Guidelines for the selection of optimal glenoid augment size for moderate to severe glenohumeral osteoarthritis

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Background: Total shoulder arthroplasty is technically demanding in regard to implantation of the glenoid component, especially in the setting of increased glenoid deformity and posterior glenoid wear. Augmented glenoid implants are an important and innovative option; however, there is little evidence accessible to surgeons to guide in the selection of the appropriate size augmented glenoid.

Methods: Solid computer models of commercially available augmented glenoid components (+3, +5, +7) contained within the software allowed placement of the best fit glenoid component within the three-dimensional reconstruct of each patient’s scapula. Peg perforation, amount of bone reamed, and amount of medialization were recorded for each augment size.

Results: There was strong correlation between the medialization of the joint line and the glenoid retroversion for each augmented component at neutral correction and correction to 6° of retroversion. At neutral, the range of retroversion that restored the anatomic joint line was −3° to −17° with use of the +3 augmented glenoid, −5° to −24° with the +5 augmented glenoid, and −9° to −31° with the +7 augmented glenoid. At 6° of retroversion, the range of retroversion that restored the anatomic joint line was −4° to −21° with use of the +3 augmented glenoid, −7° to −27° with the +5 augmented glenoid, and −9° to −34° with the +7 augmented glenoid.

Conclusions: There was a strong correlation between glenoid retroversion and medialization for all augment sizes, supporting the recommendation for glenoid retroversion as the primary guide in selecting the amount of augmentation.


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Keywords: Augmented glenoid; biomechanics; total shoulder arthroplasty; shoulder osteoarthritis; glenoid bone loss

Glenoid loosening is the leading complication associated with total shoulder arthroplasties, with heightened risk in the setting of increased glenoid deformity and glenoid bone loss.1,6,10,24,28,31,34,37 Understanding of the biomechanics of initial glenoid retroversion and correction of glenoid deformity can provide insight into glenoid failure mechanisms as well as minimize glenoid loosening.11,35 Studies have shown that adequate correction of glenoid disease and accurate placement of prosthetic components are necessary to restore Glenoid loosening is the leading complication associated with total shoulder arthroplasties, with heightened risk in the setting of increased glenoid deformity and glenoid bone loss.1,6,10,24,28,31,34,37 Understanding of the biomechanics of initial glenoid retroversion and correction of glenoid deformity can provide insight into glenoid failure mechanisms as well as minimize glenoid loosening.11,35 Studies have shown that adequate correction of glenoid 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normal glenohumeral motion. Options to address glenoid bone deficiency include asymmetric reaming of the glenoid and glenoid bone grafting, which are both technically demanding with less than optimal outcomes, especially in the setting of increased glenoid retroversion.

The literature demonstrates that glenoid component malposition is associated with early component lucent lines, component loosening, and higher glenoid failure rates. A greater amount of preoperative glenoid retroversion correlates with excessive postoperative glenoid component retroversion, particularly when a standard glenoid is used. The use of simulation software to understand the biomechanics of implant positioning with respect to glenoid vault and version has been well documented in the literature. The goal of glenoid implantation is to correct the glenoid version and use the glenoid vault anatomy to maximize fixation and minimize medialization. Furthermore, preoperative planning with three-dimensional (3D) computed tomography (CT) imaging can clearly provide advantages in accurately assessing glenoid retroversion, guiding surgical technique, and optimizing implant positioning, ultimately improving clinical outcomes and patient satisfaction.

The recent development of augmented glenoid components provides an alternative to current shoulder implant techniques. Current techniques using commercially available glenoid implants, with bone grafting or asymmetric reaming, have been shown to increase glenoid loosening in severe glenoid bone loss by either technical difficulties or compromise of the keel or peg fixation. Augmented glenoids are an important and innovative option; however, there is little evidence accessible to surgeons to guide in the selection and potential outcomes of these augmented implants.

The purpose of this study was to define clinical guidelines for selection of specific glenoid augment size to restore native glenoid morphology with 3D simulation software.

**Methods**

The study cohort consisted of 24 men and 5 women, with an average age of 66 years. All patients were indicated for total shoulder arthroplasty for treatment of osteoarthritis. We excluded all patients having a type C Walch classification of glenoid morphology consistent with a developmental hypoplasia. The study cohort consisted of 24 men and 5 women, with an average age of 66 years. All patients were indicated for total shoulder arthroplasty for treatment of osteoarthritis. We excluded all patients having a type C Walch classification of glenoid morphology consistent with a developmental hypoplasia.

