The Effect of Glenohumeral Rotation on Scapular Upward Rotation in Different Positions of Scapular-Plane Elevation

Jun Sagano, David Magee, and Masaki Katayose

Context: Glenohumeral and scapular upward rotation are important factors in functional upper extremity motion. Objectives: To determine how different amounts of glenohumeral rotation (internal, external, and neutral) affect scapular upward rotation. Design: Controlled laboratory study. Independent variables were the amounts of internal, external, and neutral glenohumeral rotation. The dependent variable was the amount of scapular upward rotation. Setting: Research laboratory. Participants: 40 subjects who were right-hand dominant, sedentary, and age 16 to 35 years. Main Outcome Measures: An inclinometer assessed scapular upward rotation with the 3 different positions of glenohumeral rotation in each 0°, 30°, 60°, and 90° of humeral elevation in the scapular plane. Results: Scapular upward rotation tended to increase with glenohumeral internal and external rotation, compared with neutral rotation in each degree of humeral elevation. This trend was seen on both right and left sides. Conclusions: Scapular upward rotation at different levels of humeral elevation in the scapular plane was affected by the positions of glenohumeral rotation. Key Words: adolescent, adult, movement, shoulder

Scapular dysfunction is thought to be one of the causes of shoulder pathology. Some clinical studies have documented significant alteration in scapular motion in athletes who use overhead motions.1–3 The importance of the scapula in shoulder motion has received much attention from those interested in preventing shoulder injuries. The scapula (and scapulothoracic joint) is known as a stable base in the kinetic chain, transmitting force from the lower extremities and trunk to the smaller segments of the arm. Kibler1 advocated 4 roles for the scapula: providing a site for muscle attachment, providing stability for the glenohumeral joint, providing retraction and protraction of the shoulder girdle around the thoracic wall during motion of the upper extremity, and elevation of the scapula. Seventeen muscles have their origin or insertion on the scapula. These muscles working with the rotator cuff, which control humeral movement, normally cause coordinated movement of the glenohumeral articulation by way of the force couples.4 This congruity in glenohumeral articulation is believed to be one of the critical factors in decreasing the risk of shoulder injuries.

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Jobe\textsuperscript{28} stated that a lack of scapular elevation and upward rotation leads to subacromial impingement. It has been reported that impingement may also occur within the coracohumeral space.\textsuperscript{6} The subacromial and coracohumeral spaces were described as decreasing with active humeral elevation, and a slight decrease in these spaces might cause shoulder-impingement symptoms. The close relationship between scapular upward rotation and the positions of the greater and lesser tuberosities, which are related to the amount of glenohumeral rotation, should be considered. If the humeral- and scapular-control muscles become fatigued, leading to greater overload and muscle weakness and muscle imbalance in the humeral force couples, abnormal compression and shear stress at the glenohumeral joint occur. Glenohumeral rotation is an important factor in functional upper extremity motion during activities of daily living and sports activities. In overhead sports such as throwing, serving in racket sports, and swimming, glenohumeral rotation is also a key motion that can affect performance and be affected by injury.\textsuperscript{7-9} To our knowledge no one has described the effect of glenohumeral rotation on scapular motion in normal subjects. It is critical to know whether and how scapular upward rotation is affected by different positions of glenohumeral rotation. It is also believed to be a clinically significant contributor to preventing shoulder injuries. Therefore, the purpose of this study was to examine the effect of glenohumeral rotation on the amount of scapular upward rotation at each position of humeral elevation in the scapular plane in normal subjects age 16 to 35 years.

**Materials and Methods**

After reading a letter describing the project, 47 subjects were screened, and 40 (20 males and 20 females) were finally included in the study. Seven subjects were dropped from the study for the following reasons: 3 females had positive general joint laxity, 1 female had a higher than normal activity level (top athlete), 1 male was left handed, 1 male had a positive sign of scapular winging at rest, and 1 male had a positive impingement sign. To eliminate age and sex deviation in our age range, only 1 male and 1 female were included in each age group. Once subjects agreed to participate in the present study, they were examined to determine whether they met the inclusion criteria. Institutional-review-board approval was granted, in the spirit of the Helsinki declaration, and all subjects signed an informed consent before taking part in the study.

