Correction of acquired glenoid bone loss in osteoarthritis with a standard versus an augmented glenoid component

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Background: The magnitude and anatomic consequences of pathologic acquired glenoid retroversion and posterior bone loss that can be surgically corrected with a standard versus an augmented glenoid component have not been studied extensively in a surgical patient population.

Materials and methods: Twenty-nine patients with glenohumeral osteoarthritis, acquired posterior bone loss, and increased retroversion were studied by use of a three-dimensional computer surgical simulation. For each case, amount of medialization was measured as the linear distance from the lateral aspect of the glenoid vault model to the center of the articular implant surface. Simulation of implant placement at 0° or 6° was performed with use of a standard glenoid having a uniform thickness and an asymmetric thickness augmented component.

Results: An increased amount of medialization was seen with the standard glenoid, 8.3 ± 4.1 mm, compared with 3.8 ± 3.3 mm with use of the augmented glenoid implant (P < .001). When glenoid retroversion was corrected to 0°, pathologic version was shown to have strong and significant relationship to the amount of medialization for both the standard (R² = 0.825) and augmented (R² = −0.68) glenoid implant. There was an increased ability to correct greater amounts of pathologic version with less medialization by use of an augmented step glenoid compared with a standard anchor peg glenoid.

Discussion: Correction of moderate to severe glenoid retroversion by asymmetric reaming cannot always be done with use of a standard component, and if it is done, it will result in greater medialization of the joint line. Use of an augmented component can allow complete correction of retroversion and minimize the effect of medialization.


Keywords: Shoulder osteoarthritis; severe glenoid bone loss; total shoulder replacement

Total shoulder arthroplasty has proved to be successful in providing pain relief and restoring range of motion for patients with glenohumeral osteoarthritis. Long-term survival of glenoid components, however,
remains the most common reason for late failure due to loosening and wear. The literature demonstrates that glenoid component malposition is associated with excessive retroversion, early component lucency lines, and component loosening. Excessive glenoid component retroversion is correlated with greater amounts of preoperative glenoid retroversion with incomplete correction of retroversion, particularly when standard glenoid components are used. Posterior glenoid bone loss and static posterior humeral head subluxation have been shown to independently predispose the patient to eccentric loading of the glenoid component and early glenoid loosening.

Two of the most commonly employed surgical interventions to correct posterior glenoid bone loss and pathologic preoperative retroversion are asymmetric anterior glenoid reaming and posterior glenoid bone grafting. Correction of glenoid retroversion of more than 15° to 20° by reaming the high side is associated with perforation of the parts of the glenoid component responsible for fixation of the component. Excessive reaming also results in removal of the cortical bone and has been suggested to be a cause of increased glenoid component loosening.

In recent years, augmented glenoid components have been designed and commercialized to treat severe glenoid bone loss (DePuy Warsaw, IN, USA; Smith & Nephew, Memphis, TN, USA; Exactech, Gainesville, FL, USA). Previous wedge-shaped augmented components with metal-backed design (Smith & Nephew, Memphis, TN, USA) demonstrated a high failure rate. Clinical evaluation of the metal-backed components with either augmented or nonaugmented design has shown excessive polyethylene wear that was attributed to the use of a thin polyethylene component on a metal backing. Given these results, there is more interest in the use of an all-polyethylene augmented component to manage moderate to severe glenoid retroversion.

We hypothesized that we could define the consequences of correction of glenoid retroversion by use of a nonaugmented and augmented component and thereby define when an augmented component may be beneficial in terms of complete correction of disease, decreased peg perforation, less medialization of the joint line, and less removal of bone.

**Methods**

The preoperative computed tomography (CT) scans of 29 patients indicated for total shoulder arthroplasty for treatment of osteoarthritis were used in this study. There were a total of 24 men and 5 women in the study cohort, with an average patient age at surgery of 66.9 years. The average pathologic retroversion was $-20.9^\circ \pm 10^\circ$ with a range of 4.5° to 43°. In all patients, the pathologic glenoid retroversion was acquired by bone loss. We excluded all patients having a type C Walch classification of glenoid morphology consistent with developmental abnormality.

