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Posterior augmented glenoid implants require less bone removal and generate lower stresses: a finite element analysis

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Hypothesis: Glenoid retroversion can be corrected with standard glenoid implants after anterior-side asymmetric reaming or by using posterior augmented glenoid implants with built-in corrections. The purpose of this study was to compare 2 augmented glenoid designs with a standard glenoid design, measure the amount of bone removed, and compute the stresses generated in the cement and bone.
Methods: Finite element models of 3 arthritic scapulae with varying severities of posterior glenoid wear were each implanted with 4 different implant configurations: standard glenoid implant in neutral alignment with asymmetric reaming, standard glenoid implant in retroversion, glenoid implant augmented with a posterior wedge in neutral alignment, and glenoid implant augmented with a posterior step in neutral alignment. The volume of cortical and cancellous bone removed and the percentage of implant back surface supported by cortical bone were measured. Stresses and strains in the implant, cement, and glenoid bone were computed.
Results: Asymmetric reaming for the standard implant in neutral version required the most bone removal, resulted in the lowest percentage of back surface supported by cortical bone, and generated strain levels that risked damage to the most bone volume. The wedged implant removed less bone, had a significantly greater percentage of the back surface supported by cortical bone, and generated strain levels that risked damage to significantly less bone volume.
Conclusions: The wedged glenoid implants appear to have various advantages over the standard implant for the correction of retroversion.
Level of evidence: Basic Science Study; Computer Modeling

Keywords: Total shoulder arthroplasty; glenoid; finite element analysis; posterior augment wedged; stepped; retroversion; arthritis

Posterior glenoid wear is common in the setting of glenohumeral osteoarthritis.[30,31] Cadaveric and computer modeling studies have revealed the potential risks of excessive retroversion on implant stability, eccentric glenoid loading, and fixation stresses, which can increase the risk for glenoid loosening.[1,7,16,29] Multiple studies have highlighted the importance of

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correcting glenoid retroversion to restore the normal biomechanics of the glenohumeral joint.[19,32] Surgical options for correcting glenoid retroversion during total shoulder replacement include asymmetric (anterior) reaming of the high side of the glenoid, correcting the posterior wear with a bone graft, and implanting an augmented glenoid component.

Although a precise threshold has not been established, there is a limit to the amount of retroversion that can be corrected with anterior reaming. This is in part due to the increased risk of peg perforation, excessive bone removal, downsizing of the glenoid component, and medialization with possible glenoid loosening.[5,7,24,28] Whereas bone grafting to correct glenoid retroversion is one alternative, it is technically demanding, and clinical results have been mixed.[12,17] A third option for treating patients with posterior wear is implanting a glenoid prosthesis with a posterior augment. This design feature can reduce glenoid bone removal due to asymmetric reaming as well as avoid the pitfalls of bone grafting while correcting retroversion.

Two posterior augmented designs have recently become commercially available: a design with a posterior step (StepTech; DePuy Orthopaedics, Warsaw, IN, USA) and a design with a posterior wedge (Equinoxe; Exactech, Gainesville, FL, USA). Despite the alternative approaches available to correct a retroverted glenoid, quantitative comparisons to inform the decision-making process are limited.[27] The purpose of this study was to determine which augmented implant design required the least amount of bone removal and resulted in the lowest stresses on the cement and adjacent glenoid bone in a finite element analysis model.

Materials and methods

Preoperative computed tomography (CT) scans of the shoulder were obtained from 121 consecutive patients with osteoarthritis scheduled for total shoulder arthroplasty. CT was performed in a GE LightSpeed RT 16 scanner (GE Healthcare, Waukesha, WI, USA) with 0.625-mm slice thickness. Glenoid version was measured with respect to the axis of the scapular body on 3-dimensional reconstructions of the CT scan as previously described.[8,13,15] From this CT data set, we selected 3 scapulae with B2 glenoids to represent increasing severity of retroversion: mild, moderate, and severe posterior glenoid wear. Our analysis of shoulders without arthritis revealed an average retroversion of 3° ± 4.5°.[13] A clinical study of our total shoulder arthroplasty patients found an average retroversion of 8.6° ± 9.8.[14] We therefore chose 8° (1 standard deviation above the average for normal retroversion) to represent a mild case and 17° (1 standard deviation above the average for arthritic shoulders) to represent a severe case. We selected a scapula approximately midway between the 2 extremes to represent a moderate degree of retroversion. The scapula with mild wear had 8° of retroversion, the scapula with moderate wear had 13° of retroversion, and the scapula with severe wear had 17° of retroversion.

Surface meshes were generated for both cortical and cancellous bone regions using 3-dimensional image segmentation software (Mimics; Materialise, Leuven, Belgium). These surface meshes were converted to solid meshes with 10-node quadratic tetrahedral element in HyperMesh (Altair Engineering, Troy, MI, USA). To simulate surgical reaming and surgical drilling for fixation of pegged glenoid components, appropriate volumes of bone were removed from the scapular models using Boolean subtraction. Correction of the retroversion of the osteoarthritic scapulae by eccentric reaming was simulated by Boolean subtraction using a sphere with a radius matching that of the back surface of the glenoid component, which was translated medially until the entire back surface was in contact with bone. The Young modulus of the elements composing cancellous bone was based on local cancellous bone density for each element obtained from the CT images with a K_2HPO_4 calibration phantom and calculated using previously described relationships.[3,26] The cortical elements were assigned a Young modulus of 20 GPa.[11]

Implant geometry

Computer-aided design models (Fig. 1) of the following glenoid designs were reverse engineered from retrievals and marketing images:

1. A standard glenoid component (Global APG+, DePuy Orthopaedics)
2. A posterior augmented glenoid with 8°, 12°, and 16° wedges (Equinoxe, Exactech)
3. A glenoid component augmented with 3-, 5-, and 7-mm steps (StepTech, DePuy Orthopaedics) with an estimated version correction of 6°, 10°, and 13°, respectively.

The polyethylene glenoid components were meshed using hexahedral elements with Young modulus of 1 GPa.[6] The humeral head was modeled as a rigid sphere with a radius of a corresponding humeral component sized for each shoulder: 24.3 mm for the 8° and 12° retroverted glenoids and 29.7 mm for the 17° retroverted glenoid. The corresponding radius of curvature for the glenoid articular surface was 30 mm for the 8° and 12° retroverted glenoids and 32.7 mm for the 17° retroverted glenoid. A cement mantle was simulated around the fixation pegs of the glenoid implants (Fig. 2). The thickness of the cement mantle represented the differences between the radius of the implant peg and that of the surgical drill bit used for drilling the peg holes. The thickness of the cement mantle was 0.2 mm around the pegs for the standard and stepped designs. The cement mantle thickness varied from 0.36 to 0.7 mm for the wedged design because of the tapered pegs. Implant-cement and cement-bone interfaces were treated as perfectly bonded to simulate ideal fixation.