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ORIGINAL ARTICLE

Implant positioning in reverse shoulder arthroplasty has an impact on acromial stresses

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Background: Acromial fractures after reverse shoulder arthroplasty (RSA) have been reported to occur in up to 7% of patients. Whereas RSA implant parameters can be configured to alter stability, range of motion, and deltoid mechanical advantage, little is known about the effect of these changes on acromial stresses. The purpose of this finite element study, therefore, was to evaluate the effect of RSA humeral and glenoid implant position on acromial stresses.

Methods: Solid body models of 10 RSA reconstructed cadaveric shoulders (38-mm glenosphere, 155° neck-shaft angle) were input into custom software that calculated the deltoid force required to achieve an abduction arc of motion (0°-120°). The resulting forces were applied to a finite element study model of the scapula to ascertain the acromial stress distribution. This process was repeated for varying glenoid inferiorizations (0, +2.5, +5.0 mm), lateralizations (0, +5.0, +10.0 mm), and humeral lateralizations (−5.0, 0, +5.0 mm).

Results: Glenosphere inferiorization decreased maximum principal stress in the acromion by 2.6% (0.7 ± 0.2 MPa; $P = .007$). Glenosphere lateralization produced a greater effect, increasing stress by 17.2% (4.1 ± 0.9 MPa; $P = .001$). Humeral lateralization caused an insignificant increase in stress by 1.7% (0.5 ± 0.2 MPa; $P = .066$), and humeral medialization decreased stress by 1.4% (0.8 ± 0.3 MPa; $P = .038$). The highest acromial stresses occurred in the region where fractures most commonly occur, Levy type II, at 33.7 ± 3.81 MPa ($P < .001$).

Conclusions: Glenosphere positioning has a significant effect on acromial stress after RSA. Inferior and medial positioning of the glenosphere serves to decrease acromial stress, thought to be primarily due to increased deltoid mechanical advantage. The greatest effect magnitudes are seen at lower abduction angles, where the humerus is more frequently positioned.

Level of evidence: Basic Science Study; Computer Modeling

Keywords: Reverse total shoulder arthroplasty; RSA; acromial stress; glenosphere lateralization; glenosphere inferiorization; humeral lateralization; cuff tear arthropathy; complications

Institutional Review Board approval is not required for this study.

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Reverse shoulder arthroplasty (RSA) is an effective treatment for symptomatic rotator cuff tear arthropathy.[6] In the rotator cuff–deficient shoulder, the RSA glenosphere reconstructs a stable center of rotation (COR) normally provided by the rotator cuff in the physiologic case. The contracting deltoid muscle may then use this COR as a fulcrum about which to move the humerus rather than translating the humeral head superiorly when attempting elevation or abduction. Furthermore, after RSA, the COR is medialized, which recruits more of the deltoid for use in abduction, and the humerus is distalized, creating a passive stretch force to maintain joint stability.[15]

Acromial fractures after RSA have been reported to occur in up to 7% of patients.[18] These fractures generally occur between 3 and 10 months after surgery, leaving patients with inferior clinical outcomes and greater risk of revision surgery.[12,25,31] Despite this, little is known about the etiology of these fractures or predisposing factors.[7] The mechanism is thought to be through stress fractures, which occur when stresses exceed a limit after which bone repair cannot reverse damage, which progresses insidiously, rather than a single traumatic event.[8,19,20] Reasons for reaching this critical stress could be altered stresses after RSA, an osteoporotic patient, wear to the acromion before surgery, or a combination of these factors.

Whereas RSA implant parameters can be configured to alter joint stability, range of motion, or deltoid mechanical advantage,[1,11,13,16,24] the effect of these changes on acromial stresses or fractures has not been studied. Because RSA alters normal anatomic relationships, we postulate that the resulting forces and lines of action of the deltoid alter the physiologic stress patterns in the acromion. The purpose of this finite element study, therefore, was to evaluate the effect of RSA humeral and glenoid implant positioning on acromial stresses in a 38-mm glenosphere and 155° neck-shaft angle implant to determine the minimal stress configuration.