All CT scans were performed with a Siemens (Sensation 64, Definition DS or AS+) scanner (Siemens Healthcare, Forchheim, Germany) using a single-energy CT protocol with 140 kVp, 300 mAs with dose modulation 0.6 mm collimation, effective pitch 0.9, B40 (medium) reconstruction kernel, reconstructed slice thickness 0.6 mm, and slice increment 0.6 mm. Three-dimensional reconstructions of preoperative CT images were performed by image analysis software (Cleveland Clinic, Cleveland, OH, USA). The plane of the scapula was defined by 3 points, one placed at the inferior angle of the scapula body, a second at the scapula trigonum, and the third in the center of the glenoid fossa such that a line from this point to the scapula trigonum is in the center of the glenoid vault and defines the center line of the scapula.

Figure 1 The plane of the scapula was defined by 3 points, one placed at the inferior angle of the scapula body, a second at the scapula trigonum, and the third in the center of the glenoid fossa such that a line from this point to the scapula trigonum is in the center of the glenoid vault and defines the center line of the scapula.

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Solid computer models of a commercially available standard and augmented glenoid component (DePuy Global APG and Step Tech APG, Warsaw, IN, USA) are contained within the software and allowed placement of each glenoid component at either 0° or 6° of retroversion with complete back side contact (Fig. 4). The augmented component types were available as 3-mm, 5-mm, and 7-mm augmentation (Fig. 5). The standard nonaugmented
component has a uniform back side radius of curvature. The articulation surfaces for both the augmented and nonaugmented components were the same and available in 5 sizes based on the radius of curvature of the articular surface and their anterior posterior and superior inferior dimensions. Both types of implant have the same number, type, and configuration of fixation pegs (Fig. 6). This consistency allowed study of the effect of augmentation on medialization of the joint line and perforation of the fixation pegs.

Each glenoid component was placed in 0° (perpendicular) and 6° retroversion with reference to the plane of the scapula. The glenoid component was sized in the anterior posterior and superior inferior dimensions of the implant to cover as much of the reamed surface of the glenoid without overhang of the component. The augmented component was sized to use the smallest thickness augment to compensate for the posterior glenoid bone loss with the same full back side contact of the implant on the simulated reamed surface of the bone. For each case, amount of

Figure 2  Three points were placed on the glenoid surface to define a plane that best represented the average version and inclination of the glenoid fossa. These points were approximated to the superior glenoid, the anterior inferior glenoid, and the posterior inferior glenoid in the area of greatest bone loss not including osteophytes.

Figure 3  The medialization of the glenoid joint line in the area of greatest bone loss was defined as distance from the most lateral aspect of the glenoid vault model to the pathologic glenoid defect. This distance (red line) defined the amount of glenoid bone loss as a linear measurement in millimeters.
medialization was measured as the linear distance from the lateral aspect of the glenoid vault model to the center of the articular implant surface when placing the best sized nonaugmented and augmented component with full back side contact (Fig. 7). Perforation of the glenoid wall by either the central or peripheral pegs of the glenoid implant was recorded (Fig. 8).

Statistical analysis

Regression analysis was used to determine the relationship between glenoid retroversion, glenoid implant size, and amount of component medialization as predictors of peg perforation at 0° and 6° for each type of glenoid component used. Regression analysis was also used to determine the relationship between glenoid retroversion, the glenoid vault model anteroposterior size, the preoperative joint line, and the amount of medialization as predictors for use of a +3, +5, or +7 augmented glenoid.

All correlations were determined by Pearson’s r, and a non-paired 2-tailed t test was used to determine the significance of any mean differences. All statistical analyses were performed in SPSS statistical software version 19 by a biostatistician. Statistical significance for all analyses was defined as P < .05.