Preoperative CT scans for each patient in our cohort were used in this study. 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 modeling of the shoulder**

Three-dimensional reconstructions of each patient’s preoperative CT images were generated by image analysis software (OrthoVis, Cleveland Clinic, Cleveland, OH, USA). Planes of the scapula and the glenoid fossa were defined to calculate the amount of retroversion. The plane of the scapula was defined by 3 points, one placed at the inferior angle of the scapular 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. The glenoid plane was defined by 3 points 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.

A plane that best represented the overall version and inclination of the glenoid fossa was defined by placing 3 points on the glenoid articular surface; these points were approximated to the superior glenoid, the anterior inferior glenoid, and the posterior inferior glenoid, in the area of greatest bone loss, to provide the most accurate reflection of glenoid retroversion (Fig. 1). The measured retroversion angle was calculated as the angle between the plane of the scapula and plane of the glenoid.

Estimation of the glenoid joint line was measured by use of the glenoid vault model as previously described. The native glenoid morphology/native premorbid joint line was calculated in the software with the previously validated vault model. The amount of glenoid bone loss was measured from the most lateral aspect of the vault model (anatomic joint line) to the posterior inferior glenoid plane, which was the area of greatest bone loss (Fig. 2).
Global APG and Step Tech APG, Warsaw, IN, USA), allowing placement of the appropriately sized glenoid component within the 3D construct of each patient’s scapula. The augmented component is available in 3 different sizes: +3, +5, and +7 (millimeters augmentation) (Fig. 3). The glenoid component (articulation surface) for the augmented components is available in 5 sizes (40, 44, 48, 42, and 56 mm) based on the anterior posterior (AP) and superior inferior dimensions. All of the implants had the same number, type, and configuration of fixation pegs (Fig. 3).

For every patient, a glenoid component was sized and positioned to cover as much of the reamed surface of the glenoid as possible, without overhang of the component. Furthermore, each component was positioned to maximize full back side contact between the reamed surface and the implant. Once the optimal diameter glenoid implant was selected, each augment size (+3, +5, +7) was individually placed at neutral (perpendicular) and at 6° retroversion, with reference to the plane of the scapula, in each patient. We determined the range of retroversion that could be corrected in restoring the joint line from neutral to −4 mm (thickness of the standard glenoid implant) after correction of the pathologic version to both neutral and 6° of retroversion. Restoration of the joint line was set from 0 to −4 mm, given the standard nonaugmented component thickness of 4 mm. Perforation of the glenoid wall by either the central or peripheral pegs of the glenoid implant was recorded (Fig. 4). For each case, the amount of medialization was measured, which was defined as the linear distance from the lateral aspect of the glenoid vault model to the center of the articular implant surface when the augmented component was placed with full back side contact (Fig. 5).

**Statistical analysis**

All statistical analyses were performed using SPSS statistical software version 19 (Armonk, NY) by a biostatistician. Analysis was performed with a power of 80% and minimum α error of \( P < .05 \). A power analysis performed before the study determined that a sample size of at least 28 subjects was required to detect a medium correlation between retroversion and medialization measurements. The data were tested for normal distribution (Q-Q plot), and regression analysis was used to determine the relationship between glenoid retroversion, glenoid implant size, and amount of component medialization for each type of augment size of the glenoid implant. All correlations were determined by Pearson’s \( r \). Statistical significance for all analyses was defined as \( P < .05 \).

**Results**

The distribution of pathologic retroversion for all 30 patients was approximately normal, with an average retroversion (glenoid bone loss) of \(-20.9° \pm 10°\) and range of \(-4.5° \to -43°\) (Fig. 6). The average preoperative joint line was \(-4.7 \pm 2.9\) mm with a range of 0 to −12 mm. The correlation between pathologic glenoid retroversion and the preoperative joint line displayed an \( R^2 \) of 0.52.

**Restoration of the anatomic joint line with the +3 augmented glenoid component**

Restoration of glenoid morphology and native joint line was considered from 0 to −4 mm of medialization for all augmented components, which accounts for glenoid implant thickness (4 mm). The retroversion range that could be corrected to place the implant in neutral (0°) glenoid version (with medialization ranging from 0 to −4 mm) with a +3 augmented glenoid was \(-3° \to -18°\) (Fig. 7), which demonstrated an \( R^2 \) of 0.785. In correcting glenoid retroversion to 0° with the +3 augmented component, the average medialization was 5.8 ± 3.5 mm. In correcting the glenoid version to 6° retroversion with the +3 augmented component, the average medialization was 4.8 ± 3.3 mm. The retroversion range that could be corrected with the +3 augmented glenoid placed in 6° retroversion was shown to be from −4° to −21° with an \( R^2 \) of 0.705 (Fig. 8).
Restoration of the anatomic joint line with the +5 augmented glenoid component

The +5 augmented component had an average medialization of 3.8 ± 3.1 mm in correcting glenoid retroversion to 0°. The range of retroversion that could be corrected with the +5 augmented glenoid was from −5° to −24° and demonstrated an $R^2$ of 0.792 (Fig. 7).

