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Title: The role of shoulder posture in pitching mechanics and injury risk in high school baseball pitchers
running title: shoulder posture in pitching mechanics
The research was conducted at the laboratory of School and Graduate Institute of Physical Therapy, College of Medicine, National Taiwan University, Taipei, Taiwan

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Clinical trial registration
This study was registered at ClinicalTrials.gov Protocol Registration and Results System. The NCT number was NCT03568487 (https://clinicaltrials.gov/study/NCT03568487).

Statements and Declarations

The authors declare that they have no competing interests. Their immediate family and any research foundation with which they are affiliated did not receive any financial payments or other benefits from any commercial entity related to the subject of this article.

CRediT authorship contribution statement

YHW was responsible for Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Visualization, Writing – original draft, and Writing – review & editing. TSH was involved in Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Visualization, and Writing – review & editing. JJL was responsible for Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Supervision, Validation, Visualization, Writing – original draft, and Writing – review & editing. All authors have read and approved the final version of the manuscript and agree with the order of presentation of the authors.

Data availability statement

Raw data were generated at the School and Graduate Institute of Physical Therapy, College of Medicine, National Taiwan University. Derived data supporting the findings of this study are available from the corresponding author on request.

Title: The role of shoulder posture in pitching mechanics and injury risk in high school baseball pitchers

Abstract

Context: Although compromised shoulder posture impacts scapular biomechanics, the interplay between shoulder posture and scapular kinematics during the dynamic pitching motion in high school baseball pitchers remains unexplored.

Objective: To characterize the shoulder postures of baseball pitchers and investigate their relationships with scapular biomechanics during pitching.

Design: Cross-sectional study.

Setting: Laboratory.

Participants: 38 high school baseball pitchers (age: 16.9 ± 0.9).

Main Outcome Measure(s): Shoulder posture was determined by acromial distance (AD), pectoralis minor index (PMI), scapular index (SI), and forward shoulder angle (FSA) in the dominant arm. The scapular kinematics and associated muscle activation (upper trapezius [UT], serratus anterior [SA], lower trapezius, biceps brachii [BB], triceps brachii [TB], anterior deltoid) during pitching were recorded.

Results: There was a moderate to strong negative correlation between AD and upward rotation ($r = -0.47$ to -0.55, $p < 0.003$) and a moderate positive correlation between AD and anterior tilt ($r = 0.40$ to 0.44, $p = 0.005$ to 0.013). PMI and FSA also showed moderate negative correlations with anterior tilt (PMI: $r = -0.37$, $p < 0.05$; FSA: $r = -0.34$ to -0.42, $p < 0.04$). AD had moderate to strong positive correlations with UT, SA, BB, TB, and anterior deltoid activation ($r = 0.36$ to 0.59, $p < 0.03$), while SI showed moderate negative correlations with UT, BB, and anterior deltoid activation ($r = -0.33$ to -0.40, $p <$

0.05). FSA displayed a moderate negative correlation with SA and BB activation ($r = -0.32$ to -0.40, $p < 0.05$).

Conclusions: Shoulder posture has a significant moderate to strong correlation with scapular biomechanics during pitching in high school baseball pitchers. Forward shoulder postures with scapular biomechanics alterations during pitching may increase the risk of shoulder fatigue or injuries. Thus, the maintenance of an appropriate shoulder posture is a critical factor in reducing injuries and maximizing performance in pitchers.

Keywords: acromial distance, pectoralis minor index, scapular index, forward shoulder angle, kinematics, electromyography

Key Points:

- High school baseball pitchers demonstrated an acromial distance of 6.1 cm, a pectoralis minor index of 9.4%, a scapular index of 65.8%, and a forward shoulder angle of 39.3°.
- Forward shoulder postures during pitching are associated with decreased scapular upward rotation and increased anterior tilt during the pitching motion.
- Forward shoulder postures during pitching are associated with increased muscle activation in the upper trapezius, serratus anterior, biceps brachii, triceps brachii, and anterior deltoid during the pitching motion.

