RESEARCH ARTICLE

Predictors of Internal Rotation after Reverse Shoulder Arthroplasty

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Abstract

Objectives: Internal rotation (IR) remains unpredictable following reverse total shoulder arthroplasty (rTSA). This study aimed to determine if increasing IR limits range of motion in other planes, and to determine pre- and intra-operative factors associated with post-operative IR.

Methods: A retrospective analysis of a single surgeon's primary rTSA with a single implant was undertaken, excluding patients with acute fracture or infection. A lesser tuberosity osteotomy (LTO) or subscapularis peel tenotomy was performed and repaired at the surgeon's discretion. One hundred sixty rTSA were included; 142 (88.8%) had documented IR both pre-operatively and at one-year follow-up. Variables were collected to determine their effect on IR at the 1-year follow-up point. A multivariate logistic regression was used to determine independent predictors of sufficient IR.

Results: Average age was 69.8 (range: 55-86) years and 55% (88/160) were female. Preoperatively, 20.4% of patients (29/142) had sufficient IR. This improved to 32.4% (46/142) one year following surgery, p<0.001). Factors associated with sufficient post-operative IR were female sex (p=0.05), decreasing body mass index (p=0.04), pre-operative IR (p=0.01), preoperative external rotation (ER) in adduction (p<0.001), radiographic evidence of LTO healing (p=0.02), increased one-year postoperative forward elevation (p<0.001), and increased one-year postoperative ER (p<0.001). Increased postoperative IR did not adversely affect forward elevation or ER. On multivariate analysis, higher preoperative IR and one-year postoperative forward elevation were independently associated with sufficient one-year postoperative IR.

Conclusion: IR following rTSA continues to be modest and unpredictable. Independent predictors of sufficient post-operative internal rotation were higher preoperative IR and one-year postoperative forward elevation. In a Grammont-style rTSA system, humeral version, glenosphere lateralization, and glenosphere size do not appear to impact IR. Importantly, achieving sufficient IR does not come at the expense of other planes of motion.

Level of evidence: III

Keywords: Internal rotation, Patient outcomes, Range of motion, Reverse shoulder arthroplasty

Introduction

Reverse total shoulder arthroplasty (rTSA) is known to significantly improve motion, patient-reported outcomes, and function for patients with massive irreparable rotator cuff tears or cuff tear arthropathy as well as degenerative, posttraumatic, and inflammatory arthropathies of the shoulder.[1-10] despite the substantial functional and pain improvement afforded by this procedure, restoration of shoulder rotational motion remains a challenge. Specifically, post-operative improvements in internal rotation (IR) are variable and unpredictable.[1,11-14] Given that IR is critical for performing activities of daily living (ADL) such as toileting and dressing,[15-19] increasing focus is being placed on understanding and improving post-operative IR following

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rTSA. Concurrent work out of this institution has demonstrated that improving internal rotation following total shoulder arthroplasty strongly predicts patient-reported single assessment numeric evaluation (SANE) and satisfaction. Furthermore, it was found that the clinical benefit of improved IR was diminished with behind-the-back motion greater than "mid-back"—establishing the threshold for sufficient IR.

Cadaveric, clinical, and radiographic studies have yielded preliminary data regarding factors that impact internal rotation after rTSA. Body mass index (BMI), pre-operative internal rotation, humeral component retroversion, glenosphere overhang, glenoid inclination, and polyethylene insert depth have been proposed as factors that may influence post-operative IR.[1,11,13,20-34] However, the patient and surgical factors which drive improvements in functional IR following RSA remain to be defined.

The aim of this study was to retrospectively characterize improvements in IR following rTSA in a cohort treated by a single surgeon using a Grammont-style implant system. Utilizing this cohort, factors associated with sufficient post-operative internal rotation were investigated. We also aimed to determine if motion in other planes—specifically external rotation—was sacrificed as a result of improved internal rotation.

