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Original Article

Three-dimensional kinematic analysis of glenohumeral, scapular, and thoracic angles at maximum shoulder external rotation associated with baseball shadow pitching: comparison with normal pitching

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Abstract. [Purpose] The glenohumeral, scapular, and thoracic angles at maximum shoulder external rotation during shadow pitching were evaluated and compared with those observed during normal pitching. [Participants and Methods] Our study included 13 healthy males with experience in pitcher activity. All participants performed both, shadow pitching using a towel and normal pitching using a ball. The external rotation of the glenohumeral joint, scapular posterior tilting, and thoracic extension angles in the cocking phase were measured using a 3-dimensional motion analysis system. The ratios of the glenohumeral external rotation angle to the scapular posterior tilting and/or thoracic extension angle were calculated to evaluate the contribution of the scapulothoracic joint at maximum external rotation during throwing/pitching activity. [Results] The glenohumeral external rotation angle at maximum shoulder external rotation was significantly smaller during shadow pitching than during normal pitching. The ratio of the glenohumeral external rotation angle to the scapular posterior tilting and/or thoracic extension angle showed no statistically significant difference. [Conclusion] We conclude that shadow pitching can reduce the external rotation motion of the glenohumeral joint compared to that during normal pitching and might be a useful pre-throwing program beneficial in the rehabilitation of those presenting with throwing injuries.
Key words: Shadow pitching, Scapulothoracic joint, Three-dimensional motion analysis

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INTRODUCTION

Shadow pitching is widely known and often used in rehabilitation, whereas few studies have investigated kinematic motion analysis. Therefore, a lot of physiotherapists do not have enough knowledge of shoulder complex motion during shadow pitching. Using a rehabilitation program for throwing injuries that involves a multiphase approach that is progressive and sequential (i.e., acute, intermediate, advanced strengthening, and return-to-activity phases) is important[1–3)]. They also expressed a necessity of gradual returning to throwing activities for rehabilitation, and shadow pitching is recommended as a pre-throwing program method in the advanced strengthening phase[1, 2)]. Many baseball players who have shoulder injuries complain about shoulder pain in the cocking phase of pitching, especially at the point of maximum shoulder external rotation

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(MER)[4]. The larger contribution of the scapular posterior tilting and thoracic extension angles at the point of MER could lessen the strain on the glenohumeral joint[5]. Thus, the purpose of this study was to determine the glenohumeral, scapular, and thoracic angles in the cocking phase, especially at MER in shadow pitching, using a three-dimensional motion analysis system and to compare them to those during normal pitching.

PARTICIPANTS AND METHODS

Thirteen healthy male volunteers (mean age of 24.9 ± 4.8 years, height of 173.9 ± 4.3 cm, weight of 72.1 ± 7.3 kg, and pitcher experience of 11.2 ± 5.2 years) who had experience in baseball, no previous history of shoulder or elbow injuries or pathologies in the preceding year and negative Neer impingement and Hawkins impingement test results participated in this study. Nine were right-handed and the others were left-handed, and all participants used overhand style in pitching. Ethical approval for this study was obtained from the Ethics Committee of Gunma University (approval code 27-29). This study was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all the participants, and their rights were protected.

The pitching data were obtained indoor. Pitching starting line was set up on the floor 5 m away from the fixed target (diameter, 30 cm) placed on the center of the net (height, 200 cm; width, 160 cm). Participants performed pitching topless and barefoot, with glove on the nondominant hand, and conducted comfortable warm-up including pitching before measurement. They were measured at two tasks starting at a set position: the first is shadow pitching with a commercially available towel (length, 85 cm; width, 35 cm) and the second is normal pitching with a ball (ball for regulation in high school baseball, 1BJBH10100, Mizuno Corp.). Both tasks were performed with their full effort intensity. The former task was conducted with an imaginary straight fastball and the latter with an actual straight fastball. The method of holding the towel in shadow pitching was unified as follows: participants hung the middle point to a long side of the towel from dorsal proximal-phalanx of the index and middle finger and held the flowing down towel with a bundle between the two fingers. Both tasks were randomized and repeated two times, and we obtained data from the average of two trial values as measures of central tendency. The failed trial was defined as a thrown ball that was quite far from the target in normal pitching.

