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A comprehensive evaluation of the association of radiographic measures of lateralization on clinical outcomes following reverse total shoulder arthroplasty

Brandon J. Erickson, MD[a,*], Brian C. Werner, MD[b], Justin W. Griffin, MD[c], Reuben Gobezie, MD[d], Evan Lederman, MD[e], Benjamin W. Sears, MD[f], Easton Bents, BS[f], Patrick J. Denard, MD[g]

[a]*Rothman Orthopaedic Institute, New York, NY, USA*
[b]*University of Virginia, Charlottesville, VA, USA*
[c]*Jordan-Young Institute, Virginia Beach, VA, USA*
[d]*Cleveland Shoulder Institute, Beachwood, OH, USA*
[e]*University of Arizona College of Medicine–Phoenix, Phoenix, AZ Banner Health, Phoenix, AZ, USA*
[f]*Western Orthopaedics, Denver, CO, USA*
[g]*Southern Oregon Orthopedics, Medford, OR, USA*

Background: Although reverse total shoulder arthroplasty (RTSA) has excellent reported outcomes and satisfaction, patients often have postoperative limitations in range of motion (ROM), specifically internal rotation. Increased lateralization is thought to improve ROM following RTSA. The purpose of this study was to evaluate the association between radiographic measurements of lateralization and postoperative ROM and clinical outcome scores following RTSA. The authors hypothesized that increased radiographic lateralization would be associated with improved postoperative ROM, specifically internal rotation, but have no significant association with clinical outcome scores.
Methods: Patients who underwent RTSA with a 135° neck-shaft angle prosthesis and minimum 2-year clinical and radiographic follow-up were included and retrospectively reviewed. Postoperative radiographs were evaluated for several lateralization measurements including the lateralization shoulder angle (LSA), distance from the lateral border of the acromion to the lateral portion of the glenosphere, distance from the glenoid to the most lateral aspect of the greater tuberosity, and the distance from the lateral aspect of the acromion to the most lateral aspect of the greater tuberosity. Linear regression analyses were used to evaluate the independent association of each radiographic measurement of lateralization on forward flexion, external rotation, internal rotation, and the American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form (ASES) index score at 2 years postoperation. Receiver operating characteristic (ROC) curves were constructed to identify significant thresholds of each radiographic lateralization measurement.
Results: A total of 203 patients were included. For internal rotation, a greater LSA ($P = .007$), shorter acromion to glenosphere distance (meaning more glenoid lateralization) ($P = .005$), and a greater acromion to greater tuberosity distance (with the tuberosity more lateral to the acromion) ($P = .021$) were associated with improved internal rotation. Overall, ROC analysis demonstrated very little significant data, the most notable of which was the LSA, which had a significant cutoff of 82° (sensitivity 57%, specificity 68%, $P = .012$).

Southern Oregon Institutional Review Board approved this study.
*Reprint requests: Brandon J. Erickson, MD, Rothman Orthopaedic Institute, 645 Madison Ave, New York, NY 10022, USA.

E-mail address: brandon.erickson@rothmanortho.com (B.J. Erickson).

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Conclusion: Of the numerous radiographic measures of lateralization after RTSA, the LSA is the most significantly associated with outcomes, including improved internal rotation and a decrease in forward flexion and ASES score. The clinical significance of these statistically significant findings requires further study, as the observed associations were for very small changes that may not represent clinical significance.
Level of evidence: Level IV; Case Series; Prognosis Study

Keywords: Reverse total shoulder arthroplasty (RTSA); range of motion (ROM); lateralization; outcome; internal rotation (IR); lateralization shoulder angle (LSA)

Reverse total shoulder arthroplasty (RTSA) has become an extremely effective treatment option for multiple shoulder conditions including rotator cuff tear arthropathy, glenohumeral arthritis, proximal humerus fractures, and others.[1,5,6,9,11,12] Although RTSA is effective at alleviating pain, depending on the preoperative functional level of each patient, the pain reduction can come at a cost of shoulder range of motion (ROM), specifically internal rotation (IR).[7,8] Unfortunately, limitations in IR can make it difficult to perform certain activities of daily living (ADL) including washing one's back, hooking and unhooking a bra, toileting, etc.[8]

As many ADLs require significant IR, there has been a recent focus on improving IR following RTSA. One potential method to improve IR is to lateralize the center of rotation either on the glenoid or humeral side.[10,15] Lateralization can also decrease bony impingement and minimize scapular notching. However, increasing lateralization increased deltoid force requirements. However, an overly excessive amount of lateralization may increase the stress on the acromion and scapular spine.[2,4] To date, the optimal amount of lateralization that will maximize rotational motion without causing significant complications has not been defined. Furthermore, there are several methods to measure lateralization following RTSA, and the optimal method to measure lateralization is also unclear.

