Three-Dimensional Scapular Kinematics During Shoulder Abduction After Reverse Total Shoulder Arthroplasty

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INTRODUCTION: Preoperative planning plays a crucial role in reverse total shoulder arthroplasty (rTSA) because implant positioning and orientation are closely associated with postoperative outcomes and complication rates.[1)] Although various preoperative planning applications are available across implant systems, none currently incorporate predictive modeling of postoperative scapular motion. Previous studies have reported that shoulders with rTSA demonstrate restricted glenohumeral motion compared with healthy shoulders, resulting in greater reliance on scapular upward rotation.[2)] It has also been reported that scapular posterior tilt during abduction increases from the preoperative to the postoperative period.[3)] However, detailed three-dimensional scapular kinematics at each abduction angle remain poorly understood. Consequently, current preoperative planning tools cannot account for postoperative scapular motion.

The purpose of this study was to quantify three-dimensional scapular kinematics at 10° increments of humeral abduction following rTSA. We hypothesized that scapular upward rotation would progressively increase with greater abduction angles, whereas posterior tilt would exhibit a relatively constant rate of increase.

METHODS: This study was approved by our institutional review board and ethics committee. Twenty shoulders of 19 patients who underwent rTSA with the same implant by a single experienced surgeon and achieved >90° of postoperative abduction were included. The patients consisted of 8 men and 12 women with a mean age of 76 years (range, 46 - 85). At least one year postoperatively, computed tomography (CT) scans and fluoroscopic images were obtained. Fluoroscopic images were acquired during scapular plane abduction. Using 2D–3D model-to-image registration, three-dimensional scapular models were iteratively aligned with fluoroscopic silhouettes. Scapular upward rotation and posterior tilt were measured at 10° increments from 20° to 90° of humeral abduction, and incremental changes per 10° were calculated. Pearson's correlation coefficients assessed associations between humeral abduction angle and scapular motion, while repeated-measures ANOVA evaluated differences in incremental changes. A P value < 0.05 was considered statistically significant.

RESULTS: Humeral abduction angle demonstrated a strong positive correlation with scapular upward rotation ($r = 0.99$, $P < 0.001$) and posterior tilt ($r = 0.99$, $P < 0.001$). The mean incremental increase in scapular upward rotation progressively rose with greater abduction angles: 2.6° (20–30°), 3.4° (30–40°), 3.8° (40–50°), 4.2° (50–60°), 4.6° (60–70°), 4.8° (70–80°), and 5.1° (80–90°) ($P < 0.001$) (Figure 1). In contrast, incremental posterior tilt remained nearly constant at approximately 2° per 10° of abduction, with no significant differences between ranges (Figure 2).

DISCUSSION: Following rTSA, lower abduction angles rely primarily on glenohumeral motion, whereas scapular upward rotation contributes increasingly at higher abduction angles. Scapular posterior tilt demonstrated a linear increase of approximately 2° per 10° of abduction, independent of abduction range. These findings provide new insights into compensatory scapular motion after rTSA and suggest that integrating predictive scapular kinematics into preoperative planning applications may improve implant positioning strategies and optimize postoperative functional outcomes.

This study had some limitations. First, the sample size was relatively small, involving 20 shoulders, which may limit the generalizability of our findings. Second, only one implant design and a single surgeon were included, which may restrict applicability to other implant systems and surgical techniques. Third, fluoroscopic analysis was limited to abduction in the scapular plane, and scapular motion during other functional movements remains unassessed. Future studies involving larger cohorts, multiple implant systems, and different movement patterns are warranted to validate and expand these findings.

SIGNIFICANCE/CLINICAL RELEVANCE: Understanding detailed three-dimensional scapular kinematics after rTSA enables more accurate prediction of compensatory motion patterns and facilitates the integration of postoperative scapular behavior into preoperative planning applications. Incorporating these kinematic insights may help optimize implant positioning, reduce the risk of postoperative complications, and improve functional outcomes for patients undergoing rTSA.

REFERENCES: 1) Tashjian RZ, et al. Clin Orthop Relat Res. 2018 Aug;476(8):1622-1629. 2) Walker D, et al. J Shoulder Elbow Surg. 2015 Jul;24(7):1129-34. 3) Kawashima I, et al. JSES Int., 2025;9(4):1357-64.

IMAGES AND TABLES:

Figure 1: The mean incremental increase in scapular upward rotation

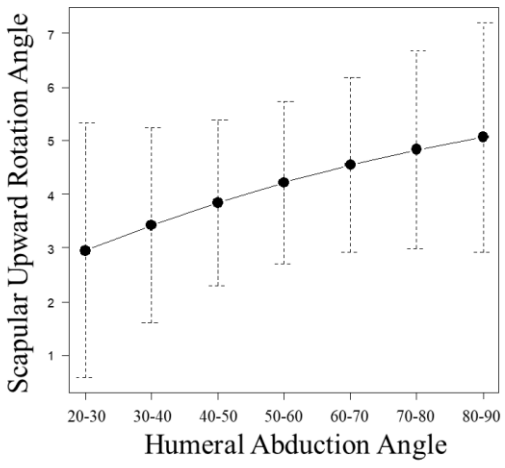

Figure 2: The mean incremental increase in posterior tilt