

# Effect of thoracic expansion restriction on scapulothoracic and glenohumeral joint motion during shoulder external rotation

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## Abstract.

**BACKGROUND:** Shoulder external rotation in the throwing motion involves movement of the scapulothoracic and glenohumeral joints, thoracic spine, and the thorax. Restriction of thoracic expansion may decrease scapulothoracic joint motion and compensate by excessive glenohumeral joint motion. However, it is unclear how restricting the expansion of the thorax alters shoulder motion.

**OBJECTIVE:** To elucidate changes in scapulothoracic and glenohumeral joint movements caused by restricted thoracic expansion.

**METHODS:** Kinematic data were obtained using an electromagnetic tracking device (Liberty; Polhemus), from 18 male participants, during shoulder external rotation in the sitting position with and without restriction of thoracic expansion. The displacements from the start position to the maximum external rotation position were compared, and Pearson's correlation coefficient was calculated.

**RESULTS:** A significant difference was observed in the scapulothoracic posterior tilt angle ( $P < 0.01$ ) and glenohumeral external rotation angle ( $P < 0.01$ ). A significant positive correlation existed between scapulothoracic posterior tilt and glenohumeral external rotation ( $P < 0.05$ ) with and without restriction.

**CONCLUSIONS:** Restriction of thoracic expansion decreased scapulothoracic motion and increased glenohumeral motion. Thus, a decrease in thoracic expansion may change scapulothoracic and glenohumeral movements, which may be a risk factor for throwing injuries.

Keywords: Scapulothoracic joint, glenohumeral joint, restriction of thoracic expansion, shoulder external rotation

## 1. Introduction

Throwing injuries of the shoulder are caused by repeated throwing motions in overhead sports such as baseball [1–3]. Most baseball players with such injuries complain of symptoms from the late cocking phase to the acceleration phase [4]. The late cocking phase, which begins after stride foot contact on the ground, involves trunk rotation and shoulder external rotation.

The acceleration phase begins after the shoulder joint has reached its maximum external rotation (MER) position [5]. After MER, the movement of the shoulder joint changes abruptly from external to internal rotation, resulting in a large internal rotation torque and forward shear force on the shoulder [6]. Chronic application of mechanical stress due to repetitive throwing motions result in throwing injuries of the shoulder. Therefore, in order to prevent these injuries, it is necessary to analyze the shoulder joint motion from the late cocking phase to the early acceleration phase, particularly focusing on the MER.

The shoulder joint motion involves the glenohumeral

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and the scapulothoracic joints. Numerous studies have shown that the coordinated functioning of these joints is important for the prevention of shoulder injuries [7,8]. In MER, the scapulothoracic joint motions are carried out by external rotation, upward rotation, and posterior tilt in the horizontal, frontal, and sagittal planes, respectively [9]. These three-axes scapulothoracic joint motions can be measured using electromagnetic tracking devices such as the Polhemus Liberty system (Polhemus, Inc., Colchester, VT, USA). According to the Liberty User's manual, the accuracy of this device is reported to be 0.8 mm and 0.15° for position and orientation, respectively. Currently, it is considered to be the most useful measurement method for scapulothoracic joint motion. A previous study investigating the relationship between the glenohumeral external rotation and the scapulothoracic posterior tilt angles during MER reported that of 145° of MER angle, the glenohumeral external rotation angle was 105° and the scapulothoracic posterior tilt angle was 25° [10]. In MER, repetitive impingement between the greater tuberosity and the glenoid fossa [11] can lead to rotator cuff injuries and other shoulder joint diseases [12]. In the upper extremity elevation motion on the scapular plane of the injured shoulder, scapulothoracic internal rotation is increased and upward rotation and posterior tilt are decreased [13]. When this relationship is disrupted, and the rate of the MER angle, that is accounted for by the glenohumeral external rotation, increases, the stress on the shoulder joint increases, which may in turn increase the risk of occurrence of throwing injuries [14].