Therefore, the purpose of this study was to evaluate the association between numerous radiographic measurements of lateralization and postoperative ROM and clinical outcome scores following RTSA. The hypothesis was that increased radiographic lateralization would be associated with improved postoperative ROM, specifically IR, but have no significant association with clinical outcome scores.

Methods

A retrospective review was performed of patients who underwent RTSA between 2016 and 2019 and were enrolled in prospective multicenter registry. Inclusion criteria were (1) primary RTSA and (2) minimum of 2-year follow-up. Exclusion criteria were (1) fracture diagnosis, (2) revision arthroplasty, (3) worker's compensation, and (4) incomplete follow-up. Institutional review board approval was obtained prior to initiating the prospective registry and all patients consented to participation at the time of enrollment.

All patients underwent RTSA via a deltopectoral approach. The subscapularis was managed per surgeon discretion, with a peel in 173 patients (82.4%), lesser tuberosity osteotomy in 19 patients (9%), and a tenotomy in 18 patients (8.6%). The subscapularis was repaired in 79 patients (39%). No patient underwent a concomitant latissimus transfer. All humeral stems had an inlay cup with a 135° inclination (Univers Revers; Arthrex, Inc., Naples, FL, USA) and 95% were placed with press-fit fixation. Two different glenoid baseplate options were used during the study period that provided a lateralization of 0-4 mm (Universal Baseplate; Arthrex, Inc.) or 0-8 mm (Modular Glenoid System; Arthrex, Inc.). The glenosphere size ranged from 33 to 42 mm. The remaining demographics of the study population are provided in Table I.

Radiographic evaluation

Grashey radiographic images from the immediate postoperative visit (within 6 weeks of surgery) were independently reviewed by 2 authors (B.J.E., E.B.). Several measurements were made on each image including the lateralization shoulder angle (LSA) (Fig. 1, *A*), distance from the lateral border of the acromion to the lateral portion of the glenosphere (Fig. 1, *B*), distance from the glenoid to the most lateral aspect of the greater tuberosity (Fig. 1, *C*), and the distance from the lateral aspect of the acromion to the most lateral aspect of the greater tuberosity (Fig. 1, *D*).[15]

Clinical evaluation

Preoperative and postoperative clinical outcome scores were recorded in all patients. These scores included the American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form (ASES), visual analog scale (VAS), Western Ontario Osteoarthritis of the Shoulder (WOOS) index, and Single Assessment Numeric Evaluation (SANE). ROM was also recorded at baseline and at 2-year follow-up for forward flexion (FF), IR, and external rotation (ER).

Statistics

The primary analyses were linear regression analyses evaluating the independent association of each radiographic lateralization measurement with each of 4 endpoints: FF, ER, IR, and ASES score. For each individual regression, in addition to the radiographic measurements of lateralization, the following additional

Table I Patient demographics, baseline and 2-year outcomes (N = 203)

Demographic variable	
Age, yr, mean (95% CI)	69.1 (68.0-70.2)
Sex, male, n (%)	110 (54.2)
BMI, mean (95% CI)	30.4 (29.6-31.3)
Race, white, n (%)	193 (95.1)
Tobacco use, n (%)	13 (6.4)
Diabetes, n (%)	22 (10.8)
Worker's compensation, n (%)	0 (0.0)
Dominant arm, n (%)	126 (62.1)
Glenosphere diameter, n (%)	
33 mm	15 (7.4)
36 mm	83 (40.9)
39 mm	60 (29.6)
42 mm	45 (22.2)
Glenoid lateralization, n (%)	
0 mm	18 (8.9)
2 mm	1 (0.5)
4 mm	127 (62.6)
6 mm	34 (16.7)
8 mm	23 (11.3)
Baseline PROs and ROM, mean (95% CI)	
VAS	5.7 (5.4-6.1)
ASES	39.5 (37.0-41.9)
WOOS	36.1 (33.4-38.7)
VR-12 Mental	50.3 (48.7-51.9)
FF, degrees	96 (91-101)
ER0, degrees	27 (24-30)
ER90, degrees	30 (26-34)
IR, spinal level	L5 (L4-L5)
IR90, degrees	24 (21-28)
2-yr PROs and ROM, mean (95% CI)	
VAS	1.1 (0.8-1.3)
ASES	82.7 (80.3-85.0)
WOOS	84.6 (82.1-87.0)
VR-12 Mental	53.6 (52.4-54.8)
FF, degrees	134 (130-138)
ER0, degrees	45 (42-48)
ER90, degrees	57 (54-61)
IR, spinal level	L4 (L4-L5)
IR90, degrees	35 (32-37)

