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Relationship between glenohumeral horizontal abduction angle and scapular internal rotation angle at maximum shoulder external rotation during baseball pitching

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A R T I C L E I N F O

Keywords:
Scapular motion
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Level of evidence: Basic Science Study; Kinesiology

Background: Increased scapulothoracic (ST) internal rotation at maximum external rotation (MER) during baseball pitching can decrease glenohumeral (GH) horizontal adduction, leading to excessive GH horizontal abduction. However, few studies have examined this direct relationship, and none have investigated the ST internal rotation angle at stride foot contact (FC) and MER. This study investigated the relationships between GH horizontal adduction and ST internal rotation angles at MER and between ST internal rotation angles at FC and MER.
Methods: We recruited 15 asymptomatic collegiate baseball pitchers and assessed the ST internal rotation angle at FC and MER and GH horizontal adduction angle at MER during pitching using an optical motion tracking system. Pearson's correlation coefficients determined the relationships between GH horizontal adduction and ST internal rotation angles at MER and between ST internal rotation angles at FC and MER.
Results: The GH horizontal adduction angle at MER was significantly related to the ST internal rotation angle at MER ($r = -0.58$, $P = .022$). The ST internal rotation angle at FC was significantly related to the ST internal rotation angle at MER ($r = 0.53$, $P = .045$).
Conclusions: The GH horizontal adduction angle at MER is associated with the ST internal rotation angle at MER in asymptomatic collegiate baseball pitchers, and the ST internal rotation angle at FC is related to the ST internal rotation angle at MER. Thus, the scapula and humerus should be controlled from FC to MER during pitching to reduce internal impingement risk in asymptomatic baseball pitchers.

Shoulder injuries in baseball pitchers generally occur at the point of maximum external rotation (MER) during pitching.[5] Walch et al reported that insertions of the supraspinatus and infraspinatus were compressed between the greater tuberosity and the posterior-superior border of the glenoid at MER.[26] This phenomenon is called internal impingement.[4] It has been theoretically recognized that excessive stresses associated with shoulder horizontal abduction at MER may result in internal impingement.[2,22] Mihata et al showed that excessive glenohumeral (GH) horizontal abduction and scapulothoracic (ST) internal rotation at MER of simulated pitching caused internal impingement *in vitro*.[16,15] This study specifically demonstrated that internal impingement occurs when the GH joint is horizontally abducted beyond 30°. Therefore, baseball pitchers should avoid excessive GH horizontal abduction at MER, known as "hyper-angulation."[4] The reduction of GH horizontal abduction and ST internal rotation at MER plays an important role in the normal biomechanics of baseball pitching and the prevention of internal impingement.

The movement of the shoulder joint during baseball pitching is accomplished by the combined motion of the ST and GH joints.[11,17,24,28] During pitching, the motion of the ST joint may affect the motion of the GH joint. In the sagittal plane,

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decreased ST posterior tilt at the MER is responsible for excessive GH external rotation.[17,24] In the horizontal plane, it is generally believed that an increase in ST internal rotation during the late cocking phase induces compensatory excessive GH horizontal abduction.[2,10] Recent studies have demonstrated that coordinated motion of the GH and ST joints on the transverse plane helps prevent excessive GH horizontal abduction (angle < 30°) at MER in asymptomatic elite baseball pitchers.[11,28] However, few studies have examined the direct relationship between the ST internal rotation angle and GH horizontal abduction angle at MER. Thus, it is not clear whether asymptomatic pitchers with increased ST internal rotation experience excessive GH horizontal abduction at MER. A detailed analysis of the relationship between the ST internal rotation angle and GH horizontal abduction angle at MER is essential for understanding the kinematic factors contributing to internal impingement mechanisms during baseball pitching.

In baseball pitchers, the kinematics in the early phase of the pitching motion is linked to the kinematics in the latter phase, because pitching involves the sequential action of body segments. Previous studies have shown that early trunk rotation at the point of stride foot contact (FC) increases shoulder horizontal abduction at MER.[12,13] Although the mechanisms of internal impingement during the late cocking phase have not been entirely confirmed, the scapula in pitchers with early trunk rotation at the FC may be improperly positioned.[9] Therefore, an increased ST internal rotation angle at the FC may be associated with an increased ST internal rotation angle at MER. However, no data exist on the relationship between the ST internal rotation angle at FC and the ST internal rotation angle at MER. A focused examination of the relationship between the ST internal rotation angle at FC and at MER is critical for optimizing scapular motion during the late cocking phase in baseball pitching.

