The relationship between the orientation of the glenoid and tears of the rotator cuff

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Our aim was to determine the most repeatable three-dimensional measurement of glenoid orientation and to compare it between shoulders with intact and torn rotator cuffs. Our null hypothesis was that glenoid orientation in the scapulae of shoulders with a full-thickness tear of the rotator cuff was the same as that in shoulders with an intact rotator cuff.

We studied 24 shoulders in cadavers, 12 with an intact rotator cuff and 12 with a full-thickness tear. Two different observers used a three-dimensional digitising system to measure glenoid orientation in the scapular plane (ie glenoid inclination) using six different techniques. Glenoid version was also measured. The overall precision of the measurements revealed an error of less than 0.6˚.

Intraobserver reliability (correlation coefficients of 0.990 and 0.984 for each observer) and interobserver reliability (correlation coefficient of 0.985) were highest for measurement of glenoid inclination based on the angle obtained from a line connecting the superior and inferior points of the glenoid and that connecting the most superior point of the glenoid and the most superior point on the body of the scapula. There were no differences in glenoid inclination (p = 0.34) or glenoid version (p = 0.12) in scapulae from shoulders with an intact rotator cuff and those with a full-thickness tear. Abnormal glenoid orientation was not present in shoulders with a torn rotator cuff.

The possible causes of tear of the rotator cuff include trauma, ischaemia or degeneration of the tendon, abnormal morphology of the acromian, an impingement syndrome and glenohumeral joint instability.1-7 A less good prognosis is associated with severe tears,8 fatty accumulation and/or atrophy of the muscle of the rotator cuff9-12 and superior positioning of the humeral head on the glenoid.13

In the normal shoulder, the humeral head is centred on the glenoid fossa throughout movement. With a severe full-thickness tear of the rotator cuff the head may displace superiorly either because of loss of the fulcrum provided by the rotator cuff,14,15 or abnormal orientation of the glenoid.16

Recently, abnormal morphology of the glenoid has been reported to be associated with severe full-thickness tears.17 A two-dimensional (2-D) radiological study of the orientation of the glenoid in the coronal plane of the scapula, described as glenoid inclination, showed that in shoulders with tears the glenoid faced more superiorly.17 This finding correlated with that of a previous biomechanical study which found that the force required to translate the humeral head superiorly decreased significantly when the glenoid inclination was more superior.16 Specifically, the percentage reduction in the force was 14.2% for an increase of 5˚ and 37.5% for an increase of 15˚ in inclination.16 Glenoid inclination, however, has not been well defined, being described previously with many different angles.17-21 Several reference points on the scapula have been used to describe these angles including the most superior point of the scapular blade medial to the suprascapular notch, the most inferior point of the scapula, the centre of the glenoid, the point where the scapular spine meets the medial border and the spinoglenoid notch. Displacement of the humeral head in the shoulder with a severe full-thickness tear may occur in a variety of planes. The most common direction is superior but if the head is no longer contained by the glenohumeral joint and the coracoacromial arch it may displace anteriorly and superiorly. Glenoid orientation in the transverse plane of the scapula, defined as glenoid version,19,22 has been reported to be associated with glenohumeral instability22-25 and osteotomy of the glenoid in the transverse plane has been proposed as a treatment.18,23,24 Some surgeons
now suggest osteotomy of the glenoid in the coronal plane as treatment for severe tears of the rotator-cuff.\textsuperscript{27}

Our aim therefore, was to determine the most repeatable angle of glenoid inclination from three-dimensional (3D) measurements and to compare glenoid orientation between shoulders with intact and torn rotator cuffs. Our null hypothesis was that the glenoid orientation in the scapulae of shoulders with a full-thickness tear was the same as that in shoulders with an intact rotator cuff.

\textbf{Materials and Methods}

The rotator cuff of 24 glenohumeral joints of cadavers was exposed by detached the deltoid muscle from its origins on the spine of the scapula, the acromion and the clavicle. Of the 24 shoulders, there were 12 with an intact rotator cuff (mean age 63.3 years; 47 to 74) and 12 with a full-thickness tear (mean age 79.3 years; 64 to 94). Of those with an intact rotator cuff eight were male and four female and with a full-thickness tear seven were male and five female. Those with a partial-thickness tear or osteoarthritis of the glenohumeral joint were excluded.

