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# The effect of body mass index on internal rotation and function following anatomic and reverse total shoulder arthroplasty

**Josef K. Eichinger, MD[a,*], Meghana V. Rao, BS[a], Jackie J. Lin, BS[a], Jonathan B. Goodloe, MD[a], Venkatraman Kothandaraman, BS[a], William R. Barfield, PhD[a], Stephen A. Parada, MD[b], Christopher Roche, MSE, MBA[c], Richard J. Friedman, MD, FRCSC[a]**

[a]*Medical University of South Carolina, Department of Orthopaedics, Charleston, SC, USA*
[b]*Medical College of Georgia at Augusta, Department of Orthopaedic Surgery, Augusta, GA, USA*
[c]*Exactech, Inc., Gainesville, FL, USA*

**Background:** The exact relationship between body mass index (BMI) and internal rotation (IR) before and after total shoulder arthroplasty has not been studied to date. The purpose of this study was to determine the effects of BMI on the preoperative and postoperative shoulder range of motion and function in anatomic (aTSA) and reverse total shoulder arthroplasty (rTSA), and specifically how IR affects patient ability to perform IR-related activities of daily living (ADLs).

**Methods:** Patients from a prospective multicenter international shoulder arthroplasty registry who underwent primary rTSA (n=1171) and primary aTSA (n=883) were scored preoperatively and at latest follow-up (2-10 years, mean = 3 years) using the Simple Shoulder Test, University of California–Los Angeles shoulder score, American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form, Constant score, and Shoulder Pain and Disability Index patient-reported outcome measures (PROMs). Measured active abduction, forward flexion, IR, and active and passive external rotation were recorded, and BMI was evaluated as a predictor of motion and patient-reported outcomes. Patient responses to questions regarding the difficulty level of IR-related ADLs were studied. The relationships between BMI, IR, and ability to perform IR-related ADLs were quantified through analysis of variance with post hoc comparisons by Tukey honestly significant difference tests, where significance was denoted as $P < .05$.

**Results:** BMI was found to be inversely correlated with IR in patients undergoing both aTSA and rTSA, both preoperatively ($P < .001$ and $P = .002$) and postoperatively ($P < .001$ and $P < .001$). BMI affected the range of motion parameters of forward flexion abduction and external rotation but to a lesser extent than that of IR. Nonobese patients demonstrated significantly greater IR than overweight, obese, and morbidly obese patients postoperatively for aTSA ($P < .001$). For rTSA, nonobese patients had a significantly greater postoperative IR than obese and morbidly obese patients ($P < .001$ and $P = .011$, respectively). For both aTSA and rTSA patients, mean IR scores significantly differed between patients reporting normal function vs. patients reporting slight difficulty, considerable difficulty, or inability to perform IR-related ADLs. Increasing IR demonstrated a significant, positive correlation with all PROMs for both aTSA and rTSA patients (Pearson correlation, $P < .001$).

**Conclusions:** BMI is an independent predictor of IR, even when controlling for age, gender, glenosphere size, and subscapularis repair. BMI was inversely correlated with the degree of IR, and decreased IR significantly negatively affected the ability to perform IR-related ADLs.

The Institutional Review Board of the Medical University of South Carolina approved this study (Pro00077486) on 06/04/2018.

*Reprint requests: Josef K. Eichinger, MD, 96 Jonathan Lucas St, CSB 708, Charleston, SC 29425, USA.
E-mail address: Joe.eichinger@gmail.com (J.K. Eichinger).


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**Clinical relevance:** Increasing BMI adversely affects shoulder ROM, particularly IR. IR is correlated with the ability to perform ADLs requiring IR in both aTSA and rTSA patients.

