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Scapular dyskinesis type is associated with glenohumeral joint and scapular kinematic alteration during pitching motion in baseball players

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ABSTRACT

Introduction: Scapular dyskinesis (SD) is associated with an increased risk of throwing-related shoulder injury onset, resulting in abnormalities in glenohumeral joint (GH) and scapular motions during pitching. The effects of SD on shoulder motion during pitching remain unknown. This study aimed to investigate kinematic alterations in GH and scapular motions during pitching in baseball players with type I SD.
Methods: Sixty-seven university and independent-league baseball players with and without SD were included. Pitching motion was measured using an optical three-dimensional motion capture system, and a SD test was conducted to evaluate SD. SD was classified into types I–IV. The inter-rater reliability of SD assessment was calculated using kappa coefficients. Three-dimensional GH and scapular kinematics during pitching motion were analyzed.
Results: The percentage of agreement representing the inter-rater reliability of SD assessment was 77.6% (52/67; kappa coefficient: 0.72). Overall, 24 and 27 participants were categorized into abnormal (type I SD) and normal group (type IV SD), respectively, with normal scapular motion; one individual with type III SD was excluded. The abnormal group exhibited a significantly increased GH external rotation angle (9°) and decreased scapular posterior tilt angle (6°) during the maximum external rotation period compared with the normal group.
Conclusions: Baseball players in the abnormal group showed increased GH motion and decreased scapular motion during pitching. The SD test for the evaluation of type I SD can help predict excessive GH external rotation and decreased scapular posterior tilt during pitching.

1. Introduction

In recent years, preventive measures against throwing injuries in baseball players have been described (Sakata et al., 2019). Nonetheless, the incidence of throwing injury continues to increase (Chalmers et al., 2019), with pitching arm injuries accounting for approximately 50% of all injuries in baseball players (Conte et al. 2016) and throwing-related shoulder injuries accounting for approximately 35% of all pitching arm injuries ($n = 1609$) (Fares et al., 2020). Moreover, throwing injury onset has reportedly been associated with shoulder dysfunction and pitching biomechanics (Bullock et al., 2021; Salamh et al., 2020). Consequently, clinicians have been investigating the risk factors for shoulder dysfunction from various perspectives and analyzing the biomechanical parameters during pitching motion to effectively prevent throwing-related shoulder injuries in baseball players (Beckett et al., 2014; Ellenbecker & Cools 2010; Laudner et al., 2006; Shitara et al., 2017).

Scapular dyskinesis (SD) is a potential risk factor for shoulder injuries, which include superior labral anterior-posterior (SLAP) lesions, rotator cuff tears, and shoulder impingement syndrome

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(Burkhart et al., 2003). Kibler et al. defined SD as a condition characterized by scapular malposition and abnormal motion (Kibler 1998). An SD incidence of >54% and >50% was reported in overhead athletes (Burn et al., 2016) and high school baseball players (Myers et al., 2013), respectively. Moreover, athletes with SD have a 43% higher risk of developing shoulder pain than those without SD (Hickey et al., 2018), suggesting a relationship between SD and shoulder pain onset. Considering these data, clinicians need to evaluate SD and take measures to manage the health of overhead athletes with shoulder injuries.

The scapular dyskinesis test (SDT) is a reliable method for SD evaluation (Huang et al., 2015;Kibler et al. 2002). In the SDT, SD is assessed by observing abnormal scapular movements when the shoulders are raised and lowered (Huang et al., 2015; Kibler et al. 2002). According to Kibler et al. SD can be categorized into the following types during the SDT: type I, prominence of the inferior scapular angle; type II, prominence of the medial scapular border; type III, excessive upward rotation and elevation of the scapula; and type IV, no abnormality (Kibler et al., 2002). Each SD type is reportedly caused by some form of scapular dysfunction, including inflexibility of the scapular muscles, muscle weakness, and posterior shoulder tightness (Ellenbecker and Cools 2010;Kibler et al. 2002).

With respect to the relationship between SD types and scapular motion, Kibler et al. reported that individuals with SD types I, II, and III presented with increased scapular anterior tilt, internal rotation, and upward rotation, respectively, upon raising and lowering their shoulders (Kibler et al., 2002). In contrast, Huang et al. revealed that individuals with mixed types I and II SD had increased scapular internal rotation and anterior tilt during the SDT compared to those with other types (Huang et al., 2015). These findings have quantitatively clarified the relationship between SD types and scapular motion during the SDT.

Regarding the relationship between SD and throwing motion, Kibler et al. and Burkhart et al. revealed that abnormal scapular motion in SD is associated with abnormal glenohumeral joint motion involving shoulder symptoms during pitching (Burkhart et al., 2003; Kibler et al., 2013). Nevertheless, the relationship between SD types and shoulder biomechanics during pitching motion has not yet been quantitatively clarified.

The maximum external rotation (MER) period refers to the crucial phase in pitching motion involving shoulder injury onset due to an anterior shearing force of 380 N on the shoulder joint (Fleisig et al., 1995). Shoulder MER during pitching motion consists of not only external rotation of the glenohumeral joint but also scapular posterior tilt and thoracic extension (Miyashita et al., 2010). A decrease in scapular posterior tilt during pitching motion results from excessive shoulder external rotation (Mihata et al., 2010; Miyashita et al., 2010; Suzuki et al., 2019). Burkhart et al. reported that baseball players with SD had excessive glenohumeral joint motion during pitching (Burkhart et al., 2003). Excessive shoulder external rotation during the MER period in SD consequently leads to SLAP injury, rotator cuff injury, and internal impingement (Burkhart et al. 2000, 2003; Fleisig et al., 1995; Kuhn et al., 2003; Mihata et al. 2008, 2010). Thus, we hypothesized that individuals with type I SD (reduced scapular posterior tilt) have a larger range of motion (ROM) in the glenohumeral joint and a smaller ROM for scapular posterior tilt at MER than those without SD (type IV). As the relationship between type I SD and pitching mechanics of the shoulder joint has not yet been described, we investigated the influence of SD types on shoulder motion during pitching to better understand the pathology during pitching motion, resulting in further applicable measures to prevent shoulder injuries. Hence, this study aimed to clarify the incidence of SD types in baseball players and investigate kinematic alterations in glenohumeral joint and scapular motion during pitching in baseball players with type I SD.

2. Methods

2.1. Design

A cross-sectional design was employed to investigate differences in the glenohumeral joint and scapular kinematics during pitching motion in baseball players with type I SD and those without SD.

2.2. Participants

In all, 67 baseball players (61 university players and six independent-league players) were included in this study. The study period was from 2019 to 2021. The a-priori power analysis ($\alpha = 0.05$, $1\text{-}\beta = 0.80$) of data from a previous study (Kim et al., 2020) was performed using G*Power (Version 3.1.9.4 Kiel University, Germany). We estimated that a sample size of 23 participants per group would be adequate to determine significant differences between the groups based on large effect size (Cohen's $d > 0.8$). Those with shoulder pain and any pain related to throwing within the past three months were excluded from the study. This study was conducted in accordance with the Declaration of Helsinki and was approved by the ethical review board of our institution (approval number: 18019). Written informed consent was obtained from each participant.