On correction to 6° retroversion, the +5 augmented component had an average medialization of 3 ± 3.1 mm. The range of retroversion that could be corrected to place the +5 augmented glenoid at 6° retroversion was from −7° to −27°, which had an $R^2$ of 0.766 (Fig. 8).

Restoration of the anatomic joint line with the +7 augmented glenoid component

The +7 augmented component had an average medialization of 2.3 ± 3.3 mm in correcting retroversion to 0°, and the range of retroversion that could be corrected was shown to be from −9° to −31° (Fig. 7). The correlation between the medialization of the joint line and the pathologic glenoid retroversion for each patient corrected to 0° demonstrated an $R^2$ of 0.701 for the +7 augmented component.

The +7 component had an average medialization of 1.8 ± 3 mm in correcting to 6° retroversion. The range of retroversion that could be corrected to place the +7 augmented glenoid at 6° was −9° to −34° (Fig. 8). The correlation between the medialization of the joint line and the pathologic glenoid retroversion for each patient corrected to 6° demonstrated an $R^2$ of 0.695.

Overall, there is a larger amount of preoperative retroversion that can be corrected to place a glenoid implant in neutral version with an augmented glenoid implant compared with standard glenoid components (Fig. 9). The average medialization was much larger in correcting pathologic retroversion to 0° with the standard glenoid component (8.5 ± 4.2 mm) compared with all augmented glenoid sizes. There was an increased amount of preoperative retroversion that was corrected with increased augment size and in placing each component in 6° retroversion compared with neutral (Table I).

Peg perforation

In looking at predictors of peg perforation, regression analyses determined that component size (AP diameter) was the only significant predictor of peg perforation at neutral
for the +3 augmented glenoid ($P = .038$), +5 augmented glenoid ($P = .024$), and +7 augmented glenoid ($P = .016$). In controlling for glenoid retroversion and the amount of medialization, the odds ratios determined that as the AP diameter of the glenoid component increased, there was a 29% to 32% decrease in the likelihood of perforation.
Glenoid retroversion and the amount of medialization were not shown to be significant predictors of peg perforation. For component placement in 6°/C14 of retroversion, there were no significant predictors of perforation for the +3 augmented glenoid. AP diameter component size, however, was a significant predictor of perforation for the +5 and +7 augmented glenoid implants placed in 6°/C14 of retroversion. Controlling for glenoid retroversion and amount of medialization, the odds ratio determined that there was a 32% to 46% decrease in the likelihood of peg perforation as the AP diameter increased for the +5 and +7 augmented components placed at 6° of retroversion.

Discussion

Total shoulder arthroplasty is technically demanding in regard to implantation of the glenoid component, especially in the setting of increased glenoid deformity and posterior glenoid wear. Studies have shown that adequate correction of glenoid retroversion and accurate placement of prosthetic components can restore normal glenohumeral motion and prevent glenoid implant failures. The ultimate goal for total shoulder arthroplasty is to replace glenoid bone loss and restore the native glenohumeral joint line. Options to address bone deficiency have the singular goal of restoring glenoid alignment to neutral; these include asymmetric reaming of the anterior glenoid, glenoid bone grafting, and use of an augmented glenoid component. The limitations of asymmetric reaming are the inability to correct significant glenoid bone loss, leading to glenoid component malposition, causing eccentric loading. This subsequently leads to implant loosening, and compromised peg fixation. The results of glenoid bone grafting demonstrate inconsistent graft incorporation, poor clinical outcomes, and increased rate of periprosthetic lucency and glenoid component loosening. Limitations in current treatment options have driven the design of new prosthetics to treat glenoid bone loss. Recent literature suggests that a step type design for an augmented glenoid implant may be the best biomechanical stability to minimize implant failure. Although augmented components

Figure 8 Relationship between glenoid retroversion and medialization of the joint line for an augmented glenoid component at correction to 6° retroversion. The shaded gray region, extending from 0 to −4 mm (red lines), defines the range of retroversion that could be corrected to completely restore the native glenohumeral joint line with the specified glenoid augment size (in millimeters). The black lines represent the confidence interval for the best-fit line.

Figure 9 The relationship between glenoid retroversion (degrees) and medialization of the joint line (millimeters) for the standard component and all 3 augment sizes (+3, +5, +7) at correction to neutral.

