SCAPULAR POSITION AND ORIENTATION IN SYMPTOMATIC THROWING SHOULDERS: A CROSS-SECTIONAL STUDY USING 3D-TO-2D REGISTRATION TECHNIQUE

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INTRODUCTION
Shoulder injuries are common in baseball players, which may be related to scapular malposition (Burkhart 2003). Although a few studies demonstrated scapular malposition in baseball players using clinical measurement (Laoudner 2010, Thomas 2010), no data currently exist that demonstrated 3-dimensional (3D) scapular position and orientation using a technique that eliminates skin artifact. Therefore, the purpose of this study was to determine if there was any 3D scapular malposition in throwers with shoulder pain. As a previous study showed forward scapular posture in asymptomatic baseball players (Laoudner 2010), we hypothesized that symptomatic dominant shoulders demonstrate decreased upward rotation and increased scapular anterior tilting compared with the asymptomatic contralateral shoulders.

MATERIALS AND METHODS
After an Institutional Review Board approval, this cross-sectional study started. Volunteers were selected if they had shoulder pain during throwing motion with positive Neer or Hawkins-Kennedy impingement sign. We excluded participants with history of shoulder dislocation, subluxation or fracture, surgery of cervical spine, shoulder, or upper back, or symptomatic, contralateral nondominant shoulder. Informed consent was obtained from all participants.

Outcome measurements included glenohumeral range of motion (ROM), plain radiography, and CT scan. We used the standard goniometer and digital inclinometer to assess ROM of glenohumeral internal and external rotation, and horizontal adduction. Participants underwent anteroposterior radiography in the upright position and CT scan covering the scapula and proximal half of the humerus of both shoulders.

Three-dimensional scapular position and orientation were analyzed using a 3D-to-2D registration technique. Geometric bone models of the scapula and humerus were created from CT images using commercially available software. In brief, the scapular origin was placed at the glenoid center, and the Y and Z-axes were defined as a line connecting superior and inferior angle of scapula, and a line connecting the most anterior and posterior bony edges of the glenoid, respectively. Using a custom software program, the 3D bone models were projected onto a distortion-corrected radiographic image, and matched with the contour of the scapular and humerus. Scapular upward rotation and anterior tilting angles were obtained as a 6-DOF scapular position relative to the global coordinate system.

Statistical analysis was performed with PASW Statistics 18 (SPSS, Inc., Chicago, IL). Paired t tests were used to compare glenohumeral ROM and 3D scapular position and orientation between symptomatic dominant and asymptomatic contralateral shoulder. The level of significance was set at P < .05.

RESULTS
Twelve baseball players (24 shoulders) with unilateral shoulder pain were enrolled from collegiate (9 players) and other (3 players) level, comprising 4 pitchers and 8 position players. Their mean age was 21.4 years (20-25 years), mean height was 1.73 m (+/-0.06 m) and mean weight was 71.7 kg (+/-7.8 kg).

The mean and standard deviation values for bilateral glenohumeral ROM are shown in Table 1, demonstrating increased external rotation and decreased internal rotation for the throwing shoulders. There were no significant differences in 3D scapular position and orientation (Table 2). Six of 12 players demonstrated decreased upward rotation and 9 of 12 players demonstrated increased anterior tilting in the symptomatic dominant shoulders as compared with asymptomatic, nondominant shoulders.

DISCUSSION
The purpose of this study was to determine if there was any 3D scapular malposition in throwers with shoulder pain. However, scapular upward rotation angle were similar for both symptomatic dominant and asymptomatic contralateral shoulders in the upright position.

The importance of scapular kinematics in shoulder function and dysfunction was discussed at the Scapular Summit 2009 (Kibler 2009). The result of the present study agreed with the previous report (Thomas 2010). Although there was a trend toward an increased scapular anterior tilting in the symptomatic dominant shoulders (P=0.0883), no significant differences were detected. Using the mean and standard deviation values of scapular anterior tilting angle in our sample, the post-hoc power to detect a difference between the symptomatic dominant shoulders and the asymptomatic contralateral shoulders was only 0.40. To obtain a power at least 0.8 to detect a 5 degree difference between the groups, 22 samples per group would be required. Therefore, the failure to find a statistically significant difference between the groups could be attributable to an insufficient sample size.

Several limitations should be recognized. First, there was a small sample size in this study as detailed above. Second, we did not use the thorax as a reference of the scapular position because it was difficult to register 3D bone models of the thoracic spine or sternum in limited field-of-view radiographic images. However, this study was the first attempt to reveal the 3D scapular position and orientation in baseball players. As the 3D-to-2D registration technique eliminates skin artifact, the data presented in this study should be more accurate and reliable than any other clinical measurements.

In conclusion, scapular upward rotation angle were similar for both symptomatic dominant and asymptomatic contralateral shoulders in the upright position. While there was a trend toward an increased scapular anterior tilting with the symptomatic dominant shoulders, no significant differences were detected.

SIGNIFICANCE
As a basis for understanding scapular kinematics, the scapular position and orientation in the upright position are similar for both shoulders. This should help clinicians to adequately reposition or mobilize the scapula in clinical practice.

REFERENCES

TABLE 1: Glenohumeral ROM

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Symptomatic shoulders</th>
<th>Asymptomatic shoulders</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal rotation</td>
<td>35.4 ± 12.1</td>
<td>58.3 ± 13.2</td>
<td>0.0002*</td>
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<tr>
<td>External rotation</td>
<td>126.3 ± 10.4</td>
<td>113.3 ± 11.5</td>
<td>0.0085*</td>
</tr>
<tr>
<td>Total arc</td>
<td>162.5 ± 16.8</td>
<td>170.8 ± 15.9</td>
<td>0.2290</td>
</tr>
<tr>
<td>Horizontal adduction</td>
<td>-13.0 ± 7.2</td>
<td>-0.7 ± 8.4</td>
<td>0.0009*</td>
</tr>
</tbody>
</table>

* Values are mean ± standard deviation in degrees.

Table 2: 3D scapular position and orientation

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Symptomatic shoulders</th>
<th>Asymptomatic shoulders</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upward rotation</td>
<td>6.4 ± 6.3</td>
<td>6.5 ± 4.7</td>
<td>0.9565</td>
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<tr>
<td>Anterior tilting</td>
<td>17.8 ± 5.9</td>
<td>13.7 ± 5.4</td>
<td>0.0883</td>
</tr>
</tbody>
</table>

* Values are mean ± standard deviation in degrees.