Kinematic data were collected with a 10-camera, three-dimensional motion capture system (Vicon Motion System Ltd., Oxford, UK) operating at a sampling rate of 250 Hz. A total of 15 reflective markers were used in this study. Markers with a 9.5 mm diameter were placed at body landmarks of the participants, as follows: processus spinosus of the seventh cervical vertebra (C7), processus spinosus of the seventh thoracic vertebra (Th7), processus spinosus of the eighth thoracic vertebra (Th8), processus spinosus of the first lumbar vertebra (L1), incisura jugularis (IJ), processus xiphoideus (PX), and dorsal side of the distal third metacarpal. The two points with an opposite direction of the ball's surface were also placed with reflective markers. Referring to the method described by Miyashita et al.[5], three lightweight cypress bars (length, 100 mm; width, 10 mm; height, 5 mm) with reflective markers attached to both edges were placed on the acromion process (acromion bar), dorsal side of the distal end of the humerus (humerus bar), and dorsal side of the distal end of the forearm (forearm bar). The acromion bar was placed along the line of the acromion process edge configuration so that two reflective markers were positioned front and back. Elasticized Velcro tapes affixed the humerus and forearm bars ahead in order to strengthen fixation, and two bars were placed on the humerus and forearm at a right angle. All bars were placed on the skin surface at each point with a double-sided tape and fixed with a kinesiology tape over them. The calculation methods of the joint angles are shown in Fig. 1[5]. Shoulder external rotation angle (S-ER) was defined as the angle between the perpendicular line to the plane composed of the middle point of the acromion and humerus bar markers and L1 and the perpendicular line to the plane composed of the middle point of the acromion and humerus and forearm bar markers. MER was defined as the maximum angle of S-ER. The glenohumeral external rotation angle (GH-ER) was defined as the angle between the perpendicular line to the plane composed of anterior and posterior markers of the humerus bar and posterior marker of the acromion bar and the perpendicular line to the plane composed of anterior and posterior markers of the acromion bar and posterior marker of the humerus bar. The scapular posterior tilting angle (SPT) was defined as the angle between the perpendicular line to the plane composed of C7 and T8 markers and the middle point of acromion bar markers and the perpendicular line to the plane composed of C7 and the middle point and posterior marker of the acromion bar markers. The thoracic extension angle (TE) was defined as the angle between the line from C7 to Th8 and the line from Th8 to L1. With regard to the TE, the thorax coordinate system (St) that was based on the global coordinate system (Sg) was used in the three-dimensional space to distinguish between extension and the side-flexion angle of the thorax, using the methods of Wu et al.[6] as reference (Fig. 2). St was determined by the triaxis of X_S, Y_S, and Z_S. The origin (Ot) was defined as the middle point of PX and Th7. Z_S was defined as the vector connecting Ot and the middle point of IJ and C7, pointing upward. X_S was defined as the cross-product between the vector from Th7 to PX and Z_S, pointing right. Y_S was defined as the cross-product between Z_S and X_S, pointing forward. The three-dimensional coordinate data of C7 and L1 translated on Y_S-Z_S plane in coordinate data of Th8 and the TE was calculated. The calculated angles' standard was set at 0° when the participant was in a standing position with the shoulder abducted and elbow flexed at 90° and forearm in intermediate position. Each angle was measured from the foot plant (FP) that was defined as the moment a step-leg foot touched a force platform (AMTI Corp., sampling rate, 1,000 Hz) to the shoulder maximum internal rotation in shadow pitching, although from FP to 8 msec after ball release which was calculated by position relation of the third metacarpal and ball in normal pitching.

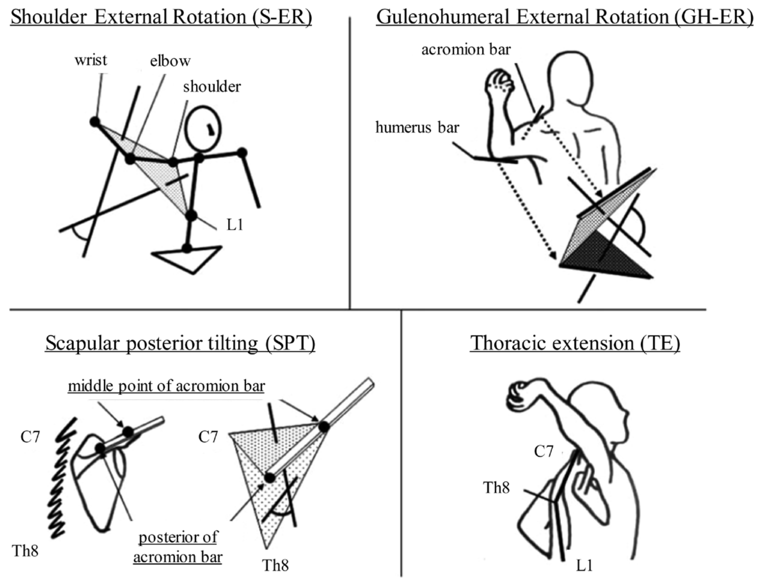

Fig. 1. Kinematic model used for angle calculation (on the basis of Miyashita's method[5]).

