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A quantitative analysis of the effect of baseplate and glenosphere position on deltoid lengthening in reverse total shoulder arthroplasty

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ABSTRACT

Context: Optimizing deltoid tension is important to achieve maximal function after reverse total shoulder arthroplasty (RTSA), but the effects of baseplate and glenosphere positions on deltoid tension have not been quantified.
Aims: To quantify deltoid elongation and elongation to failure under physiologic loads with three baseplate-glenosphere configurations with increasing inferior offset.
Settings and Design: Cadaver biomechanical study.
Materials and Methods: Twenty-four cadaver shoulders were divided into three groups. The starting point for baseplate insertion in Group 1 was the center of the glenoid, with glenospheres placed in minimal inferior offset (0.5 mm). Groups 2 and 3 baseplates were placed 2 mm inferior to the center point and glenospheres in minimal (2.5 mm) offset (Group 2) or maximal (4.5 mm) offset (Group 3). Tensile testing was done to quantify deltoid elongation and evaluate failure.
Statistical Analysis Used: A one-way analysis of variance was performed to detect statistically significant differences among treatment groups. A *post-hoc* Neuman-Keul's comparison was conducted to perform discrete comparisons among treatment groups.
Results: Deltoid elongation after loading decreased with increasing inferior offset of >2.5 mm. No significant difference in deltoid yield load was found among groups. The percent of elongation was decreased significantly between groups 2 and 3. Deltoid displacement at failure decreased from 33.3 mm for Group 2-17.3 mm for Group 3. 16 of the 24 specimens (67%) failed by anterior deltoid detachment from the acromion.
Conclusions: Increasing inferior offset in RTSA constructs appears to increase stretch forces on the deltoid, resulting in a diminished ability of the deltoid to further elongate under physiologic loads, (most pronounced when the inferior offset exceeds 2.5 mm) and significantly decreasing the yield displacement of the construct.

Key words: Baseplate and glenosphere position, cadaver study, deltoid tension, failure, reverse total shoulder arthroplasty

INTRODUCTION

Reverse total shoulder arthroplasty (RTSA) has revolutionized the treatment of rotator cuff-deficient shoulders, and its indications continue to expand to areas such as failed shoulder arthroplasty, revision arthroplasty, fracture sequelae, rheumatoid arthritis, instability and tumors.[1-4] Due to these expanding clinical applications, the number of RTSA

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performed in the United States has increased dramatically since 2004.[5] Successful outcomes ideally maximize range of motion and minimize instability and complications.[6] Central to that success is the nonanatomic biomechanics of the prosthesis and the effectiveness of the deltoid to restore shoulder function with a deficient rotator cuff.[7] Studies have shown that the deltoid generates over 50% of the force necessary to elevate the arm in the scapular plane and is the only muscle remaining in cuff-deficient shoulders to power abduction in the same plane.[8] Ackland *et al.* found that increased abductor moment arms for anterior, middle, and posterior regions of deltoid assist to overcome cuff deficiency in RTSA.[9]

Reverse total shoulder arthroplasty constructs provided a stable and fixed fulcrum for elevation and increased resting length/tone of the deltoid.[7,10] Optimizing deltoid tension is important to achieve maximal function, and lengthening of the deltoid increases the patient's ability to forward elevate, likely by recreating the force-length relationship of the deltoid muscle.[11] Intraoperative determination of deltoid tension is difficult and mostly guided by surgical experience.[7] Inferior glenosphere placement also has been found to decrease scapular notching and improve forward elevation by lengthening the deltoid.[12] This has prompted questions regarding the deltoid's ability to tolerate these increased stretch forces and may have implications for implant longevity. Until date, no studies quantifying the effect of baseplate and glenosphere position on deltoid tension exist.

The primary objective of this study was to quantify deltoid elongation under physiologic loads for three different baseplate-glenosphere configurations with increasing inferior offset. The secondary objective was to quantify elongation to failure (yield displacement) and to record the mode of failure. We hypothesized that the increased deltoid tension caused by increasing the inferior offset >2.5 mm would result in a lessened ability of the deltoid to further elongate under physiologic loads.

