The Reduction in Stability From Combined Humeral Head and Glenoid Bony Defects Is Influenced by Arm Position

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Background: Combined defects of the glenoid and humeral head are often a cause for recurrent shoulder instability. Purpose/Hypothesis: The aim of this study was to evaluate the influence of combined bony lesions on shoulder instability through varying glenohumeral positions. The hypothesis was that instability due to combined defects would be magnified with increasing abduction and external rotation.

Study Design: Controlled laboratory study.

Methods: Eighteen cadaveric shoulders were tested. Experiments were performed at combinations of glenohumeral abduction angles of 20°, 40°, and 60° and external rotations of 0°, 40°, and 80°. The various glenoid defect sizes created were 10%, 20%, and 30% of the glenoid width. Four humeral head defects were created based on humeral head diameter (6%, 19%, 31%, and 44%). Each experiment consisted of translating the glenoid in a posterior direction to simulate an anterior dislocation under a 50-N load. The instability was measured as a percentage of intact translation (ie, loss in translational distance normalized to the no-defect condition).

Results: At 20° of abduction, instability increased from 100% to 85%, 70%, and 43% with increasing glenoid defect sizes of 10%, 20%, and 30%, respectively, with a 6% humeral head defect. However, at a functional arm position of apprehension, these values were significantly decreased (\(P < .05\)) for humeral head defect sizes of 19%, 31%, and 44%, with translation values of 49%, 27%, and 2%, respectively.

Conclusion: A humeral defect leads to rotational instability with the arm rotated into a functional position rather than a resting position. However, a significant glenoid defect can lead to loss of translation independent of changes in arm position. Combined defects as large as 44% of humeral head and 20% glenoid did not show instability at 20° of abduction and neutral position; however, defects as small as 19% humeral head defect and 10% glenoid defect led to significant instability in the position of apprehension.

Clinical Relevance: Instability at lower levels of abduction and external rotation clinically indicates larger bony defects and may need to be directly addressed, depending on the patient’s age and function.

Keywords: shoulder; humeral head defect; glenoid defect; range of motion; combined defects; anterior instability; glenohumeral joint

Instability of the shoulder is a condition in which the humeral head can translate excessively on the glenoid fossa, resulting in subluxation or dislocation and eventually loss of function. Traumatic and repetitive shoulder instability can lead to glenohumeral bone loss, causing pain and dysfunction. The 2 most common bony defects associated with glenohumeral instability are the humeral head (Hill-Sachs) defect and the glenoid (bony Bankart) defect. A humeral head defect is a posterosuperior humeral head impaction injury. Anterior glenoid bone loss may come from a single glenoid defect or attritional bone loss from repeated instability episodes. Patients with significant bone loss are prone to increased instability. A humeral head defect greater than 31% of the humeral head diameter and a glenoid defect greater than 25% of the glenoid width are considered significant (Figure 1). A radiographic study showed that 95% of cases of chronic anterior shoulder instability entailed bony defects, either humeral or glenoid. Moreover, an osseous lesion of the glenoid was present in 139 of 160 shoulders (86.9%). Most important, it was shown that 73.1% of the 160 cases had a humeral head impaction fracture that was identified on anteroposterior radiographs. Burkhart and De Beer reported an overall recurrence rate of 10.8% after arthroscopic Bankart repair for traumatic anterior-inferior instability, with a 4% rate of recurrence in patients without significant bony defects and 67% in patients with...
significant bony defects. Similarly, multiple studies have reported a recurrence rate of 15% to 18% after arthroscopic soft tissue repair when bony defects are present.\(^4\,17\) Rowe et al\(^9\) showed that humeral head defects greater than 25% of the glenoid width can cause significant shoulder instability.\(^6\,21\) Many biomechanical studies have investigated the effect of an isolated humeral head or glenoid defect on glenohumeral instability.\(^8\,9\,16\,23\) Kaar et al\(^9\) showed that humeral head defects greater than five-eighths of the radius of the humeral head (31% of the diameter) caused significant shoulder instability.\(^6\,21\) Yamamoto et al\(^22\) showed that anterior glenoid bone loss greater than 25% of the glenoid width can cause significant instability leading to dislocation. While numerous authors have acknowledged that these 2 defects often present together, only a few studies have investigated the recurrent instability effects of combined bony defects.\(^1\,13\,18\,19\) Despite the fact that combined defects are more common than isolated defects, little is known about the critical size thresholds in these situations.