Glenoid retroversion and the amount of medialization were not shown to be significant predictors of peg perforation. For component placement in 6° of retroversion, there were no significant predictors of perforation for the +3 augmented glenoid. AP diameter component size was, however, a significant predictor of perforation for the +5 and +7 augmented glenoid implants placed in 6° of retroversion. Controlling for glenoid retroversion and amount of medialization, the odds ratio determined that there was a 32% to 46% decrease in the likelihood of peg perforation as the AP diameter increased for the +5 and +7 augmented components placed at 6° of retroversion.

Discussion

Total shoulder arthroplasty is technically demanding in regard to implantation of the glenoid component, especially

Table I Summary of amount of pathologic retroversion that can be corrected to restore normal glenohumeral biomechanics for each augmented glenoid size at correction to both neutral and 6° of retroversion

<table>
<thead>
<tr>
<th>Glenoid augment size</th>
<th>Range of retroversion that can be corrected to neutral</th>
<th>Range of retroversion that can be corrected to 6° of retroversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>+3</td>
<td>−17° to −3°</td>
<td>−21° to −4°</td>
</tr>
<tr>
<td>+5</td>
<td>−24° to −5°</td>
<td>−27° to −7°</td>
</tr>
<tr>
<td>+7</td>
<td>−31° to −9°</td>
<td>−34° to −9°</td>
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with a fixed polyethylene buildup theoretically may ensure more reliable restoration of the joint line, indications and technical guidelines have yet to be established.

Our results provide general guidelines for clinicians to select an appropriately sized augmented glenoid implant based on a specified amount of preoperative glenoid retroversion. There was a strong correlation between glenoid retroversion and medialization for all augment sizes, supporting the recommendation that glenoid retroversion should be the primary guide in selecting the amount of augmentation to optimally restore the joint line. In correcting to neutral with use of this principle, the +3 augmented glenoid allows correction of preoperative retroversion up to 17°, the +5 augmented glenoid up to 24°, and the +7 augmented glenoid up to 31°. There was a slight improvement in the range of retroversion that could be corrected in placing the components in 6° retroversion, with correction of preoperative retroversion up to 21° for the +3 augmented glenoid, up to 27° for the +5 augmented glenoid, and up to 34° for the +7 augmented glenoid. In severe cases of glenohumeral osteoarthritis with increased retroversion, the component in a small amount of residual retroversion up to 6° may allow better restoration of the glenohumeral joint line.

Recommendations to assist surgeons in selecting the optimal size augmented glenoid implant are based not only on restoration of the joint line but also on minimization of peg perforation. Based on our results, perforation of the glenoid vault by the fixation parts of the component cannot be prevented by use of a larger augment size. However, our results demonstrated that decreasing the overall glenoid AP diameter component size can minimize peg perforation. In cases in which preoperative planning indicates concern for peg perforation and significant pathologic glenoid retroversion, the surgeon may consider placement of a small–AP diameter, appropriately sized augmented component in 6° of retroversion on the basis of the results from this study. Although we do not fully understand the clinical importance of peripheral peg perforation, perforation of the posterior peg would be expected for all sizes of augmented glenoid, given the posterior glenoid bone deficiency and specific augmented component design used in this study.

Preoperative planning with 3D CT imaging can clearly provide advantages in accurately assessing glenoid retroversion and guiding surgical technique and selection of optimal size of the augmented implant. We recommend the use of 3D preoperative simulation to accurately measure glenoid retroversion and to guide size selection of the augmented glenoid implant.

The importance of decreasing medialization while correcting excessive glenoid retroversion is not fully understood, but it may improve joint stability and strength of the shoulder by restoring better tension of the rotator cuff. Ideally, restoring both version and medialization through accurate correction and ideal implant selection may optimize survival of glenoid components. Given the limitations of a computer-based simulation, the role of soft tissue tensioning is not considered in relation to retroversion or medialization because it was not incorporated in the simulation model. Furthermore, only one augmented glenoid design was investigated; it is possible that other augmented glenoid designs may prevent peg perforation or correct different amounts of glenoid retroversion.

Conclusions

Augmented glenoid implants provide an innovative alternative to current shoulder arthroplasty techniques, especially in the more complex cases with increased glenoid deformity and posterior glenoid wear. The goal for resurfacing the glenoid is to correct abnormal retroversion and accurately place the component to restore normal glenohumeral biomechanics and prevent glenoid implant failures. Recommendations to assist surgeons in selecting the optimal size of the augmented glenoid implant are based on restoration of the joint line, minimization of peg perforation, and premorbid retroversion. The strong correlation between glenoid retroversion and medialization for all augment sizes supports our recommendation for surgeons to select an appropriately sized augmented glenoid implant to restore the glenohumeral joint line based on a specified amount of preoperative glenoid retroversion.

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