CI, confidence interval; *BMI*, body mass index; *PRO*, patient-reported outcome; *ROM*, range of motion; *VAS*, visual analog scale; *ASES*, American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form; *WOOS*, Western Ontario Osteoarthritis of the Shoulder index; *VR-12*, Veterans Rand; *FF*, forward flexion; *ER0*, external rotation at 0° of abduction; *ER90*, external rotation at 90° of abduction; *IR*, internal rotation; *IR90*, internal rotation at 90° of abduction.

variables were included to control for potential confounders: age, sex, BMI, whether surgery was performed on the dominant arm, tobacco use, diabetes mellitus, baseline VAS pain score, baseline ASES score, preoperative FF, preoperative ER, preoperative IR, glenosphere diameter, and implant humeral version. Additionally, for each radiographic measurement, ROC analyses were performed to calculate any significant thresholds for patients achieving the patient acceptable symptomatic state for ASES (76), substantial clinical benefit for FF (22°) and ER (4°), and a functional level of L4 for IR.[3,13,14] For all comparisons, $P < .05$ was considered statistically significant.

Results

Overall, 238 patients underwent RTSA with patient-reported outcomes and ROM data and were eligible for inclusion. Of these, 28 patients did not have complete radiographs, and 7 were excluded for a combination of the other listed reasons, leaving 203 patients (85%). Demographic information, baseline ROM and PROs, and 2-year ROM and PROs for the included patients are presented in Table I. The overall revision rate was 1% (2/203), mortality rate was 0.5% (1/203), rate of nerve injury was 0.5% (1/203), and rate of intraoperative calcar/tuberosity fracture was 1.4% (3/203). There were 9 other complications (4.4%) (deep venous thrombosis, other medical, other surgical). There were no reported infections.

When evaluating IR in the regression analysis, the greater the lateralization, the greater the IR. This was evidenced by an increase in IR with a greater LSA ($P = .007$), shorter acromion to glenosphere distance (less distance from the acromion to the glenosphere indicating a more lateralized glenosphere) ($P = .005$), and a greater acromion to greater tuberosity distance (greater tuberosity was more lateral to the acromion) ($P = .021$) (Fig. 2). When evaluating forward elevation in the regression analysis, a greater LSA led to a decrease in forward elevation ($P < .001$) such that for every 1° increase in the LSA, the forward elevation decreased by approximately 1° (Fig. 3). No other lateralization factors were associated with postoperative forward elevation. When evaluating ER in the regression analysis, only greater preoperative ER was associated with a greater postoperative ER ($P < .001$) (Fig. 4). No other lateralization measurements were associated with postoperative ER. In regard to clinical outcome scores, greater LSA led to a decrease in postoperative ASES score ($P = .027$) such that for every 1° increase in the LSA, there was a 0.3-point decrease in the ASES score (Fig. 5). No other lateralization factors were associated with the postoperative ASES score.

In the ROC analysis, an LSA of 82° was a significant threshold for IR (sensitivity 57%, specificity 68%, $P = .012$). An acromion to glenosphere measurement of 15.5 mm was a statistically significant threshold for ER (sensitivity 52%, specificity 33%, $P = .015$). Finally, an acromion to greater tuberosity distance of 7.5 mm was a significant threshold for IR (sensitivity 56%, specificity 36%, $P = .043$).