Results

The average pathologic retroversion of all 30 patients was −20.9° ± 10° with a range of 4.5° to 43°. The average bone loss for all patients was −4.8 ± 2.8 mm. The average medialization when retroversion was corrected to neutral was 8.3 ± 4.1 mm with use of the standard glenoid versus 3.8 ± 3.3 mm when an augmented glenoid component was used (P < .001). The average medialization with correction to 6° retroversion was 7.2 ± 4.2 mm when the standard
The severity of pathologic glenoid retroversion was correlated with the amount of glenoid bone loss ($R^2 = 0.56$) (Fig. 8). When glenoid retroversion was corrected to $0^\circ$ of version, pathologic version was also shown to have strong and significant relationship to the amount of medialization for both the standard glenoid ($R^2 = 0.825$) and the augmented glenoid ($R^2 = -0.68$) (Fig. 9). With increasing glenoid retroversion, there is an increasing difference in the amount of component medialization between the standard glenoid and the augmented glenoid (Fig. 9). The same correlation was observed between the two types of components when retroversion was corrected to $6^\circ$ (Fig. 10).

There was an increased ability to correct pathologic version with less medialization by use of an augmented step glenoid compared with a standard anchor peg glenoid. The augmented glenoid component resulted in less medialization of the joint line and less bone removal to achieve full back side contact of the implant compared with a standard glenoid component. Use of the standard glenoid component placed in neutral ($0^\circ$) allowed correction of $8^\circ$ of pathologic retroversion with 4 mm of medialization compared with correction of an average of $20^\circ$ of pathologic retroversion with use of an augmented component (Fig. 9). When the component was placed in neutral ($0^\circ$) version with 7 mm of medialization, this allowed correction of $16^\circ$ of pathologic version with the standard glenoid component compared with an average correction of $33^\circ$ of pathologic version for the augmented glenoid (Fig. 9). When the glenoid component version was corrected to $6^\circ$, there was an increased amount of pathologic version that could be corrected for each type of implant for the same amount of medialization (Fig. 10).

Pathologic version and implant size were both shown to be significant predictors of peripheral peg perforation at neutral and $6^\circ$ retroversion for the standard anchor peg and augmented components ($P \leq .05$). Increased pathologic version and implant size were both shown to be significant predictors of peripheral peg perforation at neutral and $6^\circ$ retroversion for the standard anchor peg and augmented components ($P \leq .05$).
retroversion resulted in an increased likelihood for peripheral peg perforation. Odds ratios determined that as component size increases, there is a 47% to 58% decrease in the likelihood of perforation. The amount of pathologic glenoid retroversion was not found to be a significant factor associated with perforation of the peripheral pegs between the types of glenoid at either 0° or 6° of component version. Overall, the most common site of peg perforation was with the posterior peg, and 4 of the 11 occurrences of peg perforation with the standard anchor peg glenoid were associated with the central peg. Only 1 of these 4 cases had central peg perforation with the augmented step glenoid. The average pathologic version and amount of component medialization for patients with and without perforation when the glenoid retroversion was corrected to both neutral and 6° retroversion were calculated (Table I). Mean pathologic version and medialization at both neutral and 6° retroversion were also calculated for the patients having central peg perforation with the standard component (Table II).

The amount of pathologic retroversion determines the size of the augmentation required for correction to either 0° or 6° of component version with minimal medialization ($P < .001$). The average glenoid retroversion and the amount of medialization of the joint line using the +3, +5, and +7 mm augmented glenoid were calculated (Table III). Correction of component version to either 0° or 6° resulted in significant differences in the average amount of medialization between the standard glenoid and the augmented glenoid for the 5-mm ($P < .001$) and 7-mm ($P < .001$) augmented components. The difference in medialization between the standard glenoid and augmented glenoid with a 3-mm augment was significant when the glenoid retroversion was corrected to 0° ($P = .04$) but was not significant when the glenoid retroversion was corrected to 6° ($P = .2$).
Total shoulder arthroplasty is technically demanding in regard to implantation of the glenoid component, especially in the setting of increased glenoid deformity. It is well documented that glenoid component malposition causes eccentric loading, thereby predisposing to displacement of the glenohumeral contact point. This can result in humeral instability and implant loosening.