All of the tears were crescent or U-shaped. The mean greatest distance from the torn edge of the tendon to the avulsed humeral insertion site was 29.9 mm (21 to 48). The mean size of the tears was 29.5 mm (17 to 44). Each tear was also classified according to the size of the avulsed humeral insertion site, as small (≤ 1 cm), medium (1 cm to 3 cm), large (3 cm to 5 cm) or massive (> 5 cm).\textsuperscript{28} In eight shoulders the tears were medium-sized and in four large-sized. They were also classified by the tendon involvement as stage 1A if partial thickness, stage 1B if full thickness isolated to supraspinatus, stage 2 if there was involvement of both supraspinatus and infraspinatus, stage 3 if there was involvement of supraspinatus, infraspinatus and subscapularis, and stage 4 if rotator-cuff arthropathy had developed.\textsuperscript{9} Six tears were stage 1B and six were stage 2.\textsuperscript{3} The shape of the acromion\textsuperscript{3} was type-II in nine and type-III in three in those with an intact rotator cuff. There were eight type-II and four type-III acromions in those with a full-thickness tear.

After separating the scapula from the humerus all the soft tissues on the scapula including the labrum were removed to expose the bony surfaces. Anteroposterior and axillary lateral radiographs were taken to exclude those with intraosseous pathology.

The scapula was then secured on a platform using clamps to avoid any movement and the reference points on the scapula for calculation of the glenoid inclination and version were digitised by a 3D digitising system with an accuracy of 0.2 mm (Microscribe-3DX; Immersion Co, San Jose, California). A 3D co-ordinate was assigned for each point and the inclination and version angles were computed.

Glenoid version was defined as the angle between the line connecting the most anterior and posterior points of the glenoid and a line perpendicular to that connecting the centre of the glenoid and the point where the scapular spine meets the medial border of the scapula.\textsuperscript{19,22}

The line connecting the most superior and inferior points of the glenoid was used in all six measurements of glenoid inclination. We determined the angle between this line and the following lines in order to evaluate the repeatability of six angles of inclination of the glenoid previously described, as follows: the tangent line to the lateral border of scapula passing through the most inferior point of the glenoid (angle 1)\textsuperscript{20} the line between the most superior point of the glenoid and the most superior point of the scapular blade medial to the suprascapular notch (angle 2)\textsuperscript{21} the line between the most inferior point of the scapula and the most inferior point of the glenoid (angle 3)\textsuperscript{18} the line between the most inferior point of the scapula and the most inferior point of the glenoid (angle 4)\textsuperscript{21} a line perpendicular to the line between the midpoint of the glenoid in the scapular plane and the point where the scapular spine meets the medial border of the scapula (angle 5)\textsuperscript{19} and the line from the spinoglenoid notch to the point where the scapular spine meets the medial border of the scapula (angle 6)\textsuperscript{17} (Fig. 1). In order to assess intra- and interobserver reliability, measurements were recorded ten times on the same scapula by the same observer. Two observers (UK, RBA) then repeated the measurements on 12 specimens after an interval of two weeks.

Since 2-D measurements from radiographs had been used in a previous study,\textsuperscript{17} we obtained radiographs of our scapulae and then performed 2D measurements for comparison with our 3D measurements made directly from the scapulae. This allowed us to analyse the impact of the method of measurement on our results.

\textbf{Statistical analysis.} Intra- and interobserver reliability of the six different angles used to measure the glenoid inclination and the one measurement of glenoid version were defined by a coefficient of repeatability\textsuperscript{29} and correlation coefficients (Pearson’s method). The number of specimens needed for a power of 0.80 and alpha of 0.05 was calculated. We calculated that a minimum of 30 shoulders (15 per group) was necessary for a difference of 5˚ between means (and a SD of 4.7) from the previous study.\textsuperscript{17} Comparison of the two groups (shoulders with an intact rotator cuff and those with full thickness tears) for glenoid inclination and version were performed by an unpaired two-tailed \textit{t}-test. The level of significance was set at \(p = 0.05\). A post-hoc power analysis was used to determine the number of specimens needed if statistical significance was not obtained. SigmaStat software (Systat Software Inc, Point Richmond, California) was used for the statistical and power analysis.