Discussion

The primary finding of the current study was that increasing lateralization, particularly LSA, was associated with

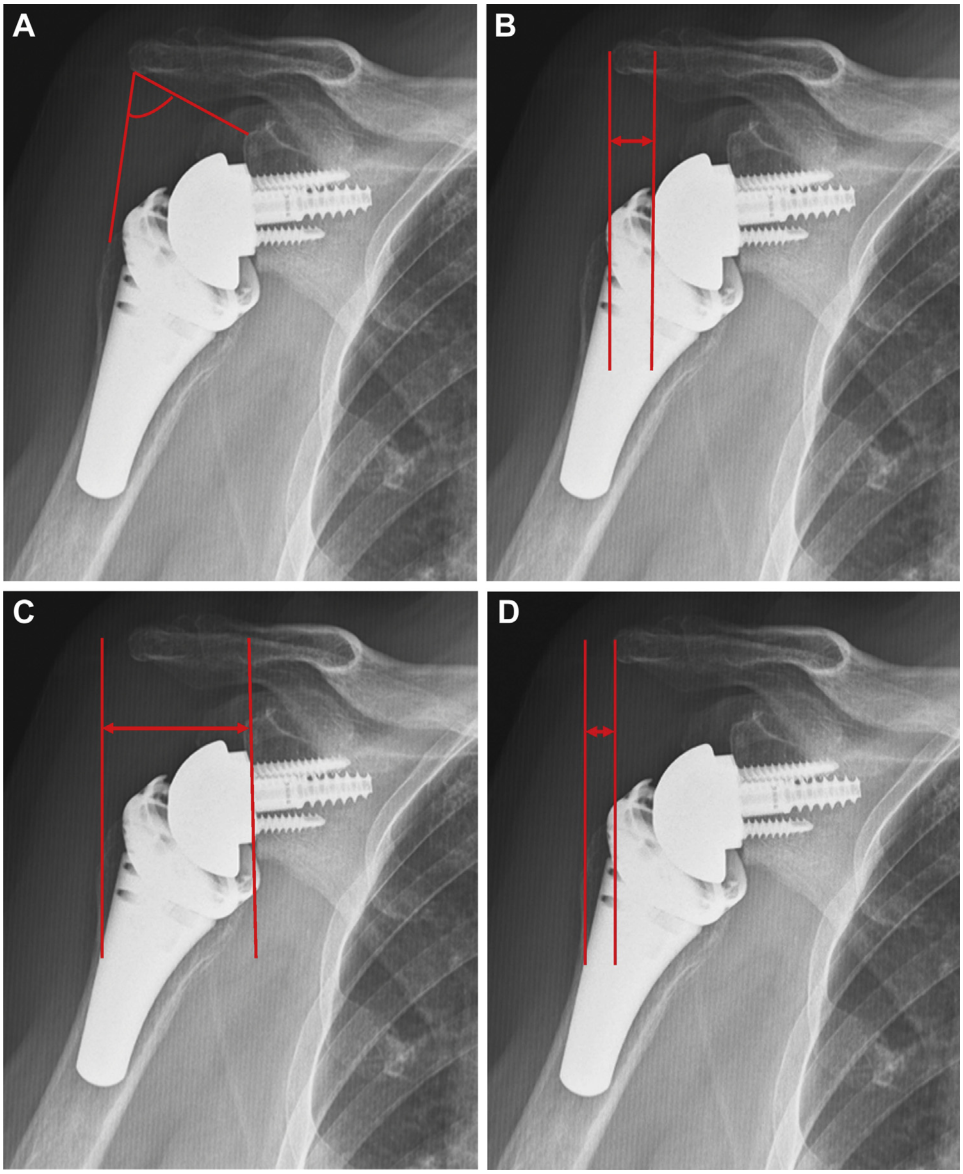

Figure 1 (**A**) The lateralization shoulder angle (LSA) is formed by a line connecting the superior glenoid tubercle and the most lateral border of the acromion and a line connecting the most lateral border of the acromion and the most lateral border of the greater tuberosity. (**B**) Distance from the lateral border of the acromion to the lateral portion of the glenosphere. (**C**) Distance from the glenoid to the most lateral aspect of the greater tuberosity. (**D**) Distance from the lateral aspect of acromion to the most lateral aspect of the greater tuberosity.

improved postoperative IR following RTSA. However, increasing LSA had a small but negative effect on postoperative FF and ASES scores.