**Level of evidence:** Level III; Retrospective Cohort Comparison; Treatment Study



**Keywords:** Shoulder arthroplasty; BMI; obesity; internal rotation; range of motion; anatomic; reverse

Total shoulder arthroplasty is an increasingly popular procedure for the treatment of various shoulder pathologies.[14] The reverse total shoulder arthroplasty (rTSA) is an option to treat glenoid bone loss or deformity, proximal humerus fractures and their sequelae, irreparable rotator cuff tears, and glenohumeral arthritis with rotator cuff tear arthropathy. Pain relief and restoration of shoulder function with respect to abduction and elevation is a typically consistent result found in patients undergoing rTSA.[1,6,8,10,12,18] Originally, restoration of external rotation (ER) was limited in rTSA, but improvements in prosthetic designs such as incorporation of a lateralized center of rotation has improved the amount of ER gained after rTSA.[2] However, internal rotation (IR) deficits after rTSA continue to be a limitation associated with poorer outcomes, especially in comparison with anatomic total shoulder arthroplasty (aTSA).[7,11,15]

Restoration of IR is important for functional recovery following aTSA and rTSA. Activities of daily living such as bathing, dressing, and perineal hygiene rely on IR of the shoulder.[13] The reasons for limited improvements of IR in rTSA are not fully known and may be related to alteration of native shoulder mechanics, including impingement during the arc of motion and subscapularis dysfunction or absence, but these factors do not explain all of the reasons for IR dysfunction before and after rTSA.[3,4,16] Limited research evaluating the effect of body mass index (BMI) on shoulder range of motion exists. Levy et al[11] found that decreased preoperative IR, increased BMI, and a history of diabetes were significant predictors of limitations in IR at 1 year following aTSA.

The exact relationship between BMI and IR before and after total shoulder arthroplasty has not been studied to date. The purpose of this study is to determine the effects of IR on patient-reported outcome measures in a large, multinational, multicenter, prospective study of patients undergoing aTSA and rTSA, and specifically evaluate the relationship of BMI and IR preoperatively and postoperatively. We hypothesized that increasing BMI results in decreased IR and significantly negatively affects the ability to perform activities of daily living (ADLs) and results in poorer outcomes in patients undergoing aTSA and rTSA even when controlling for factors such as type of arthroplasty, age, subscapularis management, and preoperative range of motion.

## Methods

This is a retrospective cohort comparison of previously collected data. A prospective, international, multicenter shoulder arthroplasty registry was queried. Patients were scored preoperatively and at latest follow-up (2-10 years, mean = 3 years) using the Simple Shoulder Test, University of California–Los Angeles shoulder score, American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form, Constant score, and Shoulder Pain and Disability Index metrics (Table I). Measured active abduction, forward flexion, IR, and ER were recorded preoperatively and at all postoperative follow-up visits. Active IR was measured using a standard clinical evaluation of vertebral level as previously published (Fig. 1).[5,9] BMI was evaluated as a predictor of motion and patient-reported outcome measure as both as a continuous variable and as a categorical variable with four levels: normal (<24.99), overweight (25.00-29.99), obese (30.00-39.99), and morbidly obese (≥40.00). Patient responses to questions regarding the difficulty level (normal, slightly difficult, very difficult, or unable) for four IR-related ADLs were studied: posterior perineal hygiene, removing an object from the back pocket, tucking in a shirt, placing the hand behind the back, and washing one's back and fastening the bra strap in the back. Age and gender were also obtained for demographic data. The size of the glenosphere was recorded for rTSA only.

A total of 2054 patients who underwent primary aTSA and rTSA were included in the study. The inclusion criteria included a minimum of two-year follow-up, aTSA patients with inflammatory arthritis, avascular necrosis, or osteoarthritis and rTSA patients with osteoarthrisitis, rotator cuff tear arthropathy, massive irreparable rotator cuff tears, or inflammatory arthritis with rotator cuff tear. Fractures and revision cases were excluded. All patients received the same platform shoulder prosthesis (Equinoxe; Exactech, Gainesville, FL, USA), and each procedure was conducted using a deltopectoral approach. There were 1171 patients included who underwent primary rTSA and 883 patients who underwent primary aTSA. Management of the subscapularis was recorded. Patients were placed in a shoulder immobilizer for the initial postoperative period and then transitioned to gradual rehabilitation progression postoperatively.