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Upper extremity injuries are a significant concern for baseball players across all levels of player, particularly among high school athletes, who experience elbow and shoulder injuries at rates of 1.39 and 0.86 per 10,000 athletic exposures, respectively.[1] Notably, pitchers are at an even higher injury risk compared to position players, given the intense and repetitive nature of their role.[1] These injuries can range from mild strains and sprains to severe conditions like ulnar collateral ligament tears and rotator cuff tears, often requiring significant rehabilitation and potentially impacting a player's long-term athletic career.[1-3]

While various injury risk factors have been identified, the critical role of shoulder posture requires significantly greater attention. Evidence suggests that deficits in range of motion, muscle strength imbalances, and improper pitching biomechanics are potential risk factors. Specifically, a forward shoulder posture is linked to altered scapular function and may raise injury risk in overhead athletes.[2] Shoulder posture can be assessed using several methods, including the acromial distance (AD), pectoralis minor index (PMI), scapular index (SI), and forward shoulder angle (FSA).[4] A commonly used metric, AD, measures forward shoulder displacement, with ≥ 7.3 cm indicating forward shoulder posture.[5, 6] A PMI of ≤ 7.65 indicates a shortened pectoralis minor, which can increase scapular internal rotation.[7, 8] SI quantifies scapular internal rotation; lower values indicate more scapular internal rotation.[8] A forward shoulder posture is indicated by an FSA, which measures shoulder translation, of ≤ 38°.[9] A few studies have used specific measurements to identify the shoulder postures of baseball players.[10, 11] The integration of these measurements allows for a clinically relevant and comprehensive evaluation of postural deviations that may predispose baseball players to shoulder mechanic alterations and increased injury risk.

Forward shoulder posture is closely linked to alterations in scapular biomechanics. Participants with a greater AD tend to exhibit increased upper trapezius (UT) activation, accompanied by decreased middle trapezius and serratus anterior (SA) activations during shoulder abduction.[12] Similarly, those with a lower PMI are more likely to experience increased scapular anterior tilt and internal rotation during arm elevation.[7] Additionally, the pitching task relies on proper energy transfer throughout the entire kinetic chain.[13, 14] Forward shoulder posture can exacerbate the problems during pitching with disruption of energy transfer in the scapula. It may affect scapular biomechanics and increase the demand on peripheral muscles such as the biceps brachii (BB), triceps brachii (TB), and anterior deltoid.[15, 16]

Despite shoulder posture being linked to range of motion and scapular biomechanics,[9, 10] its influence in the more dynamic and complex pitching movement has remained unclear. Understanding the relationship between shoulder posture and pitching scapular biomechanics could offer valuable insights into how improving shoulder posture may positively influence pitching mechanics, thereby reducing the risk of injuries among baseball players. This study aimed to identify the shoulder postures of high school baseball pitchers and investigate the relationship between shoulder posture and scapular biomechanics during pitching. It was hypothesized that forward shoulder posture (more AD and less PMI, SI, and FSA) would positively correlate with UT, BB, TB, and anterior deltoid activation and negatively correlate with scapular upward rotation, external rotation, and posterior tilt, as well as SA and LT activation.

METHOD

Participants

A cross-sectional, observational study was conducted on high school baseball pitchers. The reporting of this study follows the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational studies. Players were recruited from local baseball teams in XXX City. These participants were thoroughly informed of the objectives and procedures of the study. Participants signed a consent form approved by the XXX institutional review board (XXX). Parental/guardian consent was also obtained before the experiment. The pitchers were limited to people who were (1) active high school pitchers for at least 3 years from the ages of 16 to 18 years, and (2) able to pitch overhead. Pitchers were excluded if they had a history of surgery or traumatic injury at the shoulder or could not complete the pitching task. This study was conducted from 1 February 2019 to 30 June 2019 at our laboratory in XXX.

