Isolated Humeral Distalization Increases Muscle and Joint Reaction Forces in Reverse Total Shoulder Arthroplasty

Jared L. Zitnay[1], Madelyn R. Stout[1], Brittany Percin[1], Robert Z. Tashjian[1], Peter N. Chalmers[1], Christopher D. Joyce[1], Gilles Walch[2], Heath B. Henninger[1]
[1]University of Utah, Salt Lake City, UT, [2]Centre Orthopédique Santy, Lyon, France
jared.zitnay@utah.edu

Disclosures: **Zitnay** (N), **Stout** (N), **Percin** (N), **Tashjian** (3B-Stryker, Zimmer/Biomet, DePuy/Mitek, Enovis; 4-Connextions, Genesis; 7A-Stryker, Zimmer/Biomet, Shoulder Innovations; 7B-Springer, Journal of Bone and Joint Surgery; 8-Journal of Bone and Joint Surgery), **Chalmers** (3B-Depuy, Smith and Nephew, Responsive Arthroscopy, Exactech; 4-TitinKM Biomedical; 5-Depuy, Smith and Nephew; 7A-Depuy, Responsive Arthroscopy, Exactech; 8-Journal of Shoulder and Elbow Surgery), **Joyce** (N), **Walch** (1-Stryker; 2-Stryker; 3B-Stryker), **Henninger** (5-Stryker; 6-Stryker, DePuy, Enovis).

INTRODUCTION: The factors that affect implant stability and joint function in reverse total shoulder arthroplasty (rTSA) often produce combined modifications of rTSA glenohumeral joint geometry. Stability provided by compression across the joint due to passive muscle tension is often tuned by modifying the humeral polymer insert thickness which produces effective humeral distalization and lateralization. Glenoid side configurations that are used to improve range of motion and prevent scapular impingement, such as inferior baseplate positioning and an eccentric glenosphere, also effectively distalize the humerus. Excessive deltoid tension due to increased humeral distalization may be a factor in acromion and scapular spine fracture [1] and greater distalization is associated with increased rates of reoperation and complication [2]. While biomechanical studies have shown that isolated humeral lateralization increases joint stability with relatively small changes in muscle force [3], the isolated effect of humeral distalization is unknown. Therefore, the objective of this study was to determine the impact of isolated humeral distalization in rTSA on muscle and joint reaction forces using a biorobotic simulator. We hypothesized that both muscle and joint reaction forces would increase with an effectively distalized humerus.

METHODS: Six fresh-frozen right upper extremities (3 F/3 M; 63±5 yrs; 24.7±3.8 kg/m^2) were prepared for use with a biorobotic shoulder simulator [4, 5]. Briefly, three muscle lines were secured to the humeral insertions of the subscapularis, infraspinatus, and teres minor muscles, and three lines were secured to the deltoid tuberosity representing the three deltoid components. A supraspinatus muscle line was not included to simulate a rotator cuff tear. The humerus was dissected away from the scapula for use with a 36 mm glenosphere mounted on a 6-axis in-joint load cell oriented at 0° glenoid inclination (β angle 90°) and 0° glenoid retroversion. The relationship of the humerus and scapula coordinate systems to optical tracking clusters was obtained from 3D models generated from computed tomography scans. All specimens were implanted with an onlay humeral system (Tornier Flex, Stryker) at 30° of humeral retroversion by a board-certified shoulder surgeon (RZT), adjusting the stem size on a specimen-specific basis. Isolated humeral distalization was achieved using custom 3D printed poly inserts, modeled from the commercial poly geometry, where the articulating surface of the poly was displaced purely along the humeral stem axis. The baseline poly (+0 mm distalization) was equivalent to the minimum thickness of a commercially available polymer insert.

Specimens were mounted to a biorobotic simulator with muscle lines routed along anatomic muscle lines of action and attached to the actuators. A plate between the humerus and radius held the elbow in extension in a thumb-up orientation matching the *in vivo* orientation, where specimens were tested using an rTSA-patient derived scapular plane abduction motion trajectory [6]. Muscles were grouped for analysis based on complementary function and antagonistic roles as cumulative deltoid, posterior rotator cuff, and subscapularis. To generate quasi-continuous curves required for statistical parametric mapping (SPM), humerothoracic elevation was resampled to 0.1° increments then muscle and joint reaction forces were interpolated over the elevation and smoothed using a zero-phase, second order low-pass Butterworth filter. The effect of increased humeral length on muscle and joint reaction forces as a function of humerothoracic elevation was evaluated between 0 and +15 mm of humeral distalization using statistical parametric mapping (SPM) paired t-tests (version M.0.4.8). Significance was set at $p \leq 0.05$. To observe incremental effects, specimens were also tested at +5 and +10 mm distalization.