Other exclusion criteria included patients with a history of infection and intraoperative or postoperative complications or adverse events. The relationships between BMI, IR, and the ability to perform IR-related ADLs were quantified through analysis of variance with post hoc comparisons by Tukey honestly significant difference tests where significance was denoted as $P < .05$. The Pearson correlation coefficient was used to investigate the linear relationships between BMI and range of motion outcomes after stratifying by the type of implant (aTSA vs. rTSA). Associations

**Table I** Demographic information

| | BMI category | | | | Differences between BMI category,* *P* value |
|---|---|---|---|---|---|
| | Normal | Overweight | Obese | Morbidly obese | |
| Device type, n (%) | | | | | |
| aTSA (n = 882) | 207 (23) | 319 (36) | 295 (33) | 61 (6.9) | NA |
| rTSA (n = 1171) | 348 (29.7) | 438 (37.4) | 334 (28.5) | 51 (4.3) | NA |
| Age at surgery, yr, mean ± SD | | | | | |
| aTSA | 67.8 ± 8.4 | 66.0 ± 8.4 | 65.9 ± 8.1 | 63.2 ± 6.5 | .001 |
| rTSA | 73.6 ± 7.5 | 73.1 ± 6.6 | 70.6 ± 7.4 | 69.3 ± 7.2 | <.001 |
| Length of follow-up, mean ± SD | | | | | |
| aTSA | 4.5 ± 2.4 | 4.3 ± 2.4 | 4.5 ± 2.5 | 4.3 ± 2.3 | ns |
| rTSA | 3.5 ± 1.7 | 3.6 ± 1.7 | 3.6 ± 1.8 | 2.9 ± 1.4 | ns |
| Gender, % female | | | | | |
| aTSA | 70 | 43 | 52 | 52 | <.001 |
| rTSA | 70 | 58 | 61 | 76 | <.001 |
| Subscapularis repaired?, % | | | | | |
| rTSA | 60 | 52 | 45 | 29 | NA |

*aTSA*, anatomic total shoulder arthroplasty; *rTSA*, reverse total shoulder arthroplasty; *SD*, standard deviation; *BMI*, body mass index; *NA*, not applicable; *ns*, not significant.

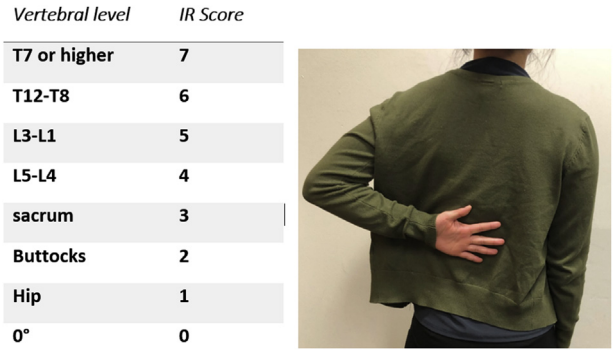


**Figure 1** IR was scored from 0 to 7 based on the highest vertebral level a patient can reach up to behind their back with the treated shoulder. A score of 0 means no degree of IR was accomplished, and higher scores indicate a larger internal range of motion. *IR*, internal rotation; *BMI*, body mass index; *aTSA*, anatomic total shoulder arthroplasty; *rTSA*, reverse total shoulder arthroplasty.

between IR measurements and ADLs were also investigated, along with the relationship between IR and the various outcome measures gathered. A multiple linear regression model was built to determine the effect of BMI on IR, while controlling for age, gender, and history of subscapularis repair. A linear regression was also created to find factors that would predict improvement in IR after rTSA, preoperatively to postoperatively.

## Results

Age was shown to be different between certain BMI groups (Table I). The higher-BMI groups tended to be younger, for both the aTSA and rTSA groups. There was an approximately equal distribution between men and women in both the obese and morbidly obese BMI categories in the aTSA group. The overweight group included a larger percentage of men, and the normal BMI group included a larger percentage of women. In the rTSA group, for all four BMI categories, the majority of the subjects were female. BMI was strongly correlated with patient weight ($R = 0.8$, $P < .001$) but not correlated with patient height ($R = –0.01$, $P = .8$).