2.3. Demographic data of study participants

Demographic data, including age, height, weight, body mass index (BMI), and competition history, were collected from all study participants via an interview using a questionnaire (Table 1). Furthermore, shoulder internal/external rotation ROM was measured on both sides with the participant in the supine position and the shoulder and elbow abducted at 90° and flexed at 90°, respectively (Wilk et al., 2011). Ball velocity was measured using a speed gun (Sports Radar Ltd. SRA3000, FL, USA).

2.4. SD evaluation

Considering its high measurement reliability, the SDT was used to evaluate SD (Huang et al., 2015; Kibler et al. 2002). Briefly, the participants grasped 2–kg weights on both sides and simultaneously performed maximum shoulder flexion and abduction along with maximum elbow extension of both sides for three cycles. Moreover, repetitions were performed at the same speed for 3 s for elevation and 3 s for descent. The scapular motion during the SDT was recorded using a digital video camera (FDR-AX60, Sony Group Corp., Tokyo, Japan) from the thoracic dorsal side and was evaluated by video observation and direct palpation on the scapular joint (Huang et al., 2015; Kibler et al. 2002). Two physiotherapists assessed SD in each participant, and only participants who were deemed to have SD by both physiotherapists completed the study. The inter-rater reliability of SD assessment between the physiotherapists was calculated using kappa coefficients. The discriminant criterion for SD was based on the classification methods of Kibler et al. and Huang et al. Each participant's SD type was classified as follows according to scapular kinematics: type I, prominence of the inferior scapular angle; type II, prominence of the medial scapular border; type III, excessive/inadequate upward rotation and elevation of the scapula; a combination of types I–III; and type IV, normal scapular motion (Fig. 1) (Huang et al., 2015; Kibler et al. 2002). To determine the effect of

Table 1
Demographic data of the abnormal and normal group.

	Abnormal group[a]	Normal group[a]	95% CI for difference	P value[b]	Effect size[c]
Age, years	20 ± 1	20 ± 1	−0.4 to 1	0.40	0
Height, cm	175 ± 5	176 ± 5	−2 to 4	0.64	0.20
Weight, kg	75 ± 8	75 ± 7	−4 to 5	0.88	0
BMI	24 ± 2	24 ± 2	−1 to 1	0.87	0
Competition history, years	12 ± 1	12 ± 3	−2 to 1	0.70	0
Shoulder internal rotation range of motion, deg					
Throwing side	34 ± 12	36 ± 13	−5 to 9	0.56	0.16
Non-throwing side	49 ± 13	51 ± 14	−6 to 10	0.59	0.15
Shoulder external rotation range of motion, deg					
Throwing side	112 ± 9	111 ± 9	−7 to 4	0.63	0.12
Non-throwing side	101 ± 8	102 ± 7	−4 to 5	0.79	0.13
Ball velocity, m/s	31 ± 2	31 ± 2	−1 to 1	0.92	0

Abbreviations: BMI, body mass index; CI, confidence interval.
[a]Mean ± standard deviation.
[b]Values less than 0.05 were considered statistically significant.
[c]Cohen's d effect size.

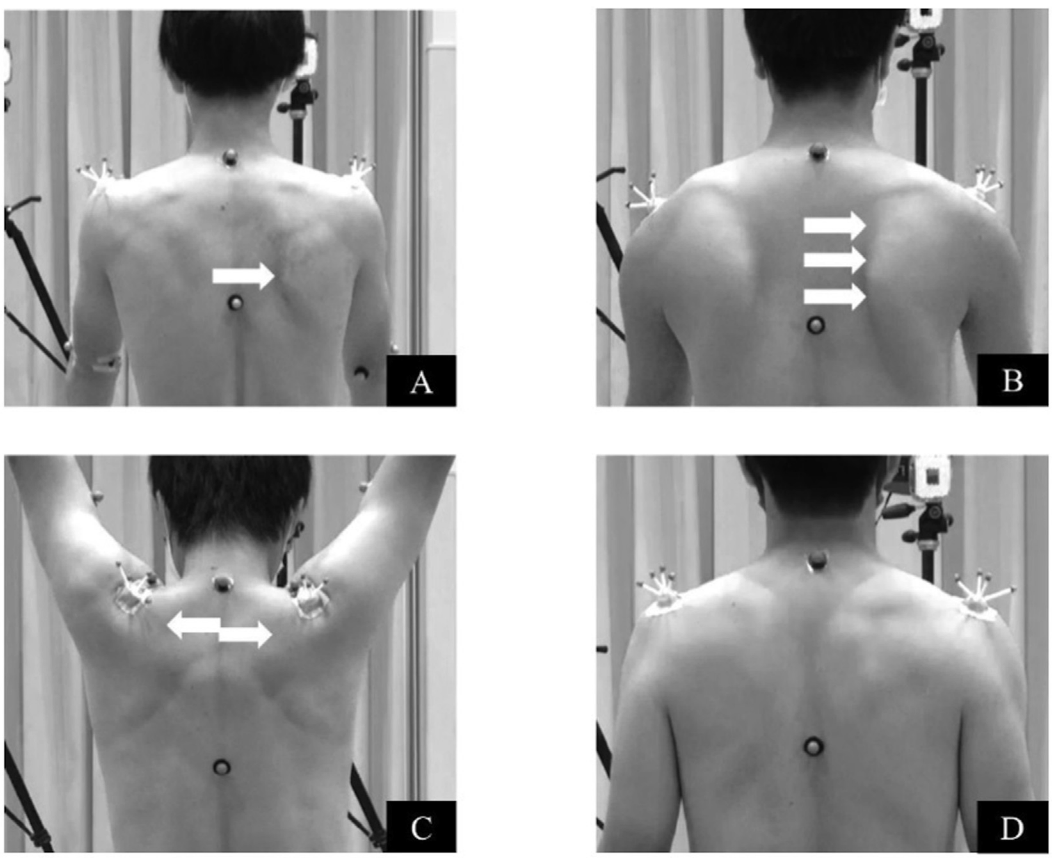

Fig. 1. Classification of scapular dyskinesis. (A) Prominence of the inferior scapular angle: type I. (B) Prominence of the medial scapular border: type II. (C) Excessive/inadequate upward rotation or elevation of the scapula: type III. (D) Normal scapular motion: type IV.

the posterior scapular tilt during the pitching motion according to SD types in baseball players, the inclusion criteria of this study were as follows: “abnormal group (with type I SD)”, which comprised subjects with isolated type I, type I + II, type I + III, and type I + II + III SD, and “normal group”, which comprised cases of type IV SD only (without SD; as a control group). Before the study, the posterior scapular tilt angle during the shoulder motion was significantly lower in the type I SD than in the other types (Huang et al., 2015). Non-type I SDs, such as isolated type II and III, were excluded from this study.