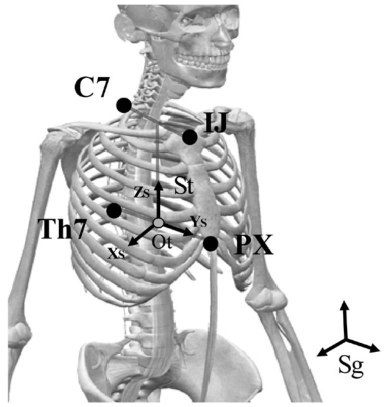

Fig. 2. Coordinate systems used in kinematic analyses.
Sg: global coordinate system; St: local coordinate system; C7: processus spinosus of the seventh cervical vertebra; Th7: processus spinosus of the seventh thoracic vertebra; IJ: incisura jugularis; PX: processus xiphoideus.

Table 1. Glenohumeral and scapulothoracic joint angles at MER (°)

Items	Normal	Shadow
S-ER	145.4 (14.2)	136.4 (16.8)**
GH-ER	98.4 (16.7)	91.8 (13.1)**
SPT	39.4 (12.2)	36.7 (13.2)
TE	17.8 (8.4)	17.7 (8.8)

Means (standard deviation); **p<0.01; MER: maximum shoulder external rotation; GH-ER: glenohumeral external rotation; SPT: scapular posterior tilting; TE: thoracic extension.

The statistical analyses were performed using SPSS version 22.0 for Windows. The Shapiro-Wilk test was used to assess the normality of the data. S-ER, GH-ER, SPT, and TE at MER were compared between shadow pitching and normal pitching using paired t-test. Relationships between each angle at MER were also evaluated using the Pearson correlation coefficient in the two tasks. The timings of maximum joint angle that were calculated by normalizing 100% from FP to MER were compared between the two tasks using the Wilcoxon signed-rank test at each joint angle, and between each joint angle in several tasks using the repeated measures analysis of variance. When a significant effect was indicated in the timing of maximum joint angle, the multiple comparisons were evaluated using the Wilcoxon signed-rank test with a Bonferroni correction. The significant level of these analyses was set at 5%.

RESULTS

Each angle at MER in the two tasks is shown in Table 1. The MER angle was significantly smaller (p=0.001) in shadow pitching (136.4° ± 16.8°) than in normal pitching (145.4° ± 14.2°). The MER angle and GH-ER at MER were significantly smaller in shadow pitching than in normal pitching (p=0.001 and p=0.009, respectively). The angle ratio of SPT and/or TE in contrast with GH-ER showed no significant difference between normal pitching and shadow pitching (Table 2). As for the relationships between each angle at MER, there were significantly negative correlation relationships between GH-ER and SPT in both tasks (normal pitching, r= −0.72, p=0.005; shadow pitching, r= −0.71, p=0.007). In addition, the timings of each maximum joint angle are shown in Table 3. The timing of maximum GH-ER was significantly later (p=0.013) in shadow pitching (113.0 ± 9.7%) than in normal pitching (107.1 ± 5.8%). The timing of maximum SPT was significantly more precedent (p<0.05) than the timing of maximum GH-ER only in shadow pitching, while the timing of maximum GH-ER was significantly later (p<0.05) than the timing of maximum S-ER (i.e., MER) in both tasks.

Table 2. The angle ratio of the scapulothoracic joint in contrast with the glenohumeral joint

Items	Normal	Shadow
SPT/GH-ER	0.42 (0.17)	0.42 (0.19)
TE/GH-ER	0.18 (0.09)	0.20 (0.10)
(SPT + TE)/GH-ER	0.61 (0.20)	0.62 (0.23)

Means (standard deviation); GH-ER: glenohumeral external rotation; SPT: scapular posterior tilting; TE: thoracic extension.