We aimed to investigate the relationship between the GH horizontal abduction and ST internal rotation angles, respectively, at MER. In the sagittal plane, pitchers with a decreased scapular posterior tilt at MER may have excessive GH external rotation.[17,21,24] In the transverse plane, we hypothesized that pitchers with an increased ST internal rotation at MER would experience excessive GH horizontal abduction. We also aimed to investigate the relationship between the ST internal rotation angle at FC and the ST internal rotation angle at MER. We hypothesized that pitchers with increased ST internal rotation at FC would also exhibit increased ST internal rotation at MER, because baseball pitching involves the sequential action of body segments.

Materials and methods

Participants

Fifteen male college baseball pitchers (age, 20.2 ± 1.9 years; height, 1.76 ± 0.05 m; body mass, 73.3 ± 6.7 kg; throwing arm, 4 lefts and 11 rights) participated in this cross-sectional study. All pitchers used an overhand style during pitching. Participants were required to have more than 3 years of experience in baseball pitching. Pitchers were excluded if they had pain in the upper or lower extremities and trunk at the time of testing or had a history of upper or lower extremity and trunk surgery at least 3 years before the day of data collection.

All participants signed a written informed consent form before participating in the study. The study protocol was approved by the Sapporo Medical University Ethical Committee (30-2-2) and the Hokusho University Ethical Committee (2017-014). The ethical aspects of the study conformed to the principles of the Declaration of Helsinki.

Instrumentation

Three-dimensional (3D) kinematic datasets of the humerothoracic (HT), GH, and ST joint angles during baseball pitching were collected using a 12-camera motion capture system (MAC3D; Motion Analysis Corporation, Rohnert Park, CA, USA) at 500 Hz, and a force plate (1000 Hz, BP6001200; AMTI, Watertown, MA, USA) synchronized with the motion capture system was used to define the FC. A set of 16 retro-reflective markers[27] was used to track the thoracic, scapular, and humeral segments (Fig. 1). Moreover, we used the Helen Hayes marker set[7] to track the lower leg. One marker was attached to the acromioclavicular joint to define the GH joint center.[14,19] Additionally, we attached two markers to the ball and one marker to the midpoint between the styloid process of the ulna and the radius of the dorsal wrist (wrist marker) to define the pitching phases. The acromion marker cluster (AMC) was attached to the flat part of the acromion.[1,3,8] It consisted of a base with three reflective markers (Fig. 2). The static standing posture was recorded to link the position of the AMC to local anatomical coordinate systems, according to the International Society of Biomechanics recommendations for the upper extremity.[27] From the combination of local anatomical coordinate systems and marker cluster motions, it was possible to calculate the scapular angles during dynamic shoulder motion.[1,27] The AMC method is a valid approach for measuring scapular motion,[1,3] offering the advantages of non-invasiveness and minimal movement restriction. The rotational joint angles were calculated using the Euler angle method, which represents the difference in the orientation of each segment (Fig. 1).

According to International Society of Biomechanics recommendations,[27] we used the Y−X−Y′ sequence (horizontal adduction or horizontal abduction, depression or elevation, and internal rotation or external rotation) for humeral rotations relative to the thorax (HT joint), the Y−X−Y′ sequence (horizontal adduction or horizontal abduction, depression or elevation, and internal rotation or external rotation) for humeral rotation relative to the scapula (GH joint), and the Y−X−Z′ sequence (internal rotation or external rotation, downward rotation or upward rotation, and posterior tilt or anterior tilt) for scapular rotations relative to the thorax (ST joint).

Testing procedure

In assessing the HT, GH, and ST joint angles during baseball pitching, all participants performed the usual warm-ups before the pitching data measurement. These warm-ups consisted of static and dynamic stretching, throwing exercises, simulated pitching motion, and pitching motion. After the warm-ups, each participant was asked to pitch three fastballs, aiming at the center of a net located 5 m ahead of the foot on the nonthrowing side. Participants were allowed to rest for 1 min between trials to avoid fatigue.