Procedures

Data were collected in the pre-season period without practice on the same day. Participant characteristics, including age, height, weight, and practice time, were collected by the main assessor, a physical therapist with more than 5 years of experience. Clinical measurements, including AD, PMI, SI, and FSA (Figure 1), were conducted by the main assessor, and the data were recorded by a second assessor. Performance/function was assessed with the Kerlan–Jobe Orthopaedic Clinic shoulder and elbow score (KJOC). The KJOC has been shown to be reliable and responsive in a tested population of adult overhead athletes. It has a score range of 0 to 100, with 100 indicating perfect shoulder health.[17] After the baseline data collection, pitching biomechanics were measured. Then the maximum voluntary isometric contraction (MVIC) was assessed in each muscle for normalization.

Clinical measurements

AD was defined as the distance from the testing table to the lateral-inferior border of the acromion while participants were in a supine position with the shoulder in a neutral alignment.[5] The intra-rater reliability for AD measurement was excellent (ICC = 0.95).[6] A greater AD indicates a more forward shoulder posture.

PMI was calculated by measuring the distance between the inferior aspect of the coracoid process and the inferior aspect of the fourth rib using a digital caliper.[7] The intra-rater reliability for PMI was also excellent (ICC = 0.96). PMI was determined by dividing the pectoralis minor muscle length by the participant's height (in centimeters) and multiplying by 100. A lower PMI value indicates a more forward shoulder posture.

SI was determined by measuring the distance from the midpoint of the sternal notch to the medial aspect of the coracoid process, and the horizontal distance from the posterolateral angle of the acromion to the thoracic spine, using a soft tape measure. Participants were seated in an upright position with their arms resting at their sides.[8] SI was calculated by dividing the sternal notch–coracoid process distance by the acromion–thoracic spine distance and multiplying by 100. A lower SI value indicates a more forward shoulder posture.

FSA was assessed using photographic analysis. Before photographs were taken, reflective markers (Styrofoam balls with a 1 cm diameter) were placed on specific anatomical landmarks: the tragus of the ear, the spinous process of the seventh cervical vertebra, and the midpoint of the acromial process. Participants were asked to remove their shirts to ensure accurate marker placement. They were instructed to look straight ahead and march in place five times before each photograph was taken.[18] Photos were captured on the dominant arm side, with the camera positioned at the height of the acromial process and set 2 meters away. The photographic analysis was conducted in Kinovea software, which determined the coordinates of the anatomical landmarks. The zoom level was standardized at 150%, and angles were measured in degrees. The angle formed at the intersection of the line between the midpoint of the humerus and the spinous process of the seventh cervical vertebra, and the horizontal line through the midpoint of the humerus, reflected the anterior translation of the shoulder in the sagittal plane. The intra-rater reliability for FSA was good (ICC = 0.89).[19] A lower FSA value represents forward shoulder posture.

Pitching biomechanics

The muscle activities were measured with a wireless surface electromyograph (sEMG), the Noraxon TeleMyo 2400T (Noraxon, USA), and processed in Myo Research XP software (MR-XP 1.07 Master Edition, Noraxon, USA). The electrodes were attached to the pitchers with their shirts removed and placed on the UT, LT, SA, BB, TB, and anterior deltoid of the dominant arm.[20, 21] The MVICs of the target muscles were collected for normalization of the sEMG data.[22, 23] Full bandwidth sEMG data were captured, and baseline relaxed muscle activity was subtracted from the recorded data. The remaining data were processed using a root mean square (RMS) algorithm to generate sEMG envelopes, with an effective sampling rate of 75 samples per second. The frequency range of the EMG signal was band-pass filtered between 20 and 500 Hz.

The LIBERTY system (Polhemus Inc., USA), an electromagnetic motion analysis tool, combined with Motion Monitor software, was utilized to collect three-dimensional scapular kinematics. Sensors were secured using Velcro elastic straps on the flat bony surface of the acromion, the eighth thoracic vertebra, the seventh cervical vertebra, the first sacral vertebra, the midpoint of the upper arm, the anterior third of the forearm, and the dorsal aspect of the third metacarpal bone.[24] The sampling rate for each sensor was set at 240 Hz. Various bony landmarks, including the sternal notch, xiphoid process, seventh cervical vertebra, eighth thoracic vertebra, twelfth thoracic vertebra, acromion, anterior and posterior glenohumeral joint, root of the spine of the scapula, inferior angle of the scapula, lateral and medial epicondyles, radial styloid process, and ulnar styloid process, were palpated and digitized using a stylus to establish the anatomical coordinate systems.[25] The position of the glenohumeral joint center was estimated by calculating the pivot point of the instantaneous helical axes of the glenohumeral joint, determined during a small circular motion.[26]