2.5. Pitching data collection

Pitching motion was measured using an optical three-dimensional motion capture system (MAC3D system; Motion Analysis Corp., MA, USA) at a sampling frequency of 240 Hz. All participants practiced pitching for approximately 10 min before the measurements were taken. All participants threw a maximal effort four−seam fastball on flat ground (Oliver & Weimar 2015). In previous studies, scapular motion was measured during pitching using an electromagnetic tracking device attached to the acromion (Konda et al., 2015; Meyer et al., 2008; Oliver & Weimar 2015). For scapular motion measurement during pitching, we employed the acromion marker cluster (AMC) method as a substitute for the electromagnetic tracking device (Matsumura et al., 2019). Video-based motion analysis, such as the AMC method, is superior to the electromagnetic tracking device as it provides a three-dimensional image, is non-invasive, and causes less movement restriction because it is cableless (Chu et al., 2012; Meyer et al., 2008). The AMC method has a measurement error of 2.96°–4.48° according to Brochard et al., (2011) and employs a marker cluster comprising 4-mm markers of four points on the acromion (Fig. 2). To reduce skin artifacts with shoulder joint motion during pitching, bilateral marker clusters made of lightweight material (3 g) were attached to the acromion using tapes. This study used the AMC method to measure the scapular position in multiple shoulder postures using a locator (Fig. 2) to correct the scapular position prior to pitching motion measurement (Matsumura et al., 2019; McClure et al., 2001). Furthermore, the locator had a 4–mm marker on each triangular top, which pointed at the acromial posterior angle, spinous triangle, and inferior angle (Matsumura et al., 2019; McClure et al., 2001). In this study, scapular motion was estimated during pitching using the scapular posture in the scapular natural position at 0°, elevation at 120°, and elevation plane at 30°. Pitching motion measurement was conducted with 60 reflective markers attached to the whole body (Wu et al. 2002, 2005). Moreover, to analyze the posture of the upper arm and thorax during pitching motion, markers were attached to the medial and lateral humeral epicondyles, 7th cervical and thoracic spinous processes, jugular notch, and xiphoid process (Wu et al., 2005).

Local coordinate systems for the scapula, humerus, and thorax based on the recommendations of the International Society of Biomechanics (ISB) were used (Wu et al., 2005). The shoulder joint center was identified as the center of the humeral head estimated from the acromion on the throwing side using the Fleisig method (Fleisig et al., 1995) as follows: (1) scapular orientation with respect to the thorax (ST): internal rotation/external rotation, posterior tilt/forward tilt, and downward rotation/upward rotation; (2) humeral orientation with respect to the scapula (GH): horizontal abduction/horizontal adduction, external rotation/internal rotation, and abduction/adduction; (3) humeral orientation with respect to the thorax (HT): horizontal abduction/horizontal adduction, external rotation/internal rotation, and abduction/adduction; and (4) thoracic orientation with respect to the ground (trunk): non-throwing-side tilt/throwing-side tilt, non-throwing-side rotation/throwing-side rotation, and extension/flexion, which were calculated using Euler angles (Wu et al., 2005). Similarly, rotational sequence was determined using the ISB method (Wu et al., 2005).

2.6. Data analysis

The fastest pitching measured in this study was selected for analysis (Oliver & Weimar 2015). The analysis period of pitching motion was defined as follows: the moment when the hand marker of the throwing side was at the lowest point (STA); stride foot contact (SFC) period; shoulder MER period; and ball release (BR) (Fig. 3) (Fleisig et al., 1995; Jobe and Bradley 1988). The interval of the analysis period was normalized from 0% at STA to 100% at BR. GH, ST, HT, and trunk joint angles were calculated during the SFC and MER periods. Moreover, the peak value of the ST joint angle was calculated from SFC to MER periods, and analysis was performed using MATLABR2019a (MathWorks, MA, USA).

2.7. Statistical analyses

Age, height, weight, BMI, bilateral shoulder internal/external rotation ROM, ball speed, and shoulder kinematic data (HT, GH, and ST joints) during pitching motion from SFC to MER periods were compared between the abnormal and normal (with and without SD) groups using the unpaired t–test. Additionally, SD (with and without) was considered the dependent variable, whereas age, height, weight, BMI, bilateral shoulder internal/external rotation ROM, ball speed, and shoulder kinematic data were considered the independent variables during pitching motion. The level of significance was set at 5%, and statistical analyses were performed using IBM SPSS Statistics version 25 (IBM Corp., Tokyo, Japan). Additionally, the effect size (Cohen's d) was calculated to clarify the degree of difference in each parameter between the two groups.

3. Results

The percentage of agreement representing the inter-rater reliability of our SD assessment was 77.6% (52/67; kappa coefficient: 0.72). In all, 51 participants were included in this study and classified into types I–IV. The incidence of SD, including types I–III, was 49% (25/51). In the total study cohort, 24 participants (47%) had type I SD; 12 participants (24%) had isolated type I SD, 8 (16%) had types I and II SD, 3 (6%) had types I and III SD, and 1 (2%) had types I, II, and III SD (Table 2). Twenty-seven individuals (53%) had type IV SD with normal scapular motion, and no one was diagnosed with isolated type II SD. Only 1 participant had isolated type III SD (Table 2) and was excluded from the study.

No significant differences in age, height, weight, BMI, competition history, and shoulder internal/external rotation ROM were observed between the abnormal and normal groups. Additionally, ball speed was not significantly different between the two groups (Table 1).

The characteristics of GH and ST motion during pitching in the abnormal and normal groups are presented in Tables 3 and 4 and Fig. 4–A, B, and C, respectively. The pitching cycle (%) for each pitching period was as follows: 56% in the abnormal group and 61% in the normal group during the SFC period, and 91% in the abnormal group and 91% in the normal group during the MER period (Figs. 3 and 4–C).

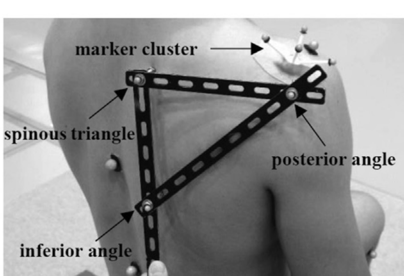

Fig. 2. Location of the acromion marker cluster and measurement of scapular posture using the locator.