Burkhart and De Beer\(^3\) suggested that the engagement of a humeral defect with the glenoid rim could increase the chance of dislocation. When the humeral head defect aligns with the anterior glenoid rim, with the shoulder in a functional position of abduction (ABD) and external rotation (ER), the humeral head defect “engages” the glenoid. However, with the potentially magnified effect of combined defects, the engagement process may occur even at a nonfunctional arm position. To understand the dynamic relationship of combined bony defects in glenohumeral instability, it is necessary to investigate the effects on a wide range of motion.

The purpose of this biomechanical study was to evaluate anterior instability of the shoulder due to combined defects and to define critical defect size combinations. Specifically, we evaluated the effect of different sizes of combined defects over varying ABD and ER angles. Our hypothesis was that the threshold humeral head and glenoid defect sizes that lead to instability would be smaller for combined defects than for isolated defects. Furthermore, we expected instability to be influenced by arm position with respect to the humeral head defects but not the glenoid defects.

**METHODS**

**Specimen Preparation**

Eighteen fresh-frozen cadaveric shoulder specimens were used from donors between the ages of 43 and 69 years at the time of death (mean age, 57 years; 9 males and 9 females; 9 left and 9 right shoulders). These specimens were thawed overnight at room temperature before experimentation. All specimens were inspected for rotator cuff tear, fractures, contracture, osteoarthritis, or other shoulder diseases, and none were excluded. The testing method and specimen preparation for this study were adapted from previous studies.\(^8\,9\,19\) Each specimen was disarticulated at the scapulothoracic joint proximally. The skin, subcutaneous tissue, and all soft tissues including the labrum were removed. The humeral shaft was then cut at a distance of 15 mm distal to the humeral head.

The scapula was potted with Woods metal (42.5% bismuth alloy; McMaster-Carr) in a rectangular aluminum container by use of a custom device to ensure that the face of the fossa was horizontal with the lateral 3 cm protruding. After potting, alignment of the superior-inferior glenoid plane was confirmed with the use of a digitizer (MicroScribe; Solution Technologies Inc). The scapula pot sat on top of a horizontal drive (Zaber Technologies Inc), and a 6 degrees of freedom load cell (Mini45; ATI Industrial Automation) was placed between the drive and the pot (Figure 2). The load cell verified a 50-N medial force applied to the glenoid. The coordinate system for the glenoid was placed at the center of the glenoid face. The x-axis was defined perpendicular to the scapula plane and directed anteriorly, the y-axis was parallel to the scapular plane directed inferiorly, and the z-axis was directed upward perpendicular to the face of glenoid fossa (Figure 2). The rotation around the x-axis was defined as ABD, while the rotation around the y-axis was defined as ER. After the scapula was potted, the humeral shaft was potted in cylindrical aluminum tubing with Woods metal. The potted end of the humeral shaft was mounted to the vertical jig with 3 degrees of freedom (Figure 2). This jig allowed for free movement in a medial-lateral (vertical) direction via near-frictionless bearings and allowed for various ER...
and ABD angle combinations. A laser displacement sensor (Renishaw Inc), with an accuracy of 4 μm, was attached to the vertical reaction frame to measure the medial-lateral displacement of the humeral head.

Biomechanical Testing

Before testing, neutral rotation was defined relative to the trunk, which was equivalent to 20° of ER in the scapular plane. Then, a reference position (home) was defined for each arm position (9 cases) configuration by translating the humeral head 7 mm along both the superior-inferior and anterior-posterior axes for intact condition. The reference position was defined as the position at which the humeral head was most medial. This step also helped to precondition the specimen before testing. Testing was then performed for the intact condition (no defect) by translating the glenoid posteriorly at a constant velocity of 0.5 mm/s (to minimize viscoelastic effects) under a medial centering load of 50 N to cause an anterior dislocation.8 The load of 50 N has been used in past studies, and it simulates the static soft tissue load as well. Moreover, it has been demonstrated that during dislocation, the 50-N force caused no damage to the humeral head.8,9,23 The real-time readings of the forces and displacements were recorded via a computer by use of a USB data acquisition card (National Instruments Corp) and custom-developed LabView code (National Instruments Corp). All data were sampled at 50 Hz frequency.