To maintain consistent pitching conditions, the experiment was conducted in a laboratory equipped with a pitching mound that simulated a real field environment, with the air conditioner set to 25° Celsius. The target catcher was positioned at the standard distance of 18.44 meters from the mound, as required for high school pitchers. Players warmed up by passing and catching the ball with the catcher for approximately 15 minutes. Once acclimated to the setup, the pitchers threw six consecutive fastballs at a self-selected pace, and any observably wild pitches were excluded. The total number of pitches was kept under 10. The ball speed and pitching movements were recorded using a radar gun and a high-speed camera (DSC-RX100M5, Sony, JP) positioned 5 meters in front of the participant. Scapular kinematics were analyzed based on key pitching events, including the lead leg reaching its highest point, foot contact, maximum shoulder external rotation, and ball release.[14] We followed the ISB guidelines for constructing a shoulder joint coordinate system.[25] Scapular orientation relative to the thorax was described using an Euler angle sequence to measure rotation about the vertical axis (internal/external rotation), the sagittal axis (upward/downward rotation), and the frontal axis (posterior/anterior tilt). Data from the 3rd to 5th pitching trials were averaged for group comparisons. The reliabilities for scapular anterior/posterior tilt, upward/downward rotation, and internal/external rotation were excellent (ICC = 0.930–0.933). The sEMG data for each muscle were collected during the early-cocking (lead leg at the highest point to foot contact), late-cocking (foot contact to maximum shoulder external rotation), and acceleration (maximum shoulder external rotation to ball release) phases across 3 pitching trials, with the mean sEMG amplitude reported as a percentage of MVIC.

Statistical analysis

Sample size estimation considered the correlations |r| > 0.3 between clinical measurements (AD, PMI, SI, FSA) and scapular biomechanics across different phases. Therefore, a total sample size of 38 participants was calculated to provide 80% power with alpha equal to 0.05 two-tailed. The sample size was calculated in G*Power 3.1.9.7 for Windows.

The Statistical Package for the Social Sciences (SPSS) 17.0 was used for data analysis. To verify the normal distribution of the outcome data, the Kruskal–Wallis test was applied. Correlation analysis was conducted using two-tailed Pearson's correlation coefficients for normally distributed data, and Spearman's correlation coefficients for data that did not meet the normality assumption. The correlations between clinical measurements (AD, PMI, SI, FSA) and scapular biomechanics across different phases were assessed. The strength of the correlations was categorized as weak ($0.1 < |r| < 0.3$), moderate ($0.3 < |r| < 0.5$), or strong ($|r| > 0.5$). Statistical significance was determined at a p-value of less than 0.05.

RESULTS

Demographic data and clinical measurements are summarized in Table 1. Thirty-eight high school baseball pitchers were recruited in the study. The majority of our participants were right-handed pitchers with an average of 7.1 hours per week of baseball practice or competition, indicating adequate exposure to the sport.

Table 2 presents the correlations between clinical measurements and scapular kinematics. A moderate to strong negative correlation was found between AD and upward rotation ($r = -0.468$ to -0.545, $p < 0.001$ to $p = 0.003$), while a moderate positive correlation was observed between AD and anterior tilt ($r = 0.399$ to 0.444, $p = 0.005$ to 0.013). Similarly, both the PMI and FSA showed moderate negative correlations with anterior tilt (PMI: $r = -0.326$ to -0.367, $p = 0.024$ to 0.046; FSA: $r = -0.342$ to -0.417, $p = 0.009$ to 0.035).

