Do healthy subjects elevate and descend both arms in a same manner?

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Abstract: Background. To determine whether or not healthy subjects elevate and descend their dominant and nondominant arms in the same manner is important in understanding the pathology of shoulder diseases: rotator cuff tear; impingement syndrome; stiff shoulder; and loose shoulder.

Methods. Twenty young healthy subjects (17 males and 3 females, average age 24 years) were enrolled in this study. They randomly elevated and lowered both arms in the scapular plane 3 times and motion was measured using a three-dimensional motion analyzer. We calculated scapulohumeral rhythm in 10° increments and analyzed the setting phase during both elevation and lowering.

Findings. There was no statistically significant difference in scapulohumeral rhythm between the dominant and nondominant arms. Scapulohumeral rhythm was stable (3.3) from 70 degrees during elevation to 70° in lowering; however, individual variations of scapulohumeral rhythm were identified, except for the previously described angles. The setting phase was identified as below 60° during elevation and a similar phase was also observed below 60° in lowering. There were two scapular motion patterns in the setting phase: the first started primarily as a scapular upward rotation; the second moved in the glenohumeral joint but less in the scapula.

Interpretation. To elevate both arms in the same manner means that we can compare both the glenohumeral joint and scapular motion between affected and non-affected shoulders. The setting phase is defined as below 60° in elevation; moreover, a phase similar to the setting phase with variable scapular motion is identified during lowering.

Key words: Shoulder joint, Scapulohumeral rhythm, Setting phase

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I Introduction

The demonstration that healthy subjects elevate and descend both arms in the same manner is valuable for the diagnosis or treatment of patients with shoulder disorders. We are able to compare the motion of the scapula or glenohumeral (GH) joint with dysfunction of the other side, and also determine the hallmarks of disorders concealed in the shoulder joint. We can make the shoulder to the similar condition of the non-affected shoulder in the treatment of the affected shoulder.

Many dysfunctions and disorders have been discovered in shoulder diseases. Alterations in the resting scapular position and dynamic scapular motion have been frequently recognized in association with many types of shoulder disorders, such as impingement, instability, rotator cuff tears and frozen shoulder\(^1\). The upward scapular rotation was significantly increased in the group with full-thickness rotator cuff tears compared with that of a control group in forward and scapular plane elevation\(^2\).

Dynamic Moiré testing demonstrated abnormal Moiré patterns in 18% of asymptomatic individuals, compared with 64% and 100% in the instability and impingement groups, respectively\(^3\). The supraspinatus and serratus anterior muscles were shown to exhibit significantly less activity during abduction and forward elevation with anterior instability compared with normal shoulders\(^4\). Compared to normal subjects, those with impingement were shown to exhibit a significantly lower posterior or tilting angle of the scapula in the sagittal plane and a higher superior-inferior scapula position with maximal arm elevation\(^5\). Finally, an increased scapular component has been generally accepted to contribute to scapulohumeral rhythm in subjects with frozen shoulder\(^6,7\). Thus shoulder disorders surely manifested as abnormal motion of the scapula or/and GH joint.

There have been many measurements of the motion of the GH joint and scapula. The motion of arm elevation has been conducted in living subjects using direct insertion of pins, radiography, cadaveric models, three-dimensional (3-D) electromagnetic tracking systems, and open magnetic resonance imaging\(^8\sim12\). However, these methodologies have both strengths and limitations: direct insertion of pins has ethical problems; radiographs are two-dimensional representations of the 3-D body; cadaver studies lack the physiological tonus of muscles and scapular motion; the most popular method of 3-D electromagnetic tracking systems have limited channels and area covered; open MRI in the seated position only provides information of static motion. 3-D motion computerized analysis can easily be utilized to record dynamic shoulder elevation and lowering.

The scapulohumeral (SH) rhythm and setting phase are simple and reasonable factors for the analysis of dynamic motion of the shoulder complex. Inman firstly quantified "the setting phase and SH rhythm"; setting phase was defined as the highly irregular SH rhythm of the shoulder below 30° of forward elevation and 60° of abduction; SH rhythm was a 2 : 1 ratio\(^9\). Analysis of the GH joint and scapular motion in the scapular plane can be simply performed according to calculation of the SH rhythm and setting phase. This study was designed to elucidate whether or not normal subjects elevate and descend both extremities in the same manner, and to determine the SH rhythm and the angle of the setting phase.