\textbf{Results}

Ten repeated 3D measurements using the Microscribe-3DX system (Immersion Co) on the same scapula were within 0.6˚, 0.4˚, 0.5˚, 0.6˚, 0.5˚, 0.6˚ and 0.6˚ for glenoid inclination angles 1, 2, 3, 4, 5 and 6 and for glenoid version,
respectively. The coefficients of repeatability for glenoid inclination angles 1, 2, 3, 4, 5 and 6 and for glenoid version were 1.49, 0.81, 2.59, 0.90, 1.22, 1.27 and 0.58, respectively. The most precise measurement of glenoid inclination was based on the most superior point of the scapular blade medial to the suprascapular notch and the most superior point of the glenoid (angle 2). Intra- and interobserver reliabilities are shown in Table I.

The value of the angle for glenoid inclination depended on the reference line used for the measurement. A larger angle was associated with a more superior-facing glenoid for angles 1, 3, 4, 5 and 6. Only for angle 2 was a smaller value for the angle associated with a more superior-facing glenoid.

There were no significant differences when shoulders with an intact rotator cuff were compared with those with a full-thickness tear for either glenoid inclination or glenoid version (Table II).

Using post-hoc power analysis, we found that the number of specimens needed to achieve statistical significance was large. When alpha was set at 0.05, the power of the statistical analysis was 0.12, 0.16, 0.24, 0.16, 0.10, 0.13 and 0.31 for glenoid inclination angles 1, 2, 3, 4, 5 and 6, and glenoid version, respectively. For a power of 0.80 and
Table I. Based on repeated measurements performed by two observers with an interval of two weeks, intra- and interobserver reliabilities of the angles were determined by the coefficient of repeatability and correlation coefficient. A method is more reliable when the coefficient of repeatability is low and the correlation coefficient is high.

<table>
<thead>
<tr>
<th>Angle</th>
<th>Intra-observer (rater 1)</th>
<th>Intra-observer (rater 2)</th>
<th>Interobserver</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient of repeatability</td>
<td>Correlation coefficient</td>
<td>Coefficient of repeatability</td>
</tr>
<tr>
<td>1</td>
<td>1.31</td>
<td>0.990</td>
<td>2.04</td>
</tr>
<tr>
<td>2</td>
<td>0.96</td>
<td>0.990</td>
<td>1.04</td>
</tr>
<tr>
<td>3</td>
<td>1.12</td>
<td>0.971</td>
<td>1.30</td>
</tr>
<tr>
<td>4</td>
<td>1.62</td>
<td>0.985</td>
<td>1.75</td>
</tr>
<tr>
<td>5</td>
<td>1.53</td>
<td>0.988</td>
<td>1.86</td>
</tr>
<tr>
<td>6</td>
<td>1.73</td>
<td>0.974</td>
<td>1.91</td>
</tr>
<tr>
<td>Version</td>
<td>2.78</td>
<td>0.922</td>
<td>1.93</td>
</tr>
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</table>

Table II. Mean (SD) values for glenoid inclination and glenoid version in shoulders with an intact rotator cuff and those with a full-thickness tear. For angle 5, negative values show that the glenoid faces inferiorly. For glenoid version positive values show retroversion.

<table>
<thead>
<tr>
<th>Angle</th>
<th>Shoulders with intact rotator cuff (˚)</th>
<th>Shoulders with full-thickness tears (˚)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>44.8 (4.3)</td>
<td>43.2 (4.9)</td>
<td>0.43</td>
</tr>
<tr>
<td>2</td>
<td>70.3 (5.3)</td>
<td>68.4 (3.4)</td>
<td>0.34</td>
</tr>
<tr>
<td>3</td>
<td>41.0 (3.1)</td>
<td>38.8 (4.5)</td>
<td>0.19</td>
</tr>
<tr>
<td>4</td>
<td>57.8 (2.9)</td>
<td>56.5 (3.2)</td>
<td>0.34</td>
</tr>
<tr>
<td>5</td>
<td>-5.2 (5.0)</td>
<td>-3.9 (3.0)</td>
<td>0.46</td>
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<tr>
<td>6</td>
<td>85.8 (5.6)</td>
<td>87.5 (3.1)</td>
<td>0.40</td>
</tr>
<tr>
<td>Version</td>
<td>3.3 (4.2)</td>
<td>6.8 (5.9)</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Table III. Comparison (mean, SD) of two-dimensional (2D) versus three-dimensional (3D) measurements for angle 2 and angle 6.