The scapula is in contact with the posterior wall of the thorax and moves along this wall when performing movement of the scapulothoracic joint. Therefore, the scapulothoracic joint movement is determined by changes in the configuration of the thorax. A study analyzing the shoulder flexion angle, scapulothoracic posterior tilt angle, and glenohumeral flexion angle during upper limb elevation with limited thoracic expansion movement stated that the shoulder flexion and scapulothoracic posterior tilt angles decreased and the mechanical stress on the glenohumeral joint relatively increased [15]. Thus, restriction of thoracic expansion motion might decrease scapulothoracic joint motion and produce excessive glenohumeral joint motion for compensation.

However, to the best of our knowledge, none of the studies used Liberty to investigate how restriction of thoracic expansion causes kinematic changes in the scapulothoracic and glenohumeral joint motions during shoulder external rotation. The purpose of this study

was to investigate this effect, to help prevent the occurrence of throwing injuries, using the electromagnetic tracking device 'Liberty'. Our hypotheses were as follows: 1) restricting thoracic expansion would decrease scapulothoracic external rotation, upward rotation, and posterior tilt angles and increase glenohumeral external rotation angle at MER compared with the same movement without restriction, and 2) there would be a positive correlation between the decrease in scapulothoracic joint angles and the increase in glenohumeral external rotation angle.

## 2. Materials and methods

### 2.1. Study design and setting

This cross-sectional study examined the kinematic changes in the scapulothoracic and glenohumeral joints during shoulder external rotation with and without restricted thoracic expansion using an electromagnetic device, Liberty. The study was conducted in a laboratory, and healthy males were recruited. All dependent variables of scapulothoracic internal rotation angle, upward rotation angle, posterior tilt angle, and glenohumeral external rotation angle were compared in each participant.

### 2.2. Participants

Eighteen right-handed healthy males (mean  $\pm$  SD: age, 21.9  $\pm$  1.8 years; height, 171.7  $\pm$  4.4 cm; weight, 63.0  $\pm$  5.9 kg; body mass index, 21.4  $\pm$  2.0 kg/m<sup>2</sup>) participated in this study. The inclusion criteria were as follows: 1) no complaints of shoulder joint pain on the measurement day, 2)  $> 90^\circ$  of passive shoulder abduction range of motion, and 3)  $> 75^\circ$  of passive shoulder external rotation range of motion at 90° shoulder abduction. The exclusion criteria were as follows: 1) history of upper extremity injury or surgery within the past one year that would affect shoulder motion, 2) history of neurological disorders that would affect shoulder motion, such as suprascapular nerve palsy, and 3) presence of a lung disease or a restrictive respiratory condition such as asthma. The inclusion and exclusion criteria were in accordance with those of previous studies [16,17].

The sample size was calculated using G\*power 3.1.9.4 software (Heinrich-Heine-University Düsseldorf, Düsseldorf, Germany). The effect size, mean power, and alpha error were set to 0.25, 0.80, and 0.05,

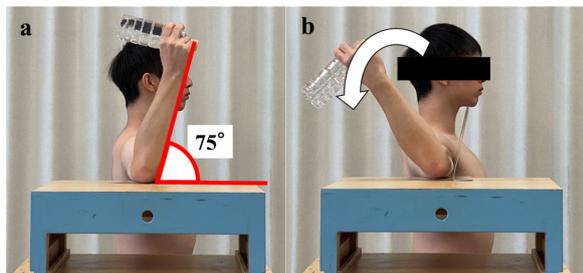


Fig. 1. Participants sat on the chair with their hip and knee joint flexed at  $90^\circ$ . (a) The start position was set at  $90^\circ$  of abduction and  $75^\circ$  external rotation, and (b) the shoulder was externally rotated until MER in a second.

respectively. The analysis revealed that at least 15 participants would make an acceptable sample size.

This study was approved by the Ethical Committee for Epidemiology of Hiroshima University (E-2177), and written informed consent was obtained from all participants in accordance with the Declaration of Helsinki.