Testing was completed at 3 ABD angles relative to the scapula: 20°, 40°, and 60°. These ABD angles simulated the arm in abduction relative to the trunk at 30°, 60°, and 90°, respectively.14 Additionally, 3 different ER angles of 0°, 40°, and 80° were tested for each condition. The arm at 60° ABD and 80° ER simulated the apprehension position of 90° ABD and greater than 90° ER relative to trunk.10

After different arm positions were tested for the intact joint, defects were created for both the humeral head and the glenoid. Four different sizes of humeral head defects were created representing 6%, 19%, 31%, and 44% of the humeral head diameter, similar to past studies.9,19 Additionally, 3 different sizes of the glenoid defect were created: 10%, 20%, and 30% of the width of glenoid.23 Since it was not feasible to test every defect combination in a single specimen, 3
different defect-creation pathways were chosen (solid, doubledotted, and dashed lines in Figure 3). Twenty different combinations of 2 different defects were possible. Because we knew from past studies that an isolated glenoid defect greater than 25% of glenoid width and a humeral defect greater than 31% of the humeral diameter cause significant instability, we did not test the conditions shown as empty boxes in Figure 3. Each of the 3 pathways (solid, dashed, and double-dotted lines in Figure 3) was assigned 6 specimens based on the power analysis. Seven defect combinations were tested for both solid-line and dashed-line pathways, and each combination was tested at 9 different arm positions. Similarly, the double-dotted-line pathways had 8 combinations of defects, which were tested at 9 different arm positions as well. Therefore, in total we tested 1188 different cases for this cadaveric study in a randomized order. This approach was used to maximize the use of each specimen for testing the maximum number of meaningful combinations.

Creation of Defects

The progressive humeral head defect-creation technique was adapted from Kaar et al. The defects were created by using a customized cutting jig and an oscillating bone saw. The position of the defects was centered in the area in which humeral head defects occur, which was at 209 from the anterior border of the humeral head articular cartilage (Figure 4A). The center point of the defect was marked; the cutting guide was aligned perpendicular to the articular surface of the humeral head. The glenoid defect-creation approach was an adaptation of a method by Yamamoto et al. An osseous glenoid defect was created stepwise in increments relative to the glenoid width by cutting off the anterior rim parallel to the y-axis of the glenoid at the 3-o’clock position (Figure 4B). The diameter was measured for both superior-inferior aspects and anterior-posterior aspects by considering the lower glenoid as a circle. At the point where these 2 diameters intersected, a Kirschner wire was inserted to align the cutting jig parallel to the superior-inferior diameter (y-axis), and then osteotomy cuts were made parallel to the y-axis.

Data Analysis

For each trial, the outcomes of interest were the percentage of intact translation (%IT) and the stability ratio (SR). The distance to dislocation was defined as the distance between the reference position (home position) and the point of dislocation along the anterior axis. This was normalized to the corresponding distance from the intact test for each defect configuration to obtain %IT. Matlab 10.1a (The MathWorks Inc) was used to compute the point of dislocation such that the reaction force in the anterior direction (x-axis) was zero. However, the SR was calculated as the ratio of horizontal reaction force (anterior-posterior direction) and a compressive load of 50 N. Also, the SR was computed as the ratio of horizontal reaction force to the compressive load (50 N). Analyses of variance (ANOVAs) were used to identify the significance of each factor (humeral head defect, glenoid defect, ABD angle, and ER angle) on the %IT and SR. A 2-way ANOVA was performed for defect size and arm position in the R3.1 statistical package (R Core Team 2014; R Foundation for Statistical Computing). Tukey post hoc analyses were used to determine

<table>
<thead>
<tr>
<th>Glenoid Defect</th>
<th>Size</th>
<th>0%</th>
<th>6%</th>
<th>19%</th>
<th>31%</th>
<th>44%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humeral Defect</td>
<td></td>
<td>0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10%</td>
<td></td>
<td>6%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td></td>
<td></td>
<td>19%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>30%</td>
<td></td>
<td></td>
<td>31%</td>
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</table>

**Figure 3.** Defect-creation matrix with 3 chosen pathways (solid, dashed, and double-dotted lines) to create defects in the specified order to maximize the combinations tested and capture the linear and curvilinear effects.