MATERIALS AND METHODS

Specimen preparation

Twenty-four fresh-frozen cadaver shoulders were divided into three groups of eight. The specimens were acquired from the Medical Education and Research Institute, Memphis, TN. Specimens were stored at −20°C. Before component implantation, the supraspinatus and infraspinatus of each specimen were sectioned to approximate a rotator cuff-deficient shoulder. The subscapularis, teres minor, pectoralis major, latissimus dorsi, and deltoid tendons were left intact. This is consistent with specimen preparation in other cadaver studies involving RTSA.[9,11,13-15]

The components were implanted according to the manufacturer's specifications (Biomet Comprehensive Shoulder System, Warsaw, IN). A starting point for the humeral stem was made in the rotator cuff footprint and enlarged with a burr. Starting with the opening reamer (4 mm), reaming proceeded sequentially in 1 mm increments until solid cortical contact was felt in the intramedullary canal. The humeral cutting guide was applied, and the humeral head was cut in 30° of retroversion. Broaching then proceeded sequentially from the 4 mm broach to the same size as the reamed diameter. The corresponding humeral stem was then impacted into position.

In group 1, the starting point for baseplate insertion was the center of the glenoid, which was identified based on the measured midpoint between the superior/inferior and the anterior/posterior margins of the glenoid. Glenospheres were placed in minimal inferior offset (0.5 mm). Group 2 baseplates were placed 2 mm inferior to the center point and glenospheres were placed in minimal offset (2.5 mm total inferior offset) [Figure 1]. Group 3 baseplates were placed in the same inferior position with glenospheres placed in maximal inferior offset (4.5 mm total inferior offset). Using a template with a 10° the inferior tilt built in, a guide pin was placed. The cannulated glenoid reamer was then used to plane the glenoid surface in 10° of the inferior tilt. The glenoid baseplate was inserted and impacted into position based on the previously described groups. Using a depth gauge, the length of the 6.5 mm center screw was measured, and the corresponding screw was placed. Four peripheral locking screws were then placed. All screws were placed in bicortical fashion for maximal fixation, with lengths varying by the size of the glenoid vault. A 36 mm glenosphere was impacted into position, again based on the parameters described for each group. A +0 mm polyethylene bearing surface was impacted into position in each specimen. After implantation, the glenohumeral joint was reduced, and all specimens were surveyed visually to inspect their condition.

Biomechanical testing

Tensile testing was done on all 24 specimens to quantify deltoid elongation and evaluate failure. To aid in gripping the specimen,

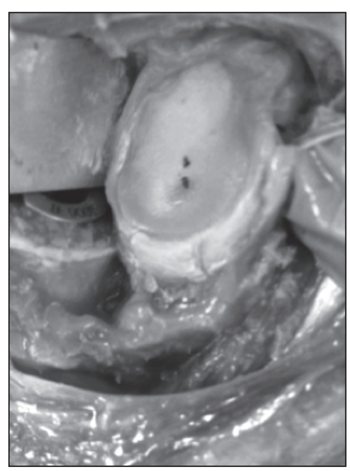

Figure 1: The starting point for baseplate insertion in Group 1 was the center of the glenoid, which was identified based on the measured midpoint between the superior/inferior and anterior/posterior margins of the glenoid. Baseplates in Groups 2 and 3 were placed 2 mm inferior to the center of the glenoid

the scapula was embedded in polyester resin. The scapula was oriented in the resin such that the shoulder was aligned in an anatomical "at rest" position when mounted to the actuator. Physiologic tension was placed on latissimus dorsi (15 N) and pectoralis major (15 N) tendons by way of pulleys and hanging weights [Figure 2]. This is consistent with specimen preparation in other studies of reverse shoulder arthroplasty.[9,13-16] Each specimen was placed into resting position, and the deltoid elongation was measured by pulling the humerus in tension to 30 N at a rate of 5 mm/min. The machine then maintained 30 N of tension for 5 min and recorded the elongation. Next, the specimen was pulled in tension at a rate of 10 mm/min until failure of the deltoid or RTSA components was observed.