Table 3 illustrates the correlation between clinical measurements and scapular muscle activation. AD was found to have moderate to strong positive correlations with activation of the UT ($r = 0.391$ to 0.416, $p = 0.009$ to 0.015), SA ($r = 0.401$, $p = 0.012$), BB ($r = 0.358$ to 0.537, $p = 0.001$ to 0.027), TB ($r = 0.438$ to 0.593, $p < 0.001$ to $p = 0.006$), and anterior deltoid ($r = 0.480$ to 0.543, $p < 0.001$ to $p = 0.002$). SI exhibited moderate negative correlations with activation in the UT ($r = -0.334$, $p = 0.041$), BB ($r = -0.329$, $p = 0.044$), and anterior deltoid ($r = -0.348$ to -0.396, $p = 0.014$ to 0.032). FSA also showed a moderate negative correlation with activation in the SA ($r = -0.321$, $p = 0.049$) and BB ($r = -0.392$, $p = 0.015$). Although PMI had a moderate negative correlation with TB activation, it did not reach a significant level ($r = -0.306$, $p = 0.062$).

DISCUSSION

The current study investigated the shoulder postures of high school baseball pitchers and correlated the parameters with scapular biomechanics during pitching. Results showed that the average shoulder posture in high school baseball pitchers did not meet the forward shoulder posture criteria reported in previous studies.[5-7, 9] However, a more forward shoulder posture showed significantly moderate to strong correlations with decreased upward rotation and increased anterior tilt, as well as UT, SA, BB, TB, and anterior deltoid activation, indicating that forward shoulder posture may contribute to altered scapular biomechanics during pitching. Changes in scapular biomechanics could further lead to injuries and interfere with pitching performance.

The high school baseball pitchers in the present study demonstrated an AD of 6.1 cm (< 7.3 cm), a PMI of 9.4% (> 7.65%), an SI of 65.8%, and an FSA of 39.3° (> 38°). Notably, none of these measurements met the forward shoulder posture criteria established in previous research.[5-7, 9] However, these established criteria were derived from studies involving normal adults and were not specifically developed for overhead athletes or baseball players. Earlier research that used the double square method reported that the distance from the anterior acromion to the wall in a standing position ranged from 14.9 to 17.1 cm in high school and collegiate baseball players.[10, 27] These findings highlight the need for improved methods to assess shoulder posture in baseball players, given the current limitations and inconsistencies. Specifically, further research is needed to establish ideal shoulder posture criteria that clinical practitioners can reliably use.

In pitchers, forward shoulder postures are associated with decreased scapular upward rotation and increased anterior tilt during the pitching motion. In the current study, greater AD and lower PMI or FSA indicated forward shoulder posture. These parameters demonstrated moderate to strong correlations with decreased scapular upward rotation and increased anterior tilt, which is consistent with findings from previous studies.[7, 9, 28] In earlier research, participants with forward shoulder posture exhibited increased scapular internal rotation and anterior tilt during arm elevation tasks, mirroring the kinematic alterations seen in patients with shoulder impingement syndrome.[24] This syndrome is characterized by decreased scapular upward rotation, increased internal rotation, and anterior tilt, all of which are risk factors for injury in pitchers who repeatedly perform overhead motions. These findings reinforce the idea that forward shoulder posture could be a significant risk factor for injury.[2] However, the cause–effect relationship between forward shoulder posture and injuries needs to be further verified.

Forward shoulder posture is also associated with specific patterns of muscle activation during pitching. The present study demonstrated that forward shoulder posture correlated with increased activation of the UT, SA, BB, TB, and anterior deltoid, supporting the hypothesis that pitchers with suboptimal posture tend to over-activate scapular and peripheral muscles. This increased reliance suggests that pitchers may not efficiently engage the core musculature required for optimal pitching mechanics without ideal posture. Professional pitchers typically recruit muscles more efficiently, while amateur players often over-recruit multiple muscle groups to complete the motion.[21, 29] This overactivation can lead to fatigue and increase the risk of injury, particularly after repetitive pitching. Conversely, previous studies have reported decreased SA and middle trapezius activations in individuals with forward shoulder posture during arm elevation tasks.[9, 12] This contrast reveals the differences in the muscle demands of the pitching motion and simple arm elevation. The overactivation of muscles during pitching underscores the importance of maintaining proper shoulder posture to prevent muscle fatigue and reduce the risk of injury in baseball pitchers.