II Methods

1. Subjects

Twenty healthy subjects (17 males, 3 females) participated in this study. The mean age of this study sample was 24 years (range: 19~30 years). The mean values (± standard deviation) of the height and weight were 1.68 ± 0.09 m and 62.1 ± 10.4 kg, respectively. Their dominant arms were right in 16 subjects and left in 4. None of the subjects had shoulder pain or a medical history of shoulder joint disorders; moreover, one of the au-
thors (H. J.) confirmed that they did not have instability using sulcus sign and load & shift test, restriction in range of motion, scoliosis, or asymmetry of the thoracic cage. Approval for this study was obtained from the internal review board of the Koriyama Institute of Health Sciences. Each subject was informed of the nature and details of this study and provided signed consent before participation.

2. Experimental protocol

Error analysis of the 3-D motion computerized analysis system was conducted to assess the system performance in terms of its repeatability and accuracy. Potential experimental error due to skin slippage was estimated by measuring the distances between bony landmarks and marker locations, using skin palpation and X-rays taken at the starting position and maximum elevation.

A mean position had to be assumed for the scapular plane; the scapula was taken to lie at $30^\circ$ to the coronal plane. Each subject stood in front of the wall, $30^\circ$ to the coronal plane and attempted to individually elevate both arms in 6 seconds, maintaining maximum elevation for 3 seconds, and then descending in 6 seconds in the scapular plane prior to measurement. Briefly, the subjects stood with their thoracic spine, both arms, pelvis, and knee exposed. Reflecting markers were set up bilaterally on the skin of the coracoid process, acromial angle, medial border of the scapular spine, medial and lateral epicondyles of the humerus, spinous processes of the 2nd and 7th thoracic vertebrae, and 5th lumbar vertebra, lateral condyle of the knee, and lateral malleolus of the ankle. Palpation of bony landmarks and sticking skin markers were performed by a senior author (H. J.). A 3-D motion computerized analyzer (MAC 3D System, Motion Analysis Corp., Santa Rosa, CA, USA) was used for collection of kinematics data. This system used 6 synchronized infrared cameras placed circumferentially around the subject and allowed for 50 Hz data capture. All subjects stood in a neutral starting position, and randomly elevated and descended their dominant and nondominant arms three times in the scapular plane. The obtained data were analyzed using the system software (KineAnalyzer, Kissei Comtec, Co., Ltd. Nagano, Japan) (Figure 1).

![Block diagram of the experiment](image-url)
The angles recorded for each individual during elevation and descent were: the angle from the humerus to the vertical — the angle of the arm (A), and the upward rotational angle of the scapular spine — the scapular angle (S). The axis of the humerus was designated as the line connecting the center of the coracoid process and the acromial angle with another center of the lateral and medial epicondyles. The line drawn between the medial border of the scapular spine and the acromial angle was recognized as the line of the scapular spine. The starting angles of both arms and the scapular spine were set at zero degrees. Moreover, measured angles were also corrected from leaning of the thoracic spine in 3-D. The range of measured angles was from 0° through maximum elevation to descend at 0°. The angles of arm elevation (A) and scapular upward rotation (S) were recorded in 10 increments. We calculated SH rhythm from the numerical formula: (A - S) ÷ S. We also calculated the coefficient of variance (CV: standard deviation ÷ mean × 100) of the SH rhythm.

3. Validity test and data analysis

Five healthy subjects (4 males and 1 female, 22 ~ 30 years old) participated in the reproducibility test. They randomly elevated and lowered both extremities five times on one day: the first day, and also repeated the same measurements one week later: the second day. The 3-D angular displacements measured for each of the five repeated lift and descend trials for each of the subjects were used to calculate intraclass correlation coefficients [ICC (1, 5)] for the upward rotational angle of the scapular spine and CV of the SH rhythm. All statistical testing was performed using SPSS for Windows version 15.0J (SPSS Japan Inc., Tokyo, Japan) with the level of significance set at P<0.05. Repeated-measure ANOVA (Mauchly’s test of sphericity) was performed to compare the angles of the scapular spine and the CV of the SH rhythm between dominant and nondominant arms in 10° increments.

III Results

1. Reproducibility of the system and rotation angle of the scapular spine and the CV of the SH rhythm

The result of calibration testing indicated excellent responses in all performance tests. Overall, the system was found to be accurate within 0.07 mm at rest and 0.42 mm on motion for length, and angular orientations of 0.13° at rest and 0.62° on motion. Error due to skin slippage of the markers was 6.2 mm for the medial border of the scapula, 3.5 mm for the acromial angle, 4.3 mm for the coracoid process measured on the X-ray, and within 1 cm for both epicondyles on surface palpation, respectively. These results were considered appropriate as noninvasive surface markers.