RESULTS: Deltoid and subscapularis muscle forces increased when the humerus was distalized +15 mm from the baseline ($p \leq 0.012$) (Fig. 1). The observed increase in posterior cuff force did not reach statistical significance. All joint reaction forces (compression, superior shear, anterior shear) increased when the humerus was distalized +15 mm from the baseline ($p \leq 0.039$). Experiments with +5 and +10 mm distalization revealed that muscle and joint reaction forces increased incrementally with the degree of distalization. On average, both maximum muscle forces and maximum joint reaction forces increased approximately 20% from the baseline +0 poly insert with each additional 5 mm increase in distalization.

DISCUSSION: Distalization of the humerus following rTSA averages nearly 30 mm compared to the preoperative anatomy [2]. Our results show that even a relatively small amount of additional distalization (+15 mm), which is easily achievable with commercial poly inserts and an inferiorly mounted glenosphere baseplate, can increase deltoid, rotator cuff, and joint reaction forces, by up to 100%. This magnitude of change counteracts the mechanical advantage inherent to the rTSA design philosophy, could negatively affect active joint function, and may help explain the reported association between increased post-operative distalization and revision or complication [2]. Experiments using intermediate amounts of distalization (+5, +10 mm) showed a continuous incremental effect of humeral distalization on muscle and joint reaction forces. Therefore, implant configurations that distalize the humerus should be approached with caution. Further clinical study to isolate distalization as a variable in patient cohorts can further establish its effect on patient outcomes. Due to a limited sample size, the present study focused on whether a distalized humerus altered muscle and joint reaction forces. This study is ongoing, and with additional samples we expect to establish the incremental relationship between distalization and rTSA biomechanics.

SIGNIFICANCE: Humeral distalization in rTSA increases the muscle force required to abduct the arm and increases joint reaction forces on the implant components which may negatively affect active range of motion or contribute to post-operative implant failure or acromial fracture.

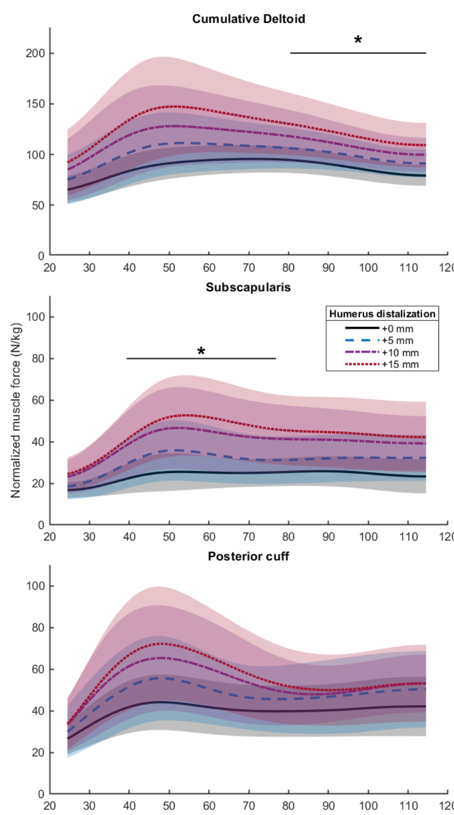

Figure 1. Muscle force as function of humerothoracic elevation with increasing levels of humeral distalization. Mean ± SD. Starred bars indicate regions of suprathreshold clusters by SPM between +0 and +15 mm ($p \leq 0.012$).

REFERENCES: [1] Haidamous, G. *J Shoulder Elbow Surg,* 2020*,* 29: 2556-2563. [2] Tashjian, RZ. *J Shoulder Elbow Surg,* 2021*,* 30: e10-e17. [3] Giles, JW. *Clin Orthop Relat Res,* 2015*,* 473: 3615-3626. [4] Sulkar, HJ. *J Biomech Eng,* 2022*,* 144: 051008. [5] Knighton, TW. *J Shoulder Elbow Surg,* 2022. [6] Sulkar, HJ. *Clin Orthop Relat Res,* 2022.

ACKNOWLEDGEMENTS: Funding from NIH NIAMS R01 AR067196 for biorobotic simulator development is gratefully acknowledged. Stryker Upper Extremity donated the implant systems.