Data analysis

Joint angles were analyzed using motion analysis software (Visual3D; C-Motion, Germantown, MD, USA). Some inverse values of the joint angles were used for the left-handers to obtain values in line with the right-handed data. To assess joint angles during baseball pitching, all kinematic data were normalized from the point of FC to that of ball release (BR) on a 100% scale. FC was defined as the instant at which the vertical ground reaction force was greater than 20 N on the foot of the nonthrowing side. The MER was defined as the instant at which the minimum value of the HT internal rotation angle was recorded. We defined the midpoint between the two markers on the ball as the ball center and measured the distance between the wrist marker and the ball

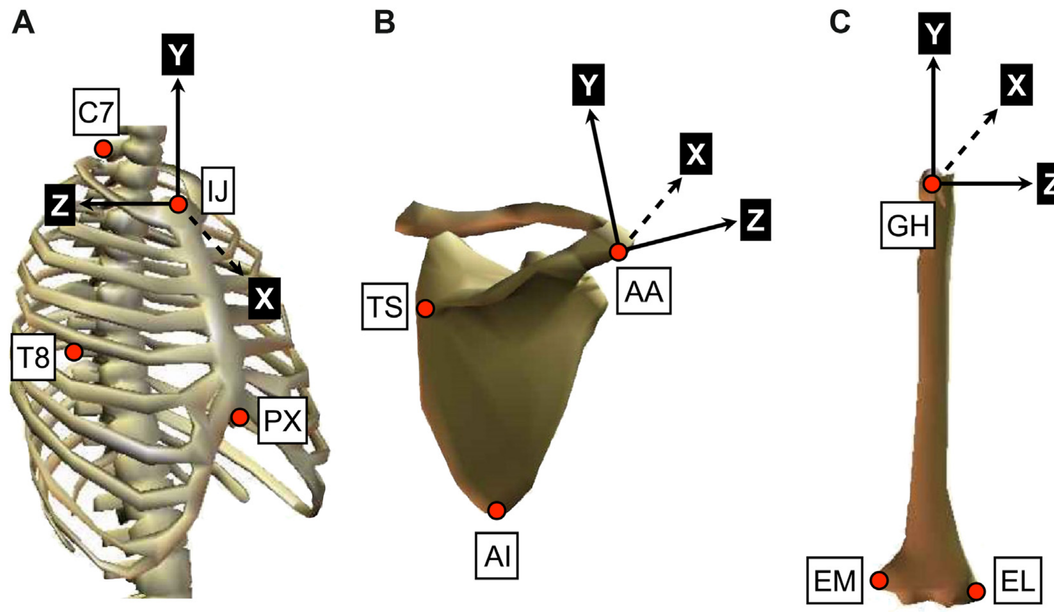

Figure 1 Anatomical bony landmarks and the defined local coordinate system. (**A**). To define the thoracic coordinate system, we attached four markers to the spinous process of the seventh cervical vertebra (C7), spinal process of the eighth thoracic vertebra (T8), incisura jugularis (IJ), and processus xiphoideus (PX). (**B**). To define scapular coordinate systems, we attached three markers to the scapular spine trigonum (TS), inferior angle (AI), and acromial angle. (**C**). To define humerus coordinate systems, we attached three markers to the most caudal point on the lateral epicondyle (EL), most caudal point on the medial epicondyle (EM), and the acromioclavicular (AC) joint. The glenohumeral joint *Center* was estimated by calculating the marker position of the AC joint (GH).

center (ball-wrist distance). To define BR, the mean value and standard deviation of the ball-wrist distance were recorded from 300 frames before the MER to the point of MER. BR was defined as the instant at which the ball-wrist distance was greater than the value obtained by adding the mean value and five times the standard deviation of the ball-wrist distance. The GH horizontal adduction and ST internal rotation angles in the FC and MER were determined. Representative values were calculated as the mean of the GH horizontal adduction and ST internal rotation angles at the FC and MER in three trials for each participant.

Statistical analyses

The Shapiro–Wilk test was used to determine whether the variables followed a normal distribution. All data had a normal distribution. Pearson's correlation coefficients were used to determine the strength of the relationship between the GH horizontal adduction angle at MER and the ST internal rotation angle at MER and between the ST internal rotation angle at FC and the ST internal rotation angle at MER. All data were analyzed using SPSS statistical software (IBM Corp., Armonk, NY, USA). The level of statistical significance was set at $P < .05$.

Results

The participants' demographic information is summarized in Table I. The graphs of HT elevation, HT internal rotation, HT horizontal adduction, GH horizontal adduction, and ST internal rotation angle during pitching are shown in Fig. 3. The mean values and standard deviations of GH horizontal adduction and ST internal rotation angle at FC and MER are shown in Table II.