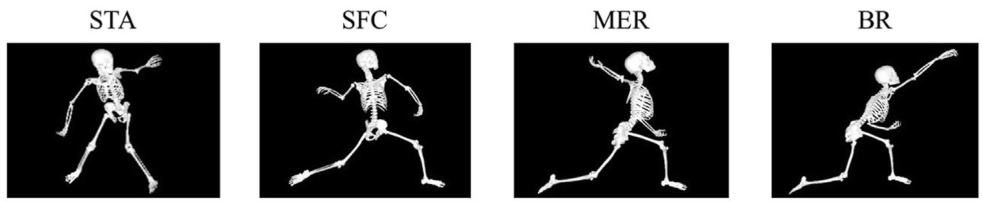

Fig. 3. Phases of a pitching cycle. The pitching cycle in the abnormal and normal groups was as follows: SFC: 56% in the abnormal and 61% in the normal group; MER: 91% in the abnormal and 91% in the normal group. The STA and BR periods in the abnormal and normal groups were 0% and 100%, respectively. STA, hand marker of the throwing side at the lowest point; SFC, stride foot contact; MER, maximum external rotation; BR, ball release.

Table 2
Incidence of scapular dyskinesis (n = 51).

	Number (% total)	Detail (% total)
Abnormal group (with type I)	24 (47)	
Isolated type I		12 (24)
Type I + II		8 (16)
Type I + III		3 (6)
Type I + II + III		1 (2)
Normal group (with type IV)	27 (53)	

Only 1 participant was diagnosed with isolated type III SD and was excluded.

GH external rotation during the MER period was significantly higher in the abnormal group than in the normal group ($P < 0.01$, $d = 0.75$; Table 3). No significant differences in other GH parameters during the SFC and MER periods were identified between the two groups (Table 3).

ST posterior tilt during the MER period was significantly lower in the abnormal group than in the normal group ($P = 0.02$, $d = 0.71$; Table 3). No significant differences in other ST parameters during the SFC and MER periods were noted between the two groups (Table 3).

Table 3
Scapulothoracic joint, glenohumeral joint, humerothoracic joint, and trunk angles during pitching motion in the two groups. [a].

	SFC						MER				
	Abnormal group	Normal group	95% CI for difference	P value[b]	Effect size[c]		Abnormal group	Normal group	95% CI for difference	P value[b]	Effect size[c]
Scapulothoracic joint, deg						Scapulothoracic joint, deg					
Upward rotation	19 ± 10	21 ± 8	−5 to 5	0.93	0.22	Upward rotation	26 ± 10	25 ± 7	−3 to 7	0.37	0.12
Internal rotation	−15 ± 11	−15 ± 10	−8 to 4	0.48	0	Internal rotation	2 ± 15	2 ± 9	−9 to 4	0.45	0
Posterior tilt	5 ± 12	9 ± 10	−3 to 10	0.26	0.36	Posterior tilt	19 ± 9	25 ± 8	1 to 10	0.02b	0.71
Glenohumeral joint, deg						Glenohumeral joint, deg					
Horizontal abduction	20 ± 20	22 ± 14	−9 to 6	0.64	0.12	Horizontal abduction	0 ± 11	3 ± 6	−6 to 3	0.50	0.07
Abduction	67 ± 12	65 ± 12	−7 to 6	0.86	0.17	Abduction	74 ± 10	74 ± 6	−5 to 5	0.97	0
External rotation	28 ± 28	29 ± 26	−15 to 14	0.95	0.04	External rotation	142 ± 11	133 ± 13	−15 to −2	<0.01b	0.75
Humerothoracic joint, deg						Humerothoracic joint, deg					
Horizontal abduction	34 ± 11	33 ± 13	−8 to 6	0.76	0.08	Horizontal abduction	−6 ± 7	−7 ± 7	−4 to 4	0.84	0.14
Abduction	84 ± 11	82 ± 9	−8 to 4	0.48	0.20	Abduction	101 ± 8	99 ± 5	−5 to 2	0.46	0.15
External rotation	41 ± 29	44 ± 30	−15 to 19	0.79	0.10	External rotation	160 ± 9	157 ± 9	−9 to 1	0.14	0.33
Trunk, deg						Trunk, deg					
Non-throwing-side tilt	−6 ± 8	−4 ± 6	−7 to 1	0.13	0.28	Non-throwing-side tilt	24 ± 8	26 ± 6	−6 to 2	0.35	0.28
Non-throwing-side rotation	−7 ± 11	−5 ± 12	−4 to 10	0.34	0.17	Non-throwing-side rotation	100 ± 8	100 ± 8	−5 to 5	0.99	0
Extension	−1 ± 10	−3 ± 9	−4 to 7	0.60	0.21	Extension	14 ± 7	16 ± 9	−5 to 4	0.71	0.25

Abbreviations: CI, confidence interval; MER, maximum external rotation; SFC, stride foot contact.
aMean ± standard deviation.
[b]Values less than 0.05 were considered statistically significant.
[c]Cohen's d effect size.

Table 4
Peak value of scapulothoracic joint angle during pitching motion in the two groups. [a].

	Peak value (SFC-MER)				
	Abnormal group	Normal group	95% CI for difference	P value[b]	Effect size[c]
Scapulothoracic joint, deg					
Upward rotation	29 ± 8	26 ± 8	−2 to 7	0.24	0.38
Internal rotation	−18 ± 11	−21 ± 10	−8 to 4	0.44	0.29
Posterior tilt	24 ± 9	28 ± 9	0.1 to 9	0.06	0.44

Abbreviations: CI, confidence interval; MER, maximum external rotation; SFC, stride foot contact.
[a]Mean ± standard deviation.
[b]Values less than 0.05 were considered statistically significant.
[c]Cohen's d effect size.