In this study, upward and downward rotation of the scapula were defined as rotation of the scapula about an axis perpendicular to the plane of the scapula\textsuperscript{10} (Figure 1). The plane of humeral elevation (scapular plane) was defined as 30° anterior to the frontal plane. Scapular upward rotation was measured in 3 different positions of glenohumeral rotation (neutral, external, and internal rotation) at each position of humeral elevation in the scapular plane. The neutral position was defined as the position of the arm in which the palm faces front. External rotation was defined as the position of the arm in which maximum outward rotation was actively applied to the glenohumeral joint, and internal rotation was defined as the position of the arm in which maximum inward rotation was actively applied to the glenohumeral joint.

To be included in this study, subjects had to be between 16 and 35 years of age. We chose this age range to eliminate (a) the factor of degeneration that appears after
35 years of age and might cause primary impingement and (b) growth factors for those less than 16 years old.\textsuperscript{11,12} Other criteria were having no history of shoulder pain, trauma, or surgery; no difficulty in using the upper extremities in activities of daily living; a negative impingement test; no sign of anterior instability (negative anterior apprehension test and relocation test); no sign of scapular winging at rest or with movement; no sign of multidirectional instability (general laxity tests negative, sulcus and Feagin tests negative); no sign of posterior instability (posterior apprehension test and load and shift tests negative); and no history of participating in overhead sports or activity of similar intensity in the past and being right-hand dominant (the dominant hand was defined as the hand that is usually used in writing and in throwing and serving in sports activity). All subjects underwent a clinical examination by the same physical therapist to determine whether they met the inclusion criteria. If the examiner was unsure whether a subject’s tests were positive or negative, the subject was excluded from participation in the study to avoid any potential selection bias. After the clinical examination to check the inclusion criteria, all subjects were positioned supine on an examination table for measurement of glenohumeral internal and internal rotation. Internal and external rotation at 90° of abduction were assessed with standard goniometric techniques.

Each subject was seated on a chair with the back and side supported to control for trunk movement (Figure 2). As in a study by McQuade et al,\textsuperscript{13} vertical poles were positioned in the plane of the scapula (30° anterior to the frontal plane) as a guide for humeral elevation in the scapular plane. A digital inclinometer (EDI-320, Cybex) was used (Figure 3) to measure scapular upward rotation. The inclinometer was modified using a platform to stabilize the bottom of instrument. Based on the study of Johnson et al,\textsuperscript{14} this platform consisted of 2 wooden rods with Y-shaped ends to attach over the spine of the scapula and posterolateral acromion. The length between the 2 rods could easily be adjusted to the length of the scapular spine of each subject. A bubble level was attached on the platform to prevent anterior and posterior tilt of the inclinometer and to calibrate each measurement. To increase reliability, a small adhesive dot was placed on the skin over the spine of the scapula and posterior acromion at each measurement position of humeral elevation in the scapular plane and each position of glenohumeral rotation (Figures 4 and 5).
Figure 2 — Guides for humeral elevation in the scapular plane. The scapular plane was defined as 30° anterior to the frontal plane. The plastic pipe was aligned on the scapular plane.

Figure 3 — Platform for the inclinometer. To minimize the measurement error, a bubble level was attached on the platform to prevent the anterior and posterior tilt of the inclinometer and to calibrate each measurement.
Figure 4 — Small adhesive dots were placed along the spine of the scapula on the skin at each position of humeral elevation in the scapular plane and each position of glenohumeral rotation to minimize measurement error.

Figure 5 — Measurement of scapular upward rotation. The inclinometer was placed in the plane of the scapula. During measurement, the inclinometer was maintained in the position using a bubble level to prevent tilt that might cause measurement error.
Static humeral elevation relative to the vertical axis in the scapular plane was assessed at 4 different positions (arm at 0°, 30°, 60°, 90°). Each position of humeral elevation in the scapular plane was marked on the poles, which guided humeral elevation in the scapular plane in the second and third trials. While actively holding the arm in neutral or actively rotating the humerus at the glenohumeral joint into maximum internal rotation or external rotation, the subjects actively lifted the humerus to the indicated angle of humeral elevation. The researcher did not apply any load for each rotation. While subjects actively held the arm at each position, the researcher measured scapular upward rotation. In this study, subjects actively held each position of glenohumeral rotation. The inclinometer was placed on the spine of the scapula to measure the amount of scapular upward rotation. Then, subjects returned the arm to 0° before each subsequent testing position. Because it took about 80 minutes to complete the measurement for each subject, the position of glenohumeral rotation for each subject was determined in random order to minimize subject fatigue. In addition, subjects had 30-second rests between trials. All measurements were taken on both limbs and with the elbow extended.