When treated as a continuous variable, BMI is inversely correlated with IR in patients undergoing both aTSA and rTSA, both preoperatively and postoperatively (Table II). Abduction follows a similar trend, although the result is not significant for aTSA preoperatively. Greater BMI is inversely correlated with only preoperative ER for aTSA. The effect of increasing BMI remains statistically significant in a multivariable model where higher BMI demonstrates worse IR both preoperatively and postoperatively. This is consistent even when controlling for age, gender, and a history of subscapularis repair (Table III). In patients who underwent rTSA, the presence of a larger-diameter glenosphere, female gender, and a repaired subscapularis predicts better pre- to postoperative IR improvement.

Patients with a normal BMI demonstrated significantly greater IR than overweight, obese, and morbidly obese patients postoperatively for aTSA ($P < .001$ for all). For rTSA, patients with a normal BMI had a significantly greater postoperative IR than obese and morbidly obese patients ($P < .001$ and $P = .011$, respectively) (Fig. 2). aTSA pre- to postoperative improvements in IR were not significantly different than rTSA pre- to postoperative improvements in IR (1.9 vs. 1.9, $P = .99$). IR measurements were higher for rTSA than for aTSA patients preoperatively

**Table II** Pearson correlation tests for range of motion and BMI

| | Pearson correlation test between BMI and range of motion,* *R* coefficient; *P* value | | | | |
|---|---|---|---|---|---|
| | aER | pER | IR | Forward elevation | Abduction |
| Preoperative | | | | | |
| aTSA | −0.05; ns | −0.06; ns | −0.12; <.001 | −0.13; <.001 | −0.06; .051 |
| rTSA | 0.01; ns | 0.01; ns | −0.09; .002 | 0.03; ns | 0.07; .02 |
| Postoperative | | | | | |
| aTSA | −0.08; .02 | −0.06; .04 | −0.22; .001 | −0.09; .01 | −0.12; <.001 |
| rTSA | −0.01; ns | 0.05; ns | −0.19; .001 | −0.05; ns | 0.08; .004 |
| Improvement | | | | | |
| aTSA | −0.03; ns | 0.00; ns | −0.06; ns | 0.03; ns | −0.05; ns |
| rTSA | 0.01; ns | 0.03; ns | .01; ns | −0.01; ns | −0.01; ns |

*aTSA*, anatomic total shoulder arthroplasty; *rTSA*, reverse total shoulder arthroplasty; *BMI*, body mass index; *aER*, active external rotation; *ns*, nonsignificant; *pER*, passive external rotation; *IR*, internal rotation.
* Age, gender, and subscapularis repair were not controlled for.

**Table III** Predictors of internal rotation from a multivariate linear model

| | Covariates | | | | |
|---|---|---|---|---|---|
| | Age | Gender | Subscapularis repair | Glenosphere size (rTSA only) | BMI |
| Preoperative | | | | | |
| aTSA | ns | ns | NA | NA | Negative correlation, .009 |
| rTSA | ns | .008 (higher for men) | NA | NA | Negative correlation, .001 |
| Postoperative | | | | | |
| aTSA | ns | <.001 (lower for men) | NA | NA | Negative correlation, <.001 |
| rTSA | ns | ns | <.001 (higher for those repaired) | ns | Negative correlation, <.001 |
| Improvement | | | | | |
| aTSA | ns | <.001 (lower for men) | NA | NA | ns |
| rTSA | ns | .02 (lower for men) | <.001 (higher for those repaired) | .03 (higher for largest diameter) | ns |

*aTSA*, anatomic total shoulder arthroplasty; *rTSA*, reverse total shoulder arthroplasty; *ns*, not significant; *NA*, not applicable; *BMI*, body mass index.

(aTSA: 3.10 vs. rTSA: 3.24, $P = .02$) but were higher for aTSA patients postoperatively (aTSA: 5.0 vs. 4.4, $P < .001$). Improvements in IR, pre- to postoperatively, did not significantly differ by BMI category for patients undergoing rTSA or aTSA.