The GH horizontal adduction angle at MER was significantly related to the ST internal rotation angle at MER ($r = -0.58$, $P = .022$). Moreover, the ST internal rotation angle at FC was significantly related to the ST internal rotation angle at MER ($r = 0.53$, $P = .045$). A moderately strong relationship was observed between the GH horizontal adduction angle at MER and ST internal rotation angle at MER and between the ST internal rotation angle at FC and ST internal rotation angle at MER (Fig. 4).

Discussion

We aimed to investigate the relationship between the GH horizontal abduction and ST internal rotation angles at MER and between the ST internal rotation angle at FC and ST internal rotation angle at MER. In asymptomatic collegiate baseball pitchers, we found that the GH horizontal abduction angle at MER was significantly related to the ST internal rotation angle at MER during pitching, and the ST internal rotation angle at FC was associated with the ST internal rotation angle at MER. In addition, we showed that the mean GH horizontal adduction angle at MER was $-10.7°$, and the mean value of the ST internal rotation angle at MER was $9.3°$. Previous studies[11,24] have reported that the GH horizontal adduction angle at MER ranged from $-6°$ to $-3°$ and the ST internal rotation angle at MER ranged from $2°$ to $15°$. In our study, GH horizontal abduction and ST internal rotation at MER showed a similar trend as that reported in previous research,[11,24] suggesting that these may be typical shoulder positions at MER.

Previous studies have shown that decreased scapular motion is associated with excessive GH rotation during baseball pitching.[2,10,17,21,24] In the sagittal plane, the decreased ST posterior tilt at MER is involved in excessive GH external rotation.[17,21,24] In the transverse plane, it has been theoretically recognized that decreased ST external rotation during the late cocking phase induces compensatory excessive GH horizontal abduction.[2,10] Our results showed that the GH horizontal abduction angle at MER was associated with the ST internal rotation angle at MER, which is consistent with our first hypothesis. Two studies have demonstrated that the coordination of the humerus and scapula helps maintain the alignment of these segments in the transverse plane and prevent excessive GH horizontal abduction at MER in asymptomatic elite baseball pitchers.[11,28] However, these studies did not

Figure 2 Location of the marker set.

Table I
Participant demographic information.

Variable	
Age (y)*	20.2 (1.9)
Height (m)*	1.76 (0.05)
Body mass (kg)*	73.3 (6.7)
BMI (kg/m^2)*	23.6 (1.4)
Throwing arm (dominant hand)	4 left; 11 right
Baseball experience (y)*	11.5 (2.3)
Pitching experience (y)*	9.1 (3.1)

BMI, body mass index.
*Values are presented as the mean (standard deviation).

examine the direct relationship between the GH horizontal abduction angle and ST internal rotation angle at MER. Our study provides novel insights into the relationship between the GH horizontal abduction and ST internal rotation at MER. Mihata et al reported that increase in the GH horizontal abduction angle and ST internal rotation angle at MER contribute to internal impingement of the shoulder *in vitro*.[16,15] In our study, one participant exhibited improper alignment of the humerus and scapula at MER during baseball pitching, with a GH horizontal adduction angle of −31.1° and an ST internal rotation angle of 32.0°. These results suggest that increase in the GH horizontal abduction angle and ST internal rotation angle at MER may occur simultaneously.

Takahashi et al reported that the impingement area of the rotator cuff muscles between the greater tuberosity and posterior glenoid rim was larger in throwing shoulders than in nonthrowing shoulders in asymptomatic male college baseball players. Moreover, cystic changes in the greater tuberosity and degeneration in the posterior labrum were more frequent in throwing shoulders than in nonthrowing shoulders.[23] These findings indicate that internal impingement of the shoulder can occur even in asymptomatic baseball players. Therefore, asymptomatic baseball pitchers with increased GH horizontal abduction and ST internal rotation at MER may be at risk of internal impingement of the shoulder.

However, no consensus exists regarding scapular kinematics during pitching in symptomatic players. Saka et al reported that ST internal rotation during the late cocking of a simulated throwing activity was larger in symptomatic throwing arms than in asymptomatic contralateral arms.[20] Miyashita et al reported that injury-prone pitchers exhibited less ST internal rotation during the cocking phases of baseball pitching compared to healthy controls.[18] The participants, equipment, and movement tasks used in these studies