Before data collection, 2 examiners repeated the measurements. Because intertester reliability calculated by interclass correlation coefficients (ICC_{2,1}) was not satisfactory between 2 examiners, 1 examiner collected all the data for this study. Intratester reliability (ICC_{1,1}) was calculated for all positions, and scores had a mean of .91 and ranged from .77 to .98. Results for intertester reliability and standard errors of measurement are shown in Table 1. Three trials were completed in each position of shoulder rotation, and the average was recorded. Movement was measured in both scapulas.

Means were calculated for all measurements in each extremity. The dependent variables were scapular upward rotation at 0°, 30°, 60°, and 90° of humeral elevation in the scapular plane. The independent variables were neutral, internal, and external glenohumeral rotation. Scapular upward rotation is dependent on the amount of shoulder abduction, called scapulohumeral rhythm. The present study investigated the effect of glenohumeral rotation on the amount of scapular upward rotation at each position of humeral elevation in the scapular plane. Therefore, 8 separate ANOVAs were completed for the dependent variables to investigate the effect of glenohumeral rotation on scapular upward rotation in each position of humeral elevation in the scapular plane (within-subject factor). If ANOVA demonstrated a significant difference, Bonferroni post hoc analysis was employed to compare the difference between the positions of glenohumeral rotation (neutral, external, and internal rotation). The significance level for all analyses was \( P < .05 \).

**Results**

The means and standard deviations for shoulder internal rotation were 65.8° ± 8.2° for the right limb and 69.8° ± 8.5° for the left limb. The means and standard deviations for shoulder external-rotation range of motion were 108.6° ± 12.5° for the right limb and 107.8° ± 13.4° for the left limb. Table 2 (right limb) and Table 3 (left limb) present the means and standard deviations of scapular upward rotation in different amounts of glenohumeral rotation at each position of humeral elevation in the scapular plane. In 0° of humeral elevation, the ANOVA results revealed no significant difference in glenohumeral rotation for scapular upward rotation, \( F_{2,117} \).
Table 1  Intertester Reliability for Scapular Upward Rotation

<table>
<thead>
<tr>
<th>Position</th>
<th>ICC$_{1,1}$</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right neutral 0°</td>
<td>.98</td>
<td>0.56</td>
</tr>
<tr>
<td>Neutral 30°</td>
<td>.89</td>
<td>0.88</td>
</tr>
<tr>
<td>Neutral 60°</td>
<td>.79</td>
<td>1.33</td>
</tr>
<tr>
<td>Neutral 90°</td>
<td>.95</td>
<td>2.11</td>
</tr>
<tr>
<td>External 0°</td>
<td>.98</td>
<td>0.53</td>
</tr>
<tr>
<td>External 30°</td>
<td>.99</td>
<td>1.00</td>
</tr>
<tr>
<td>External 60°</td>
<td>.86</td>
<td>1.67</td>
</tr>
<tr>
<td>External 90°</td>
<td>.98</td>
<td>2.22</td>
</tr>
<tr>
<td>Internal 0°</td>
<td>.95</td>
<td>0.56</td>
</tr>
<tr>
<td>Internal 30°</td>
<td>.96</td>
<td>0.88</td>
</tr>
<tr>
<td>Internal 60°</td>
<td>.87</td>
<td>1.32</td>
</tr>
<tr>
<td>Internal 90°</td>
<td>.77</td>
<td>2.11</td>
</tr>
<tr>
<td>Left neutral 0°</td>
<td>.97</td>
<td>0.62</td>
</tr>
<tr>
<td>Neutral 30°</td>
<td>.92</td>
<td>0.88</td>
</tr>
<tr>
<td>Neutral 60°</td>
<td>.87</td>
<td>1.33</td>
</tr>
<tr>
<td>Neutral 90°</td>
<td>.91</td>
<td>0.98</td>
</tr>
<tr>
<td>External 0°</td>
<td>.82</td>
<td>0.53</td>
</tr>
<tr>
<td>External 30°</td>
<td>.80</td>
<td>1.45</td>
</tr>
<tr>
<td>External 60°</td>
<td>.94</td>
<td>0.50</td>
</tr>
<tr>
<td>External 90°</td>
<td>.93</td>
<td>0.60</td>
</tr>
<tr>
<td>Internal 0°</td>
<td>.97</td>
<td>0.13</td>
</tr>
<tr>
<td>Internal 30°</td>
<td>.96</td>
<td>0.30</td>
</tr>
<tr>
<td>Internal 60°</td>
<td>.78</td>
<td>0.11</td>
</tr>
<tr>
<td>Internal 90°</td>
<td>.88</td>
<td>0.29</td>
</tr>
</tbody>
</table>
In 30° of humeral elevation, there was no significant difference in the right limb, $F_{2,117} = 2.164, P = .119$. In the left limb, there was a significant difference, $F_{2,117} = 3.220, P < .05$. Follow-up testing demonstrated a statistically significant difference in the internal-rotation position relative to neutral and external rotation ($P < .05$).