Materials and Methods

After local institutional review board (IRB) approval, a retrospective analysis of a single surgeon's prospectively-maintained case list was performed. All primary rTSA (n=305) from January 2017 through December 2019 were vetted for potential inclusion in this analysis. Inclusion criteria were: 1) primary rTSA and 2) minimum 1-year post-surgical clinical follow-up. Exclusion criteria were: 1) revision arthroplasty surgery 2) rTSA indicated for acute proximal humerus fracture and 3) implant system other than Trabecular Metal Reverse Shoulder System; Zimmer; Warsaw, IN.

All patients were implanted with a Grammont-style system consisting of a 150° or 155° humeral neck-shaft angle and 2.5 or 4.5 millimeters of glenoid lateralization (Trabecular Metal Reverse Shoulder System; Zimmer; Warsaw, IN). Subscapularis takedown was achieved by either peel tenotomy or lesser tuberosity osteotomy (LTO). Takedown was performed without repair in most cases, with select patients undergoing LTO repair with stem-based heavy suture Varepair, or rarely peel repair with heavy suture. Patients with repair of a peel were considered to not have a healed subscapularis given the poor healing rates of peel previously described.[8] The decision to perform an LTO and/or subsequent repair was based upon a host of factors including inclusion in a prospectively randomized study evaluating LTO repair, and surgeon discretion in attempts to improve dominant arm IR. Post-operatively, patients were immobilized in a sling for the first 2 post-operative weeks and shoulder motion was restricted. Post-operative passive and active-assisted motion focusing on forward elevation and external rotation was begun at two to three weeks. Active and passive internal rotation was restricted for the first six post-operative weeks.

Variables with potential impact on postoperative IR were collected. These variables included patient characteristics (age, sex, BMI, smoking status, operative laterality, dominant arm, prior surgeries, and indications for surgery), pre-operative range of motion assessed by a single surgeon during the pre-operative clinic visit without the use of a goniometer, intra-operative factors (glenosphere size, humeral version assessed intra-operatively by a single surgeon, humeral height, the presence of a constrained or non-constrained liner, if a latissimus dorsi transfer was performed, and post length), post-operative range of motion assessed by the surgeon at the final clinic visit one year post-operatively, and evidence of LTO healing assessed by two separate surgeons radiographically. Range-of-motion was assessed as active motion in forward elevation, external rotation in adduction, external rotation in abduction, and internal rotation behind-the-back without the use of a goniometer. Internal rotation was recorded as vertebral level achieved with the hand behind the back with active motion. Sufficient active internal rotation was defined as the ability to reach above the lumbar spine with the hand behind the back and thumb extended. One year was determined as the cutoff point for minimum follow-up based on prior studies documenting a plateau in IR gains after one year of follow-up.[22,34]

The primary outcome was the ability to achieve sufficient post-operative internal rotation. In assessing variables associated with this primary outcome, a chi-squared analysis was performed for binomial independent variables. A Student's t-test was utilized for continuous variables with a normal distribution. Normal distribution was confirmed for each variable with a skewness less than two and kurtosis less than 12. Patient's with missing data for specific variables (reported in the results) were excluded for that specific analysis with replacement of the missing data. Multivariate logistic regression was used to determine independent predictors of insufficient internal rotation (Statistical Product and Service Solutions, Armonk, NY: IBM Corp.).

Results

Of the 305 primary rTSA's performed by the single surgeon during the study period, 160 shoulders met all inclusion/exclusion criteria. Of the 160 shoulders included in the study, 55.0% (88/160) were female, with a mean age of 69.8 years (SD: 6.9 years) [Table 1]. The most common indications for rTSA were irreparable rotator cuff tears (60/160, 37.5%) and glenohumeral osteoarthritis (55/160, 34.4%). One hundred forty-two (88.8%) patients had both pre-operative and one-year post-operative internal rotation adequately documented and were therefore included in analysis of factors involving pre- or post-operative IR. Pre-operatively, 20.4% (29/142) patients had sufficient internal rotation (ability to reach above the lumbar spine). At 1-year follow-up, 32.4% (46/142) demonstrated sufficient internal rotation ($p<0.001$), representing a significant increase in the proportion of the cohort with satisfactory internal rotation.

