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Determining the Resting Position of the Glenohumeral Joint in Subjects Who Are Healthy

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Background and Purpose
The resting position is frequently used by clinicians in the examination and early treatment of patients with joint impairments. However, there is a lack of research on the kinematic characteristics of the resting position of the glenohumeral (GH) joint. The aim of this study was to define the resting position of the GH joint by quantifying the humeral head translation and axial rotational range of motion (ROM).

Subjects and Methods
The anterior and posterior translation of the humeral head and the rotational ROM of the dominant arm were assessed in the seated position at multiple abduction positions in 15 subjects who were healthy by use of an electromagnetic tracking device. A force of 80 N and a torque of 4 Nm were applied during the measurement procedures for the translation of the humeral head and the rotational ROM, respectively.

Results
The mean resting position determined by rotational movement was located at 49.8 degrees of GH abduction. However, the mean resting position determined by translational movement was located at 23.7 degrees of GH abduction and was significantly lower than the resting position determined by rotational movement ($t=5.45$, $P=.000$).

Discussion and Conclusion
The mean resting position for rotational movement is consistent with the already accepted range of 30 to 60 degrees for a “loosely packed” position of the GH joint. The mean resting position for translational movement appears to be lower than 30 to 60 degrees. The results of this study suggest that, at least for the GH joint, different resting positions should be assessed with different movement criteria (accessory or physiological movement).
The resting position is the position of a joint in which the joint tissues are under the least amount of stress and in which the joint capsule has its greatest laxity.1-4 It is also called the "maximal loosely packed position" or "loosely packed position" as opposed to the "closely packed position."4,5 The resting position also is regarded as the position of minimal congruence between joint surfaces allowing the greatest passive separation between articular surfaces.3-5 Clinically, the resting position of a joint is usually considered to be a single position and to be located in the middle of its full range of motion (ROM). For the in vivo glenohumeral (GH) joint, the resting position is generally considered to be located at a position in neutral rotation between 55 and 70 degrees of shoulder abduction with respect to the trunk in the plane of the scapula (commonly defined as the plane 30° anterior to the frontal plane).2,4,5 Because the resting position allows joint surface movements such as glide, roll, and spin to occur easily, it is frequently chosen as one of the positions for the initial evaluation and early treatment of a painful and inflammatory joint or a joint with hypomobility or hypermobility.2,4,5 Despite frequent use in clinics, there is no specific rationale for the methods currently used for determining the resting position of the GH joint. These methods were based not on experimental studies but on clinical experience and anecdotal information.

The resting position is generally considered to be the position of maximal mobility. Because the evaluation of GH joint mobility usually includes both accessory (humeral head translation) and physiological (ROM) joint mobility,6,7 many translational or laxity tests and angular mobility tests are potentially useful clinically for the determination of the resting position. For the GH joint, the most common mobility or laxity tests used in the clinical setting are related to the assessment of anterior, posterior, or inferior instability and the ROM for internal rotation (IR) or external rotation (ER).8-11 Therefore, the translational and rotational laxity of the GH joint may be useful for determining the resting position in vivo.

Noninvasive quantitative measurements of GH joint laxity in vivo are still difficult because of the complex movement of the shoulder and the difficulty of fixation of the scapula. Several studies9,12-14 have attempted to quantify passive GH joint movements, including translational and rotational laxity. Translation can be defined as the amount of linear movement between the humeral head and the glenoid fossa when stress is applied by the examiner, whereas rotational laxity refers to humeral rotational ROM relative to the scapula at the applied rotational torque.

Tibone et al12 measured shoulder translation by holding one electromagnetic tracking sensor beneath the thumb directly on the anterior aspect of the proximal shoulder and applying manual forces to the humerus in the anterior-posterior (A-P) direction. The direction of humeral head translation and the force applied by the examiner were not reported. Borsa and colleagues15,16 measured A-P and posterior-anterior (P-A) GH joint laxity in subjects who were healthy by using a shoulder arthrometer. A mechanical restraining system stabilized the trunk and scapula to prevent scapular retraction or protraction. Two linear displacement transducers were affixed to the skin surface of the acromion and the lateral portion of the humeral head to measure the translation of the humeral head resulting from an applied force of up to 134 N. However, the position of the humeral cuff wrapped around the proximal humerus and the direct use of linear displacement transducers on the skin to measure GH laxity may have affected the accuracy of humeral head translation.

In a study by McQuade and Murthi,14 the internal humeral head center was determined for translation tracking, and the true scapular reference frame was used to define GH head translation relative to scapular orientation. The scapular sensor compressed by body weight was assumed to have been placed stably. For rotational laxity, Novotny et al9 quantified the IR and ER ROM values at an applied torque of 4 Nm in subjects who were healthy. The scapula and clavicle of the subjects were immobilized with a clamp, and the defined IR-ER ROM of the GH joint was 139.4 degrees at 45 degrees of abduction in the plane of the scapula.

Few studies have quantitatively investigated the resting position.1,13,17 Helmirg et al18 reported that maximal inferior excursion of a GH joint specimen during an inferior humeral head translation test occurred at 20 degrees of abduction. Debski et al17 proposed that there was less translation of the humeral head in both the anterior and the posterior directions at the extreme range of abduction (0° and 90°) than in the midrange (30° and 60°) in the scapular plane under a maximum load of 89 N. They reported that the resting position of the in vitro GH joint was located between 30 and 60 degrees of abduction in the plane of the scapula (the plane 30° anterior to the frontal plane). However, no detailed data for anterior or posterior translation between 30 and 60 degrees of abduction were reported, nor was the rotational laxity of the GH joint reported.