In 60° of humeral elevation, a statistically difference was seen in both limbs, $F_{2,117} = 5.313, P < .05$, for the right limb and $F_{2,117} = 8.527, P < .05$, for the left limb. Follow-up testing for the right limb demonstrated a statistically significant difference between neutral rotation and internal rotation ($P < .05$). Follow-up testing for the left limb demonstrated a statistically significant difference between neutral rotation and internal rotation ($P < .05$). In 90° of humeral elevation, a statistically significant difference was seen, $F_{2,117} = 13.958, P < .05$, for the right limb and $F_{2,117} = 18.379, P < .05$, for the left limb. Follow-up testing demonstrated a statistically significant difference between neutral and external rotation and between neutral and internal rotation ($P < .05$). This trend was seen on both sides. Figure 6 demonstrates the results for the right limb, and Figure 7, for the left limb.

### Table 2  Scapular Upward Rotation for Right Limb (°)

<table>
<thead>
<tr>
<th>Humeral elevation in the scapular plane</th>
<th>Internal rotation, mean ± SD</th>
<th>Neutral rotation, mean ± SD</th>
<th>External rotation, mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.9 ± 6.5</td>
<td>2.3 ± 5.7</td>
<td>0.3 ± 6.5</td>
</tr>
<tr>
<td>30</td>
<td>8.3 ± 8.8</td>
<td>4.9 ± 7.0</td>
<td>5.3 ± 7.9</td>
</tr>
<tr>
<td>60</td>
<td>21.9 ± 6.5</td>
<td>14.1 ± 9.4</td>
<td>18.7 ± 11.2</td>
</tr>
<tr>
<td>90</td>
<td>40.2 ± 10.2</td>
<td>27.5 ± 9.1</td>
<td>36.2 ± 13.2</td>
</tr>
</tbody>
</table>

### Table 3  Scapular Upward Rotation for Left Limb (°)

<table>
<thead>
<tr>
<th>Humeral elevation in the scapular plane</th>
<th>Internal rotation, mean ± SD</th>
<th>Neutral rotation, mean ± SD</th>
<th>External rotation, mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5.2 ± 6.5</td>
<td>4.8 ± 5.1</td>
<td>2.8 ± 6.4</td>
</tr>
<tr>
<td>30</td>
<td>11.3 ± 8.2</td>
<td>7.3 ± 6.3</td>
<td>8.2 ± 7.6</td>
</tr>
<tr>
<td>60</td>
<td>24.0 ± 9.7</td>
<td>15.4 ± 7.8</td>
<td>21.7 ± 11.1</td>
</tr>
<tr>
<td>90</td>
<td>42.9 ± 9.1</td>
<td>30.3 ± 7.5</td>
<td>38.3 ± 11.2</td>
</tr>
</tbody>
</table>
As Codman\textsuperscript{15} suggested with his “scapulohumeral rhythm,” there was a close relationship between the glenohumeral joint and the scapulothoracic joint. The ideal relationship between these 2 joints increases the congruity of glenohumeral

**Comments**

As Codman\textsuperscript{15} suggested with his “scapulohumeral rhythm,” there was a close relationship between the glenohumeral joint and the scapulothoracic joint. The ideal relationship between these 2 joints increases the congruity of glenohumeral
articulation, and this congruity helps the greater and lesser tuberosities pass under the coracoacromial arch. During humeral elevation in the scapular plane, the scapula provides a stable base for the upper extremity so that the rotator-cuff muscles effectively compress the humeral head into the glenoid, decreasing the amount of the translation between the glenoid and the humeral head. This lessens the risk of soft-tissue impingement under the coracoacromial arch, such as in the rotator-cuff tendons and joint capsule. Kibler\textsuperscript{1} and Jobe\textsuperscript{28} stated that the abnormal biomechanics and physiology that can occur in the shoulder create abnormal scapular positions and motions that decrease normal shoulder function. Therefore, the integrated movement at the glenohumeral and scapulothoracic joints during humeral elevation has received much attention.