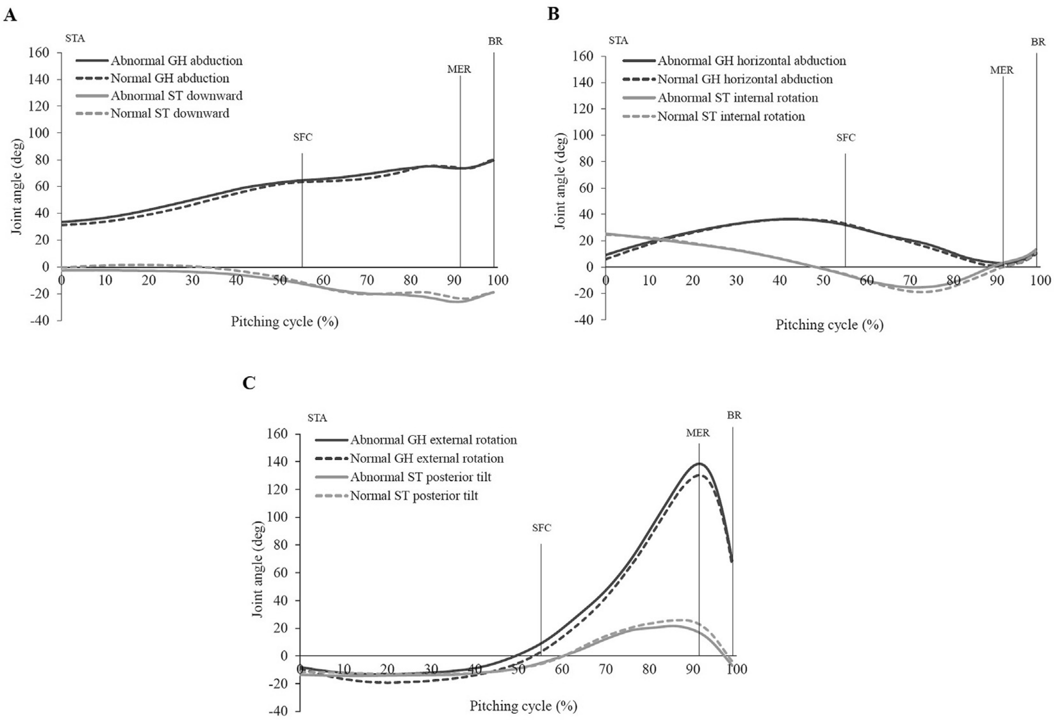

Fig. 4. (A, B and C) — Temporal changes in the scapulothoracic and glenohumeral joint angles during pitching motion in the two groups (solid line: abnormal group, dashed line: normal group). The pitching cycle during each period shows the average value between the four types of scapular dyskinesis. STA, hand marker of the throwing side at the lowest point; SFC, stride foot contact; MER, maximum external rotation; BR, ball release; GH, humeral orientation with respect to the scapula: abduction (+)/adduction (−), horizontal abduction (+)/horizontal adduction (−), external rotation (+)/internal rotation (−). ST, scapular orientation with respect to the thorax: downward rotation (+)/upward rotation (−), internal rotation (+)/external rotation (−), posterior tilt (+)/anterior tilt (−).

The peak value of ST posterior tilt from SFC to MER periods was tended to be lower in the abnormal group than in the normal group ($P = 0.06$, $d = 0.44$; Table 4). Moreover, the timing of the peak angle of ST posterior tilt (abnormal group: 85%, normal group: 88%) was prior to the MER period (abnormal group: 91%, normal group: 91%) (Fig. 4-C). No significant differences in the kinematic parameters of peak values of ST motion from SFC to MER periods were observed between the two groups (Table 4). Furthermore, there were no significant differences in HT posture parameters and trunk motion parameters during the SFC and MER periods between the two groups (Table 3).

4. Discussion

This study investigated the characteristics of GH and ST motion during pitching in baseball players in the abnormal (with type I SD) and normal groups (with type IV SD). Our results indicated that during the MER period, the abnormal group had significantly increased GH external rotation (9°) and decreased ST posterior tilt (6°) compared to the normal group. Our results reveal that the abnormal group exhibited increased GH motion and decreased ST motion compared to the normal group during the MER period.

The findings of this study were similar to those reported by Kibler et al. and Kawasaki et al. (Kawasaki et al., 2012; Kibler et al. 2002). Besides, the high inter-rater reliability of SD assessment in this study showed that the SDT was sufficiently reliable. The incidence of SD, including types I–III, was 49% (25/51) in our study. A systematic review conducted by Burn et al. revealed that the incidence of SD was approximately 55% in overhead athletes, including baseball, handball players and swimmers (Burn et al., 2016). Additionally, Myers et al. reported that the incidence of SD was 46% (122/246) among American high school baseball players (Myers et al., 2013). Thus, the incidence of SD in our study was roughly similar to the incidence reported by previous studies.

Among the four SD types, type I was the most common, accounting for 47% (24/51) of SD types, contrary to the results obtained by Kawasaki et al. who used the four−type classification in 103 rugby players and reported the incidence of different types of SD to be 5.8% (6/103) for type I, 3.9% (4/103) for type II, 22.3% (23/103) for type III, and 68% (70/103) for type IV and that the number of type III cases was greater than the number of cases of SD types I and II (Kawasaki et al., 2012). Hence, the difference in SD characteristics between our baseball players and rugby players may be attributed to differences in SD types among baseball players and other competitive athletes. Nonetheless, studies on the incidence of SD in baseball players using the four-type classification are limited. Thus, further larger-sample studies are required to confirm our findings.

In this study, the ball speed was 31 m/s in the abnormal group and 31 m/s in the normal group (Table 1). Previous studies reported a ball speed of approximately 35–36 m/s at university and professional levels (Fleisig et al., 2016; Kageyama et al., 2015; Konda et al., 2015). The kinematic parameters of pitching motion indicated a slower ball speed in this study than in previous studies (Fleisig et al., 2016; Kageyama et al., 2015; Konda et al., 2015). Therefore, the baseball players in this study might have lower performance levels than those in previous studies. Furthermore, our study participants threw the ball on flat ground (throwing without a pitching mound), which might have further affected the ball speed.

Regarding the shoulder motion from SFC to MER periods, the GH angle in this study showed horizontal abduction, abduction, and external rotation in both abnormal and normal groups (Fig. 4), whereas the ST angle increased upward rotation, internal rotation,

Table 5
Glenohumeral joint and scapular kinematic data at MER during pitching motion reported in the literature.

a		Miyashita et al.	Konda et al.	Oliver and Weimar	The present study (abnormal)	The present study (normal)
Glenohumeral joint	External rotation	106	114	–	142	133
	Horizontal abduction	–	6	–	0	3
	Abduction	–	85	–	74	74
Scapular	Posterior tilt	24	11	14	19	25
	Internal rotation	–	15	22	2	2
	Upward rotation	–	23	37	26	25

b)Trunk Kinematic Data at MER During Pitching Motion Reported in the Literature

		Miyashita et al.	Oyama et al.	Kageyama et al.	Barfield et al.	The present study (abnormal)	The present study (normal)
Trunk	Extension	9	–	–	–	14	16
	Non-throwing-side rotation	–	96	80	–	100	100
	Non-throwing-side tilt	–	22	–	13	24	26

Abbreviations: MER, maximum external rotation.

and posterior tilt in both abnormal and normal groups (Fig. 4). Oliver and Weimar and Meyer et al. reported that the ST motion from SFC and MER periods changed to upward rotation, internal rotation, and posterior tilt (Meyer et al., 2008; Oliver & Weimar 2015). Previous studies reported that the shoulder motions at MER were as follows: GH abduction at approximately 85° (Konda et al., 2015) and ST upward rotation at 25°–37°, (Konda et al., 2015; Oliver & Weimar 2015), GH horizontal adduction at 6° (Konda et al., 2015) and ST internal rotation at 15°–22°(Konda et al., 2015; Oliver & Weimar 2015); and GH external rotation at 106°–114° (Konda et al., 2015; Miyashita et al., 2010) and ST posterior tilt at 11°–24° (Tables 3 and 5). Thus, in this study, ST upward rotation, GH horizontal adduction, and ST posterior tilt showed a similar trend to the results of previous studies (Tables 3 and 5).