Hsu et al1 defined the resting position of the GH joint by using an in
Determining Glenohumeral Joint Resting Position

vitro model. A materials testing system was used to simulate translational and rotational movements performed by physical therapists. The use of the materials testing system and a GH joint specimen allowed rigid fixation of the scapula and precise control of repeated movements during the translational and rotational movement testing. According to the data reported by Hsu et al, the resting position was located at an average of 39 degrees of GH abduction in the plane of the scapula (45% of the maximal GH abduction ROM). However, there was no active muscle tension, and the core temperatures in their cadaver specimens were inconsistent. Moreover, the material properties of living tissue may differ from those of cadaver tissue.

To our knowledge, no previous study has determined the resting position of the GH joint in vivo. Such information is necessary to clarify whether the resting position of the GH joint is the same in vivo as it is in cadaver specimens. In addition, recent advances in 3-dimensional (3-D) motion analysis techniques have improved the precision and accuracy of estimates of the center of rotation (COR) during GH joint motion.\(^9\)\(^{15}\)\(^{19}\) The use of a computed internal humeral head center for translation tracking and a true scapular reference frame to define GH translation and GH joint rotational movement relative to scapular orientation enables GH movement to be measured with reasonable accuracy and reliability. Therefore, the purpose of this study was to define the resting position of the GH joint in subjects who are healthy by investigating the magnitudes of anterior and posterior translation of the head of the humerus and the rotational ROM of the humerus at different GH abduction angles. The clinical relevance of this study was to provide physical therapy clinicians with important quantitative information regarding the resting position of the GH joint as well as the translational and rotational mobility of this joint at different abduction positions. Such information is important during the evaluation and treatment of patients with GH joint problems.

**Method**

**Subjects**

Fifteen volunteers with no shoulder symptoms were recruited. Subjects with histories of shoulder impairment as a result of any orthopedic or neurological disorder or any surgery associated with the shoulder girdle were excluded from the study. All subjects read and signed informed consent forms before participating in this study.

Basic information on the subjects, such as sex, age, and health status, was recorded. Because the ranges of translational and rotational movements of the humeral head are known to be different between the dominant shoulder and the non-dominant shoulder, we tested only the shoulder on the dominant side. The shoulder ipsilateral to the dominant hand (the writing hand) of each subject was tested. The maximal values for active range of motion (AROM) and passive range of motion (PROM) for the shoulder were assessed with a goniometer, and joint play was assessed with a 7-point scale proposed by Kaltenborn\(^20\) to rule out subjects with inadequate or excessive mobility of the shoulder. For these procedures, participants were tested in the supine position on the examination table. Throughout the duration of testing for GH joint rotational ROM, the arm of each subject was placed at 90 degrees of GH abduction. Scapular stabilization was provided by the examiner applying a posteriorly directed force against the subject’s coracoid process and clavicle with the hand. From the anatomical zero rotation in 90 degrees of abduction, the rotational AROM and PROM values of each subject were determined until the subjects achieved a stable end-point position. The IR and ER angles then were recorded from the goniometer. Demographic data for the subjects are shown in Table 1.

**Instrumentation**

A 3-D electromagnetic tracking device (FASTRAK)* with a transmitter and 4 receivers was used for collecting kinematic information. Three electromagnetic sensors were used to track the position and orientation of the thorax, scapula, and humerus of each subject. A stylus was used to digitize anatomic landmarks for defining the anatomic coordinates of each segment. The residual errors of angles and linear translations after calibration were less than 0.12 degree and 0.7 mm, respectively. In this study, all of the measurements were taken within 76 cm of the system origin as recommended by Biryukova et al.\(^21\)

A force sensor (MLP-50)† and a torque transducer (SWS-100)† were used to detect the force and the torque applied by the examiner to ensure good repeatability and reliability. Signals from the force sensor and torque transducer were sampled at 20 Hz. A custom-made remote control device was used to synchronize the acquisition of kinematic data from the FASTRAK system and data from the force sensor and torque transducer.

**Experimental Procedure**

**Digitization.** Prior to testing, the FASTRAK system, the force sensor, and the torque transducer were calibrated. Each subject was seated on a specially designed, sturdy chair with...
clamps grasping the spine of the scapula superiorly and posteriorly and the clavicle anteriorly. The lateral borders of the scapula were blocked with another clamp. The subject was instructed to sit relaxed while the trunk was stabilized with pelvis and chest belts. An adjustable elbow brace was applied to the elbow to immobilize the elbow joint at 90 degrees of flexion. Three sensors were attached to the sternal notch, the flat surface of the acromion, and a thermoplastic cuff secured to the distal humerus with straps. While subjects sat with their dominant arms hanging relaxed at the sides with the forearm pointing forward and the elbow braced at 90 degrees of flexion (neutral position), 9 bony landmarks (Fig. 1) were palpated and digitized. With these digitized points and the estimated GH joint COR (center of glenoid [CG]/center of humeral head [CH]; described in the next paragraph), the local coordinate systems of the trunk, humerus, and scapula were determined according to the suggestions of the International Shoulder Group22 (Fig. 1).