IR following RTSA can be one of the most difficult movements for patients to regain.[7-9] Unfortunately, there are several activities of daily living that require significant IR to properly perform. Kim et al[8] retrospectively reviewed 77 patients who underwent medialized RTSA between 2008 and 2015 with a minimum follow-up of 3 years and evaluated the patient's ability to perform specific ADLs, especially those associated with IR. At final follow-up, the authors found significant improvement in pain scores, and that active FF, ER at the side, and IR were 92.5%, 79.6%, and 48.4% of the contralateral side, respectively. Interestingly, they found that forward elevation and ER recovered by 6 months and were similar to the ROM at final follow-up whereas IR did not reach its maximum until final follow-up. Furthermore, in regard to specific ADLs, only 36.4% of patients were able to wash their back, 55% were able to wash the opposite shoulder, and 64% were able to manage the toilet with their operative arm. The current study did not evaluate specific ADLs but did note that lateralization improved IR, which may benefit the ability of the patient to perform ADLs.

Werner et al[15] performed a retrospective review of 455 patients to evaluate the effect of glenoid lateralization on IR

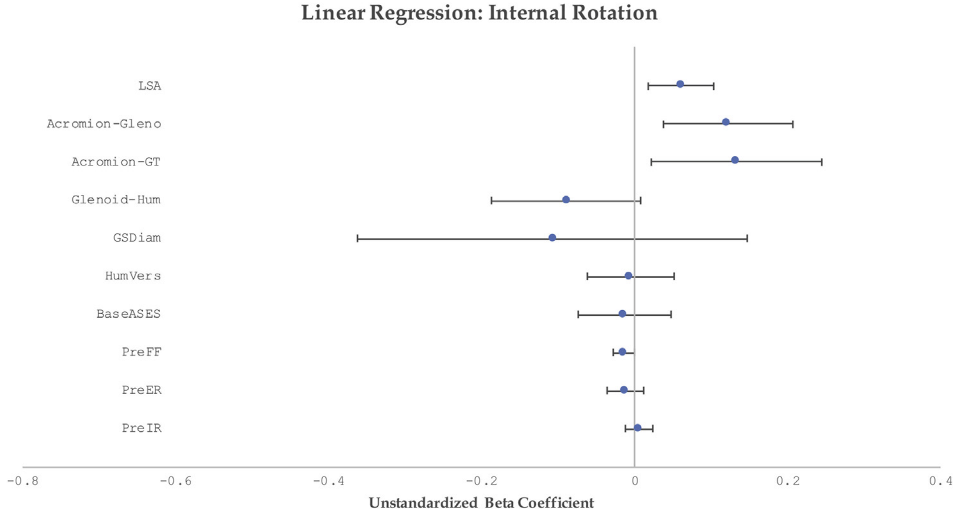

Figure 2 Linear regression for internal rotation. *LSA*, lateralization shoulder angle; *Acromion-Gleno*, distance from the lateral border of the acromion to the lateral portion of the glenosphere; *Acromion-GT*, distance from the lateral aspect of acromion to the most lateral aspect of the greater tuberosity; *Glenoid-Hum*, distance from the glenoid to the most lateral aspect of the greater tuberosity; *GSDiam*, glenosphere diameter; *HumVers*, humeral version; *BaseASES*, baseline American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form score; *PreFF*, preoperative forward flexion; *PreER*, preoperative external rotation; *PreIR*, preoperative internal rotation.