This study has some limitations that should be acknowledged. First, the generalizability of our findings to players experiencing pain or to position players may be limited, as the study primarily focused on healthy high school pitchers without distinguishing between different player roles. Additionally, the scapular kinematics may have been affected by skin artifacts or any additional movement artifacts of the Velcro strap housing the sensor. The scapular kinematics beyond arm elevation of 120° were not analyzed in this study because these possible artifacts could lead to inadequate reliability and validity of the measurement instruments, as mentioned in previous studies.[24, 30] Therefore, the changes in scapular kinematics beyond 120° remain unclear. Furthermore, the cross-sectional design of the study restricts our ability to draw conclusions about the causal relationship between shoulder posture and injury development. A longitudinal study would be necessary to investigate how these postural and biomechanical factors might contribute to the development of injuries over time.

In conclusion, shoulder posture has a significant moderate to strong correlation with scapular biomechanics during pitching in high school baseball pitchers. Specifically, forward shoulder posture is linked to decreased scapular upward rotation, increased anterior tilt, and heightened muscle activation in the UT, SA, BB, TB, and anterior deltoid. These alterations in scapular biomechanics during pitching increase the risk of shoulder fatigue or injuries in high school baseball pitchers. This research provides valuable information for the prevention of shoulder injuries in high school baseball pitchers.

Therefore, it is crucial for clinical practitioners or players to monitor and maintain an optimal shoulder posture.

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Figure legend

Figure 1. Shoulder posture assessment

1a: AD was defined as the distance from the testing table to the lateral-inferior border of the acromion while participants were in a supine position.

1b: PMI was calculated by measuring the distance between the inferior aspect of the coracoid process and the inferior aspect of the fourth rib using a digital caliper.

1c: SI was determined by measuring the distance from the midpoint of the sternal notch to the medial aspect of the coracoid process, and the horizontal distance from the posterolateral angle of the acromion to the thoracic spine, using a soft tape measure.

1d: FSA was assessed using photographic analysis. Photos were captured on the dominant arm side, with the camera positioned at the height of the acromial process and set 2 meters away. The angle formed at the intersection of the line between the midpoint of the humerus and the spinous process of the seventh cervical vertebra and the horizontal line through the midpoint of the humerus reflects the anterior translation of the shoulder in the sagittal plane.

