoulder is restored through this process. It is recommended that soft tissue mobilization and stretching are first performed for baseball players to increase shoulder joint IR ROM, followed by stabilization exercises once mobility is secured.

One limitation of this study is that only 18 subjects were included; thus, the results cannot be generalized. However, despite the limited number of subjects, the significant relationship between IR isometric strength and IR ROM at 25° IR is considered meaningful. Second, the injuries sustained by the participants more than six months before this study were not considered. However, the subjects of this study were diagnosed with no abnormality in the shoulder joint by a clinician. Finally, since the subjects of this study were professional baseball players, the training programs of each player were not equally controlled prior to taking measurements. However, the subjects were instructed to refrain from training two days before the measurements.

5. Conclusions

The HHRA of the dominant and non-dominant arms of professional baseball pitchers differed, with the HHRA of the dominant arm being approximately 7° greater than that of the non-dominant arm. When the IR ROM of the shoulder joint increased by 1° in professional baseball pitchers, the IR isometric strength at 25° IR increased by 0.448% of the body weight after adjustments were made for HHRA. Therefore, exercises to increase the flexibility of the posterior capsule, ligament, and muscles are recommended for professional baseball pitchers to increase the shoulder joint IR ROM of the dominant arm.

Abbreviations

ER, external rotation; GIRD, glenohumeral internal rotation deficit; HHRA, humeral head retroversion angle; IR, internal rotation; MLB, major league baseball; ROM, range of motion.

Author contributions

Conception and design: BGK, SKL Data analysis: SK Data interpretation and manuscript writing: BGK, SKL Revision of the manuscript and contribution to intellectual content: BGK, SK, SKL Guarantor of the manuscript: SKL.

Ethics approval and consent to participate

All examinations were performed before the commencement of the season, and this study was performed with the approval of the Institutional Review Board of Sungkyunkwan University (SKKU 2020 11 026).

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Conflict of interest

The authors declare no conflict of interest.

References

[1] Fares MY, Fares J, Baydoun H, Fares Y. Prevalence and patterns of shoulder injuries in Major League Baseball. The Physician and Sportsmedicine. 2020; 48: 63-67.

[2] Fares MY, Salhab HA, Khachfe HH, Kane L, Fares Y, Fares J, *et al.* Upper limb injuries in Major League Baseball. Physical Therapy in Sport. 2020; 41: 49-54.

[3] Posner M, Cameron KL, Wolf JM, Belmont PJ, Owens BD. Epidemiology of Major League Baseball injuries. The American Journal of Sports Medicine. 2011; 39: 1676-1680.

[4] Makhni EC, Lee RW, Nwosu EO, Steinhaus ME, Ahmad CS. Return to competition, re-injury, and impact on performance of preseason shoulder injuries in Major League Baseball pitchers. The Physician and Sportsmedicine. 2015; 43: 300-306.

[5] Myers JB, Laudner KG, Pasquale MR, Bradley JP, Lephart SM. Glenohumeral range of motion deficits and posterior shoulder tightness in throwers with pathologic internal impingement. The American Journal of Sports Medicine. 2006; 34: 385-391.

[6] Dines JS, Frank JB, Akerman M, Yocum LA. Glenohumeral internal rotation deficits in baseball players with ulnar collateral ligament insufficiency. The American Journal of Sports Medicine. 2009; 37: 566-570.

[7] Tooth C, Gofflot A, Schwartz C, Croisier J, Beaudart C, Bruyère O, *et al.* Risk factors of overuse shoulder injuries in overhead athletes: a systematic review. Sports Health: a Multidisciplinary Approach. 2020; 12: 478-487.

[8] Dodds FT, Knotts SS, Penrod MI, Scoggins WA, Conners RT. Shoulder strength and range of motion between collegiate pitchers and position players in baseball. International Journal of Exercise Science. 2020; 13: 123-130.

[9] Byram IR, Bushnell BD, Dugger K, Charron K, Harrell FE, Noonan TJ. Preseason shoulder strength measurements in professional baseball pitchers: identifying players at risk for injury. The American Journal of Sports Medicine. 2010; 38: 1375-1382.

[10] Brown LP, Niehues SL, Harrah A, Yavorsky P, Hirshman HP. Upper extremity range of motion and isokinetic strength of the internal and external shoulder rotators in major league baseball players. The American Journal of Sports Medicine. 1988; 16: 577-585.

[11] Astolfi MM, Struminger AH, Royer TD, Kaminski TW, Swanik CB. Adaptations of the shoulder to overhead throwing in youth athletes. Journal of Athletic Training. 2015; 50: 726-732.

[12] Crockett HC, Gross LB, Wilk KE, Schwartz ML, Reed J, O'Mara J, *et al.* Osseous adaptation and range of motion at the glenohumeral joint in professional baseball pitchers. The American Journal of Sports Medicine. 2002; 30: 20-26.

[13] Osbahr DC, Cannon DL, Speer KP. Retroversion of the humerus in the throwing shoulder of college baseball pitchers. The American Journal of Sports Medicine. 2002; 30: 347-353.