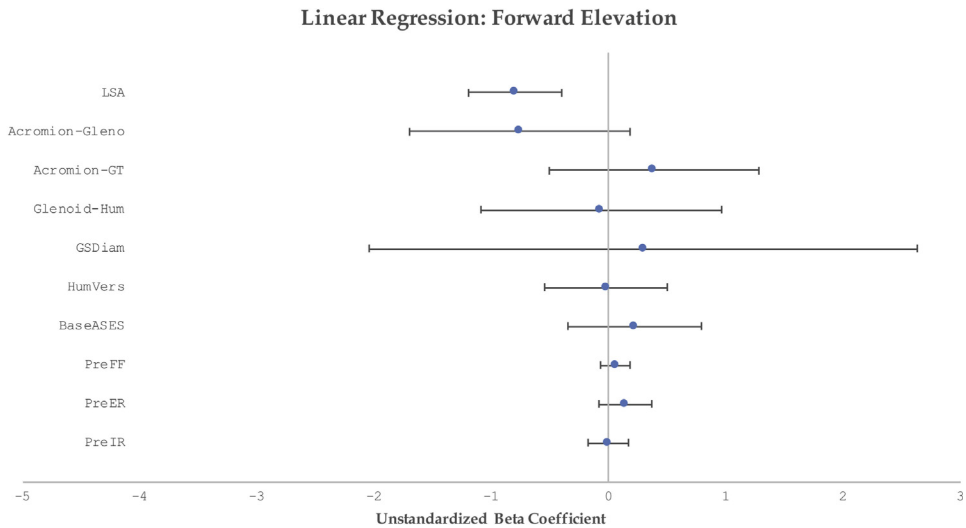

Figure 3 Linear regression for forward elevation. *LSA*, lateralization shoulder angle; *Acromion-Gleno*, distance from the lateral border of the acromion to the lateral portion of the glenosphere; *Acromion-GT*, distance from the lateral aspect of acromion to the most lateral aspect of the greater tuberosity; *Glenoid-Hum*, distance from the glenoid to the most lateral aspect of the greater tuberosity; *GSDiam*, glenosphere diameter; *HumVers*, humeral version; *BaseASES*, baseline American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form score; *PreFF*, preoperative forward flexion; *PreER*, preoperative external rotation; *PreIR*, preoperative internal rotation.

following RTSA. The authors found that patients with 8 mm of glenoid lateralization had significantly improved IR compared with all other lateralization groups (0, 2, 4, and 6 mm). They also found that patients with 6 mm of glenoid lateralization had significantly improved IR compared with the 0-, 2-, and 4-mm groups. The authors determined the amount of lateralization based on the glenosphere and glenoid baseplate components, so this provided information on general amounts of lateralization but was not specific to each patient. These results are similar to the current study as an increase in the amount of lateralization improved IR, even when effective lateralization was determined based on radiographs and not just on glenosphere lateralization.

This study used new lateralization measurements, including the distance from the lateral border of the acromion to the lateral portion of the glenosphere, the distance from the glenoid to the most lateral aspect of the greater tuberosity, and the distance from the lateral aspect of

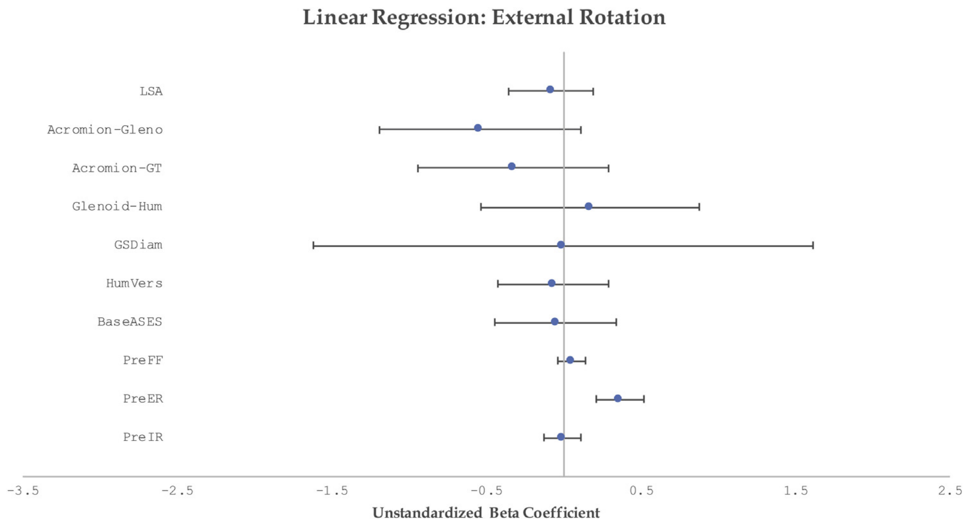

Figure 4 Linear regression for external rotation. *LSA*, lateralization shoulder angle; *Acromion-Gleno*, distance from the lateral border of the acromion to the lateral portion of the glenosphere; *acromion-GT*, distance from the lateral aspect of acromion to the most lateral aspect of the greater tuberosity; *Glenoid-Hum*, distance from the glenoid to the most lateral aspect of the greater tuberosity; *GSDiam*, glenosphere diameter; *HumVers*, humeral version; *BaseASES*, baseline American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form score; *PreFF*, preoperative forward flexion; *PreER*, preoperative external rotation; *PreIR*, preoperative internal rotation.