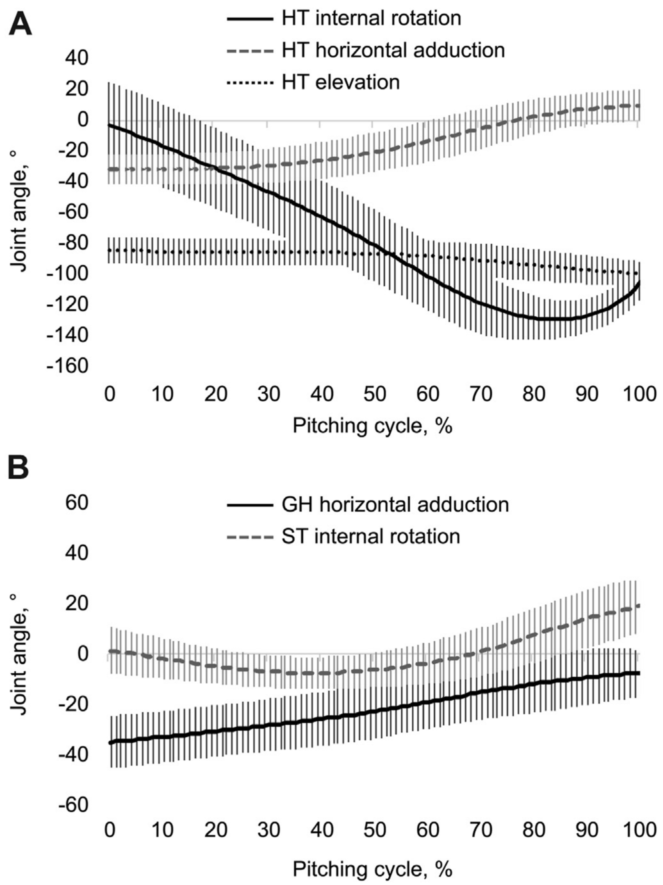

Figure 3 Graphs of joint angle during baseball pitching. (**A**). Graph showing the HT internal rotation, HT horizontal adduction, and HT elevation angles from FC to BR. (**B**). Graph showing the GH horizontal adduction and ST internal rotation angles from FC to BR. *BR*, ball release; *FC*, foot contact; *GH*, glenohumeral; *HT*, humerothoracic; *ST*, scapulothoracic.

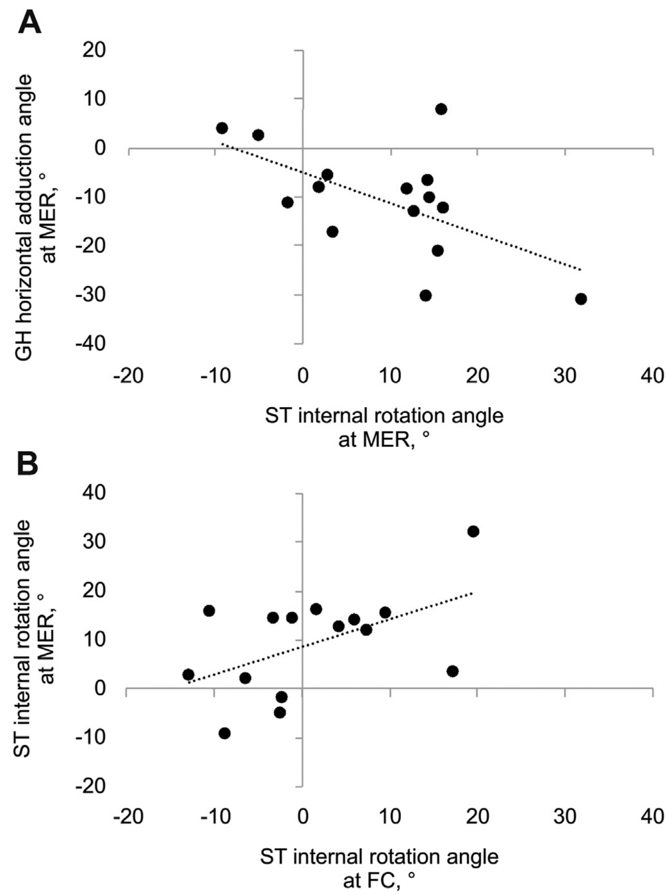

Figure 4 Scatter plots of joint angle during baseball pitching. (**A**). Scatter plot showing the relationship between GH horizontal adduction angle at MER and ST internal rotation angle at MER. (**B**). Scatter plot showing the relationship between ST internal rotation angle at FC and ST internal rotation angle at MER. *FC*, foot contact; *GH*, glenohumeral; *MER*, maximum shoulder external rotation; *ST*, scapulothoracic.

Table II
GH and ST angles at FC and MER during pitching.