In our study, we observed that the values of GH external rotation (approximately 133°–142°) were high, whereas those of GH abduction (74°) and ST internal rotation (2°) were low compared to the previously reported values (Tables 3 and 5). This might be because of the variations in the data for GH and ST motions during pitching in previous studies (Konda et al., 2015; Miyashita et al., 2010; Oliver & Weimar 2015) or due to various factors, such as differences in competition level and pitching form among countries, which may influence GH and ST motions during pitching (Escamilla et al., 2002; Fleisig et al., 1999).

Previous studies showed that the trunk posture at MER led to contralateral rotation (Kageyama et al., 2015; Oyama et al., 2013), contralateral tilt (Barfield et al., 2018; Oyama et al., 2013), and extension (Miyashita et al., 2010). The measured trunk motion during pitching in our study suggested the possibility of measuring it with a similar tendency as in previous studies (Tables 3 and 5). Finley and Lee and Suzuki et al. reported that trunk posture affected scapular motion during shoulder joint motion. (Finley and Lee 2003; Suzuki et al., 2019). Nevertheless, the trunk posture relative to scapular motion was not significantly different between the two groups. Therefore, the difference in the effects of trunk posture (rotation, lateral tilt, and extension) between non–SD individuals and players with SD might be minimal in this study.

Similarly, ball velocity showed no significant difference between the two groups. Wang et al. reported that the external rotation angle of the shoulder joint at MER during pitching (measured at 152° in the HT joint angle) was positively correlated with ball velocity (Wang et al., 1995). Similarly, in this study, the external rotation angle of HT at MER was approximately 160° and 157° in the abnormal and normal groups, respectively; however, the difference between the two groups was not significant. Therefore, ball velocity may not result in any difference in pitching performance between the two groups. However, the GH external rotation angle and ST posterior tilt angle at MER significantly increased and decreased, respectively, in participants with type I SD compared to those with type IV SD. Thus, each ratio of GH external rotation and ST posterior tilt, including shoulder external rotation (Miyashita et al., 2010), could differ between the abnormal and normal groups.

The abnormal group exhibited an increase in GH external rotation and a decrease in ST posterior tilt. Previous studies have reported on the effect of excessive GH external rotation on the onset of internal impingement and SLAP tear (Kuhn et al., 2003; Mihata et al. 2004, 2012) due to the posterior-superior shift of the humeral head (Mihata et al., 2015) and excessive extension of superior labral and biceps–superior labral complexes (Kuhn et al., 2003; Pradhan et al., 2001). Moreover, the decrease in scapular posterior tilt at MER during pitching motion involves the development of throwing-related shoulder injuries due to excessive GH external rotation (Burkhart et al., 2003; Miyashita et al., 2010; Suzuki et al., 2019). We observed greater GH external rotation and smaller ST posterior tilt angle in the abnormal group than in the normal group, which may result in an increased risk of throwing–related injuries, such as internal impingement and SLAP tear, in the abnormal group. Hence, suppression of an excessive increase in GH external rotation during pitching motion, which can be attributed to an increase in scapular posterior tilt, may prevent throwing–related shoulder injuries.

SD with prominence of the inferior scapular angle reportedly affects the function of muscles around the scapula and results in pectoralis minor muscle tightness (Burkhart et al., 2003), muscle weakness, fatigue, and abnormalities in the firing patterns of the serratus anterior muscle (Ellenbecker and Cools 2010; Huang et al., 2015; Martin and Fish 2008) during shoulder motion. Tightness in the pectoralis minor muscle and dysfunction of the serratus anterior muscle has been suggested as a cause of decrease in ST posterior tilt at MER (Burkhart et al., 2003; Ellenbecker & Cools 2010; Huang et al., 2015). Additionally, pectoralis minor stretching and scapular stabilization exercises involving the serratus anterior muscle have been demonstrated to be useful for an increase in ST posterior tilt (Başkurt et al., 2011; Morais and Cruz, 2016). Thus, it is crucial to improve the flexibility of the pectoralis minor muscle and the strength of the serratus anterior muscle by specific exercises for scapular rehabilitation, including stretching and stabilization exercises, in baseball players with reduced scapular posterior tilt at MER (Burkhart et al., 2003; Ellenbecker & Cools 2010; Longo et al., 2020).

4.1. Limitations

This study has some limitations. First, the method for measuring scapular motion during pitching in this study might have measurement errors in the gliding of the AMC on the skin over the scapula (Konda et al., 2018). Previous studies on measurement errors have indicated that the AMC method is accurate for up to 120°

of shoulder elevation (Chu et al., 2012). The elevation angle of the shoulder joint during the pitching motion measured in this study was less than 120° (Table 3). According to a previous study, the measurement errors of scapular motion may be lower in the high-speed acceleration phase (from MER to BR) during pitching motion compared to those in other phases (Konda et al., 2015). In this study, we analyzed shoulder motion during pitching prior to the acceleration phase. Thus, we consider that the data on shoulder joint angles without the acceleration phase were reliable. Second, the kinematic characteristics of shoulder motion during pitching in participants with type II and III SD could not be clarified because the data of participants with type I and types II and III SD was mixed. In the future, it is necessary to evaluate the effect of types II and III SD on the pitching motion of baseball players. Third, it was not possible to determine whether the results were directly attributable to the cause of throwing injury rather than the cross-sectional study design. Therefore, longitudinal studies exploring the correlation of excessive increase in GH external rotation and decrease in ST posterior tilt during pitching with throwing injury onset are required in the future.

4.2. Clinical relevance

- The use of the SDT for the evaluation of type I SD can be a useful and simple screening method to predict excessive GH external rotation and decreased scapular posterior tilt during pitching.
- To reduce the excessive GH external rotation during pitching in baseball players with prominence of the inferior scapular angle, it is crucial to improve the scapular function.
- Our results provide useful insights about the shoulder exercise programs for overhead athletes, such as baseball, handball, and tennis players, with healthy and injured shoulders.

5. Conclusion

This study showed that participants in the abnormal group (type I SD) exhibited a significantly increased GH external rotation angle and decreased ST posterior tilt angle at MER compared to those in the normal group. Our results indicated that baseball players who had SD with prominence of the inferior scapular angle might be at an increased risk of shoulder injury onset during pitching motion.

Declaration of interest

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

CRediT authorship contribution statement

Atsushi Ueda: Conceptualization, Writing introduction and methods, results, discussion. **Takafumi Shinkuma:** Discussion. **Takeshi Oki:** Methodology. **Yasuo Nakamura:** Data analyses and supervision.

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References

Barfield, J.W., Anz, A.W., Andrews, J.R., Oliver, G.D., 2018. Relationship of glove arm kinematics with established pitching kinematic and kinetic variables among youth baseball pitchers. Orthopaedic Journal of Sports Medicine 6, 2325967118784937.