The ability to postoperatively perform ADLs that require IR correlated with measured clinical IR. For both aTSA and rTSA patients, mean IR scores significantly differed between patients reporting normal function vs. patients reporting slight difficulty, considerable difficulty, or inability to perform the four ADLs (Fig. 3). Seventy-five percent of rTSA patients reporting normal function demonstrated IR to L5 or higher for rTSA, and aTSA patients reporting normal function demonstrated IR to L3 or higher. For each IR-related ADL, aTSA patients reporting normal postoperative function demonstrated IR that was on average 0.25-0.4 points higher than rTSA patients reporting normal postoperative function for the same ADLs (mean scores: 5.3-5.4 for aTSA, 5.0-5.1 for rTSA, $P \leq .002$).

We also examined the percentage of patients reporting normal function given a minimum level of measured IR. For patients undergoing rTSA with clinically measured IR to L5 or higher, 50% report normal function for tucking in a shirt behind back, 64% report normal function for reaching into back pocket, 85% report normal function for toilet use and perineal hygiene, and 35% report they are able to wash their back and fasten their bra in the back. These percentages are higher for three of the four activities in patients undergoing aTSA with clinically measured IR to L5 or higher. For aTSA patients, 65% report normal function for tucking in a shirt behind back, 80% report normal function for reaching into back pocket, 81% report normal function for toilet use and perineal hygiene, and 53% report they are able to wash their back and fasten their bra strap in the