### 2.3. Procedures

The participants performed shoulder external rotation in two conditions: with and without restriction of the thorax by taping. Participants sat on a chair with the hip and knee joints flexed at  $90^\circ$  and the right shoulder joint abducted at  $90^\circ$ . The starting position of shoulder external rotation by a metal plate was set at  $75^\circ$  [17] (Fig. 1a). In accordance with a previous study, the thorax expansion movement was restricted using two types of tapes: non-elastic and elastic tapes [15] (Fig. 2). First, a 38 mm wide non-elastic tape (CB tape, Nitoms, Inc., Tokyo, Japan) was applied without tension to the thorax in the maximal expiratory state. In addition, a 50 mm wide elastic tape (EB tape, Nitoms, Inc., Tokyo, Japan) was applied over the non-elastic tape in the same manner as reinforcement. The tape was applied at the 5th and 10th rib positions, where the thoracic motion could be restricted without interfering with the scapula. A previous study showed that restrictions at these positions limit the thoracic expansion during inspiration [18]. In this study, we also measured the circumference of the thorax during maximal inspiration and maximal expiration and calculated the difference to confirm the degree of restriction of thoracic expansion. All the tapes were applied by the same examiner who had at least three years of experience as a physical therapist and who routinely performed taping.

In each condition, the participants performed shoulder external rotation while grasping a 500 mL plastic water bottle with the right hand [17]. The electronic

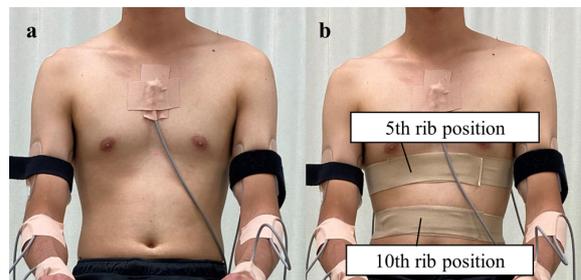


Fig. 2. (a) Without restriction, (b) With restriction. One round of non-elastic tape was applied to the thorax in the maximal expiratory state without applying tension. In addition, an elastic was applied over the non-stretch tape in the same manner for reinforcement. The tape was applied at the 5th and 10th rib positions.

metronome was set to 60 beats per minute and the shoulder external rotation from the starting position ( $75^\circ$  of external rotation) to the MER angle was performed in a second (Fig. 1b). After the participants had practiced sufficiently, five trials were conducted in each condition. The trial was started after the examiner confirmed that no scapular elevation or shoulder horizontal abduction occurred during practice. The order of trials was randomized for each participant, with a rest period of at least one hour between trials.

### 2.4. Measurement of kinematic data

Kinematic data were measured using an electromagnetic tracking device, Liberty<sup>TM</sup> (Polhemus, Inc., Colchester, VT, USA). The sampling frequency was 240 Hz. Sensors were attached on the sternum, sacrum, bilateral acromion, bilateral humerus, and bilateral forearm. Segmental models composed of thorax, pelvis, scapula, and humerus were defined [19]. The electronic unit determined the three-dimensional position and orientation of these sensors within the electromagnetic field. Each segment was defined by digitized body landmarks in accordance with the definition of a joint coordinate system as proposed by the International Society of Biomechanics [20]. The sternal notch (SN), xiphoid process (XP), seventh cervical vertebrae (C7), and eighth thoracic vertebrae (Th8) were used as anatomical markers to determine the position and orientation of the thorax. The bilateral anterior superior iliac spines ( $ASIS_R$ ,  $ASIS_L$ ) and pubic symphysis (PS) were used as markers to determine the position and orientation of the pelvis. Bilateral acromial angles ( $AA_R$ ,  $AA_L$ ), medial borders ( $SP_R$ ,  $SP_L$ ), and inferior angles of scapula ( $IA_R$ ,  $IA_L$ ) were used as markers to determine the position and orientation of the scapula. The bilateral medial ( $ME_R$ ,  $ME_L$ ) and lateral ( $LE_R$ ,