<table>
<thead>
<tr>
<th>Angle</th>
<th>2D (˚)</th>
<th>3D (˚)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 (intact)</td>
<td>67.6 (6.2)</td>
<td>70.3 (5.3)</td>
<td>0.09</td>
</tr>
<tr>
<td>2 (tear)</td>
<td>68.8 (2.9)</td>
<td>66.4 (3.4)</td>
<td>0.71</td>
</tr>
<tr>
<td>6 (intact)</td>
<td>93.8 (2.6)</td>
<td>85.8 (5.6)</td>
<td>0.03</td>
</tr>
<tr>
<td>6 (tear)</td>
<td>95.9 (5.0)</td>
<td>87.5 (3.1)</td>
<td>0.01</td>
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</tbody>
</table>

alpha of 0.05, the number of shoulders which would have been necessary to achieve statistical significance for glenoid inclination angles 1, 2, 3, 4, 5 and 6, and glenoid version was 142, 92, 55, 96, 172, 120 and 41 shoulders per group, respectively.

Two-dimensional measurements from radiographs of our most repeatable angle (angle 2) and that used in a previous study were compared with our 3D measurements which were made directly from the cadaver scapulae. The differences between the 2D, radiological and 3D measurements were significant for angle 6 but not for angle 2 (Table III).

Discussion
In our study we first defined the repeatability of different 3D measurements of glenoid inclination. Of six angles of inclination of the glenoid which had been described previously, that with a reference line between the most superior point of the glenoid and the most superior point of the scapular blade medial to the supraspinatus notch (angle 2), was most reliably measured. Except for angle 6 our measurements were consistent with those of previous studies. We then compared glenoid orientation in shoulders with intact rotator cuffs with that in full thickness tears. No significant difference in either glenoid inclination or glenoid version was found, differing from a previous study on eight paired cadaver shoulders with 2D measurements from radiographs using angle 6 in which significantly increased glenoid inclination in shoulders with tears (98.6˚, SD 5.6˚) was reported in comparison with contralateral shoulders with an intact rotator cuff (91.0˚, SD 4.7˚). This discrepancy in the findings may have resulted from differences in the methods used in the two studies. In our study, measurements in 3D were made directly from cadaver shoulders in our study while in the previous investigation 2D measurements from radiographs had been used. Analysis of the impact of the method of the measurement on the results, showed that the difference between the 2D, radiological and 3D measurements from cadaver scapulae was significant for angle 6 but not for angle 2 (Table III). Contrary to the findings of the previous study, our 2D measurements of glenoid inclination using angle 6 were not significantly different in scapulae with intact rotator cuffs and those with tears (p = 0.26). Another reason for the discrepancy in the findings may have been differences in the severity of the tears between the two studies. It has been reported that shoulders with the most severe tears have wear of the articular surface of both the humeral head and the glenoid. The anterosuperior aspect of the glenoid is most commonly involved. This may cause the glenoid to become orientated more anteriorly and superiorly in shoulders with cuff arthropathy. In our study, eight of the tears were medium- and four were large-sized with a mean size of 29.5 mm (17 to 44; SD 9.2). None had rotator-cuff arthropathy. In the previous study, the shoulders were also not classified as having rotator-cuff arthropathy, but the mean size of their tears was larger than that of ours, being 40 mm (SD 6.0). If some of their shoulders had rotator-cuff arthropathy, eburnation of the anterosuperior articular cartilage may have resulted in a greater glenoid inclination when measured using angle 6.
Statistical analysis of our study was open to type-II error. While intra- and interobserver reliability were highest for glenoid inclination based on the line connecting the most superior point of the glenoid and the most superior point on the body of the scapula, we found that 96 shoulders would have been needed to achieve statistical significance between shoulders with and without tears.

The difference between the mean ages of the shoulders in the two groups is another limitation. Shoulders with an intact rotator cuff were a mean of 16 years younger than those with a full-thickness tear. This difference in age resulted from difficulty in obtaining large numbers of cadaver shoulders, especially with tears, but is unlikely to have had a bearing on the result and conclusions. If there was a congenital difference in glenoid orientation between shoulders with and without tears, we would have found this difference regardless of age. If there had been a difference in glenoid orientation between shoulders with and without tears which was acquired, a mean age of 63.3 years was likely to have been sufficient to demonstrate the difference. A control group of a younger age would not have changed the outcome of our study.

We conclude that glenoid inclination determined by a reference line between the most superior point of glenoid and the most superior point of the scapular blade medial to the supraspinatus notch (angle 2) should be used for measurement of glenoid inclination. Using 3D measurements, glenoid orientation did not differ in shoulders with intact and torn rotator cuffs.

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References