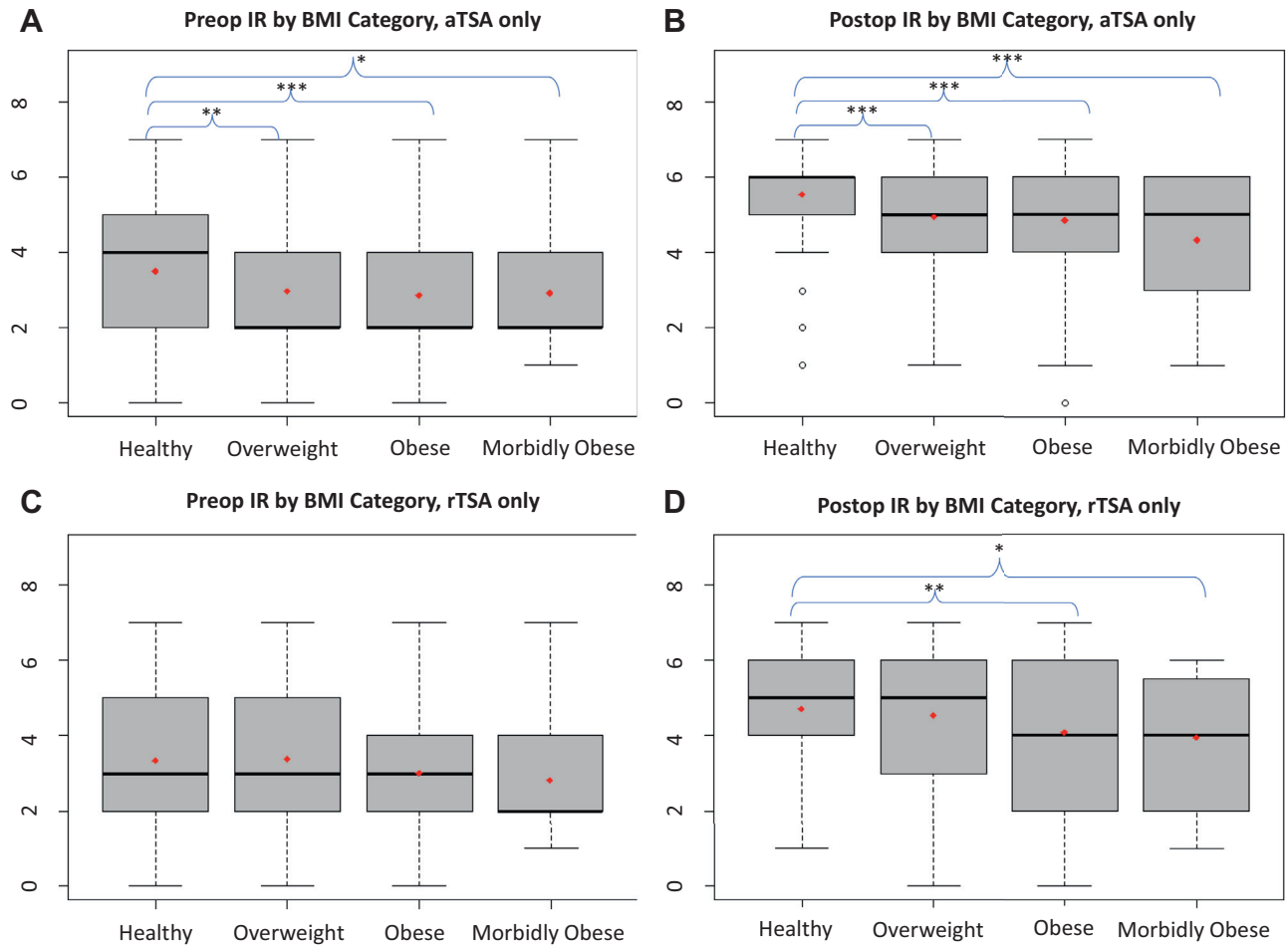


**Figure 2** BMI category and IR range of motion. *P* values correspond to Tukey honestly significant difference test for pairwise comparisons: $*P < .05$; $**P < .001$; $***P < .001$. *IR*, internal rotation; *BMI*, body mass index; *aTSA*, anatomic total shoulder arthroplasty; *rTSA*, reverse total shoulder arthroplasty.

back. These differences between rTSA and aTSA patients are statistically significant for all ADLs ($P < .001$), except for perineal hygiene ($P = .20$). IR scores correlated significantly with all five postoperative patient-reported outcome measures for both aTSA and rTSA patients (Pearson correlation, $P < .001$); these correlation coefficients range from $R = .33$ for the correlation between IR motion and University of California–Los Angeles shoulder scores to $R = .48$ for the correlation between IR motion and Constant scores.

## Discussion

Factors affecting IR motion after shoulder arthroplasty are not well studied but has significant functional importance to patients' activities of daily living and quality of life. We found that clinically measured IR is correlated with the ability to perform ADLs requiring IR in both anatomic and reverse shoulder arthroplasty patients. The median IR scores for patients reporting normal function are consistent across all IR-related ADLs. The median IR for patients undergoing rTSA corresponds to L3-L1; the median for aTSA patients corresponds to T12-T8 for three out of four ADLs, with patients reporting normal perineal hygiene demonstrating a median IR score of 5. This is consistent with previously published literature comparing aTSA with rTSA.[17] A query of prospectively collected outcomes from a single institution revealed significantly inferior outcomes two years postoperatively in clinician-measured and subjectively evaluated IR for rTSA patients relative to aTSA patients.[17] Furthermore, a significantly higher percentage of aTSA patients than rTSA report successfully reaching the small of the back and being able to wash the back.[17] Although performing these ADLs involves access to different anatomic regions, the similarities in the distribution of IR scores for normal function across all four ADLs reveals the significance of patients' subjective assessment of their function at a given level of motion. A 2012 study by Namdari and colleagues[13] examined range of motion of the shoulder in 20 healthy volunteers (40 shoulders) by having them perform several ADLs and measuring shoulder