The technical goal for resurfacing the glenoid associated with acquired bone loss is to correct the pathologic version to its native state and to reduce eccentric loading of the prosthetic glenoid. This can be accomplished by preferentially reaming the relatively higher anterior glenoid bone, bone grafting, or implantation of an augmented glenoid component. Use of a bone graft or an augmented glenoid component will result in less medialization of the component, fewer central peg perforations, and removal of less bone for the same degree of correction than with use of a standard component. With greater than 16° of preoperative glenoid version, our results suggest the need to augment with either a posterior glenoid bone graft or an augmented glenoid component to successfully correct pathologic glenoid retroversion and to minimize medialization of the component joint line. The use of an augmented component having a step design with different amounts of augmentation allows correction of larger amounts of glenoid retroversion and less medialization of the joint line. The importance of decreasing medialization while correcting excessive glenoid retroversion is not fully understood but may improve joint stability and strength of the shoulder by restoring better tension of the rotator cuff. Ideally, survival of glenoid components may be optimized by restoring both version and medialization through accurate correction and ideal implant selection.

When the vault model is placed within the pathologic glenoid, the native premorbid joint line can be determined. In this study, as in other studies, the premorbid joint line is on average 6° to 7° retroverted in relation to the plane of the scapula. In correcting the glenoid to 0°, almost all glenoid components were medialized more than in correcting version to 6° and had better restoration of the joint line as measured by the vault model. Our data support the recommendation for correction of the glenoid version to 6° in all patients to optimize implant position and results.

The results from this study support recent evidence suggesting that glenoid retroversion is the strongest predictor of determining the amount of medialization and successful glenoid implantation without perforation of the vault. Perforation of the glenoid vault by the fixation parts...
of the component are dependent on the size of the glenoid, position of the implant and amount of bone loss, medialization of the joint line, and design of the prothetic. In this study, we defined the effect of vault size, amount of bone loss, and medialization of the joint line as it affected peg perforation with the augmented component. Of the 4 patients with central peg perforation with both the standard and the augmented component, 3 of them did not have central peg perforation with the augmented component. One patient had central peg perforation with both the standard and the augmented component.

In this study, there were 4 cases of central peg perforation for standard glenoid implants and only 1 case for augmented components. This was a result of greater amount of medialization of the standard component to achieve full back side contact. Although we do not fully understand the clinical importance of peg perforation for any of these pegs, we consider the central peg to be of primary importance for fixation of this particular implant. Preoperative planning with three-dimensional CT imaging can clearly provide advantages in accurately assessing glenoid retroversion, guiding surgical technique, and selecting the implant to minimize bone loss by reaming and medialization of the joint line. Although our results did not demonstrate improvement in the rate of peripheral peg perforation with this implant design, there was a significant improvement in central peg perforation and the amount of medialization. As suggested by Nowak et al., a glenoid component design with peripheral pegs regardless of augmentation may have a higher rate of peg perforation compared with an in-line pegged glenoid component.

Our results provide a guideline for the use of an augmented component of this design and the selection of an

