Optimizing Deltoid Efficiency with Reverse Shoulder Arthroplasty Using a Novel Glenosphere Geometry

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Introduction: Much of the recent clinical and commercial success associated with reverse shoulder arthroplasty can be attributed to Dr. Paul Grammont’s innovations in prosthesis design. In 1991, Dr. Grammont first recommended a glenosphere geometry whose thickness was one-half its diameter to position the center of rotation on the glenoid face in order to reduce torque on the glenoid fixation interface while also increase the deltoid abductor moment arms in order to improve deltoid efficiency. This hemispherical glenosphere concept has been the geometric predicate for nearly every reverse shoulder prosthesis released in the marketplace since that time. To our knowledge, no one has ever developed a glenosphere whose thickness is less than one-half its diameter (e.g. less than its spherical radius); theoretically, such a glenosphere would have a more medialized center of rotation which would increase the deltoid abductor moment arms and improve deltoid efficiency. To this end, this computer analysis quantifies the impact of modifying glenosphere geometry on the deltoid abductor moment arms during abduction in the scapular plane from 0 to 140°.

Methods: A 3-D computer model was developed in Unigraphics (Siemens, Inc) to quantify muscle moment arms during various simulated shoulder motions. In this study we quantified the abductor moment arms of the anterior, middle, and posterior heads of the deltoid during scapular abduction of the normal anatomic shoulder and 1 reverse shoulder design (Equinoxe, Exactech, Inc) having 3 different glenosphere geometries. The specific glenosphere diameter/thicknesses utilized in this study were: 38x21, 46x25, and 46x21mm. Each of these implants were geometrically modeled and implanted in a 3-D digitized scapula and humerus (Pacific Research, Inc) so that each glenoid baseplate aligns with the inferior glenoid rim as the humeral component was oriented in 20° retroversion. The computer simulated each muscle as three lines from origin to insertion as the arm was elevated; positional data was exported to Matlab (Mathworks, Inc) where the abductor moment arms were calculated for the anterior, middle, and posterior deltoid from 0° to 140° humeral abduction in the scapular plane using a 1.8:1 scapular rhythm.

Results: The abductor moment arms for the anterior, middle, and posterior heads of the deltoid for each glenosphere geometry during scapular abduction from 0 to 140° are presented relative to the anatomic shoulder in Figures 1-3, respectively. The novel 46x21mm glenosphere had the largest abductor moment arms for all three heads of the deltoid throughout the range of motion and was associated with a 2.9mm average increase in the anterior deltoid, a 2.8mm average increase in the
middle deltoid, and a 2.5mm average increase in the posterior deltoid relative to the other 2
glenosphere geometries evaluated. Relative to the anatomic shoulder, the 46x21mm glenosphere was
associated with a 134% average increase in the abductor moment arms of the anterior deltoid (15.6%increase relative to the other glenospheres), a 127% average increase in the middle deltoid (15.2%increase relative to the other glenospheres), and a 132% average increase in the posterior deltoid
(16.3% increase relative to the other glenospheres) over the range of motion.

Discussion: The results of this study demonstrate that the abductor moment arms of the deltoid can be
increased by subtle changes in glenosphere geometry, where the novel 46x21mm glenosphere was
associated with >15% increase in efficiency of each head of the deltoid relative to other glenospheres
having similar diameters or thicknesses. The 38x21 and 46x25mm glenospheres, being nearly equivalent
sections of spheres (55.3% and 54.3%, respectively) had nearly equivalent centers of rotation; and as
such, were associated with similar deltoid abductor moment arms. Conversely, the 46x21mm
glenosphere, being a smaller section of a sphere (45.7%), had a center of rotation that was 4mm more
medial than the other glenospheres and as a result, had a larger abductor moment arm for all 3 heads of
the deltoid. These larger abductor moment arms increase the efficiency of the deltoid and by definition
proportionally decrease the force necessary by each muscle to elevate the arm. Previous work has
demonstrated that lateralizing the center of rotation by increasing glenosphere thickness independent
of its diameter decreases the deltoid abductor moment arms and reduces deltoid efficiency.1-2 This
analysis builds upon that work by demonstrating that deltoid abductor moment arms can be further
increased with reverse shoulder arthroplasty by decreasing glenosphere thickness to less than its
spherical radius; design advances such as these offer the potential to improve function with next
generation reverse shoulder prostheses. This study is limited by its evaluation of deltoid abductor
moment arms in only one digitized anatomy during only one motion; future work should evaluate the
impact of this novel glenosphere geometry in multiple different anatomies during different motions.

Significance: This computer analysis provides new biomechanical insights on the impact of glenosphere
geometry on deltoid abductor moment arms with reverse shoulder arthroplasty. This novel design
concept may be useful to orthopaedic surgeons, designers, and manufacturers to develop prostheses
that minimize the force required by the deltoid to elevate the arm in order to reduce the joint reaction
force and thereby, reduce complications related to over-loading, such as aseptic glenoid loosening or
acromial stress fractures.
Figure 1. Comparison of Anterior Deltoid Moment Arms of 3 Different Glenosphere Geometries During Scapular Abduction from 0 to 140°.

Figure 2. Comparison of Middle Deltoid Moment Arms of 3 Different Glenosphere Geometries During Scapular Abduction from 0 to 140°.
Figure 3. Comparison of Posterior Deltoid Moment Arms of 3 Different Glenosphere Geometries During Scapular Abduction from 0 to 140°.

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