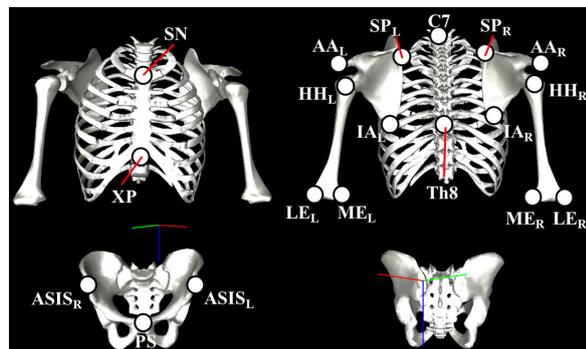


Fig. 3. SN: sternal notch, XP: xiphoid process, ASIS: anterior superior iliac spine, PS: pubic symphysis, AA: acromial angle, SP: medial border of the scapular spine, IA: inferior angle, HH: humeral head, ME: medial epicondyle, LE: lateral epicondyle.

LE<sub>L</sub>) epicondyles were used to determine the position and orientation of the humerus. The central position of the glenohumeral joint was estimated by calculating the central axis of the rotational motion of the arm [21] (Fig. 3).

### 2.5. Data analysis

The joint kinematic data were calculated and represented by the Euler angles based on relative orientations of the thorax, scapula, and humerus. The motion of the scapula relative to that of the thorax (scapulothoracic joint) was classified as internal (+) or external (-) rotation, downward (+) or upward (-) rotation, and posterior (+) or anterior (-) tilt (Fig. 4). The motion of the humerus relative to the scapula (glenohumeral joint) was classified as horizontal adduction (+) or abduction (-), elevation (-), and internal (+) or external (-) rotation (Fig. 4).

The internal rotation, upward rotation, and posterior tilt angles of the scapulothoracic joint, and the external rotation angle of the glenohumeral joint were measured at two time points: 75° of external rotation (ER 75°) and at MER angle. In this study, the MER angle was defined as the maximum external rotation angle of the humerothoracic joint. The humerothoracic motion was defined as the motion of the humerus relative to that of the thorax. The difference between each variable of ER 75° and MER was calculated to examine the angular displacement. For both the variables, the mean of three trials, excluding the maximum and minimum values, was used during data analysis.

### 2.6. Statistical analysis

IBM SPSS Statistics version 27.0 for Windows (IBM Corp., Armonk, NY, USA) was used for all statistical

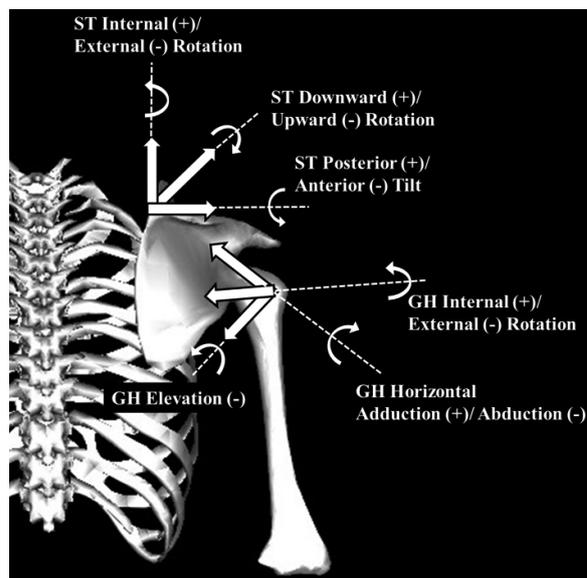


Fig. 4. ST: scapulothoracic joint, GH: glenohumeral joint.

analyses. The Shapiro-Wilk test was used to check the normality of the data. Since normality could not be obtained for the data, a Wilcoxon signed-rank test was used to compare the difference in thoracic expansion and kinematic data in the two conditions. Effect size ( $r$ ) was calculated using the formula  $r = Z/\sqrt{N}$  and defined as follows: small for  $r > 0.10$ , medium for  $r > 0.30$ , and large for  $r > 0.50$  [22]. Additionally, for the scapulothoracic and glenohumeral joint variables, the difference between with and without restriction conditions for displacements of ER75° and MER (displacement in the “with restriction condition” – displacement in the “without restriction condition”), was calculated. Since the Shapiro-Wilk test was not significant, Spearman’s rank correlation coefficient was calculated to examine the relationship between the variables. The intensity of Pearson’s correlation coefficient was defined as small for values from 0.20 to 0.40, medium for 0.40 to 0.70, and large for 0.70 to 1.0. The significance level was set at  $P < 0.05$ .

