Humeral Retroversion and Glenoid Tilt Influence Implant Impingement after Reverse Shoulder Arthroplasty

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INTRODUCTION: Internal rotation (IR) is a vital component of activities of daily living and it is not reliably improved after reverse shoulder arthroplasty (RSA)[1] as only 36% of patients can wash their back with the affected arm after RSA[2]. Impingement of the humeral implant on the scapula is commonly cited as the limiting factor of IR[3]. Computer models suggest that less retroverted humeral implants and less inferior glenoid tilt are associated with less impingement[4,5]. Few, if any, studies analyze the influence of surgical parameters on *in vivo* kinematics of impingement after RSA. Thus, the purpose of this study was to determine which surgical parameters predict impingement during the hand-to-back motion after RSA. We hypothesized that less inferior glenoid tilt, more glenoid lateralization, and less humeral retroversion would predict less impingement during the hand-to-back motion. Additionally, we hypothesized that patients who impinge during the hand to back motion would report poorer patient-reported outcomes (PROs) and less clinical IR range of motion (ROM).

METHODS: Written informed consent was obtained for this IRB-approved study. All participants received a RSA by a single surgeon using a standard 135-degree humeral implant or a 145-degree humeral implant within the previous 1-5 years for rotator cuff arthropathy, irreparable cuff tear, or glenohumeral arthritis. All participants completed a supervised post-operative physical therapy and rehabilitative program. Chart review was used to identify patients so that the overall test cohort encompassed a range of glenosphere size, tilt, and lateralization, as well as planned humeral retroversion. Lateralization, glenosphere size, and eccentricity were recorded from surgical notes. Humeral retroversion and glenoid tilt were measured on post-operative CT. PROs including ASES, DASH, and CMS were collected. Clinical IR ROM was measured as the furthest position participants could place their hand up their back. Participants performed 3 trials of hand-to-back motions while synchronized biplane radiographs of the shoulder were collected at 50 images/s for 2 seconds (90 kV, 50mA, 2ms pulse width). Digitally reconstructed radiographs, created from subject-specific segmented bone tissue of the humerus and scapula with their respective implants, were matched to biplane radiographs with sub-millimeter accuracy[6] to determine six degree-of-freedom scapular (upward rotation, protraction, tilt) and glenohumeral (abduction, rotation, plane of elevation) kinematics. A 3D model of the humeral liner, provided by the manufacturers, was fit into the CT-based humeral tray, and the humerus kinematics were used to drive the humeral tray kinematics. The minimum distance between the bone portion of the scapula/implant model and the humeral liner was calculated at every frame of data, interpolated to the percentage of the motion trial, and averaged across all 3 trials at corresponding percentages of the motion cycle (Figure 1). Impingement was then defined as the first instance in the motion cycle when the minimum distance fell below 0.5mm (the accuracy of our measurement system), and the position of the six kinematics rotations were saved for analysis (Figure 2). Unpaired T-tests compared surgical parameters between patients who did versus those who did not impinge. Multiple linear regression was used to identify implant parameters that predicted scapular or glenohumeral kinematics at impingement. Finally, Pearson's correlations were used to identify associations between kinematics at impingement and outcomes, with significance set at $p < 0.05$ for all tests.

RESULTS: This study included 34 patients who were tested 2.2±1.1 years after receiving RSA (17M, 17F, 72.8±7.3 years). Of the 34 participants, 11 did not reach the 0.5mm impingement threshold. Humeral retroversion was the only parameter that differentiated between patients who did impinge (19.3°±11.3°) and those who did not impinge (8.8°±7.0°, $p = 0.008$). Glenoid tilt was the only surgical parameter that predicted kinematics at impingement. A more inferior glenoid tilt predicted a more posterior plane of elevation (Figure 3A, $p < 0.001$; $\beta = 2.833$) and more IR (Figure 3B, $p < 0.001$; $\beta = -1.421$) at impingement. No associations between kinematics at impingement and PROs or clinical IR ROM were identified.

DISCUSSION: The main findings were that humeral retroversion and glenoid tilt are the surgical parameters that affect impingement during the hand-to-back motion after RSA. These *in vivo* results agree with computer models that predict humeral retroversion and glenoid tilt influence impingement. Unlike cadaver studies and computer models, this study also considers the effect of healing and rehabilitation on patient outcomes and kinematics. The lack of association between clinical outcomes and impingement, or kinematics at the time of impingement, suggest that other parameters (pain, ability to do activities of daily living outside of the hand-to-back motion, etc.) may influence PROs to a greater degree than impingement. These results are limited to the hand-to-back motion.

CLINICAL RELEVANCE: The surgeon may be able to affect impingement during the hand-to-back motion after RSA by modifying humeral retroversion and glenoid tilt, however, these changes may not affect PROs.

REFERENCES: 1) Hochreiter, et al. (2021) JSES Int. 2) Kim, et al. (2020) JSES. 3) Krämer et al. (2016) Clin. Biomech. 4) Kontaxis, et al. (2017) JSES 5) Patel, et al. (2021) JSES. 6) Bey, et al. (2006) J Biomech.

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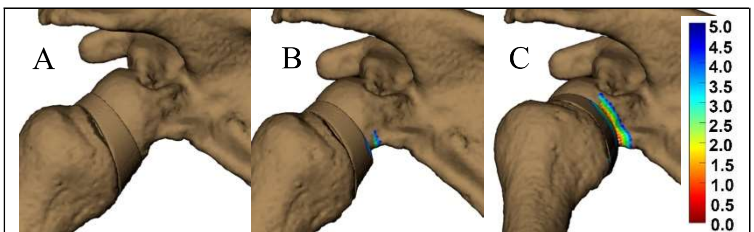

Figure 1: The gap between humeral liner and scapula at (A) the start of motion, (B) the middle of the motion and (C) at impingement during the hand-to-back motion. Colors indicate distance between liner and scapula.

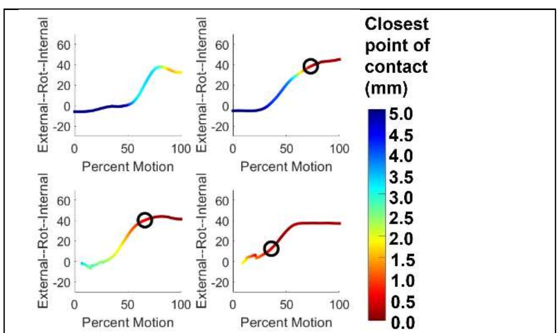

Figure 2: Internal rotation during hand to back, color-coded by the average closest point of contact for 4 participants. Circles indicate the moment impingement occurred.

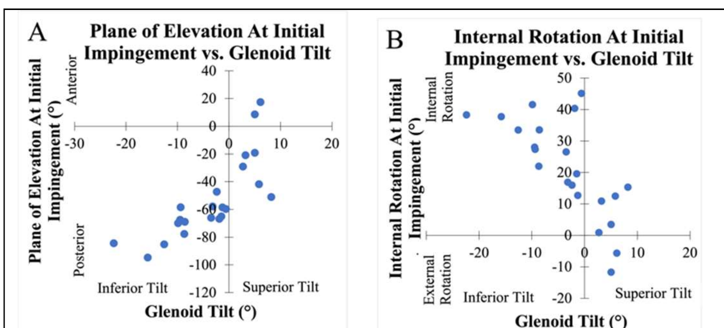

Figure 3: Plane of elevation (A) and internal/external rotation (B) reached at impingement with respect to glenoid tilt. Each blue dot represents data from one patient.