**Determination of the COR.** It was assumed that during small-arc movements of the GH joint, the electromagnetic sensors on the humerus segment remained at a constant distance from the COR. The sensor coordinates were recorded during passive small-arc arm movements of the segment to locate the mean COR of the GH joint. During small-arc movements of the GH joint, the glenoid fossa is in full contact with the head of the humerus. Therefore, the electromagnetic sensors on the humerus segment defined part of a sphere and remained at a constant distance from the COR of the GH joint, where the CH and the CG coincide. To evaluate the suitability of this least-squares method for estimating the COR of the GH joint, we collected electromagnetic sensor positions within the PROM of 45 degrees of shoulder abduction/adduction, flexion/extension, and circumduction before the experiment. The standard deviations from the defined joint center were 2.41, 0.61, and 1.16 mm in the x, y, and z axes, respectively. These low standard deviations demonstrated that estimating the GH center by use of the method developed by Gamage and Lasenby23 should be repeatable.

**Computation of translation of the humeral head.** For measuring the translation of the humeral head, we applied A-P and P-A force to the humeral head of each subject at positions from 0 degrees to the end position of GH abduction in 10-degree increments in neutral rotation in the plane of the scapula. An 80-N A-P or P-A force monitored by a force sensor was applied during A-P glide and P-A glide, and the electromagnetic sensors were tracked to assess the mobility of the GH joint at the 10-degree increments of GH abduction (Figs. 2A and 2B). A height-adjustable arm support was designed to prop up the arm during humeral head translation testing. With the scapula stabilized, we adjusted the height of the support at increments of 10 de-

### Table 1.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean (SD)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>23.2 (2.6)</td>
<td>20–29</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>167.6 (5.9)</td>
<td>155–179</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>57.0 (8.4)</td>
<td>44–71</td>
</tr>
<tr>
<td>Shoulder range of motion (°)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forward flexion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active</td>
<td>173.0 (7.0)</td>
<td>165–190</td>
</tr>
<tr>
<td>Passive</td>
<td>179.6 (6.3)</td>
<td>170–200</td>
</tr>
<tr>
<td>Abduction (frontal)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active</td>
<td>164.3 (7.9)</td>
<td>145–170</td>
</tr>
<tr>
<td>Passive</td>
<td>173.3 (7.2)</td>
<td>155–180</td>
</tr>
<tr>
<td>External rotation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active</td>
<td>101.3 (9.1)</td>
<td>90–120</td>
</tr>
<tr>
<td>Passive</td>
<td>112.6 (11.3)</td>
<td>95–130</td>
</tr>
<tr>
<td>Internal rotation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active</td>
<td>55.3 (12.0)</td>
<td>40–80</td>
</tr>
<tr>
<td>Passive</td>
<td>69.6 (14.6)</td>
<td>45–90</td>
</tr>
<tr>
<td>Joint play (points)</td>
<td>3 (0)</td>
<td>3</td>
</tr>
</tbody>
</table>

The study subjects were 8 men and 7 women. Relative to the thorax.
degrees of GH abduction. The magnitude of force (80 N) used in this study was similar to that used by Sauers et al., Debski et al., and Warner et al. (89 N) to simulate the amount of force required to reach the clinical end point of the GH joint. This loading was reported to allow steady load-displacement performance of the GH joint after conditioning with a low chance of damage to the capsular ligament and surrounding tissues.,

As stated previously, during small-arc movements of the GH joint, the CG and the CH coincide at the COR of the GH joint. After the COR of the GH joint is determined, the relationship between the distal humeral receiver position and the COR (and, therefore, the CG) within the scapular local coordinate system can be determined. Likewise, the relationship between the acromial receiver position and the COR (and, therefore, the CG) within the scapular local coordinate system can be determined. Once these relationships are established, the coordinates of the CH and the CG can be derived separately from the humeral and acromial sensor data, irrespective of the initial position of the COR of the GH joint. During translation testing, the amount of translation can be computed from the vector difference between the CG and the CH at the initial position (neutral rotation at every abduction angle in the plane of the scapula) and that at the end position of the A-P and P-A procedures (Fig. 3).

Validation of the method used in the present study was carried out with a plastic ball-and-socket joint model. The root-mean-square errors for the estimation of the COR were 0.04, 0.19, and 1.31 mm in the x (A-P), y (medial-lateral), and z (superior-inferior) directions, respectively; for the relative translation of the head and glenoid components, the errors ranged from 0.21 to 0.51 mm.

**Calculation of rotation of the humerus.** After the humeral head translation procedures, medial and lateral rotational ROM testing was executed, and ROM was measured. Manual support was used to hold the distal arm of each subject instead of height-adjusted arm support for the sake of smoothness of the movement. A torque transducer was used during rotational ROM testing to ensure a consistent torque of 4 N·m for IR and ER (Figs. 2C and 2D). A torque of 4 N·m has been shown to have reasonable reliability and a stable torque-angle curve. The change in the orientation of the humerus relative to the scapula was described as the Euler angle, which is a sequence of 3 angles of rotation against the initial position. After experimenting with different rotation se-
sequences, we adopted the $\gamma\alpha'\zeta''$ rotation sequence (representing transverse-, sagittal-, and frontal-plane movements, respectively) to describe the 3 rotation angles of the GH joint. The same rotation sequence ($\gamma\alpha'\zeta''$) was used to derive the 3-D scapular movements of winging, tipping, and upward/downward rotation, respectively (Fig. 1). Coordinates and orientations of sensors were tracked at every 10-degree increment in the plane of the scapula from the neutral position to the end position of GH abduction in neutral rotation during rotational ROM testing. Three tests of translation of the humeral head and rotational ROM were recorded at each angle of GH abduction in the scapular plane.