Of the 29 patients with sufficient internal rotation pre-operatively, 48.3% (14/29) were able to achieve sufficient IR at 1-year of follow-up, compared to only 28.3% (32/113) of patients that had deficient pre-operative rotation ($p=0.013$) [Table 2]. In addition, those with sufficient post-operative IR were noted to have demonstrated greater external rotation ROM in

adduction on pre-operative evaluation (mean 41.8°, range 0°-90°) than those with insufficient post-operative IR (mean 28.0°, range -10° - 70°; *p<0.001*). Female patients were more likely to achieve satisfactory internal rotation compared to their male counterparts (35/88, 39.8% and 18/72, 25%, respectively; *p=0.05*) [Table 2].

Table 1. Cohort characteristics

Variable	N[a]	Number (%) or Mean (SD)
Age (Years)	160	69.8 (6.9)
Sex	160	
Male		72 (45.0%)
Female		88 (55.0%)
BMI (kg/m^2)	160	29.0 (6.3)
Smoking Status		
Active	140	1 (0.6%)
Former		89 (55.6%)
Never		70 (44.8%)
Laterality	160	
Left		62 (38.8%)
Right		98 (61.3%)
Dominant Upper Extremity	131	
Yes		84 (64.1%)
No		47 (35.9%)
Prior Surgery	160	
Yes		53 (33.1%)
No		107 (66.9%)
Indication for Surgery		
Irreparable Rotator Cuff Tear	160	60 (37.5%)
Osteoarthritis		55 (34.4%)
Cuff Tear Arthropathy		37 (23.1%)
Post-Traumatic Arthritis		5 (3.1%)
Rheumatoid Arthritis		3 (1.9%)

BMI, body mass index. aNot all categories have N=160 due to deficiencies in documentation

Table 2. Association between preoperative variables and postoperative internal rotation

Preoperative Variable	N[a]	Sufficient Postoperative IR Mean (SD) or N (%)	Insufficient Postoperative IR Mean (SD) or N (%)	P-value
Age (Years)	160	69.8 (0.9)	69.7 (0.7)	0.96
Sex				
Female	160	35 (39.8%)	53 (60.2%)	0.05
Male		18 (25.0%)	54 (75.0%)	
BMI (kg/m^2)	160	27.6 (6.6)	29.8 (6.1)	0.04
Smoking Status		0 (0.0%)	1 (100.0%)	
Active	140	24 (34.3%)	46 (65.7%)	0.76
Former		29 (32.6%)	60 (67.4%)	
Never				
Laterality	160	32 (32.7%)	66 (67.3%)	0.87
Right		21 (33.9%)	41 (66.1%)	
Left				

Table 2.Continued

Dominant Upper Extremity Yes No	131	30 (35.7%) 16 (34.0%)	54 (64.3%) 31 (66.0%)	0.51
Previous Surgery Yes No	160	13 (24.5%) 40 (37.4%)	40 (75.5%) 67 (62.6%)	0.10
Indication Irreparable RCT OA CTA PTA RA	160	25 (41.7%) 15 (27.3%) 12 (32.4%) 1 (20.0%) 0 (0.0%)	35 (58.3%) 40 (72.7%) 25 (67.6%) 4 (80.0%) 3 (100.0%)	0.32
Preoperative IR – 0˚ Abduction (˚) Insufficient Sufficient	142	32 (28.3%) 14 (48.3%)	81 (71.7%) 15 (51.7%)	0.01
Preoperative Forward Elevation (˚)	158	109.3 (35.6)	101.9 (38.5)	0.25
Preoperative ER – 0˚ Abduction (˚)	156	41.8 (22.3)	28.0 (28.1)	<0.01

IR, internal rotation; BMI, body mass index; RCT, rotator cuff tear; OA, osteoarthritis; CTA, cuff-tear arthropathy; PTA, post-traumatic arthropathy; RA, rheumatoid arthritis; ER, external rotation.
aNot all categories have N=160 due to deficiencies in documentation

Patients who achieved sufficient IR had, on average, lower BMI (mean 27.6 kg/m^2, range 18.0-46.0 kg/m^2) compared to patients who did not achieve adequate IR (mean 29.8 kg/m^2, range 16.0-49.0 kg/m^2; *p=0.04*). There were no associations between any intra-operative variables and achieving sufficient IR [Table 3].