	FC	MER
GH angle (°)		
Horizontal adduction (+)/Horizontal abduction (−)	−35.2 ± 10.7	−10.7 ± 11.2
	(−41.1 to −29.3)	(−16.9 to −4.5)
ST angle (°)		
Internal rotation (+)/External rotation (−)	1.2 ± 9.6	9.3 ± 10.5
	(−4.1 to 6.5)	(3.5 to 15.1)

FC, foot contact; *GH*, glenohumeral; *MER*, maximum shoulder external rotation; *ST*, scapulothoracic.
Values are presented as the mean ± standard deviation (95% confidence interval).

varied, making direct comparison of data challenging. Further research is warranted to understand scapular kinematics during pitching in symptomatic baseball players.

In this study, the ST internal rotation angle at FC was significantly related to the ST internal rotation angle at MER, supporting our second hypothesis. This finding highlights the importance of evaluating the scapular internal rotation angle at both FC and MER to help mitigate the risk of internal impingement in asymptomatic baseball pitchers. Our results can be attributed to the characteristics of baseball pitching, in which kinematics in the early phase of the pitching motion are linked to those of the latter phase. At the individual level, the maximum value of the ST internal rotation angle at FC was 19.5°, and the minimum value of the ST internal rotation angle at FC was −12.9°. Moreover, the maximum value of the ST internal rotation angle at MER was 32.0°, and the minimum value of the ST internal rotation angle at MER was −9.1°. These findings suggest that there are individual differences in ST internal rotation angles at FC and MER (Fig. 5). Previous studies have shown that physical factors that affect ST internal rotation during shoulder movement include tightness of the pectoralis minor muscle,[25] thoracic flexion posture,[21] and decreased serratus anterior and lower trapezius activities.[6] These physical factors may affect individual differences in ST internal rotation during baseball pitching. In clinical settings, we suggest that the evaluation of these physical factors should be incorporated into the screening test for pitchers with increased ST internal rotation at FC and MER.

This study has some limitations. First, AMC methods have measurement errors associated with skin displacement. Changes in the soft-tissue shape, resulting from deltoid-muscle contraction, significantly affect the accuracy of the AMC. This error of 3.5-9.5° occurs owing to the sliding acromion of the scapula beneath the skin surface.[1,3] The AMC method can be used below 120° of shoulder elevation.[3] In this study, the shoulder elevation angle from FC to BR ranged from 84.2° to 94.8° (Fig. 3). Moreover, previous studies reported that skin displacement was attributed to the inertial effect.[11,24] We analyzed shoulder and scapular motion only during the arm-cocking phase, excluding the acceleration phase of baseball pitching. Second, all participants in this study were asymptomatic college baseball pitchers who used an overhand

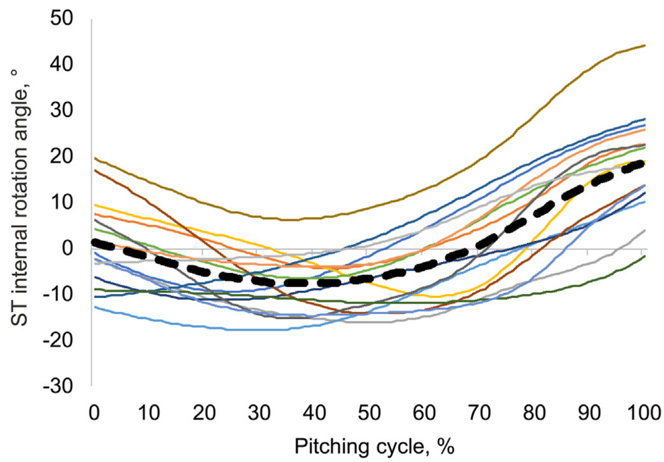

Figure 5 ST internal rotation angle during baseball pitching. The *dashed line* shows the mean value, and the *solid lines* show the individual cases. *ST*, scapulothoracic.

style. Further research is needed on various factors, such as differences in pitching form, competition level, and asymptomatic or symptomatic.

Conclusion

In asymptomatic collegiate baseball pitchers, we showed that the GH horizontal abduction angle at MER was associated with the ST internal rotation angle at MER during pitching. Additionally, our results showed a relationship between the ST internal rotation angle at FC and the ST internal rotation angle at MER. These findings suggest that effective control of the scapula and humerus throughout the pitching motion from FC to MER is crucial for reducing the risk of internal impingement in asymptomatic baseball pitchers.

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Disclaimers:

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Conflicts of interest: The authors, their immediate families, and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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