Data Analysis

All 3 replications of the translational and rotational measurements were used for data analysis. The intraclass correlation coefficient (ICC\([3,1]\)) was used to test the intrasession reliability of the respective translation of the humeral head and rotational ROM. To determine the resting position, we modified the method used by Hsu et al.\(^1\) All 3 trials of total translational and rotational ROM data were used to define the resting position for each subject. Curvilinear regression analyses were performed to derive the relationship between abduction angles and total translational as well as total rotational ROM data. Interpolation was performed to calculate translation (A-P, P-A) and rotation (IR, ER) at exactly 0, 10, 20, 30, 40, 50, and 60 degrees and the end position of GH abduction. The abduction angle at which total translation was maximal was determined. The same procedure was used to find the abduction angle for maximal total rotational ROM. The resting positions for translation and rotational ROM were determined from the location (abduction angle) at which maximal total translation occurred and the position at which maximal
total rotation occurred, respectively. A Student paired t test was used to inspect the differences between angles of abduction for maximal total translation and those for maximal total rotation.

A 3-way analysis of variance (ANOVA) was used to assess the effects of sex, the effects of abduction angles (8 positions), and the effects of the direction of translation (A-P, P-A) and the direction of rotational ROM (IR, ER) on the translation of the head of the humerus and rotational ROM, respectively. To assess the effects of sex and abduction angles on total translation and total rotational ROM, a separate 2-way ANOVA was used. All P values of less than .05 were considered significant.

The electromagnetic sensor attached to the flat surface of the acromion was used to track scapular motion and monitor the status of immobilization of the scapula. We investigated the effectiveness of the scapular immobilization frame by computing the variability of the scapula-trunk angular relationship during translational and rotational testing at different GH abduction positions. The mean values of the scapula-trunk angles for 3 replications were used in the analysis. A 2-way repeated-measures ANOVA was used to evaluate the effects of GH abduction position (8 positions) and direction of translation (2 directions: anterior and posterior) on scapula-trunk angles for the translational procedure. The Friedman test was used to evaluate the effects of GH abduction position on scapula-trunk angles for the rotational procedure.

**Results**

The intrarater reliability (ICC[3,1]) values for measurements of humeral head translation (in millimeters) during A-P glide and P-A glide procedures and ROM (in degrees) during IR and ER procedures were .86 to .975, .83 to .977, .98 to .99, and .97 to .99, respectively (Tab. 2). With the scapula restrained by the immobilization frame, the mean maximal excursion for GH abduction was 68.3 degrees (SD=5.9°). Because all subjects were able to achieve at least 60 degrees of GH abduction in neutral rotation, we chose to present data from 0 to 60 degrees of abduction and the end position for the sake of simplicity in reporting. The mean values for humeral head translation at 0 degrees (neutral position), at 10, 20, 30, 40, 50, and 60 degrees, and at the end position of GH abduction are shown in Table 3 and Figure 4. The mean values for rotational ROM at 0 degrees (neutral position), at 10, 20, 30, 40, 50, and 60 degrees, and at the end position of GH abduction are shown in Table 4 and Figure 5. The maximal total translation (mean±SD) occurred at 23.7±8.4 degrees (33.8±11.2% of the GH maximal abduction ROM), and the maximal rotational ROM occurred at 49.8±16.0 degrees (70.0±25.3% of the maximal abduction ROM). There

### Table 2.

**Intraclass Correlation Coefficients [ICC(3,1)] for 3 Replicates of Translation During Anterior-Posterior Glide (A-P), Translation During Posterior-Anterior Glide (P-A), Internal Rotation (IR), and External Rotation (ER) Measurements for 15 Subjects**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>ICC(3,1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IR</td>
<td>.98–.99</td>
</tr>
<tr>
<td>ER</td>
<td>.97–.99</td>
</tr>
<tr>
<td>A-P</td>
<td>.86–.98</td>
</tr>
<tr>
<td>P-A</td>
<td>.83–.98</td>
</tr>
</tbody>
</table>

### Table 3.

**Translation Measurements for the Center of the Humeral Head Interpolated at Specific Glenohumeral Abduction Angles for 15 Subjects**