Data analysis

The tensile load and displacement data recorded for each specimen were analyzed in TestWorks 4 (MTS 2004). The test method was configured to calculate the yield load, yield displacement, peak load, and peak displacement.

Statistical analysis was conducted to provide a comparison among treatment groups with respect to the deltoid elongation, percent of elongation, and yield load observed. A one-way analysis of variance (ANOVA) was performed to detect statistically significant differences among treatment groups. A *post-hoc* Neuman-Keul's comparison was conducted to perform discrete comparisons among treatment groups after the performed ANOVA was found to be significant. Differences with $P < 0.05$ were considered as significant.

RESULTS

For all specimens, the average deltoid elongation was 1.1 mm (0.4 mm to 2.6 mm), with an average yield load to failure of 582.5 N (range 305.9 N to 848.3 N) and an average peak load of 864.1 N (range 431.2 N to 1747.7 N). No significant difference in deltoid yield load was found among groups ($P > 0.05$) [Table 1].

Deltoid elongation after loading decreased with increasing inferior offset of >2.5 mm. The average deltoid elongation after loading was 1.3 ± 0.7 mm for Group 1, 1.3 ± 0.5 mm for Group 2, and 0.7 ± 0.2 mm for Group 3 ($P = 0.05$). The percent of elongation of the deltoid also was decreased significantly between groups 2 and 3 (20% vs. 10%, $P = 0.007$). Deltoid displacement at failure (yield displacement) decreased from 33.3 mm for Group 2-17.3 mm for Group 3 ($P = 0.007$).

Sixteen of the 24 specimens (67%) failed by anterior deltoid detachment from the acromion [Figure 3]. Other modes of failure included deltoid tendon failure (16%), specimen pull-out of the polyester resin (8%), distal acromion fracture (4%), and humeral implant loosening (4%).

DISCUSSION

Intuitively, deltoid tension is increased by increasing inferior baseplate and/or glenosphere offset. RTSA takes advantage of this tension by increasing the deltoid moment arm, and an inferior baseplate position has been shown to increase the efficiency of the deltoid up to 30%.[3,4,6,9,15,17-19] Previous studies have shown inferior baseplate position and glenosphere tilt are protective against scapular notching with improved function, more uniform compressive forces with decreased shear force on the bone-baseplate interface and greater range of motion before impingement.[12,20-22] The ability of the deltoid to accommodate lengthening has not been quantified.

Conceptually, the muscle tension-elongation relationship is set by Blick's curve, which suggests that lengthening of a muscle

Table 1: Significant changes in deltoid yield displacement and percentage of elongation after inferior offset exceeded 2.5 mm

Groups	Yield load (N)	Yield displacement (mm)	Deltoid displacement (mm)	Percentage of elongation
Group 1	640	32.4	1.3	15
Group 2	498	33.3	1.3	20
Group 3	610	17.3	0.7	10
P	>0.05	<0.007	0.05	0.007

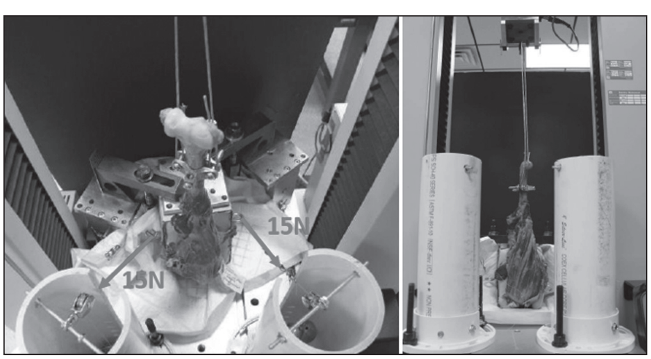

Figure 2: Test apparatus with shoulder specimen embedded in resin with pulley system arranged to apply constant physiologic loads