Table 3. Association between operative variables and postoperative internal rotation

Operative Variable	**N[a]**	**Sufficient Postoperative IR Mean (SD) or Number (%)**	**Insufficient Postoperative IR Mean (SD) or Number (%)**	**P-value**
Glenosphere Size 36 mm 40 mm	156	44 (35.8%) 9 (27.3%)	79 (64.2%) 24 (72.7%)	0.36
Humeral Version (˚)	159	23.1 (5.0)	22.8 (5.3)	0.75
Humeral Height (mm)	160	2.7 (3.1)	3.0 (3.2)	0.56
Liner Constrained Non-constrained	159	14 (24.1%) 38 (37.6%)	44 (75.9%) 63 (62.4%)	0.08
Latissimus Dorsi Transfer Yes No	160	0 (0.0%) 53 (34.0%)	4 (100.0%) 103 (66.0%)	0.15
Extended Post Yes No	160	51 (34.7%) 2 (15.4%)	96 (65.3%) 11 (84.6%)	0.16

IR, internal rotation. aNot all categories have N=160 due to deficiencies in documentation

Patients with a repaired LTO who displayed radiographic evidence of osteotomy healing demonstrated an improved rate of sufficient internal rotation post-operatively (22/25, 46.8%) compared to patients without evidence of healing and those undergoing subscapularis peel tenotomy (27/100; 27.0%; *p=0.02*) [Table 4]. Interestingly, when comparing 3 groups of patients (patients with a repaired LTO and radiographic evidence of healing, patients with an LTO and no evidence of healing, and patients undergoing a subscapularis peel tenotomy), the data also suggests that LTO healing may play a role in predicting post-operative internal rotation (*p=0.05*).

Table 4. Association between postoperative variables and postoperative internal rotation

Postoperative Variable	N[a]	Sufficient Postoperative IR Mean (SD) or Number (%)	Insufficient Postoperative IR Mean (SD) or Number (%)	P-value
Repaired LTO Status		22 (46.8%)	25 (53.2%)	
Healed	147	27 (27.0%)	73 (73.0%)	0.02
All others (non-healed LTO, peel)				
Subscapularis Status		22 (46.8%)	25 (53.2%)	
Healed	147	1 (16.7%)	5 (83.3%)	0.05
Not Healed		26 (27.7%)	68 (72.3%)	
Not Repaired or Peel				
Postoperative Forward Elevation (˚)	160	150.7 (6.9)	139.5 (13.5)	<0.01
Postoperative ER – 0˚Abduction (˚)	160	54.1 (14.9)	40.3 (15.5)	<0.01
Postoperative ER – 90˚ Abduction (˚)	155	84.5 (9.2)	74.5 (15.8)	<0.01

LTO: lesser tuberosity osteotomy. aNot all categories have N=160 due to deficiencies in documentation

Patients with sufficient post-operative IR demonstrated greater post-operative ROM in all planes compared to those who did not achieve sufficient IR. At one-year following surgery those with sufficient IR had greater forward elevation (150.7° versus 139.5°; *p<0.001*), external rotation in adduction (54.1° versus 40.3°; *p<0.001*), and external rotation in abduction (84.5° versus 74.5°; *p<0.001*) compared to those that did not [Table 4, Figure 1].