<table>
<thead>
<tr>
<th>Glenohumeral Abduction Angle (°)</th>
<th>Measurement (mm)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A-P</td>
<td>P-A</td>
<td>T-A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( \bar{X} )</td>
<td>SD</td>
<td>( \bar{X} )</td>
<td>SD</td>
<td>( \bar{X} )</td>
<td>SD</td>
</tr>
<tr>
<td>0</td>
<td>11.5</td>
<td>3.2</td>
<td>13.2</td>
<td>3.8</td>
<td>24.8</td>
<td>6.0</td>
</tr>
<tr>
<td>10</td>
<td>12.0</td>
<td>4.1</td>
<td>14.3</td>
<td>3.8</td>
<td>26.4</td>
<td>6.9</td>
</tr>
<tr>
<td>20</td>
<td>11.7</td>
<td>4.4</td>
<td>14.8</td>
<td>4.1</td>
<td>26.6</td>
<td>7.2</td>
</tr>
<tr>
<td>30</td>
<td>10.9</td>
<td>4.0</td>
<td>14.7</td>
<td>3.8</td>
<td>25.7</td>
<td>6.3</td>
</tr>
<tr>
<td>40</td>
<td>9.7</td>
<td>3.3</td>
<td>14.2</td>
<td>3.5</td>
<td>24.0</td>
<td>5.5</td>
</tr>
<tr>
<td>50</td>
<td>8.5</td>
<td>3.0</td>
<td>13.3</td>
<td>3.7</td>
<td>21.9</td>
<td>5.7</td>
</tr>
<tr>
<td>60</td>
<td>7.5</td>
<td>3.0</td>
<td>12.2</td>
<td>3.9</td>
<td>19.8</td>
<td>6.3</td>
</tr>
<tr>
<td>End position</td>
<td>7.9</td>
<td>2.2</td>
<td>9.9</td>
<td>3.4</td>
<td>17.8</td>
<td>4.6</td>
</tr>
</tbody>
</table>

* A-P=translation during anterior-posterior glide, P-A=translation during posterior-anterior glide, T-A=total translation. End position=maximal angle of glenohumeral abduction (\( \bar{X} \pm SD \): 68.3°±5.9°.*
was a significant difference between the position in abduction at which the maximal total translation occurred and the position at which the maximal total rotational ROM took place ($t=5.45, P=0.000$).

The results of the ANOVAs revealed no significant interactions among sex, direction, and abduction position on the values for humeral head translation. There were significant main effects of direction (A-P versus P-A) ($F=48.39; df=1,234; P=0.000$) and of abduction position ($F=7.73; df=7,234; P=0.000$) but not of sex on the values for humeral head translation (Fig. 4); neither was there a sex effect on total translation of the humeral head. Post hoc cross-comparisons (adjusted $\alpha=0.006$) demonstrated that the values for total translation at the neutral position and at 10, 20, 30, and 40 degrees of GH abduction were significantly greater than those at the end position (Fig. 4).

For rotational ROM, a significant interaction of sex and direction (IR and ER) was found. In comparison with their male counterparts, women had greater IR ROM values at 40, 50, and 60 degrees and at the end position of abduction (Tab. 4). For total rotational ROM (the sum of IR and ER), however, there was no interaction between abduction position and sex. Significant main effects of abduction position ($F=13.65; df=7.91; P=0.003$) and of sex ($F=6.85; df=1,13; P=0.021$) on the magnitude of total rotational ROM were found. The total rotational ROM value at the neutral position was significantly different from those at 10, 20, 30, and 40 degrees of GH abduction ($P<0.001$). The total rotational ROM values at 20, 30, and 40 degrees were greater than that at 10 degrees of abduction ($P<0.005$). The total rotational ROM value at 30 degrees of abduction was greater than that at 20 degrees of abduction ($P<0.005$) (Fig. 5).

Even with the application of the scapular immobilization device, the abduction angle had a significant main effect on the scapular upward rotation angle during A-P glide ($F=23.48; df=7.98; P=0.000$), P-A glide ($F=35.17; df=7.98; P=0.000$), and rotation ($F=48.05; df=7.98; P=0.000$) tests, respectively. The magnitude of scapular upward rotation at 0 degrees (neutral position) was significantly different from those at 30 degrees to the end position of abduction for the A-P glide test, from those at 40 degrees to the end position for the P-A glide test, and from those at 20 degrees to the end position for the rotation test (Tab. 5). Nevertheless, there was a main effect of direction on scapular winging and tipping but no effect of direction on scapular upward-downward movement. Greater lateral rotation of the scapula and larger posterior tipping angles were found in the P-A direction than in the A-P direction.

**Discussion**

By using a 3-D electromagnetic tracking device to monitor shoulder translation and rotation, we quantified the
magnitudes of translation and rotational ROM at different GH abduction angles. Therefore, the resting position of the GH joint in subjects who are healthy could be defined by investigating the magnitudes of anterior and posterior translation of the humeral head and the rotational ROM of the humerus.

The findings of the present study indicated that the peak magnitudes of anterior and posterior translation and rotational ROM occurred at 24 and 50 degrees of GH abduction, respectively. As the angular difference between the locations of maximal translational and rotational mobility was quite large, the resting positions were determined separately at the locations at which translation and rotational ROM were maximal. The resting position for rotational ROM in young subjects who are healthy appears to be consistent with the findings of Hurschler et al.²⁹ who reported that rotational ROM values were larger at the midrange (30° and 60° of GH abduction) than at the end positions (0° and 90° of abduction) because of variations in joint laxity and tissue extensibility at different joint positions. The resting position for translation, however, was located at 23.7 degrees of GH abduction in the plane of the scapula; this location is lower than the midrange of 30 to 60 degrees within which greater translational mobility was reported by Debski et al.¹⁷ and Hurschler et al.²⁹

### Table 4.
Glenohumeral Rotation Range-of-Motion Measurements Interpolated at Specific Abduction Angles for Men, Women, and All Subjects Combined (Total)