Although most clinicians would agree that the evaluation of the scapula is critical,\textsuperscript{16} it has been reported that 2-dimensional scapular upward-rotation data have variability that is evident between subjects.\textsuperscript{5,17} Because of differences in study design, subject selection, instrument, and the definition of the scapular angle, the results of this study cannot be compared directly with those of previous studies describing average scapular upward rotation. Nonetheless, in comparing the dispersion of between-subjects variability with the other previous study, the dispersion of between-subject variability in this study is almost consistent with the previous value, which ranged from 4° to 6°. In the present study, the dispersion of between-subjects variability in scapular upward rotation at all positions measured ranged from 6° to 9°. The dispersion of variability in the 3-dimensional data,\textsuperscript{18} with standard deviations ranging from 4° to 9°, is also consistent with our data.

It should be noted that although there was between-subjects variability in scapular upward rotation, the patterns of scapular upward rotation with different amounts of glenohumeral rotation during humeral elevation were consistent across subjects. For all subjects in this study, progressive scapular upward rotation tended to increase when glenohumeral internal and external rotation were applied, compared with neutral rotation in each degree of humeral elevation except 0°. Internal rotation demonstrated greater scapular upward rotation than the other glenohumeral rotations. It is believed the one of the causes of subacromial- and subcoracoid-space encroachment is related to motion of the scapula.\textsuperscript{10} We thought that the findings in this study might have implications for the prevention of clinical impingement because lack of scapular upward rotation at the humeral elevation with glenohumeral rotation (especially with internal rotation) would increase the risk for impingement (decrease in the subacromial and subcoracoid spaces).

Some clinicians have seen scapular dysfunction in patients with shoulder pathologies. Subjects with impingement were described as having different scapular kinematics (anterior tilt) during scapular-plane elevation.\textsuperscript{19} Hebert at al\textsuperscript{20} also reported that subjects with impingement demonstrated decreased posterior tilting of the scapula. In addition, scapular motion in healthy subjects was also reported to be easily affected by several conditions such as the plane of humeral elevation,\textsuperscript{21} muscle fatigue,\textsuperscript{22} applied load,\textsuperscript{23} decrease in range of motion,\textsuperscript{10,24,25} and speed of elevation.\textsuperscript{26} The results of this study with subjects with no shoulder problems revealed that glenohumeral rotation affected scapular motion (upward rotation). We think that this is a clinically relevant finding. Because the functional motions of the shoulder demand glenohumeral rotation during humeral elevation, the precise mechanism of these results was unclear. We speculate, however, that the end-range position of
humeral rotation (active maximum humeral rotation in this study) might tighten the
glenohumeral-joint capsule complex and then cause progressive scapular upward
rotation and might also be caused by the greater tuberosity pushing the scapula
into greater scapular upward rotation.\textsuperscript{27}

To decrease several confounders in the present study, the scapular plane was
utilized, no load was applied, and each scapular position was measured statically
at each position of humeral elevation in the scapular plane. In addition, participants
returned their arms to 0° before each testing position to decrease the effect of
muscle fatigue. Subjects 16 to 35 years old were recruited for the study. Generally,
the mechanism of shoulder impingement could differ in elderly people and young
people.\textsuperscript{28} Therefore, extrapolation of the results of this study to other age groups is
not recommended. Other limitations must also be noted. Ludewig et al\textsuperscript{10} reported
in their 3-dimensional study in scapular kinematics that as the arm elevated in the
scapular plane, progressive scapular upward rotation and posterior tilting were
demonstrated. Because the present study only assessed scapular upward rotation
using a 2-dimensional inclinometer, we could not know how the amount of gleno-
humeral rotation affected posterior tilting of the scapula, which could be related to
shoulder-impingement mechanisms. In addition, in this study each scapular position
was measured statically in each position of humeral elevation in the scapular plane.
An isometric contraction by the subjects was needed to maintain the positions. In
this sense, isometric muscle activity is different from dynamic motion. In dynamic
motion, the muscles around the shoulder work concentrically or eccentrically.
Therefore, we propose that this study serve as a starting point for further clinical
prospective studies to determine the difference between unimpaired subjects and
patients with shoulder pathologies.

This study was interesting in the amount of scapular upward rotation displayed
when the different amounts of glenohumeral rotation were applied. Although precise
mechanisms causing these results are not clear because of limited methodology
in this study, the results of this study could be used in practical application in
functional rehabilitation and injury prevention. Future studies are needed to fully
describe comprehensive shoulder kinematics including muscle function during
humeral elevation in the scapular plane when different amounts of glenohumeral
rotation are applied.

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