On multivariate analysis, only pre-operative IR (Odds Ratio [OR] =3.5; 95% confidence interval [CI]:1.1-11.0; p=0.03) and post-operative forward elevation (OR=1.1 [95% CI: 1.0-1.2]; p=0.001) were independently associated with sufficient post-operative IR.

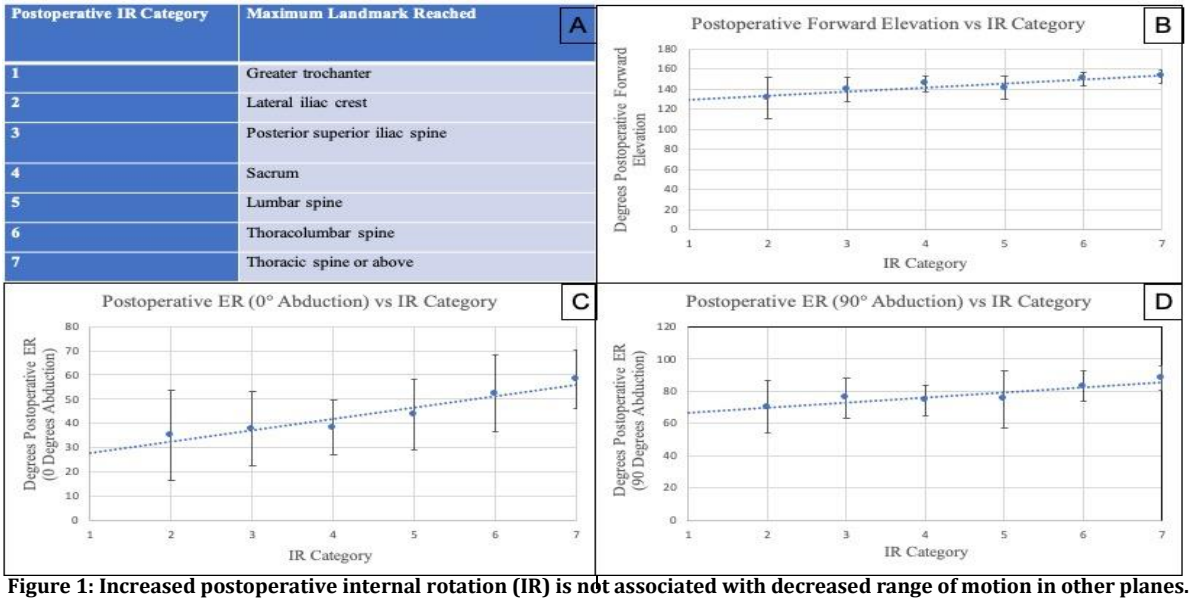

Figure 1: Increased postoperative internal rotation (IR) is not associated with decreased range of motion in other planes. 1A: IR categories, defined as the maximum landmark reached with active IR. 1B: forward elevation vs IR. 1C: external rotation (ER) at 0 degrees abduction vs IR. 1D: ER at 90 degrees abduction vs IR

Discussion

Despite the success of rTSA in the treatment of an expanding array of shoulder pathologies, post-operative IR remains variable.[1,11-14] Internal rotation is critical to many activities of daily living, including toileting, bathing, and,[15-19] and is a driver of patient satisfaction following shoulder arthroplasty.[15] Determining factors associated with post-operative IR following rTSA is therefore essential to improving patient outcomes. This study aimed to identify patient and surgical factors associated with sufficient internal rotation at one year following rTSA.

In this cohort, there was a statistically significant increase in the proportion of patients who demonstrated sufficient internal rotation from pre- to post-operatively (20.4% to 33.1%). However, approximately two-thirds of patients were deficient in IR at one-year post-operatively, in line with prior studies demonstrating the difficulty in attaining sufficient IR after.[1,11-14] This highlights the need for continued exploration of factors that can improve motion post-operatively.

