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Reverse total shoulder arthroplasty component center of rotation affects muscle function

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Background: Medialization of the glenohumeral center of rotation alters the moment arm of the deltoid, can affect muscle function, and increases the risk for scapular notching due to impingement. The objective of this study was to determine the effect of position of the glenosphere on deltoid efficiency and the range of glenohumeral adduction.

Methods: Scapulohumeral bone models were reconstructed from computed tomography scans and virtually implanted with primary or reverse total shoulder arthroplasty implants. The placement of the glenosphere was varied to simulate differing degrees of "medialization" and inferior placement relative to the glenoid. Muscle and joint forces were computed during shoulder abduction in OpenSim musculoskeletal modeling software.

Results: The average glenohumeral joint reaction forces for the primary total shoulder arthroplasty were within 5% of those previously reported in vivo. Superior placement or full lateralization of the glenosphere increased glenohumeral joint reaction forces by 10% and 18%, respectively, relative to the recommended reverse total shoulder arthroplasty position. The moment arm of the deltoid muscle was the highest at the recommended baseline surgical position. The baseline glenosphere position resulted in a glenohumeral adduction deficit averaging more than 10° that increased to more than 25° when the glenosphere was placed superiorly. Only with full lateralization was glenohumeral adduction unaffected by superoinferior placement.

Discussion/Conclusion: Selecting optimum placement of the glenosphere involves tradeoffs in bending moment at the implant-bone interface, risk for impingement, and deltoid efficiency. A viable option is partially medializing the glenosphere, which retains most of the benefits of deltoid efficiency and reduces the risk for scapular notching.

Level of evidence: Basic Science Study, Computer Modeling.

Keywords: Shoulder arthroplasty; reverse shoulder arthroplasty; glenosphere; deltoid function; glenohumeral forces; shoulder biomechanics

Severe shoulder arthropathy is often associated with poor rotator cuff function, which complicates the outcomes of shoulder arthroplasty. In the 1970s, constrained shoulder arthroplasty prosthetic designs were investigated to compensate for the loss of function of the rotator cuff muscles. In reverse total shoulder arthroplasty (RTSA), the glenohumeral joint is converted into a ball-and-socket articulation by implantation of a metallic glenosphere on the glenoid and a stem with a concave polyethylene articulation in the humerus.[8] This design increases the stability of the shoulder, thus allowing the deltoid to actively abduct

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the shoulder in the absence of supraspinatus function. RTSA is therefore indicated for the treatment of end-stage shoulder arthropathy associated with significant rotator cuff deficiency.[7,8,18]

One of the important failure mechanisms of the early RTSA designs was aseptic loosening of the glenosphere.[13,17] Prostheses often loosened secondary to large bending and shear forces on the glenoid component. These forces were attributed to the constrained design and the lateral center of rotation relative to the implant-bone interface. In 1985, Paul Grammont designed a large, medially placed prosthesis with no neck that placed the center of rotation at the glenoid prosthesis-bone interface on the basis of the theory that the constrained design and lateral center of rotation increase rotational moment arm loosening of the glenoid component. This medialization of the center of rotation reduces the bending and tensile forces at the implant-bone interface.[20] Unfortunately, medialization also introduces laxity in the deltoid muscle and increases the potential for impingement, particularly between the humeral prosthesis and scapular margin below the glenoid. To correct for these adverse effects, the glenosphere is placed inferiorly on the glenoid. Whereas this inferior placement reduces deltoid muscle laxity, it does little to reduce the laxity in the external rotator muscles, and patients often complain of reduced strength in external rotation.[20] In addition, medialization of the humeral shaft alters the normal contour of the shoulder, resulting in a poor cosmetic outcome.

To address the issues with medialization, some glenosphere designs (such as the Reverse Shoulder Prosthesis; Encore Medical, Austin, TX, USA) lateralize the center of rotation. To counter the greater bending moment at the glenoid baseplate-bone interface, these designs enhance baseplate fixation, resulting in stability to cyclic loading equivalent to that of medialized designs (Delta III).[11] Bone grafting under the glenosphere is another alternative to neutralize the effects of medialization. The implant-bone graft interface is protected from deleterious stresses, which are transferred to the interface between graft and host bone. After healing of the bone graft, these stresses are no longer significant for implant fixation. Proposed advantages of lateralizing the center of rotation include reduced laxity of the external rotators, reduced potential for prosthesis-bone impingement, and improved appearance of the shoulder contour.[4]

The effects of surgical placement of components and implant design on range of motion have been previously studied. One study using a computer model found that lateralizing the center of rotation resulted in the greatest increase in shoulder abduction, followed by tilt of the glenosphere, the angle between the humeral neck and humeral shaft, and the size of the glenosphere.[9] Reduced humeral neck-shaft angle and inferior placement of the glenoid reduced adduction deficit. Mechanical studies have also shown that center of rotation, glenosphere position, and neck-shaft angle had a major impact on range of motion before impingement.[10]

Patients with severe rotator cuff deficiency and shoulder arthritis often have compromised deltoid function.[20] Medializing the components alters the moment arm of the deltoid and can affect muscle function. However, the precise contribution of medial placement to deltoid muscle strength is not known. Further, the quantitative effect of medial placement on glenohumeral range of motion and the potential for impingement has not been fully studied. We therefore analyzed the mechanical advantage of prosthetic position on deltoid function to identify the optimum placement that would maximize muscle function as well as range of motion. Our primary objective was to determine the effect of position of the glenosphere on the force generated by the deltoid during shoulder abduction. The secondary objective was to determine the effect of glenosphere placement on impingement during shoulder adduction.

Methods

Construction of bone geometry

In a previous study, computed tomography (CT) scans were obtained from cadaveric shoulder specimens (N = 40) and segmented by the commercially available software Mimics (Materialise, Leuven, Belgium).[12] The 3-dimensional CT reconstructions were validated by physical measurements and surgical reconstruction. Differences between physical measurements made on cadaveric specimens and virtual measurement on 3-dimensional CT reconstructions ranged from 0.7 to 2.7 mm. In addition, cadaveric implantation was performed on 7 specimens to assess peg perforation; the same scapulae that perforated during cadaveric surgery (3 of 7) also perforated during the virtual surgery. From that database, we selected 3 scapulohumeral models that corresponded to small, medium, and large humeral head sizes. All 3 specimens were healthy and had no visible signs of significant deformity, degenerative disease, or wear. Each of the 3 specimens was then virtually implanted with primary shoulder implants and reverse shoulder implants with varying centers of rotation relative to the anatomic glenoid articular surface (Fig. 1).

Primary shoulder reconstruction

The humeral head was virtually osteotomized at an anatomic humerus neck-shaft angle of 135° and was replaced with an appropriately sized humeral head component (Fig. 1, *B*). We replicated the templating procedure used at our institution to select the size of the humeral head component. A sphere was fit to the native humeral head, and the head size with a radius closest to the radius of the anatomic head was selected for each CT model. The small humerus was implanted with a humeral head with radius of curvature of 20.5 mm; the medium with radius of curvature of 24 mm; and the large with radius of curvature of 26 mm.

The glenoid bone subchondral surface was fitted with a computer-aided design model representing the geometry of a