**Figure 4.** (A) Humeral head defect creation at 209° location with 4 different osteotomy cuts (6%, 19%, 31%, and 44%) respective of the humeral head diameter. (B) Osteotomy cuts for glenoid defects for defect sizes 10%, 20%, and 30% of the width of glenoid, adapted from Yamamoto et al.
significance of differences between factor levels. Statistical significance was set at $\alpha = .05$.

RESULTS

Results for both %IT and SR were described for varying arm positions divided into 3 groups. Groups A, B, and C represent the corresponding arm positions of 20° ABD and 0° ER, 40° ABD and 40° ER, and 60° ABD and 80° ER, respectively. Figure 5 illustrates the effect of increasing sizes of the humeral head defect tested in the study when combined with different glenoid defects. For group A, the differences for %IT were not significant for the humeral defect sizes (6%, 19%, 31%, and 44%) from an intact humeral head (0% by definition). However, the value for %IT was decreased significantly for group B (humeral head defect of 44%) and group C (humeral head defects of 19%, 31%, and 44%) ($P < .001$). The SR for 44% humeral head defect significantly decreased only for group C, as shown in Figure 6B ($P < .01$). The mean and standard deviation values of %IT and SR for increasing humeral head defect sizes are shown in Table 1.

The %IT for increasing glenoid defect size showed a significant difference at all levels when the humeral head defect size (6%) was kept constant (Figure 7A). The %IT was reduced from 100% (by definition) to 43% ± 10% (30% glenoid defect) (Tables 2 and 3). These values did not change among the 3 groups of arm positions (Table 2). With the exception of a 10% glenoid defect, all other glenoid defect sizes were significantly different from the intact condition ($P < .001$). Additionally, Figure 7B shows the results of %IT for the combined effect of a 19% humeral head defect with various sizes of the glenoid defects. The results for %IT were similar to those of Figure 6A only for groups A and B. However, results for group C were significantly different from groups A and B at each glenoid defect size.
defect. The SR for 20% and 30% glenoid defect combined with a 6% humeral defect was significantly different ($P < .001$) from the no glenoid defect condition for all 3 groups (Figure 6A).

The mean humeral head diameter for all specimens was $43 \pm 4$ mm (range, $36-50$ mm). The mean glenoid width for all specimens was $23 \pm 2$ mm (range, $17.5-25.5$ mm). Finally, the mean glenoid concavity depth for all specimens was $1.43 \pm 0.73$ mm (range, $0.36-3.03$ mm). A linear relationship was also observed between the SR and concavity depth. This relationship was represented as $SR = 0.0881 + 0.1023 \times \text{Depth}$, with an $R^2 = 0.74$ (Figure 8).

### DISCUSSION

This model simulated the effects of combined humeral head and glenoid defects for a wide range of arm positions by using a cadaveric model. In this study, we showed that even with the arm at 40° ABD and 40° ER (group B), there

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#### TABLE 1
Percentage Intact Translation and Stability Ratio for Increasing Humeral Head Defect Sizes Combined With a 20% Glenoid Defect

<table>
<thead>
<tr>
<th>Humeral Head Defect Size</th>
<th>Group A %IT</th>
<th>SR</th>
<th>Group B %IT</th>
<th>SR</th>
<th>Group C %IT</th>
<th>SR</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>69 ± 10</td>
<td>0.17 ± 0.04</td>
<td>71 ± 10</td>
<td>0.16 ± 0.04</td>
<td>74 ± 11</td>
<td>0.18 ± 0.04</td>
</tr>
<tr>
<td>6%</td>
<td>64 ± 13</td>
<td>0.15 ± 0.06</td>
<td>70 ± 10</td>
<td>0.15 ± 0.06</td>
<td>70 ± 15</td>
<td>0.16 ± 0.07</td>
</tr>
<tr>
<td>19%</td>
<td>65 ± 11</td>
<td>0.16 ± 0.07</td>
<td>67 ± 16</td>
<td>0.17 ± 0.07</td>
<td>49 ± 24</td>
<td>0.19 ± 0.08</td>
</tr>
<tr>
<td>31%</td>
<td>67 ± 9</td>
<td>0.19 ± 0.07</td>
<td>56 ± 14</td>
<td>0.18 ± 0.07</td>
<td>27 ± 25</td>
<td>0.09 ± 0.10</td>
</tr>
<tr>
<td>44%</td>
<td>69 ± 14</td>
<td>0.18 ± 0.08</td>
<td>23 ± 21</td>
<td>0.12 ± 0.08</td>
<td>2 ± 4</td>
<td>0.00 ± 0.01</td>
</tr>
</tbody>
</table>