## 3. Results

### 3.1. Difference in thoracic expansion

Table 1 shows the results of the difference in thorax expansion. With restriction, a significant decrease was observed in both the 5th and the 10th rib positions, compared to conditions without restriction (5th rib position:  $P < 0.001$ ,  $r = 0.93$ ; 10th rib position:  $P < 0.001$ ,  $r = 0.91$ ).

Table 1  
Difference in thoracic expansion

Values	Without restriction		With restriction			P value	Effect size	
	Mean $\pm$ SD	95% CI		Mean $\pm$ SD	95% CI			
		Lower	Upper		Lower			Upper
5th rib position (cm)	5.1 $\pm$ 1.4	4.4	5.8	2.1 $\pm$ 0.9	1.6	2.5	< 0.001*	0.93
10th rib position (cm)	5.6 $\pm$ 2.0	4.5	6.6	1.9 $\pm$ 0.8	1.5	2.3	< 0.001*	0.91

SD: standard deviation, CI: confidence interval. \*Significant difference between with and without restriction ( $P < 0.05$ ).

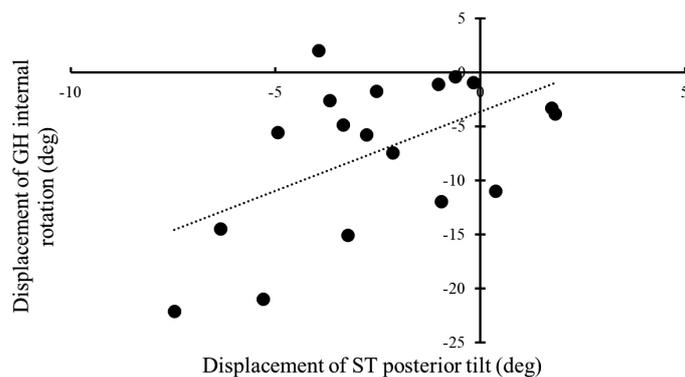


Fig. 5. The difference between the displacement with and without restriction was calculated. Spearman's rank correlation coefficient was used to determine the relationships. A positive displacement of ST posterior tilt indicates posterior tilt and a negative indicates an anterior tilt. On the other hand, positive displacement of GH internal rotation indicates internal rotation, while negative displacement indicates external rotation. A significant positive correlation was observed ( $P < 0.05$ ).

### 3.2. Kinematic data

Table 2 shows the results of the kinematic data of the scapulothoracic and glenohumeral joints between the two conditions. Significant differences were observed in scapulothoracic posterior tilt ( $P = 0.047$ ,  $r = 0.50$ ) and glenohumeral external rotation ( $P = 0.005$ ,  $r = 0.67$ ) at MER, and there were significant differences in the displacement of scapulothoracic posterior tilt ( $P = 0.001$ ,  $r = 0.74$ ) and displacement of glenohumeral external rotation ( $P = 0.006$ ,  $r = 0.66$ ). On the other hand, no significant differences occurred in scapulothoracic internal rotation and upward rotation angles in terms of both angle at MER and displacement.

Figure 5 shows the relationship between the difference in displacement of the scapulothoracic and the glenohumeral joints and the presence of restriction. A significant positive correlation existed between the posterior tilt of the scapulothoracic joint and the internal rotation of the glenohumeral joint with a correlation coefficient of 0.54 ( $P = 0.021$ ).