Measured angles of leaning of the thoracic spine in maximum elevation were 11.3° in axial rotation, 3.0° in coronal plane, and 3.0° in the setting phase, respectively. The reproducibility for the upward rotation angle of the scapular spine was high (ICC = 0.97 ~ 0.99) on the first, second day, and both days; on the other hand, the reproducibility of SHR was not so high (ICC = 0.71 ~ 0.98). The CV of the SH rhythm indicated high reproducibility between 70° of elevation and 70° during lowering on both extremities; however, that the CV was outside this range of angles. These data could suggest that SH rhythm variability in the setting phase influenced the CV value.

2. Comparison between dominant and nondominant arms in 20 subjects

Figure 2A and 2B present the raw kinematic data of active elevation and descent of both arms and the concomitant scapular upward rotation angle in all of the subjects. The average maximum elevation angles of the arms were 129.1° (117.3° ~ 152.9°) with an average scapular rotation angle of 33.3° for the dominant arms, and 129.6° (117.8° ~ 148.7°) and 32.5° for the nondominant arms, respectively. Motion of the scapular spine was stable throughout the ranges of motion. There was no
statistically significant difference in the upward rotation angle of the scapular spine between both arms using Mauchly's test of sphericity (P-value: 0.767). Raw data of SH rhythm in 10° increments.
for all subjects are shown in Figure 3A and 3B. SH rhythm varied from the staring point to about 60° and gradually became a constant ratio, and then became disarranged again on closing to the end point. Between participants, there were small and large ratios of SH rhythm in the setting phase.
The CV of the SH rhythm is shown in Figure 4. The stable phase, in which the CV of the SH rhythm was more than 50, ranges from the starting position to 60° during elevation and from 60° descending to the end position. On the other hand, CV values less than 49 were obtained from 70° during elevation to 70° during lowering on the dominant arm. On the nondominant arm the stable phase ranged from 70° during elevation to 50° in lowering. The average value of SH rhythm was 3.2 (3.0-4.0) on the dominant arms and 3.3 (3.0-4.3) on the nondominant ones in the stable phase. We determined the setting phase as below 60° during elevation, based on the finding that the value of SH rhythm was much more variable below 60° during elevation between individuals, and a phase in the descending range similar to the setting phase was also identified below 60° on the dominant arm and below 50° on the nondominant side. Raw data of the SH rhythm in 10° increments between the dominant and nondominant arms was not only statistically different by Mauchly's test of sphericity (P-value: 0.337) in each individual, but was also different between the upward rotation angle of the scapular spine, as previously mentioned. We concluded that healthy subjects elevated and lowered both arms in a similar manner from these results.

IV Discussion

1. Accuracy in the position of skin markers and reproducibility of motion

We employed a 3-D motion computerized motion analyzer that reflected infrared light on skin markers to measure motion of the shoulder complex. The reliability in this study focused primarily on the accuracy of skin surface markers to the actual

![Figure 4](https://example.com/figure4.png)

**Figure 4 CV of scapulohumeral rhythm on dominant and nondominant arms**

SH: scapulohumeral, CV: coefficient of variance

CV value less than 50 ranged from 70° in elevation and 70° in lowering on dominant arm

CV value less than 50 ranged from 70° in elevation and 50° in lowering on nondominant arm
position of scapular and spinal bony landmarks at the starting position, and secondly on the validity of skin markers as indicating exact positions in maximum elevation. Skin surface palpation has previously been validated as accurately indicating the location of thoracic and scapular landmarks (Lewis et al., 2002\textsuperscript{13}). As described above, the angle of arm elevation was measured as the corner that describes the line connecting the center of the coracoid process and the acromial angle with the center of the lateral and medial epicondyles and the vertical line. The upward scapular rotation angle was determined from the rotation of the line between the medial border of the scapular spine and the acromial angle. We confirmed that the positions of these skin markers moved less between the starting position and the maximum elevation, as shown previously; therefore the calculated angles from the marker positions are very close to the actual angles.

Reproducibility of the upward rotation angle of the estimated scapular spine ICC was found to be very high on the first, second, and both days. The CV of the SH rhythm indicated high reproducibility between 70° during elevation and 70° during lowering on the dominant arm and from 70° of elevation from 60° on the nondominant arm. Based on these findings, we considered that the experimental protocol was reasonable.