*Results are reported as mean ± SD. Groups A, B, and C represent the corresponding arm positions of 20° of abduction (ABD) and 0° of external rotation (ER), 40° ABD and 40° ER, and 60° ABD and 80° ER, respectively. %IT, percentage intact translation; SR, stability ratio.

#### TABLE 2
Percentage of Intact Translation and Stability Ratio for Increasing Glenoid Defect Sizes Combined With a 6% Humeral Head Defect

<table>
<thead>
<tr>
<th>Glenoid Defect Size</th>
<th>Group A %IT</th>
<th>SR</th>
<th>Group B %IT</th>
<th>SR</th>
<th>Group C %IT</th>
<th>SR</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>104 ± 3</td>
<td>0.26 ± 0.09</td>
<td>104 ± 3</td>
<td>0.27 ± 0.08</td>
<td>103 ± 4</td>
<td>0.31 ± 0.09</td>
</tr>
<tr>
<td>10%</td>
<td>83 ± 16</td>
<td>0.19 ± 0.08</td>
<td>86 ± 10</td>
<td>0.20 ± 0.09</td>
<td>85 ± 12</td>
<td>0.19 ± 0.09</td>
</tr>
<tr>
<td>20%</td>
<td>65 ± 13</td>
<td>0.15 ± 0.06</td>
<td>70 ± 10</td>
<td>0.15 ± 0.06</td>
<td>70 ± 15</td>
<td>0.16 ± 0.07</td>
</tr>
<tr>
<td>30%</td>
<td>41 ± 21</td>
<td>0.09 ± 0.05</td>
<td>40 ± 20</td>
<td>0.08 ± 0.05</td>
<td>43 ± 10</td>
<td>0.08 ± 0.06</td>
</tr>
</tbody>
</table>

*Results are reported as mean ± SD. Groups A, B, and C represent the corresponding arm positions of 20° of abduction (ABD) and 0° of external rotation (ER), 40° ABD and 40° ER, and 60° ABD and 80° ER, respectively. %IT, percentage intact translation; SR, stability ratio.

#### TABLE 3
Instability at 60° of Abduction and 80° of External Rotation

<table>
<thead>
<tr>
<th>Defect Matrix</th>
<th>Humeral Head Defect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>0%</td>
</tr>
<tr>
<td>0%</td>
<td>100 ± 0</td>
</tr>
<tr>
<td>10%</td>
<td>85 ± 9</td>
</tr>
<tr>
<td>20%</td>
<td>74 ± 11</td>
</tr>
<tr>
<td>30%</td>
<td>74 ± 11</td>
</tr>
</tbody>
</table>

*Instability is given as a percentage of intact translation; results are reported as mean ± SD. Gray-shaded boxes show the isolated defects determined to be repaired by past studies. The current study shows that the defect combinations with black shading might need restoration of either defect; the boxes with no numbers are combinations not tested. A 100% value shows the no-defect condition, signifying full stability.
was instability with increasing sized humeral head and glenoid defects. The instability effect due to a humeral head defect was magnified with increasing ABD angle and ER. Furthermore, similar to a finite element study,\textsuperscript{18} the current study found that instability caused by a glenoid defect was dependent only on the size of the defect but remained unaffected by arm abduction or rotation. However, our model did not have soft tissue, so physiologically some restraint may be present at the midrange of motion due to soft tissue. The interactions between the glenoid and humeral head defects show the increased instability effect.