## 4. Discussion

This study aimed to clarify the effect of restricted thoracic expansion on scapulothoracic and glenohumeral

joint motions during shoulder external rotation. It was revealed that restriction of thoracic expansion decreased the scapulothoracic posterior tilt angle and increased the glenohumeral external rotation angle in MER. However, no significant change was observed at MER angle with or without restriction of thoracic expansion. Therefore, increase in glenohumeral external rotation is a compensatory movement for the decrease in scapulothoracic posterior tilt associated with restricted thoracic expansion.

As reported previously, the present study also observed restricted thoracic expansion during maximal expiration and maximal inspiration. Thoracic expansion occurs by rotational movements around the costovertebral joints that occur antero-posteriorly in the upper thorax and medio-laterally in the lower thorax [23]. In the middle of the thorax, the axis of the costovertebral joint is at  $45^\circ$  angle [24], so that the thoracic expansion motion occurs equally in the anterior-posterior and medial-lateral directions. Therefore, the restriction of motion, especially in the medial-lateral direction, is considered to have resulted in a restriction of 3.0 cm in the 5th rib position and 3.7 cm in the 10th rib position.

The scapulothoracic posterior tilt angle in the restricted condition in MER was significantly lower than that in the unrestricted condition. Previous studies

Table 2  
Kinematic data of scapulothoracic and glenohumeral motions with and without restriction

Values	Without restriction			With restriction			P value	Effect size
	Mean $\pm$ SD	95% CI		Mean $\pm$ SD	95% CI			
		Lower	Upper		Lower	Upper		
MER (deg)	103.4 $\pm$ 10.8	97.4	109.4	106.1 $\pm$ 9.7	100.7	111.5	0.162	0.37
ST Internal Rotation (deg)								
ER 75°	15.0 $\pm$ 8.6	10.2	19.8	16.5 $\pm$ 9.8	11.0	21.9	0.241	0.31
MER	7.6 $\pm$ 10.1	2.0	13.2	9.4 $\pm$ 9.8	4.0	14.8	0.106	0.42
Displacement	-7.4 $\pm$ 3.6	-9.4	-5.4	-7.1 $\pm$ 4.0	-9.3	-4.9	0.627	0.13
ST Downward Rotation (deg)								
ER 75°	-21.6 $\pm$ 5.5	-24.7	-18.6	-21.1 $\pm$ 6.6	-24.8	-17.4	0.485	0.19
MER	-26.3 $\pm$ 6.2	-29.7	-22.8	-26.1 $\pm$ 7.4	-30.1	-22.0	0.805	0.07
Displacement	-4.7 $\pm$ 2.6	-6.1	-3.2	-5.0 $\pm$ 3.4	-6.9	-3.1	0.820	0.04
ST Posterior Tilt (deg)								
ER 75°	13.2 $\pm$ 9.9	7.7	18.7	9.6 $\pm$ 12.5	2.7	16.5	0.217	0.33
MER	21.4 $\pm$ 10.6	15.5	27.2	15.5 $\pm$ 14.4	7.5	23.4	0.047*	0.50
Displacement	8.2 $\pm$ 3.8	6.1	10.3	5.8 $\pm$ 4.1	3.6	8.1	0.001*	0.74
GH Internal Rotation (deg)								
ER 75°	-41.5 $\pm$ 24.4	-55.0	-28.0	-47.6 $\pm$ 23.7	-60.7	-34.5	0.073	0.46
MER	-64.5 $\pm$ 28.0	-80.0	-49.0	-76.3 $\pm$ 30.1	-93.0	-59.6	0.005*	0.67
Displacement	-23.0 $\pm$ 10.0	-28.5	-17.4	-28.7 $\pm$ 11.8	-35.3	-22.2	0.006*	0.66

SD: standard deviation, CI: confidence interval, MER: maximum external rotation, ST: scapulothoracic joint, GH: glenohumeral joint, ER 75°: 75° of external rotation. \*Significant difference between with and without restriction ( $P < 0.05$ ).

showed that changes in the configuration of the thorax were a factor in the restriction of the scapulothoracic joint. The thoracic extension motion is considered to be the cause of this change in thoracic configuration. Backward rotational movement of the ribs by the costovertebral joint is caused by extension of the thoracic spine, especially the lower thoracic spine [25]. As the thorax expands, it is elevated superiorly and anteriorly, and its posterior wall tilts backward. In this study, taping the thorax could have possibly decreased the posterior tilt of the scapulothoracic joint by limiting these movements.