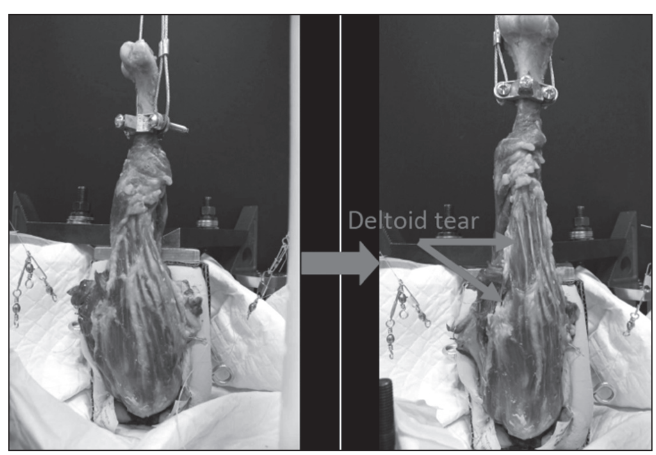

Figure 3: Specimen after load to failure showing anterior deltoid detachment

results in increased tension but at a certain tension, the muscle will no longer be able to lengthen.[23] Our study suggests that RTSA constructs with inferior offset of >2.5 mm diminish the ability of the deltoid to further elongate under physiologic loads. This was most pronounced between Groups 2 and 3 where total inferior offset of the constructs increased from 2.5 mm to 4.5 mm. When comparing these two groups, deltoid elongation under physiologic loading conditions decreased from 1.3 mm to 0.7 mm. While this represents merely a 0.6 mm difference in absolute terms, it reflects the diminished ability of the deltoid to tolerate increasing tension, effectively demonstrating Blick's curve. Further, increasing inferior offset significantly decreased the percent of elongation between these two groups. Most significantly, the deltoid yield displacement of 33.3 mm in Group 2 dropped to 17.3 mm in Group 3. This suggests a dramatic change in the ability of the deltoid to accommodate physiologic loads when inferior offset is increased from 2.5 mm to 4.5 mm. Essentially, at the tension generated with 4.5 mm of inferior offset, the deltoid can lengthen only an additional 17 mm before failing compared to an additional 33 mm when the RTSA construct is set at 2.5 mm of inferior offset.

Increased deltoid force may have clinical implications after RTSA, such as increased recovery length or increased risk of acromial stress fracture.[15,24] Increased deltoid forces over a longer period may lead to deltoid-related pain and accelerate the decline in function that has been reported at mid-term follow-up.[15,25] In our study, the most common mode of deltoid failure in these nonpathologic specimens was detachment of the anterior deltoid from the acromion, which may lead to increased pain and functional loss.[9] In a case series of anterolateral deltoid ruptures following RTSA in a group who had previous open RTC repairs, all patients had significant declines in functional outcome after rupture.[8] Anterior deltoid insufficiency also has been linked to instability and is underestimated in revision surgery.[26] Postoperative fractures of the acromion and scapular spine are rare,[26] and our study's 4% rate of acromion fracture is similar to that of previous studies.[27,28] While this particular complication remains uncommon, function decreases significantly after fracture.[29]

As with other biomechanical and cadaver studies, recognized limitations exist. Mechanical actuators and static loads could not simulate active muscle contraction, proprioceptive control, and dynamically changing muscle lines of action.[6] The cadaver model with the scapula locked statically in resin was unable to account for the increased scapulothoracic motion and altered kinematics in RTSA.[30] Furthermore, the specimens used in this study were not pathologic and may not precisely mimic the degenerative changes seen in most patients who have RTSA. Finally, while we used baseplate and glenosphere positions as the primary variables to increase deltoid tension, these are not the only two factors involved in setting deltoid tension in RTSA. We speculate that any configuration that increases deltoid tension (including humeral-sided factors such as the size of the head cut or augmented humeral bearing trays) may well result in similar changes.

Increasing inferior offset in RTSA constructs appears to increase stretch forces on the deltoid. This results in a progressively diminished ability of the deltoid to further elongate under physiologic loads and is most pronounced when the inferior offset exceeds 2.5 mm. This configuration also significantly decreases the yield displacement of the construct, suggesting that the deltoid may not tolerate this additional lengthening to the same extent as with other less-tensioned constructs; however, this potential disadvantage may be balanced by the ability to minimize scapular notching with inferiorly offset configurations.

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