Table 3. The timings of each maximum joint angle (%)

Items	Normal	Shadow
S-ER	100.0 (0.0)	100.0 (0.0)
GH-ER	107.1 (5.8)$^{£}$	113.0 (9.7)*$^{£}$
SPT	91.0 (22.0)	79.9 (22.7)§
TE	84.5 (22.0)	87.0 (28.4)

Means (standard deviation); normalizing 100% from the foot plant to maximum shoulder external rotation; *$p<0.05$, compared with "Normal" using Wilcoxon signed-rank test; $^{£}p<0.05$, compared with "S-ER" using Wilcoxon signed-rank test in several tasks; $^{§}p<0.05$, compared with "GH-ER" using Wilcoxon signed-rank test in the task; S-ER: shoulder external rotation; GH-ER: glenohumeral external rotation; SPT: scapular posterior tilting; TE: thoracic extension.

DISCUSSION

For the rehabilitation of shoulder injuries in the baseball athlete, shadow pitching has been recommended as a pre-throwing program method, and physiotherapists should understand kinematic differences in the shoulder complex between shadow and normal pitching to consider the effect on the glenohumeral joint. Previous studies have reported that excessive glenohumeral external rotation in the cocking phase has been linked to a variety of shoulder injuries[7–10], and the larger contribution of the scapulothoracic joint in the cocking phase could lessen the strain of the glenohumeral joint. Therefore, we investigated the glenohumeral, scapular, and thoracic angles at MER in shadow pitching and compared them to those in normal pitching.

In this study, there was no significant difference between normal and shadow pitching as regards the ratio of SPT and/or TE in contrast with GH-ER, showing contribution of the scapulothoracic joint at MER. On the other hand, while the SPT and TE at MER showed no significant difference, the S-ER and GH-ER at MER was significantly smaller in shadow pitching than in normal pitching. In the cocking and acceleration phases, rapid sequential rotation of the pelvis, upper torso, and shoulder causes distal segments to lag behind the proximal segment[11]. Especially in the late cocking phase, rapid upper torso rotation and shoulder horizontal adduction cause the forearm to lag behind the arm by inertia, which leads to external rotation of the shoulder. Because inertia force is proportional to mass, the inertia force of shadow pitching with a towel (about 60 g) could be smaller than that of normal pitching with a ball (about 145 g). Meanwhile, the scapula and thoracic spine might be difficult to influence by inertia due to their location being near the arm. As mentioned above, it is suggested that shadow pitching was performed relatively on smaller range of humeral external rotation in contrast with the glenoid cavity of the scapula at MER. Excessive humeral external rotation results in elongation of the anterior band of the inferior glenohumeral ligament, which kept anterior translations of the humeral head at arm abduction and external rotation, and this leads to anterior instability of the shoulder[12]; therefore, it would be related to shoulder injuries. In addition, some researchers have mentioned that excessive glenohumeral external rotation in the cocking phase is linked to a variety of shoulder injuries, such as subacromial impingement[7], posterior impingement[8], and superior labrum anterior-posterior (SLAP) lesion[9, 10]. As for the relationship between each angle at MER, it revealed a negative correlation between GH-ER and SPT in both tasks. Therefore, external rotation motion of the glenohumeral joint can be excessively enlarged if the scapula does not have enough posterior tilting at MER. Consequently, we suggested that shadow pitching will have less mechanical microtrauma to the glenohumeral joint than normal pitching with a ball because of the minor humeral external rotation motion at MER. In the rehabilitation of throwing injuries, it is important to consider the strain to the glenohumeral joint for promotion of lesion healing.

In this study, the timing of maximum SPT was significantly more precedent than the timing of maximum GH-ER in shadow pitching, and the timing of maximum GH-ER was significantly later than in normal pitching. These reasons are perhaps because of moderate grasping on relax in shadow pitching. Excessive conscious effort in pitching the ball at the target in normal pitching may be lead to strong grasping and throwing motion depending on the arm. Thus, it is suggested that appropriate the kinetic chain which scapular posterior tilting ahead arise to glenohumeral external rotation caused in shadow pitching. Moreover, arm relaxation might be affected by inertia for a long time so that the timing of maximum GH-ER is later in shadow pitching than in normal pitching. Because we did not measure grasping strength in this study, the above remains a matter of speculation.

The limitation of this study is that we did not conduct radiography because of ethical issues so we do not know whether the calculated joint angles were similar with the angles in vivo. Furthermore, rapid motion of pitching expected skin movement and wave of bars that would influence not a little calculated kinematic data.

In conclusion, the results of this study suggested that shadow pitching can reduce the external rotation motion of the glenohumeral joint as compared with normal pitching and might be one of the useful pre-throwing program methods in the rehabilitation of throwing injuries. In the future, we will perform not only kinematics analysis but also kinetics analysis, that is, glenohumeral joint load and force in pitching, to clarify the difference between shadow and normal pitching.

Conflicts of interest

None.

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