The most important finding of this study was that there was no significant difference in MER angle between conditions, despite the restricted scapulothoracic joint motion. A previous study reported that a decrease in scapulothoracic joint motion resulted in a decrease in MER angle [17]. However, in the present study, MER angle did not change with restriction. This was because the excessive glenohumeral external rotation compensated for the decreased motion of the scapulothoracic joint, as shown in the results of the moderate correlation between displacement of the scapulothoracic posterior tilt and displacement of the glenohumeral internal rotation. It is obvious that the coordinated movement of the scapulothoracic and glenohumeral joints is essential for shoulder movement. It has been reported that malfunctioning of one of the joints directly affected the other joint [26]. Thoracic expansion was reduced and scapulothoracic joint motion was limited. However, it

is possible that the glenohumeral movement was increased more to prevent the decrease in shoulder external rotation. These results indicate that MER angle was not altered by limitation of thoracic extension, but ST posterior tilt was increased and GH external rotation was decreased.

One throwing injury caused by excessive glenohumeral external rotation is shoulder internal impingement [11]. This is characterized by contact between the greater tuberosity of the humerus and the glenoid fossa during the late cocking phase and early acceleration phase, when the shoulder exhibits abduction and external rotation, and most athletes with internal impingement complain of pain in the posterior shoulder joint [27,28]. Previous studies have shown that the narrowing of the distance between the glenoid fossa and the humeral head due to restricted scapulothoracic motion and excessive glenohumeral motion is a factor in the development of shoulder internal impingement [29]. These findings suggest that restriction of thoracic expansion is a risk factor for the development of shoulder internal impingement, as it may cause narrowing of the shoulder joint distance due to excessive glenohumeral external rotation. Improving scapulothoracic joint function by strengthening the middle and lower trapezius is used for rehabilitation for throwing injuries [30]. However, the findings of the present study indicate that thoracic expansion are essential for improving scapulothoracic joint function and that thoracic exercises should also be focused on the rehabilitation of throwing in-

juries. Future research including people with restricted thoracic expansion is warranted to clarify the causal relationship with shoulder internal impingement.

This study had several limitations. First, the restriction of thoracic expansion was done manually by the same examiner by taping. Therefore, skin movement could possibly have influenced the measurements. Second, the participants were young healthy adult males. The elevation motion in patients with shoulder joint disease may differ from that in healthy individuals. Moreover, the static alignment in overhead athletes may be adapted to competition-specific movements. Thus, there is a need to investigate patients with shoulder joint diseases and overhead athletes in the future. Finally, this study was conducted in the sitting position, so it is not clear whether the results would be similar during actual pitching motion. For detailed clarification of the effect of restricted thoracic expansion on throwing motion, future studies should investigate scapulothoracic and glenohumeral joints motion during actual throwing motion.

## 5. Conclusion

This study investigated the effects of thoracic expansion restriction on scapulothoracic and glenohumeral joint motions during shoulder external rotation in a sitting position assuming MER. Restriction of thoracic expansion motion decreased the scapulothoracic posterior tilt and increased the glenohumeral external rotation, suggesting that restriction of thoracic expansion increases mechanical stress on the glenohumeral joint. The results indicate that it is necessary to focus on thoracic expansion exercises as the foundation for interventions to improve scapulothoracic joint motion, such as scapular mobilization and periscapular muscle exercises. Emphasis on thoracic extension movement during shoulder joint exercises may reduce the stress on the glenohumeral joint and contribute to the prevention of pitching disorders.

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## Conflict of interest

The authors have no conflict of interest relevant to this article.

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