<table>
<thead>
<tr>
<th>Glenohumeral Abduction Angle (°)</th>
<th>Group</th>
<th>Internal Rotation (°)</th>
<th>External Rotation (°)</th>
<th>Total Rotation (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>X</td>
<td>SD</td>
<td>X</td>
</tr>
<tr>
<td>0</td>
<td>Men</td>
<td>43.5</td>
<td>16.7</td>
<td>78.7</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>43.3</td>
<td>8.8</td>
<td>82.7</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>43.4</td>
<td>13.1</td>
<td>80.5</td>
</tr>
<tr>
<td>10</td>
<td>Men</td>
<td>48.8</td>
<td>14.9</td>
<td>79.5</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>49.9</td>
<td>10.9</td>
<td>84.2</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>49.3</td>
<td>12.7</td>
<td>81.7</td>
</tr>
<tr>
<td>20</td>
<td>Men</td>
<td>52.3</td>
<td>13.3</td>
<td>81.0</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>58.9</td>
<td>13.1</td>
<td>86.2</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>55.4</td>
<td>13.2</td>
<td>83.5</td>
</tr>
<tr>
<td>30</td>
<td>Men</td>
<td>52.9</td>
<td>13.8</td>
<td>83.3</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>65.7</td>
<td>14.3</td>
<td>88.0</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>58.9</td>
<td>15.0</td>
<td>85.5</td>
</tr>
<tr>
<td>40</td>
<td>Men</td>
<td>50.5°</td>
<td>15.7</td>
<td>86.1</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>69.5°</td>
<td>14.6</td>
<td>89.9</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>59.3</td>
<td>17.6</td>
<td>87.9</td>
</tr>
<tr>
<td>50</td>
<td>Men</td>
<td>45.2°</td>
<td>17.5</td>
<td>89.0</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>69.2°</td>
<td>14.9</td>
<td>92.3</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>56.4</td>
<td>20.1</td>
<td>90.5</td>
</tr>
<tr>
<td>60</td>
<td>Men</td>
<td>37.0°</td>
<td>18.2</td>
<td>91.7</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>64.1°</td>
<td>17.7</td>
<td>95.6</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>49.6</td>
<td>22.2</td>
<td>93.5</td>
</tr>
<tr>
<td>End position</td>
<td>Men</td>
<td>25.4°</td>
<td>14.6</td>
<td>94.6</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>57.9°</td>
<td>17.0</td>
<td>98.7</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>39.5</td>
<td>23.4</td>
<td>96.5</td>
</tr>
</tbody>
</table>

* The magnitudes of rotation were significantly different between the sexes at P<.05.

² The magnitudes of rotation were significantly different between the sexes at P<.005.
In the present study, the resting position was determined on the basis of quantifiable measurements of translational and rotational laxity. However, the position at which maximal translational laxity occurred (23.7° of GH abduction) did not coincide with the location of maximal rotational ROM laxity (49.8° of GH abduction). These findings appear to suggest different resting positions for different accessory and physiological movements of the GH joint.

An explanation for such discrepancies in the locations of maximal translational and rotational mobility is that the resting positions might have been movement dependent, that is, 2 different resting positions for translational and rotational movements. Although relatively small differences in flexion and abduction ROM values have been reported for sitting and supine positions, differences in rotational ROM values have not been reported.30 However, the posture of subjects during measurements (sitting) might be an important factor influencing the magnitude of translational mobility because unintentional contractions of the antigravity muscles in abducted positions may alter the resting position.

### Table 5.
Angular Displacements of the Scapula Relative to the Thorax at Each Abduction Angle During Translation and Rotation Procedures for 15 Subjects

<table>
<thead>
<tr>
<th>Glenohumeral Abduction Angle (°)</th>
<th>Angular Displacement, X (SD), for the Following Task:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A-P</td>
</tr>
<tr>
<td>0</td>
<td>1.3 (4.7)</td>
</tr>
<tr>
<td>10</td>
<td>1.8 (4.5)</td>
</tr>
<tr>
<td>20</td>
<td>1.3 (4.2)</td>
</tr>
<tr>
<td>30</td>
<td>0.4 (6.5)</td>
</tr>
<tr>
<td>40</td>
<td>-3.3 (6.0)</td>
</tr>
<tr>
<td>50</td>
<td>-6.3 (7.0)</td>
</tr>
<tr>
<td>60</td>
<td>-6.8 (8.1)</td>
</tr>
<tr>
<td>End position</td>
<td>-7.9 (7.5)</td>
</tr>
</tbody>
</table>

* A-P = translation during anterior-posterior glide, P-A = translation during posterior-anterior glide.

* The magnitudes of scapular upward rotation at 0° (neutral position) were significantly different from those of glenohumeral abduction during the testing procedures (P<.002, P=.01, and P<.001 for A-P, P-A, and rotation tests, respectively).
Positions might result in maximal translational laxity (the resting position) at smaller angles of GH abduction. Such a situation might have occurred in our study.

Further studies should record the electromyographic activity of the involved muscle and address whether sitting and supine positions affect muscle tone and the measurement of GH laxity. Another potential explanation for differences in rotational mobility is humeral retroversion, which might result in discrepancies in the magnitudes of rotational mobility. This adaptation of the bony architecture of the GH joint enables ER of the shoulder joint to a greater extent and less IR before constraints are imposed by soft tissue.