2. SH rhythm and the setting phase

Early kinematics investigations of the shoulder complex suggested decoupling of the GH and scapulothoracic joints. The integrated, coupled and interdependent motion of the GH joint and scapula was described as the SH rhythm\textsuperscript{14}. Inman first observed the precise setting phase and SH rhythm; setting phase was related to the setting action of the rotator cuff and scapulothoracic muscles and described within 60° in abduction; SH rhythm was quantified as 2 : 1 ratio\textsuperscript{8}. Our data showed that the average SH rhythm was approximately 3.2 between 70° during elevation and 70° in the descent phase, on the other hand SH rhythm was variable except for during the stable phase. Taken collectively, the reported ratios of SH rhythm have ranged from 1.35 : 1 to 7.9 : 1\textsuperscript{8, 9, 15 ~ 20}. The reason the ratio of SH rhythm was so variable depended upon the methods of measurement. We have little concern with the dispute about these differences, because SH rhythm cannot be calculated easily without a measurement instrument during evaluation of patient with shoulder disorders. It is noteworthy that SH rhythm is variable during the setting and is constant during the stable phase.

Some authors have reported that the setting phase of elevation in the scapular plane was below 60°\textsuperscript{3, 12}. Our findings concur with these studies because SH rhythm varied below 60° between each individual, and this diversity may depend on the initial scapular behavior. We found a phase on descending process that was similar to the setting phase; below 60° on the dominant arm and 50° on the nondominant side. We have termed this phase as "the downward scapular fragile state", therefore, the setting phase focused elevation angle would be defined as "the upward scapular fragile state". Scapular motion becomes indefinite during two scapular fragile states: scapulothoracic muscles contract concentrically to stabilize and rotate the scapula upward on the thoracic wall in the upward scapular fragile state in contrast with eccentrically controlled motion of downward rotation and stabilization of the scapula in the downward scapular fragile state. We propose that there are two types in the upward scapular fragile state: the first initially moves the scapula and exhibits a small ratio in the SH rhythm; the second primarily starts the GH joint and exhibits a large SH rhythm. The scapular motion and activity of related muscles will require further investigation in the future in order to observe differences between both types.

3. Clinical implication

We compared the SH rhythm between the dominant and nondominant arms of 20 individuals re-
respectively in 10° increments, using repeated-measures ANOVA. There was no statistically significant difference in SH rhythm between both arms; therefore healthy subjects elevate and lower their arms in a similar manner. We will be able to utilize these findings for the clinical evaluation and treatment of shoulder disorders: multidirectional instability, stiff shoulder, impingement syndrome, rotator cuff tears, and scapula mal-configuration. We rarely visualize the motion of the GH joint or scapula in the clinical circumstance. If we observe the motion of the scapula, especially in the two scapular fragile states, we will be able to compare an affected shoulder with the opposite one. We may thus determine the dysfunction and pathology of the shoulder complex1,3. In addition, patients with shoulder diseases should undergo treatment of the affected shoulder similar to the condition of non-affected side.

4. Limitations

Even though reproducibility was high, we utilized skin markers in a static position and performed dynamic measurements. Additionally, accuracy between the precise location of bony landmarks and the position of skin markers was not completely correct. These limitations of this measurement remain and should be corrected in the future. Our study sample consisted of normal young individuals. Therefore, caution must be used to in extrapolating these findings to other populations. Participants in this study did not elevate and lower their extremities at speed, nor did they flex their elbow joints similar to the conditions of motions in daily life: speed of motion is generally faster, and the arm is elevated below flexed elbow joint. In future investigations, we will design the experiment to measure below the conditions described previously. Finally we will obtain more information about the two scapular fragile states, using classification of motion types, and analysis with electromyography.

V Conclusions

We analyzed the motion of elevation on both arms with a 3-D motion computerized motion analyzer. Healthy subjects elevated and lowered both arms in the same manner. The setting phase was quantified below 60° on both arms and also identified a similar phase to the setting phase with a fragile scapula during descent: below 60° on the dominant arm and 50° on the nondominant side. SH rhythm was stable except for outside the range of both the scapular fragile states. In future investigations of the kinematics of shoulder disorders, the present findings will provide essential data for comparison.

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要 旨：【目的】肩甲骨面での上肢外転・内転の際、健常者は利き手側と非利き手側を同じパターンで動かすか否かを調べること。【方法】健常成人20名を対象とした。両上肢の運動は、三次元動作解析装置を用いて解析し、10°ごとの肩甲上腕リズムを算出して比較した。【結果】利き手側と非利き手側の肩甲上腕リズムには統計学的な差はなく、肩甲骨が安定する外転70°から内転70°までの間では、肩甲上腕リズムは平均3.3で一定であった。一方外転60°までと内転60°以下では肩甲上腕リズムの変動が大きかった。また、外転60°までは肩甲骨の上方回旋が大きいタイプと小さいタイプに分けられた。【結論】肩甲骨面における上肢外転・内転では、利き手側と非利き手側の差はなかった。外転初期と内転後期に肩甲骨回旋角度の大きさが2タイプあった。
キーワード：肩関節、肩甲上腕リズム、setting phase

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