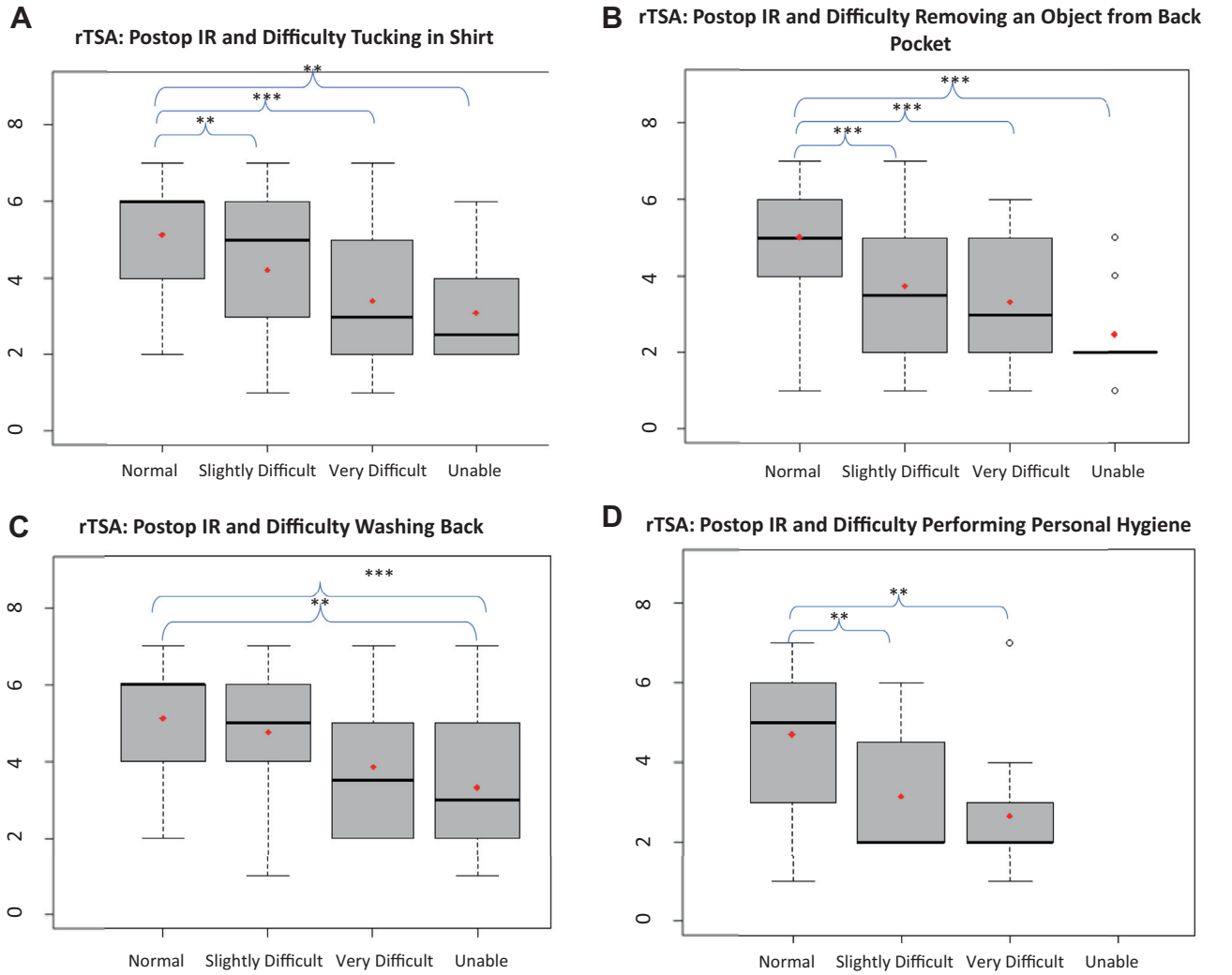


**Figure 3** IR scores and IR-related ADLs in rTSA postoperatively. *P* values correspond to Tukey honestly significant difference test for pairwise comparisons: $**P < .001$; $***P < .001$. *rTSA*, reverse total shoulder arthroplasty; *IR*, internal rotation; *ADLs*, activities of daily living.