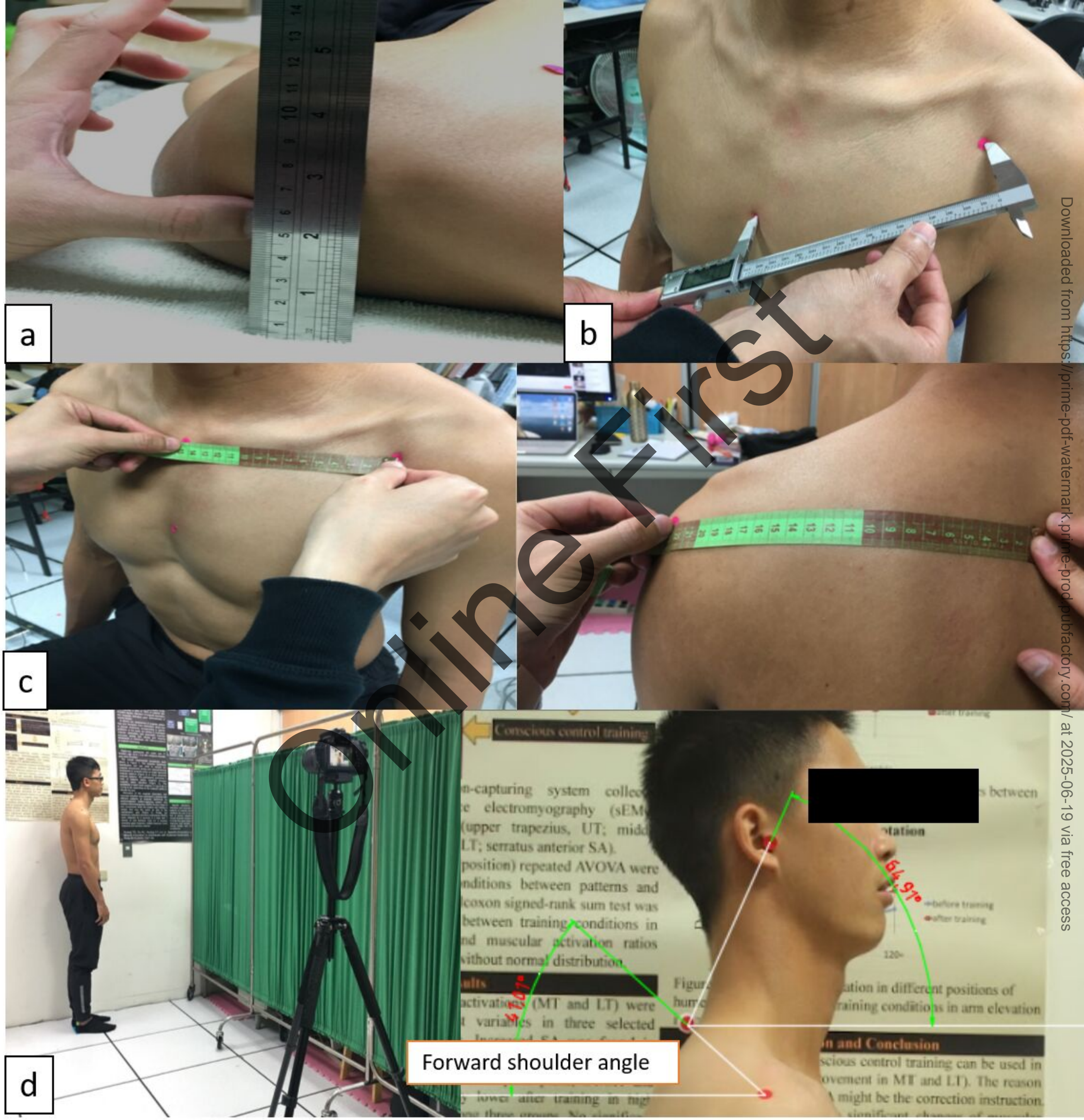
a
b
c
d
Forward shoulder angle
64.91°

Table 1: Demographic data and clinical measurements (n=38).

Variables	mean ± standard deviation
Age (y)	16.9 ± 0.9
Height (cm)	176.7 ± 4.7
Weight (kg)	70.3 ± 7.3
Dominant arm (right)	32
Practice time (hours per week)	7.1 ± 1.9
Ball speed (m/s)	32.3 ± 1.8
KJOC	69.7 ± 15.7
Acromial distance (cm)	6.1 ± 1.0
Pectoralis minor index (%)	9.4 ± 0.9
Scapular index (%)	65.8 ± 0.1
Forward shoulder angle (degree)	39.3 ± 10.5

KJOC: Kerlan–Jobe Orthopaedic Clinic shoulder and elbow self-report questionnaire

Table 2: Correlations between clinical measurements and scapular kinematics during pitching phases.