Başkurt, Z., Başkurt, F., Gelecek, N., Özkan, M.H., 2011. The effectiveness of scapular stabilization exercise in the patients with subacromial impingement syndrome. J. Back Musculoskelet. Rehabil. 24, 173–179.

Beckett, M., Hannon, M., Ropiak, C., Gerona, C., Mohr, K., Limpisvasti, O., 2014. Clinical assessment of scapula and hip joint function in preadolescent and adolescent baseball players. Am. J. Sports Med. 42, 2502–2509.

Brochard, S., Lempereur, M., Rémy-Néris, O., 2011. Double calibration: an accurate, reliable and easy-to-use method for 3D scapular motion analysis. J. Biomech. 44, 751–754.

Bullock, G.S., Menon, G., Nicholson, K., Butler, R.J., Arden, N.K., Filbay, S.R., 2021. Baseball pitching biomechanics in relation to pain, injury, and surgery: a systematic review. J. Sci. Med. Sport 24, 13–20.

Burkhart, S.S., Morgan, C.D., Kibler, W.B., 2000. Shoulder injuries in overhead athletes. The "dead arm" revisited. Clin. Sports Med. 19, 125–158.

Burkhart, S.S., Morgan, C.D., Kibler, W.B., 2003a. The disabled throwing shoulder: spectrum of pathology Part III: the SICK scapula, scapular dyskinesis, the kinetic chain, and rehabilitation. Arthroscopy 19, 641–661.

Burkhart, S.S., Morgan, C.D., Kibler, W.B., 2003b. The disabled throwing shoulder: spectrum of pathology. Part II: evaluation and treatment of SLAP lesions in throwers. Arthroscopy 19, 531–539.

Burn, M.B., McCulloch, P.C., Lintner, D.M., Liberman, S.R., Harris, J.D., 2016. Prevalence of scapular dyskinesis in overhead and nonoverhead athletes: a systematic review. Orthopaedic Journal of Sports Medicine 4, 2325967115627608.

Chalmers, P.N., Erickson, B.J., D'Angelo, J., Ma, K., Romeo, A.A., 2019. Epidemiology of shoulder surgery among professional baseball players. Am. J. Sports Med. 47, 1068–1073.

Chu, Y., Akins, J., Lovalekar, M., Tashman, S., Lephart, S., Sell, T., 2012. Validation of a video-based motion analysis technique in 3-D dynamic scapular kinematic measurements. J. Biomech. 45, 2462–2466.

Conte S, Camp CL, Dines JS 2016 Injury trends in major league baseball over 18 seasons: 1998-2015.Am. J. Orthoped. 45: 116-123.

Ellenbecker, T.S., Cools, A., 2010. Rehabilitation of shoulder impingement syndrome and rotator cuff injuries: an evidence-based review. Br. J. Sports Med. 44, 319–327.

Escamilla, R., Fleisig, G., Barrentine, S., Andrews, J., Moorman 3rd, C., 2002. Kinematic and kinetic comparisons between American and Korean professional baseball pitchers. Sports BioMech. 1, 213–228.

Fares, M.Y., Salhab, H.A., Khachfe, H.H., Kane, L., Fares, Y., Fares, J., Abboud, J.A., 2020. Upper limb injuries in major league baseball. Phys. Ther. Sport 41, 49–54.

Finley, M.A., Lee, R.Y., 2003. Effect of sitting posture on 3-dimensional scapular kinematics measured by skin-mounted electromagnetic tracking sensors. Arch. Phys. Med. Rehabil. 84, 563–568.

Fleisig, G.S., Andrews, J.R., Dillman, C.J., Escamilla, R.F., 1995. Kinetics of baseball pitching with implications about injury mechanisms. Am. J. Sports Med. 23, 233–239.

Fleisig, G.S., Barrentine, S.W., Zheng, N., Escamilla, R.F., Andrews, J.R., 1999. Kinematic and kinetic comparison of baseball pitching among various levels of development. J. Biomech. 32, 1371–1375.

Fleisig, G.S., Laughlin, W.A., Aune, K.T., Cain, E.L., Dugas, J.R., Andrews, J.R., 2016. Differences among fastball, curveball, and change-up pitching biomechanics across various levels of baseball. Sports BioMech. 15, 128–138.

Hickey, D., Solvig, V., Cavalheri, V., Harrold, M., McKenna, L., 2018. Scapular dyskinesis increases the risk of future shoulder pain by 43% in asymptomatic athletes: a systematic review and meta-analysis. Br. J. Sports Med. 52, 102–110.

Huang, T.S., Huang, H.Y., Wang, T.G., Tsai, Y.S., Lin, J.J., 2015a. Comprehensive classification test of scapular dyskinesis: a reliability study. Man. Ther. 20, 427–432.

Huang, T.S., Ou, H.L., Huang, C.Y., Lin, J.J., 2015b. Specific kinematics and associated muscle activation in individuals with scapular dyskinesis. J. Shoulder Elbow Surg. 24, 1227–1234.

Jobe, F.W., Bradley, J.P., 1988. Rotator cuff injuries in baseball. Prevention and rehabilitation. Sports Med. 6, 378–387.

Kageyama, M., Sugiyama, T., Kanehisa, H., Maeda, A., 2015. Difference between adolescent and collegiate baseball pitchers in the kinematics and kinetics of the lower limbs and trunk during pitching motion. J. Sports Sci. Med. 14, 246–255.

Kawasaki, T., Yamakawa, J., Kaketa, T., Kobayashi, H., Kaneko, K., 2012. Does scapular dyskinesis affect top rugby players during a game season? J. Shoulder Elbow Surg. 21, 709–714.

Kibler, W.B., 1998. The role of the scapula in athletic shoulder function. Am. J. Sports Med. 26, 325–337.

Kibler WB, Uhl TL, Maddux JW, Brooks PV, Zeller B, McMullen J 2002 Qualitative clinical evaluation of scapular dysfunction: a reliability study. J. Shoulder Elbow Surg. 11: 550-556.

Kibler, W.B., Wilkes, T., Sciascia, A., 2013. Mechanics and pathomechanics in the overhead athlete. Clin. Sports Med. 32, 637–651.

Kim, Y., Lee, J.M., Wellsandt, E., Rosen, A.B., 2020. Comparison of shoulder range of motion, strength, and upper quarter dynamic balance between NCAA division I overhead athletes with and without a history of shoulder injury. Phys. Ther. Sport 42, 53–60.

Konda, S., Sahara, W., Sugamoto, K., 2018. Directional bias of soft-tissue artifacts on the acromion during recording of 3D scapular kinematics. J. Biomech. 73, 217–222.

Konda, S., Yanai, T., Sakurai, S., 2015. Configuration of the shoulder complex during the arm-cocking phase in baseball pitching. Am. J. Sports Med. 43, 2445–2451.