Previous studies have investigated the effect of an isolated humeral head defect or an isolated glenoid defect and have shown that glenoid defects greater than 25% of the width or humeral head defects greater than 31% of the diameter can significantly cause instability (Table 3).\textsuperscript{9,16,23} Results from the present study are similar to those from past studies when looking at these 2 defects in isolation. However, we found that a combination of smaller defects of the glenoid and humeral head could significantly cause instability. A 19% humeral head defect combined with a 10% glenoid defect resulted in a 15% increase in instability (%IT) at 20° ABD and 0° ER (group A); however, instability doubled (30%) at a functional arm position of 60° ABD and 80° ER (group C) (see Figure 7). This decrease in %IT was similar to that from an isolated 20% glenoid defect (27% decrease in %IT), as shown in Table 3. Therefore, it is suggested that a combination of 10% glenoid defect and 19% humeral head defect will require augmentation through a procedure such as the Latarjet.

This cadaveric model outlined different types of instability from either defect. The glenoid defect leads to a translational instability due to the loss of curvature of the articular surface, and the humeral head defects lead to rotational instability. Increasing glenoid defect sizes had a significant effect on shoulder instability, as the increased bone loss reduced the %IT and SR. Moreover, the changes in arm position did not affect the values of %IT. This shows that translational stability is lost with the loss of glenoid articular surface. However, the magnified effect of the humeral head defect results from a rotational effect. When the arm was at a resting position (group A), even the largest humeral defect (44%) represented no instability. Nevertheless, when the arm was elevated and rotated at apprehension position (group C), the instability was significant. This reduction in %IT demonstrates the magnified instability from the humeral head lesion, which is caused by rotating the head onto the glenoid defect. Similarly, the glenoid track concept shows that the baseline stability is determined by glenoid track, which is 84% of the glenoid width, and the engagement of a humeral head defect is dependent on its location and the arm position.\textsuperscript{22} These findings indicate the importance of testing in multiple arm positions to fully understand the relationship between bone defects and glenohumeral instability.

Previous studies have reported instability in terms of percentage of intact translation, horizontal reaction forces,
and stability ratios.\textsuperscript{19,23} The present study reports the instability in terms of both %IT and SR. The standard deviation for the SR results was higher than that for %IT. The likely explanation for this was specimen variability, specifically variation in glenoid width, glenoid height, and concavity depth. The ranges for glenoid width and height were 17.5 to 25.4 mm and 30 to 36 mm, respectively. However, concavity depth was variable among specimens, with an observed range of 0.36 to 3.03 mm. Most similar studies have used SR as the primary outcome of shoulder instability and have found it to be dependent on the concavity depth. Additionally, the relationship between the concavity depth and the SR was found to be linear (Figure 8). Hence, the SR should be reported along with concavity depth.\textsuperscript{11,12}

Due to the higher standard deviation of SR for each specimen, the %IT was used as a primary outcome and a mode for sensitivity analysis. In addition, the adoption of glenoid track by other researchers is in consensus with our findings. The glenoid track is the value calculated based on the width of the glenoid and is reported in millimeters.\textsuperscript{22}

Limitations of this study are similar to those of other cadaveric studies. One limitation is the absence of soft tissue; however, this study focused only on the geometric effects of the glenohumeral joint. The mechanisms of instability due to the capsuloligamentous structures need to be assessed in future studies. The osseous defects created in the current study may not be reproduced clinically, as these were created in a controlled, laboratory environment; however, this was found to be a reliable way to test the defect factors.\textsuperscript{9} Another limitation was that not all defect combinations were tested on each specimen. However, it is not possible to test every combination in a single specimen, and the isolated defect data are still available in literature.

In summary, combined bony defects led to magnified anterior shoulder instability. In the setting of combined bone loss in recurrent instability, lower critical size thresholds are required. Humeral head defects greater than 19% of the diameter combined with a small glenoid defect (10%) should be considered as a critical size and may need direct surgical intervention. The suggested management of combined defects needs to be tested with a Latarjet procedure in a future study. However, the results from this study imply that humeral head defects and glenoid defects have different pathophysiologic causes of instability. Humeral head defects are intricately related to the rotational effect of the humeral head, whereas glenoid defects cause translational instability. This study is the first to provide basic science data that can be used for the treatment of combined bony defects and can be used to design future studies.

REFERENCES