Finding the resting position is important to clinicians who want to evaluate the GH joint in a resting position. Maximal A-P and P-A translational mobility in a seated position occurs at approximately 24 degrees of GH abduction. With the scapula and clavicle securely fixed, this position is located at approximately 35% of the total available abduction ROM, which corresponds to about 40 degrees of abduction in a normal GH joint, with the assumption of a 120-degree GH abduction range. Glenohumeral rotation excursions were greatest at approximately 50 degrees of GH abduction (70% of the available ROM or 84° of abduction in a normal GH joint). For other accessory or physiological movements in different directions, such as distraction, inferior glide, and lateral glide, the resting positions may be different from those found in the present study (ie, A-P and P-A translation and rotation). The results of the present study suggest the possibility that, at least for the GH joint, there exists not one but more than one resting position. Therefore, different resting positions may need to be determined for a particular joint, depending on the criterion accessory or physiological movements used for assessment or treatment.

Existing literature did not provide a unified conclusion on the issue of the effect of sex on GH joint mobility. Many reports showed no significant differences in translation, rotation angles, and stiffness between male and female subjects, whereas some authors found that female subjects had greater anterior GH laxity and rotational ROM than male subjects had. In the present study, we demonstrated that the values for A-P and P-A translation and ER ROM were similar for men and women. Such findings are consistent with the majority of previous reports on this issue. The failure to find sex differences in translational mobility may have arisen from insufficient numbers of participating subjects or insufficient instrumental precision to detect sex differences in translation with our method. However, we found that women had a greater range of IR than men had at positions of greater abduction. This finding is in contrast to previous reports showing no differences in IR and ER ranges between male and female subjects when the scapula was stabilized.

Comparisons of the translation data obtained in the present study with those reported in the existing literature are difficult because of differences in experimental design and subject status (eg, age, posture [sitting or supine], and status of muscular activation). Hsu et al applied a force of 80 N and a torque of 1 Nm to cadaver specimens at different abduction angles in order to quantify humeral head translation and GH joint rotational ROM, respectively. The values that they obtained for head translation were much larger than those obtained in the present study, possibly because of the absence of muscle tone in cadaver specimens. Sauers et al reported that at 20 degrees of GH abduction in subjects who were healthy, the total humeral head translation was 20 mm; this value is lower than the value (25 mm) obtained in the present study. During translation tests, we computed the translation of the GH relative to the scapula (CG) rather than directly recording the translation via linear motion sensors affixed to the skin surface. In addition, differences in the scapular immobilization method and the experimental setup might have accounted for this difference. In the present study, the translation values obtained during P-A glide were greater than those obtained during A-P glide at each GH abduction angle, in contrast to those reported by Sauers et al, who demonstrated equal magnitudes of translation in the A-P and P-A directions.

The roles played by different sectors of the GH joint capsule during anterior and posterior translation of the humeral head have been reported. The anterior capsule, especially the anteroinferior sector, is the primary stabilizer for the GH joint during anterior translation; the posterior capsule, especially the posteroinferior sector, primarily constrains the posterior translation of the humeral head.

In a magnetic resonance imaging study, Urayama et al reported a slightly longer capsule length (34.8±5.6 mm) for the anteroinferior capsule than for its posterior counterpart (31.3±6.6 mm) in unaffected shoulders in a group of subjects with anterior GH instability. The anterior band of the inferior GH ligament was reported to be less stiff than the posterior band of the inferior GH ligament. McQuade et al also reported slightly less stiffness in the anterior direction than in the posterior direction at GH abduction angles of 45, 90, and 180 degrees.
gree in neutral rotation. Therefore, the greater anterior as opposed to posterior translation of the humeral head might have been the result of the interplay of capsule length and mechanical property.

The same pattern regarding the magnitude of humeral head translation has been observed in several research studies.1,17-39,40,46-49 However, the relative magnitudes of anterior translation and posterior translation are dependent not only on the types of subjects tested but also on the positions in which tests are conducted. The magnitude of anterior or posterior translation may rely on the stiffness of each portion of the ligament or on the capsular constraint. In the studies of Borsa and colleagues,50,51 posterior translation was much more lax than anterior translation in baseball pitchers and swimmers. In their studies, the shoulder of each subject during force-displacement measurements was kept at 90 degrees of abduction and 60 degrees of ER. Under these testing conditions, the anterior band of the inferior GH ligament might have acted as the primary constraint and might have limited anterior translation of the head of the humerus.43,50

In the present study, total rotational ROM values of 147.2 and 147.0 degrees were obtained at 40 and 50 degrees of GH abduction, respectively. Such values are similar to those reported in the literature for the corresponding position (139.4° of rotational ROM at 45° of abduction).9 These values are lower than those reported without scapular fixation for subjects who are healthy11,38 because the accessory scapulothoracic motions necessary for humerus rotational movements are restrained by scapular stabilization.11,34 In the present study, the ER range increased with increasing angle of abduction. Earlier selective cutting studies indicated that the inferior GH ligament is the most important restraint for humerus ER in both neutral52 and abduced52,53 positions, whereas the coracohumeral ligament provides more restraint to ER only when the arm is in the neutral position.52-54 In the abducted position, the coracohumeral ligament becomes loose, places less restraint on ER, and allows a greater range of ER in abduction. Our results concur with the findings of Kuhn et al,52 who reported a greater range of ER at larger abduction angles than at smaller abduction angles.