[14] Reagan KM, Meister K, Horodyski MB, Werner DW, Carruthers C, Wilk K. Humeral retroversion and its relationship to glenohumeral rotation in the shoulder of college baseball players. The American Journal of Sports Medicine. 2002; 30: 354-360.

[15] Neumann DA. Kinesiology of the musculoskeletal system-e-book: foundations for rehabilitation (3th ed). Elsevier Health Sciences. 2017.

[16] Cameron KL, Tennent DJ, Sturdivant RX, Posner MA, Peck KY, Campbell SE, *et al.* Increased glenoid retroversion is associated with increased rotator cuff strength in the shoulder. The American Journal of Sports Medicine. 2019; 47: 1893-1900.

[17] Rhi SY, So WY. Analysis of range of motion and isokinetic strength of internal and external rotation according to humeral retroversion of the dominant shoulder in youth baseball players: a pilot study. Iranian Journal of Public Health. 2014; 43: 178-184.

[18] Cameron KL, Tennent DJ, Sturdivant RX, Posner MA, Peck KY, Campbell SE, *et al.* Increased glenoid retroversion is associated with increased rotator cuff strength in the shoulder. The American Journal of Sports Medicine. 2019; 47: 1893-1900.

[19] Kim BG, Yoon WY. The effect of game participation by a professional pitcher on isokinetic and isometric muscle. Indian Journal of Science and Technology. 2015; 8: 123-132.

[20] Söderlund V, Kronberg M, Broström LA. Radiologic assessment of humeral head retroversion. Description of a new method. Acta Radiologica. 1989; 30: 501-505.

[21] Öztuna V, Öztürk H, Eskandari MM, Kuyurtar F. Measurement of the humeral head retroversion angle. Archives of Orthopaedic and Trauma Surgery. 2002; 122: 406-409.

[22] Awan R, Smith J, Boon AJ. Measuring shoulder internal rotation range of motion: a comparison of 3 techniques. Archives of Physical Medicine and Rehabilitation. 2002; 83: 1229-1234.

[23] McClure P, Balaicuis J, Heiland D, Broersma ME, Thorndike CK, Wood A. A randomized controlled comparison of stretching procedures for posterior shoulder tightness. The Journal of Orthopaedic and Sports Physical Therapy. 2007; 37: 108-114.

[24] Laudner KG, Sipes RC, Wilson JT. The acute effects of sleeper stretches on shoulder range of motion. Journal of Athletic Training. 2008; 43: 359-363.

[25] Thompson SF, Guess TM, Plackis AC, Sherman SL, Gray AD. Youth baseball pitching mechanics: a systematic review. Sports Health. 2018; 10: 133-140.

[26] Wilk KE, Meister K, Andrews JR. Current concepts in the rehabilitation of the overhead throwing athlete. The American Journal of Sports Medicine. 2002; 30: 136-151.

[27] Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. Kinetics of baseball pitching with implications about injury mechanisms. The American Journal of Sports Medicine. 1995; 23: 233-239.

[28] Fleisig G. Biomechanics of the shoulder during throwing. The Athlete's Shoulder. 1994.

[29] Chant CB, Litchfield R, Griffin S, Thain LMF. Humeral head retroversion in competitive baseball players and its relationship to glenohumeral rotation range of motion. The Journal of Orthopaedic and Sports Physical Therapy. 2007; 37: 514-520.

[30] Tokish JM, Curtin MS, Kim Y, Hawkins RJ, Torry MR. Glenohumeral internal rotation deficit in the asymptomatic professional pitcher and its relationship to humeral retroversion. Journal of Sports Science & Medicine. 2008; 7: 78-83.

[31] Hibberd EE, Shutt CE, Oyama S, Blackburn JT, Myers JB. Physical contributors to glenohumeral internal rotation deficit in high school baseball players. Journal of Sport and Health Science. 2015; 4: 299-306.

[32] Bailey LB, Shanley E, Hawkins R, Beattie PF, Fritz S, Kwartowitz D, *et al*. Mechanisms of shoulder range of motion deficits in asymptomatic baseball players. The American Journal of Sports Medicine. 2015; 43: 2783-2793.

[33] Greenberg EM, Lawrence JTR, Fernandez-Fernandez A, McClure P. Humeral retrotorsion and glenohumeral motion in youth baseball players compared with age-matched nonthrowing athletes. The American Journal of Sports Medicine. 2017; 45: 454-461.

[34] Reuther KE, Sheridan S, Thomas SJ. Differentiation of bony and soft-tissue adaptations of the shoulder in professional baseball pitchers. Journal of Shoulder and Elbow Surgery. 2018; 27: 1491-1496.

[35] Prentice WE. Rehabilitation techniques for sports medicine and athletic training. New York, NY: McGraw-Hill. 2011.

[36] Kay J, Kirsch JM, Bakshi N, Ekhtiari S, Horner N, Gichuru M, *et al*. Humeral retroversion and capsule thickening in the overhead throwing athlete: a systematic review. Arthroscopy. 2018; 34: 1308-1318.

[37] National Academy of Sports Medicine. NASM essentials of corrective exercise training: first edition revised. Jones & Bartlett Learning. 2013.