motion with electrical motion trackers while they performed these tasks. This study defined IR/ER as humeral rotation (in degrees) along the long axis of the humerus. They found that nearly 90° of IR was necessary to tuck in the shirt behind the back, and approximately 100° of IR was necessary to wash the back or fasten a bra in the back. The authors did not correlate degree of IR to specific vertebral level, which makes the findings of their study less useful in the clinical scenario because few clinics have the capability to use motion tracking to evaluate range of motion. Using vertebral level to measure IR is a useful and clinically relevant method to evaluate functional IR. In contrast, our study correlated a clinician-measured vertebral level IR measurement with patient-reported functional ability for IR-related ADLs. The majority of patients who are able to internally rotate to at least L5 report little or no difficulty in performing functions like washing their back, which may require IR to the interscapular region. This finding points to the need for further research to identify a minimum level of IR to allow for patient satisfaction in their ability to perform ADLs; this level of motion can then be set as a goal for patients, physicians, and physical therapists. Optimizing IR to this extent is especially significant for patients undergoing rTSA as the risk of dislocation must be balanced with the goal of achieving acceptable functional motion.

Of those who demonstrate the same minimum level of IR (ie, to L5 or higher), a significantly higher proportion of aTSA patients report normal function in performing their ADLs than the rTSA patients. This finding further supports that a patient's perception of normal function is multifactorial in nature, and although subjective function is correlated with range of motion, subjective function is not entirely determined by range of motion. Pain relief is likely

a principal subjective factor influencing subjective outcome scores. A further explanation may be IR strength, which was not analyzed. Patients undergoing aTSA may have better postoperative strength than rTSA patients, which would correspond to better functional outcomes.

Limitations of this study include the lack of description of handedness and accounting for patients with bilateral arthroplasties. Individuals undergoing shoulder arthroplasty on their dominant extremity may experience a greater degree of dysfunction for IR-related ADLs compared with individuals undergoing arthroplasty on their nondominant arm. Although this study identifies BMI as a factor affecting IR, the exact reason is unknown. Hypothesized reasons for lower IR include the relative weight of arm, physical restriction of motion from a larger torso or buttocks, deconditioning, or a combination of factors. Because abduction is also negatively associated with increasing BMI, arm weight and deconditioning may be the more relevant causative factors because abduction is not affected by the size of the torso or buttocks. It is worthwhile to note that IR behind the back requires abduction, which accounts for the negative association between abduction and BMI. Another limitation could be the variability in the management of the subscapularis, because of slight differences in the techniques of the surgeons. Multiple surgeons were included in the registry, and each surgeon has her or his own subtle differences in technique. Furthermore, the degree of lateralization could be a possible confounding variable because it could not be accurately quantified. This was because the study did not account for the amount of humeral resection, degree of glenoid reaming, and factors related to the size of the patient. However, the fact that the same platform system was used across all patients allows for basic assumptions to be made regarding lateralization, including a medialized glenoid and lateralized humerus.

The indications for aTSA and rTSA are different and varied. aTSA is done for one indication, glenohumeral osteoarthritis with intact rotator cuff function, thus representing a homogeneous group. Alternatively, rTSA is done for several different indications. Therefore, if one compared aTSA and rTSA done for OA with intact cuff, they may have similar outcomes with regard to IR. Although we were not able to account precisely for the indications for all patients undergoing rTSA, this knowledge likely does not affect the results of this study because we compared two large cohorts of patients and evaluated their ROM before and after surgery.

To our knowledge, this is the largest study of prospectively collected data describing the effect of BMI on range of motion of the shoulder before and after arthroplasty. There is an inverse association between BMI and IR of the shoulder. This association is present preoperatively and postoperatively, including both anatomic and reverse shoulder arthroplasty. Abduction, forward elevation, and ER are also negatively associated with BMI, at various preoperative and postoperative outcomes, but did not show the consistent correlation that IR did. Although an inverse correlation between BMI and postoperative IR was noted in the study by Levy et al,[11] we have found that this correlation is present both preoperatively and postoperatively. Furthermore, BMI is an independent predictor of IR, even when controlling for age, gender, glenosphere size, and subscapularis repair. This highlights the unique effect of BMI on IR and suggests that future research that examines and seeks to improve postoperative IR outcomes take BMI into account. Further research is also necessary to discern whether this effect of BMI on IR is biomechanical in nature or whether it is driven by trends in the severity of shoulder pathology, by the number of medical comorbidities, or by differences in body habitus.

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