### Table I

<table>
<thead>
<tr>
<th>Component type</th>
<th>Perforation with correction to neutral</th>
<th>No perforation with correction to neutral</th>
<th>Significance</th>
<th>Perforation with correction to 6°</th>
<th>No perforation with correction to 6°</th>
<th>Significance</th>
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<tbody>
<tr>
<td>Differences in pathologic version</td>
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<tr>
<td>Standard component</td>
<td>$-27.4^\circ \pm 9.8^\circ$</td>
<td>$-15.7^\circ \pm 7.3^\circ$</td>
<td>.002</td>
<td>$-29.2^\circ \pm 8.1^\circ$</td>
<td>$-15.9^\circ \pm 8^\circ$</td>
<td>.000</td>
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<tr>
<td>Augmented component</td>
<td>$-28.6^\circ \pm 8.8^\circ$</td>
<td>$-17.4^\circ \pm 8.9^\circ$</td>
<td>.005</td>
<td>$-31^\circ \pm 8.7^\circ$</td>
<td>$-17.9^\circ \pm 8.9^\circ$</td>
<td>.006</td>
</tr>
<tr>
<td>Differences in medialization</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard component</td>
<td>$-10.3 \pm 4.2$ mm</td>
<td>$-7.1 \pm 3.8$ mm</td>
<td>.042</td>
<td>$-9.7 \pm 3.9$ mm</td>
<td>$-5.7 \pm 3.7$ mm</td>
<td>.012</td>
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<tr>
<td>Augmented component</td>
<td>$-5.2 \pm 3.1$ mm</td>
<td>$-3.4 \pm 3.3$ mm</td>
<td>.17</td>
<td>$-4.1 \pm 3.3$ mm</td>
<td>$-2.7 \pm 2.9$ mm</td>
<td>.319</td>
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</table>

Comparisons of both mean pathologic version and medialization between patients with and without peripheral peg perforation with significance of differences for both component types. Mean medialization of the augmented component at both neutral and 6° retroversion was the only group difference that did not reach statistical significance.

### Table II

<table>
<thead>
<tr>
<th>Component type</th>
<th>Central peg perforation, standard component ($n = 4$)</th>
<th>No central peg perforation, augmented component ($n = 3$)</th>
<th>Central peg perforation, augmented component ($n = 1$)</th>
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<tr>
<td>Pathologic version</td>
<td>$-38.5^\circ \pm 3.7^\circ$</td>
<td>$-38.4^\circ \pm 4.5^\circ$</td>
<td>$-38.6^\circ$</td>
</tr>
<tr>
<td>Medialization with correction to neutral</td>
<td>$-15.08 \pm 2.5$ mm</td>
<td>$-10.23 \pm 1.1$ mm</td>
<td>$-5.3$ mm</td>
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<tr>
<td>Medialization with correction to 6°</td>
<td>$-13.98 \pm 2.1$ mm</td>
<td>$-9.07 \pm 1.1$ mm</td>
<td>$-4.5$ mm</td>
</tr>
</tbody>
</table>

Comparisons of mean pathologic version and medialization between the patients who had central peg perforation with the standard component but not with the augmented component. Of the 4 patients with central peg perforation with use of the standard component, 3 of them did not have central peg perforation when fit with the augmented component. One patient had central peg perforation with both the standard and the augmented component.
appropriately sized augmented glenoid to minimize medialization while correcting pathologic retroversion. This study cannot make conclusions about the clinical implications of this approach to correct pathologic retroversion. Our data do demonstrate the advantages for use of an augmented component by minimizing removal of glenoid bone by asymmetric reaming for correction of moderate to severe pathologic glenoid retroversion. Correction of retroversion with less bone removal may have advantages in improved clinical outcomes.

Conclusion

Our results support the use of an augmented step glenoid implant in patients with greater than 16° of preoperative glenoid retroversion to successfully correct pathologic glenoid retroversion. In correcting pathologic glenoid version, our data support the recommendation for correction of the glenoid retroversion to 6° in all patients to optimize implant position and outcomes. Results from this study provide a guideline for the use of an augmented component of this design and the selection of an appropriately sized augmented glenoid to minimize medialization while correcting pathologic retroversion. Ideally, survival of glenoid components may be optimized by correcting version and minimizing medialization through accurate correction and ideal implant selection.

Disclaimer

Joseph Iannotti designed the augmented glenoid component used in this study and receives royalties from DePuy Johnson & Johnson. He receives consulting income from Tornier and DePuy and royalty income from Tornier, DePuy, Zimmer, and the Musculoskeletal Transplant Foundation.

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