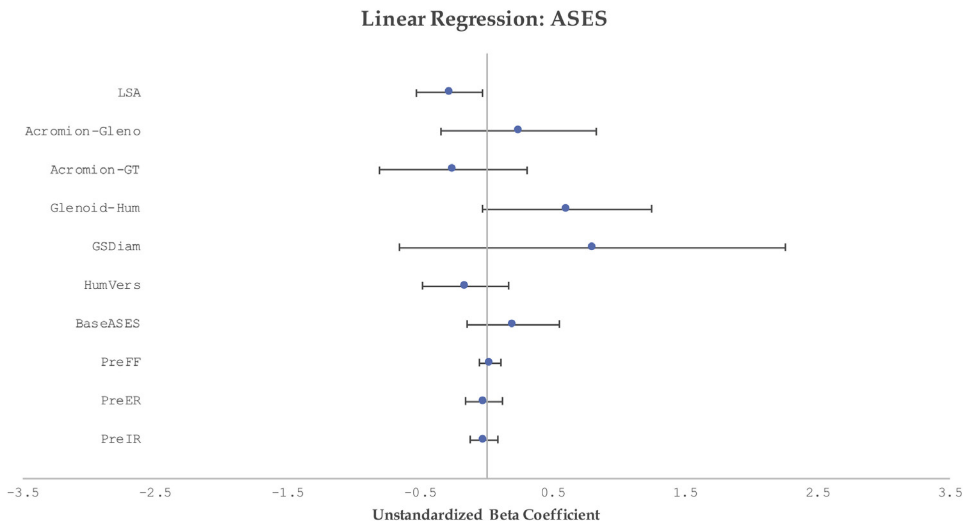

Figure 5 Linear regression for the American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form (ASES) score. *LSA*, lateralization shoulder angle; *Acromion-Gleno*, distance from the lateral border of the acromion to the lateral portion of the glenosphere; *acromion-GT*, distance from the lateral aspect of acromion to the most lateral aspect of the greater tuberosity; *Glenoid-Hum*, distance from the glenoid to the most lateral aspect of the greater tuberosity; *GSDiam*, glenosphere diameter; *HumVers*, humeral version; *BaseASES*, baseline ASES score; *PreFF*, preoperative forward flexion; *PreER*, preoperative external rotation; *PreIR*, preoperative internal rotation.

acromion to the most lateral aspect of the greater tuberosity. These are patient-specific measurements that take placement of the components as well as the patient's anatomy into account. Of these new lateralization measurements, the acromion to glenosphere distance and the acromion to greater tuberosity distance were found to be significant. The LSA, which has been previously reported, was also significant. Although increased lateralization was associated with increased IR, these measurements also saw a statistically significant, although likely clinically insignificant, decline in ASES and FF. The magnitude of these decreases in ASES (0.3 points) and FF (1°) for each degree increase in LSA were small, and as such would not meet the minimal clinically important difference. Hence, it seems that increased lateralization, as seen with several different measurements, is beneficial in RTSA. Further work is needed to determine how to maximize forward elevation and ER following RTSA.

Limitations

This study reported outcomes at 2 years and as such cannot comment on the long-term outcomes. There were several surgeons included in this study who performed the RTSA. Although all surgeons performed the surgery through a deltopectoral approach, there were subtle differences in surgical technique, including subscapularis management, that could have impacted outcomes. Statistically significant differences were found in this study, but the clinical significance is still unclear. Additionally, preoperative diagnoses differed among patients and could have affected outcomes. Furthermore, although the radiographic measurements are straightforward to make on postoperative radiographs, these measurements may be difficult to determine intraoperatively or preoperatively, so the clinical use of these thresholds must be better defined. Postoperative rehabilitation protocols were not taken into account for this study. These patients will continue to be followed so long-term outcomes can be obtained and reported.

Conclusion

Of the numerous radiographic measures of lateralization after RTSA, the LSA is the most significantly associated with outcomes, including improved IR, and a decrease in FF and ASES score. The clinical significance of these statistically significant findings requires further study, as the observed associations were for very small changes that may not represent clinical significance.

Disclaimer

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