In the present study, the angular displacement of the scapula, especially for scapular rotation, varied with the angle of GH abduction. It is difficult to immobilize the scapula with the immobilization frame at larger angles of elevation. However, the maximal arm elevation angles for each subject in our study were within 120 degrees of arm abduction relative to the thorax. According to Karduna et al,55 the scapular motions recorded by surface sensors were almost the same as those recorded by sensors on bone pins surgically fixed on the scapula when the humerothoracic elevation was less than 120 degrees. The results of their study indicated that skin motion artifacts are not a significant factor as long as the shoulder joint is maintained at less than 120 degrees of abduction. Therefore, it seems appropriate in the present study to represent scapular motion with the use of a sensor on the acromion when the shoulder is at less than 120 degrees of elevation.

Limitations
The present study had several limitations. Only anterior and posterior translation and rotational ROM were used to define the resting position. Other GH joint accessory movements in various planes and directions, such as distraction, inferior glide, and lateral glide, are potential parameters for determining the resting position.

In the present study, we incorporated the method described by Gamage and Lasenby23 for the derivation of COR from small-arc movements of the GH joint. This method was originally used for the hip joint. The GH joint, unlike the hip joint, lacks passive stability and requires the GH capsuloligamentous structures and surrounding muscles to act as passive and active stabilizers to constrain humeral head translation. During small-arc movements, however, the influence of the GH joint capsule and muscle was not likely to be significant in the present study because the coaptation of the glenoid and the head of the humerus was ensured by a medially directed compressive force applied to the head of the humerus. Under such conditions, the GH joint acts as an ideal ball-and-socket joint, and the centers of the glenoid and humeral head coincide at the COR of the GH joint during small-arc movements. Even with greater abduction, the amount of translation of the humeral head has been reported to be relatively small.47-51,56,57

The magnitude of translational or rotational laxity may be dependent on factors such as age, sex, race, and the magnitude of the applied load. In the present study, young subjects who were healthy were recruited; therefore, the findings may be specific to the study’s subject pool. Furthermore, the scapula was immobilized in our study; this condition resembled clinical testing situations in which the scapula of a subject is constrained manually by a therapist. Thus, generalization of the results obtained from the present study for test conditions in which the scapula is not constrained should be made with caution.
Conclusions
In the present study, the resting position of the GH joint was determined by measuring A-P and P-A translation and rotational ROM with a fixed scapula in 15 young subjects who were healthy. In the dominant GH joint of the tested population, we found that the mean resting position for A-P and P-A translation was located at 23.7 degrees and that the mean resting position for rotational ROM was located at 49.8 degrees of GH abduction in the plane of the scapula. The position at which maximal translational laxity occurred did not coincide with that of maximal rotational ROM laxity. Our results suggest the possibility that the resting position for each joint may not be a unique position, at least for the GH joint. Although the concept of one resting position for each joint has been universally accepted in clinical practice, on the basis of the findings of the present study, we suggest that multiple resting positions should be determined depending on the criterion accessory or physiological movements used for mobility assessments.

Determined Glenohumeral Joint Resting Position

Dr. Hsu provided concept/idea/research design. Dr. Lin, Dr. Hsu, and Dr. An provided writing and data analysis. Dr. Lin provided data collection and subjects. Dr. Chang and Dr. Hsu provided fund procurement. Dr. Hsu, Dr. Chang, Dr. Chang Chien, and Dr. Su provided facilities/equipment. Dr. Chang and Dr. An provided consultation (including review of manuscript before submission). The authors acknowledge the assistance of Dr. Jia-Hao Chang for consultation in software implementation at the initial stage of the study.

The research protocol used in this study was approved by the Institutional Review Board of the National Cheng Kung University Hospital, Tainan, Taiwan.

This study was supported, in part, by an Allied Health Research Grant from the College of Medicine, National Cheng Kung University.

This research, in part, was presented at the 20th Congress of the International Society of Biomechanics and the 29th Annual Meeting of the American Society of Biomechanics; July 31-August 5, 2005; Cleveland, Ohio.

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References
Determining Glenohumeral Joint Resting Position


Invited Commentary

Paula M Ludewig

Lin and colleagues have undertaken an investigation to identify the resting or “loose-packed” position of the glenohumeral joint by quantifying the humeral head anterior and posterior translations and axial rotation range of motion across a variety of scapular-plane abduction positions in subjects who are healthy. I thank the authors for their efforts in contributing to the expansion of knowledge on shoulder biomechanics. Such studies provide a potential foundation for refinement of current diagnostic and treatment approaches for shoulder joint pathology in patients. From a measurement perspective, a specific strength of the study was the use of controlled forces and torques imposed on the joint during the test procedures.

Measurement of glenohumeral joint translation is particularly challenging in vivo. The authors used a technique to estimate the glenohumeral joint center that has been demonstrated to be stable in a plastic ball-and-socket model. However, any surface-based testing method is not immune from errors due to sensor and skin motion distinct from the underlying bone, particularly at higher angles of humeral elevation. Lin and colleagues present reliability data for their translation measurements in the form of intraclass correlation coefficient (ICC) values. These values provide proportional variability information and suggest good within-day repeatability across trials for these methods. However, values are not presented distinctly for different abduction positions. Were ICC values consistent at all positions of
Determining the Resting Position of the Glenohumeral Joint in Subjects Who Are Healthy
Hui-Ting Lin, Ar-Tyan Hsu, Guan-Liang Chang, Jia-rea Chang Chien, Kai-Nan An and Fong Chin Su
PHYS THER. 2007; 87:1669-1682.
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