Pitching phases	LH	FC	MER	BR
Upward rotation of the scapula				
Acromial distance	-0.25 (0.14)	**-0.47* (< 0.01)**	**-0.53* (< 0.01)**	**-0.55* (< 0.001)**
Pectoralis minor index	0.08 (0.65)	-0.08 (0.65)	0.02 (0.90)	0.07 (0.67)
Scapular index	0.23 (0.17)	0.24 (0.15)	0.21 (0.20)	0.19 (0.25)
Forward shoulder angle	0.01 (0.96)	0.02 (0.92)	0.04 (0.83)	0.06 (0.73)
External rotation of the scapula				
Acromial distance	-0.13 (0.44)	-0.02 (0.91)	-0.09 (0.58)	-0.12 (0.46)
Pectoralis minor index	0.12 (0.47)	-0.10 (0.56)	-0.13 (0.43)	-0.06 (0.71)
Scapular index	0.15 (0.38)	-0.06 (0.73)	-0.21 (0.21)	-0.18 (0.28)
Forward shoulder angle	-0.03 (0.84)	0.07 (0.68)	0.02 (0.89)	-0.02 (0.93)
Anterior tilt of the scapula				
Acromial distance	0.07 (0.69)	0.09 (0.60)	**0.40* (0.01)**	**0.44* (0.01)**
Pectoralis minor index	-0.22 (0.19)	**-0.37* (0.02)**	**-0.33* (0.04)**	-0.25 (0.13)
Scapular index	-0.20 (0.23)	0.04 (0.81)	<0.01 (0.99)	-0.05 (0.78)
Forward shoulder angle	**-0.42*(0.01)**	-0.23 (0.17)	**-0.35* (0.03)**	**-0.34* (0.04)**

*: significant correlation; r-value (p-value)

LH: Leg highest; FC: Foot contact; MER: Maximum external rotation; BR: Ball release

Table 3: Correlations between clinical measurements and scapular muscle activation during pitching phases.

Pitching phases	Early-cocking	Late-cocking	Acceleration
Upper trapezius			
Acromial distance	**0.12* (0.47)**	**0.39* (0.02)**	**0.42* (0.01)**
Pectoralis minor index	0.15 (0.36)	-0.18 (0.27)	-0.11 (0.50)
Scapular index	-0.01 (0.98)	-0.21 (0.20)	**-0.33* (0.04)**
Forward shoulder angle	-0.18 (0.29)	0.13 (0.43)	0.01 (0.97)
Serratus anterior			
Acromial distance	0.21 (0.20)	0.30 (0.07)	**0.40* (0.01)**
Pectoralis minor index	-0.26 (0.11)	-0.23 (0.16)	-0.19 (0.25)
Scapular index	-0.20 (0.22)	-0.18 (0.29)	-0.20 (0.24)
Forward shoulder angle	0.10 (0.55)	**-0.32* (0.04)**	0.02 (0.91)
Lower trapezius			
Acromial distance	0.02 (0.93)	0.09 (0.61)	0.03 (0.85)
Pectoralis minor index	-0.12 (0.47)	-0.19 (0.26)	-0.16 (0.35)
Scapular index	-0.18 (0.28)	-0.13 (0.43)	-0.27 (0.10)
Forward shoulder angle	0.19 (0.24)	0.14 (0.42)	0.16 (0.35)
Biceps brachii			
Acromial distance	**0.36* (0.03)**	**0.54* (0.001)**	**0.46* (0.004)**
Pectoralis minor index	-0.13 (0.44)	-0.02 (0.91)	-0.14 (0.41)
Scapular index	-0.22 (0.18)	**-0.33* (0.04)**	-0.29 (0.078)
Forward shoulder angle	**-0.31 (0.06)**	**-0.39* (0.02)**	-0.27 (0.11)
Triceps brachii			
Acromial distance	**0.59* (<0.001)**	**0.44* (0.01)**	**0.54* (<0.001)**
Pectoralis minor index	**-0.31 (0.06)**	-0.01 (0.96)	-0.12 (0.49)
Scapular index	-0.12 (0.47)	0.17 (0.32)	0.09 (0.58)
Forward shoulder angle	-0.20 (0.24)	0.02 (0.90)	-0.07 (0.66)
Anterior deltoid			
Acromial distance	0.19 (0.25)	**0.54* (<0.001)**	**0.48* (0.002)**
Pectoralis minor index	0.03 (0.87)	0.22 (0.18)	0.23 (0.16)
Scapular index	**-0.40* (0.01)**	0.02 (0.89)	**-0.35* (0.03)**
Forward shoulder angle	0.02 (0.91)	-0.18 (0.29)	-0.09 (0.59)

*: significant correlation; r-value (p-value)