Kuhn, J.E., Lindholm, S.R., Huston, L.J., Soslowsky, L.J., Blasier, R.B., 2003. Failure of the biceps superior labral complex: a cadaveric biomechanical investigation comparing the late cocking and early deceleration positions of throwing.

Arthroscopy 19, 373–379.
Laudner, K.G., Myers, J.B., Pasquale, M.R., Bradley, J.P., Lephart, S.M., 2006. Scapular dysfunction in throwers with pathologic internal impingement. J. Orthop. Sports Phys. Ther. 36, 485–494.
Longo, U.G., Risi Ambrogioni, L., Berton, A., Candela, V., Massaroni, C., Carnevale, A., Stelitano, G., Schena, E., Nazarian, A., DeAngelis, J., Denaro, V., 2020. Scapular dyskinesis: from basic science to ultimate treatment. Int. J. Environ. Res. Publ. Health 17, 2974.
Martin, R.M., Fish, D.E., 2008. Scapular winging: anatomical review, diagnosis, and treatments. Current Reviews in Musculoskeletal Medicine 1, 1–11.
Matsumura, A., Ueda, A., Nakamura, Y., 2019. A new method of estimating scapular orientation during various shoulder movements: a comparison of three non-invasive methods. J. Electromyogr. Kinesiol. 44, 46–55.
McClure, P.W., Michener, L.A., Sennett, B.J., Karduna, A.R., 2001. Direct 3-dimensional measurement of scapular kinematics during dynamic movements in vivo. J. Shoulder Elbow Surg. 10, 269–277.
Meyer, K.E., Saether, E.E., Soiney, E.K., Shebeck, M.S., Paddock, K.L., Ludewig, P.M., 2008. Three-dimensional scapular kinematics during the throwing motion. J. Appl. Biomech. 24, 24–34.
Mihata, T., Gates, J., McGarry, M.H., Neo, M., Lee, T.Q., 2015. Effect of posterior shoulder tightness on internal impingement in a cadaveric model of throwing. Knee Surg. Sports Traumatol. Arthrosc. 23, 548–554.
Mihata, T., Jun, B.J., Bui, C.N., Hwang, J., McGarry, M.H., Kinoshita, M., Lee, T.Q., 2012. Effect of scapular orientation on shoulder internal impingement in a cadaveric model of the cocking phase of throwing. The Journal of Bone and Joint Surgery. American Volume 94, 1576–1583.
Mihata, T., Lee, Y., McGarry, M.H., Abe, M., Lee, T.Q., 2004. Excessive humeral external rotation results in increased shoulder laxity. Am. J. Sports Med. 32, 1278–1285.
Mihata, T., McGarry, M.H., Kinoshita, M., Lee, T.Q., 2010. 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. 38, 369–374.
Mihata, T., McGarry, M.H., Tibone, J.E., Fitzpatrick, M.J., Kinoshita, M., Lee, T.Q., 2008. Biomechanical assessment of Type II superior labral anterior-posterior (SLAP) lesions associated with anterior shoulder capsular laxity as seen in throwers: a cadaveric study. Am. J. Sports Med. 36, 1604–1610.
Miyashita, K., Kobayashi, H., Koshida, S., Urabe, Y., 2010. Glenohumeral, scapular, and thoracic angles at maximum shoulder external rotation in throwing. Am. J. Sports Med. 38, 363–368.
Morais, N., Cruz, J., 2016. The pectoralis minor muscle and shoulder movement-related impairments and pain: rationale, assessment and management. Phys. Ther. Sport 17, 1–13.
Myers, J.B., Oyama, S., Hibberd, E.E., 2013. Scapular dysfunction in high school baseball players sustaining throwing-related upper extremity injury: a prospective study. J. Shoulder Elbow Surg. 22, 1154–1159.
Oliver, G., Weimar, W., 2015. Scapula kinematics of youth baseball players. J. Hum. Kinet. 49, 47–54.
Oyama, S., Yu, B., Blackburn, J.T., Padua, D.A., Li, L., Myers, J.B., 2013. Effect of excessive contralateral trunk tilt on pitching biomechanics and performance in high school baseball pitchers. Am. J. Sports Med. 41, 2430–2438.
Pradhan, R.L., Itoi, E., Hatakeyama, Y., Urayama, M., Sato, K., 2001. Superior labral strain during the throwing motion. A cadaveric study. Am. J. Sports Med. 29, 488–492.
Sakata, J., Nakamura, E., Suzuki, T., Suzukawa, M., Akeda, M., Yamazaki, T., Ellenbecker, T.S., Hirose, N., 2019. Throwing injuries in youth baseball players: can a prevention program help? a randomized controlled trial. Am. J. Sports Med. 47, 2709–2716.
Salamh, P., Jones, E., Bashore, M., Liu, X., Hegedus, E.J., 2020. Injuries and associated risk factors of the shoulder and elbow among adolescent baseball pitchers: a systematic review and meta-analysis. Phys. Ther. Sport 43, 108–119.
Shitara, H., Kobayashi, T., Yamamoto, A., Shimoyama, D., Ichinose, T., Tajika, T., Osawa, T., Iizuka, H., Takagishi, K., 2017. Prospective multifactorial analysis of preseason risk factors for shoulder and elbow injuries in high school baseball pitchers. Knee Surg. Sports Traumatol. Arthrosc. 25, 3303–3310.
Suzuki, Y., Muraki, T., Sekiguchi, Y., Ishikawa, H., Yaguchi, H., Suzuki, Y., Morise, S., Honda, K., Izumi, S.I., 2019. Influence of thoracic posture on scapulothoracic and glenohumeral motions during eccentric shoulder external rotation. Gait Posture 67, 207–212.
Wang, Y.T., Ford 3rd, H.T., Ford Jr., H.T., Shin, D.M., 1995. Three-dimensional kinematic analysis of baseball pitching in acceleration phase. Percept. Mot. Skills 80, 43–48.
Wilk, K.E., Macrina, L.C., Fleisig, G.S., Porterfield, R., Simpson 2nd, C.D., Harker, P., Paparesta, N., Andrews, J.R., 2011. Correlation of glenohumeral internal rotation deficit and total rotational motion to shoulder injuries in professional baseball pitchers. Am. J. Sports Med. 39, 329–335.
Wu, G., Siegler, S., Allard, P., Kirtley, C., Leardini, A., Rosenbaum, D., Whittle, M., D'Lima, D.D., Cristofolini, L., Witte, H., Schmid, O., Stokes, I., 2002. ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion–part I: ankle, hip, and spine. International Society of Biomechanics. J. Biomech. 35, 543–548.
Wu, G., van der Helm, F.C., Veeger, H.E., Makhsous, M., Van Roy, P., Anglin, C., Nagels, J., Karduna, A.R., McQuade, K., Wang, X., Werner, F.W., Buchholz, B., 2005. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion–Part II: shoulder, elbow, wrist and hand. J. Biomech. 38, 981–992.