Of the pre-operative patient factors assessed in our cohort, baseline internal rotation and external rotation in adduction, BMI, and patient sex were significantly associated with post-operative internal rotation. In a study of 36 patients undergoing rTSA due to massive rotator cuff tears or osteoarthritis utilizing implants with either 145° or 155° of inclination and minimum 6 months of follow-up, Rol et al reported that pre-operative internal rotation may predict post-operative internal rotation.[15] This is consistent with the findings of the current study; pre-operative IR was one of two factors independently associated with sufficient post-operative IR. Previous investigations have demonstrated that greater BMI is a risk factor for inadequate internal rotation following rTSA.[13,24] While our data shows that increased BMI is associated with insufficient IR post-operatively, it is not an independent predictor. The association between patient sex and post-operative motion has not been previously described. Differences in skeletal stature, muscle bulk, and body habitus may contribute to the higher proportion of females demonstrating sufficient post-operative IR compared to males.

Of the intra-operative variables analyzed, successful subscapularis repair via a healed LTO was associated with improved post-operative internal rotation; however, this association was lost on multivariate analysis. The effect of subscapularis repair on internal rotation following rTSA is controversial, as prior studies have reported conflicting results.[11,13,35,36] Our data supports the notion that a healed subscapularis repair using an LTO may improve post-operative internal rotation. The role of other implant parameters in determining post-operative range of motion also remains unclear. Prior studies have reported conflicting data related to glenosphere[13,20,37-39] and humeral version.[1,13,20,28,36,37] In this cohort of patients treated with a Grammont-style implant, neither of these factors were associated with post-operative IR. In addition, glenosphere overhang has previously been suggested as a predictor of post-operative IR.[1,11,13,21,23,26,27,29,31-33] While we did not assess this variable, this single surgeon was consistently cognizant of providing adequate glenosphere overhang regardless of glenosphere size. With limited impact from intra-operative variables in this single-surgeon cohort, it is possible that that post-operative IR (and range of motion in general) is more dependent on extrinsic rather than intrinsic factors.

Theoretical concerns may exist that greater motion in one direction comes at the expense of motion in other planes. While a cadaveric study of 7 shoulders by Stephenson et al suggests that increasing humeral version positively correlates with post-operative internal rotation and negatively correlates with post-operative external rotation,[36] data from this cohort indicates that functional post-operative IR is significantly associated with greater motion in all planes. On multivariate analysis, forward elevation was one of two factors independently associated with sufficient post-operative IR (along with pre-operative IR), suggesting that while good surgical technique is necessary to provide impingement-free range of motion, extrinsic factors, rather than intrinsic operative factors, are more important in determining final IR sufficiency.

This study has several limitations that must be considered. By nature of the retrospective design, we could not control for pre-operative indications or intra-operative surgical decision making. In addition, minimum follow-up was set at 1 year; patients may continue to gain IR past the 1-year mark post-operatively.[18] However, other studies suggest that IR plateaus at the 1-year post-operative mark.[22,34] Furthermore, deficiencies in documentation led to incomplete data for some parameters. Lack of a standardized approach to subscapularis management may have created variability in both passive and active post-operative internal rotation that we were unable to account for. Choosing a cohort from a single surgeon and single implant system minimized variations in intraoperative variables, however, it limits the applicability of our findings to a minimally lateralized Grammont-style system. A further limitation is that based on prior data suggesting a poor rate of tendon healing following subscapularis peel tenotomy, all peel tenotomies were assumed to have not healed. Finally, no goniometer was used to assess range of motion pre-operatively or post-operatively. However, the utilization of a single surgeon in this study eliminates the possibility of inter-observer bias in determining range of motion and allows for a standardized examination with consistent estimations of motion.

Conclusion

This retrospective analysis of 160 rTSA cases performed by a single surgeon using a Grammont-style implant demonstrates that improvements in IR following this procedure continue to be modest. Pre-operative internal rotation and 1-year post-operative forward elevation

were found to independently predict post-operative internal rotation. Our data indicates that achieving sufficient internal rotation does not preclude post-operative improvements in all other planes of motion. Further research is needed to identify modifiable implant- and technique-specific factors that improve IR following rTSA.

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