Materials and Methods

Three-dimensional models of 10 fresh frozen cadaveric shoulders (average age, 68 ± 19 years) were created from computed tomography (CT) data using Mimics (Materialise, Leuven, Belgium) software. The scapula was oriented according to International Society of Biomechanics convention,[29] and then a 10° anterior tilt was applied about the Z_s axis to match the physiologic orientation of the scapula.[14] The humerus was also oriented using International Society of Biomechanics convention (option 1) and then constrained relative to the scapula using a humeral head position taken from CT data. By setting the humeral YZ_h plane parallel to the scapular YZ_s plane and setting the humeral Y_h axis parallel to the plane of the glenoid, the arm was placed in 0° abduction.[1] Further abduction was performed by rotating the humerus about the scapular X_s axis.

The clavicle was also added to models based on its CT position. The models then underwent RSA reconstruction in SolidWorks (Dassault Systèmes, Vélizy-Villacoublay, France), based on an implant with a 38-mm glenosphere, 155° neck-shaft angle, and 20-mm humeral offset (Delta Xtend; DePuy Synthes, Warsaw, IN, USA). From these native and RSA models, 7 origins of the deltoid were mapped on the basis of Wickham and Brown's identification of functionally independent segments[26,27] as well as a common deltoid insertion on the deltoid tuberosity of the humerus.

These models then performed an abduction arc of motion (0°-120°) in the scapular plane. A computational model (MATLAB; MathWorks, Natick, MA, USA) was created to calculate force vectors across abduction for 7 sections of the deltoid. The first step was to determine the path that the deltoid takes in traveling from the acromion or clavicle around the humeral head and shaft to reach the insertion through wrapping points on the humerus (Fig. 1). An obstacle-set method previously used on the deltoid and validated was adapted to determine the wrapping points on the humerus where the deltoid first contacts the bone as well as total muscle length.[10] As the obstacle-set method approximates the humerus as a sphere-capped cylinder, wrapping points found using the method were then projected onto the surface of the 3-dimensional model for increased accuracy. By use of the calculated data, the deltoid lines of action on the acromion as well as moment arms for each deltoid segment about the COR were found.

From these data, it was possible to perform a moment balance about the COR to determine the required deltoid force to hold the arm in abduction. This moment balance was performed in the plane of abduction so each moment arm was projected onto the scapular plane. Once muscle forces were calculated, the projection was undone to find the respective 3-dimensional forces. By balancing in the plane of abduction, the most efficient deltoid activations were found, and it is assumed that other muscles of the shoulder girdle would activate to provide stability in other planes. The antagonistic moment came from the weight of the arm (F_{opp}), using 5% of the mass of a 75-kg person applied 320 mm from the center of the humeral head along the axis of the humerus.[24] The entire shoulder model was rotated with respect to gravity in a 2 to 1 scapulohumeral rhythm after 30° of abduction (1° of scapular rotation for every 2° of humeral rotation) to account for rotation of the scapula with respect to the thorax.[1,21] Force contributions from each deltoid segment (F_n) could then be found by equating the sum of each force multiplied by its moment arm to the antagonistic moment.

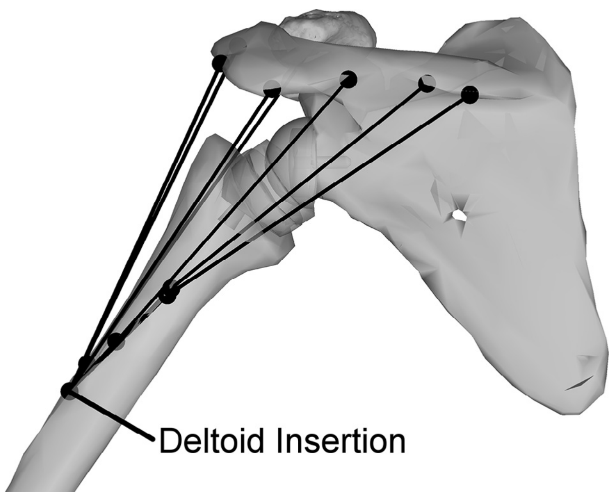

Figure 1 Deltoid segments wrapping and lines of action for a representative specimen implanted with a reverse total shoulder arthroplasty. The first contacts between deltoid segments and the humerus before wrapping to the deltoid insertion are indicated by *circles* on the deltoid paths.