

# Impact of Intra-operative Joint Loads on Range of Motion and Patient-Reported Outcome Measures After Reverse Total Shoulder Arthroplasty

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**INTRODUCTION:** The optimal joint tension to maximize outcomes and minimize the likelihood of complications after reverse total shoulder arthroplasty (rTSA) is unknown. Joint tension is a function of humeral position, which dictates muscle lengths, paths, and moment arms. Assessment of joint tension intra-operatively is subjective in nature and may rely on surgeon experience. Outcomes, including range of motion (ROM) and patient-reported outcome measures (PROMs), may be dependent on optimizing biomechanics of the joint and avoiding “over stuffing” the leading to stiffness. Complications related to joint tension could include instability, acromial fracture, and nerve injury, however the relationships between intra-operative joint tension and rTSA outcomes are largely unknown. Therefore, the objective of this study was to investigate relationships between intra-operative joint loading and range of ROM and PROMs after rTSA.

**METHODS:** Primary rTSA cases performed using a single medialized glenoid, lateralized humerus shoulder prosthesis in combination with a wireless, load-sensing humeral liner trial and available 1-year minimum clinical follow-up were reviewed retrospectively from a multi-center, international database collected using standardized, IRB-approved forms. Intra-operatively, the treating surgeon selected implant components based on preferred tension, and trialed with the instrumented humeral liner trial such that maximum loads during four dynamic maneuvers (internal/external [IE] rotation at 0°, 45°, and 90° of abduction, and flexion/extension [F/E]) and at three static positions (arm overhead [OH], behind back [BB], and cross body [CB]) were captured. Post-operatively collected ROM measures included: active abduction, active forward elevation, active internal rotation (IR) score, and both active and passive external rotation (ER), which were used to calculate ER lag (passive-active ER). PROMs included visual analog scale (VAS) pain, global shoulder function, Constant score, American Shoulder and Elbow Surgeons (ASES) score, and the shoulder arthroplasty smart (SAS) score. Spearman correlations between load and outcomes were performed. For the highest observed correlations, univariate analyses were performed between above and below average post-operative outcomes groups for select demographics, surgical parameters, and loads using 2-tailed, unpaired, Welch’s t-tests. Significant covariates ( $p < 0.05$ ) were included in multivariate logistic regression to determine if loads were predictive of outcomes while controlling for other parameters that may be impact outcomes.

**RESULTS SECTION:** Intra-operative load data and clinical outcomes at an average follow-up of 23.1±10.0 months from 119 patients with procedures performed by 9 different surgeons were analyzed. The average age of the cohort was 72.7±6.3 years, of which 35% were female and the average BMI was 28.6±4.8. Spearman correlations revealed no moderate correlations between outcomes and max load during any dynamic maneuver or at any static position. The strongest correlations were observed between abduction and BB (0.30), abduction and F/E (0.30), active ER and IE at 90° (0.38), and ER lag and IE at 0° (-0.32). No correlations between PROMs and load for any maneuver/position exceeded 0.22. The analyses for above and below average abduction revealed significant differences in BB ( $p=0.002$ ), CB ( $p=0.039$ ), and F/E loads ( $p=0.008$ ) between groups, none of which remained significant on multivariate analysis (Table 1). The analyses for above and below average active ER revealed significant differences in expanded glenosphere usage ( $p=0.043$ ) and loads in both IE at 90° (0.003) and F/E ( $p=0.009$ ), none of which remained significant on multivariate analysis (Table 2). The analyses for above and below average ER lag revealed significant differences in maximum load during IE at 0°, which remained significant on multivariate analysis (Table 3).

**DISCUSSION:** Several correlations between outcomes after rTSA and intra-operative loads exceeded 0.3. The strongest correlations were observed between load and ROM measures as opposed to load vs PROMs. On univariate analysis, there were several differences between cohorts with above and below average abduction, active ER, and ER lag, however few of these differences remained significant after multivariate analysis. Interestingly, higher maximum intra-operative load during IE at 0° was predictive of below average ER lag. This suggests that sufficient tension may be required for patients to actively achieve more of their available passive arc of motion in ER. While the remaining differences were only significant on univariate analysis, in general, above average active abduction and active ER had higher average loads. However, it should be noted that a limitation of this study was that maximum loads up to 70lbf could be recorded, even if the load in the joint exceeded that value. Additionally, the average follow-up was relatively short and complications were not assessed due to limited sample sizes.

**SIGNIFICANCE/CLINICAL RELEVANCE:** Several near moderate correlations between intra-operative loads and clinical outcomes of rTSA were observed. As Spearman correlations only quantify monotonically increasing relationships between variables, more advanced statistical techniques may be required to elucidate the appropriate range of tension values that optimize outcomes, since some significant differences in maximum loads were observed with above and below average ROM.

**Table 1.** Univariate and multivariate analyses between groups having above and below average abduction.

		Above Average	Below Average	p-value (univariate)	p-value (multivariate)	Odds Ratio (Reference group = above average)
<b>Demographic</b>	Gender	35.1%	32.1%	0.841		
	BMI	28.8±4.6	27.9±4.5	0.310		
<b>Surgical</b>	Paralytic	84.2%	75.5%	0.341		
	Glenosphere size (% 42mm)	60.7%	51.9%	0.438		
	Liner/Tray Offset (% > 0mm)	35.3%	30.8%	0.787		
	Expanded Glenosphere	30.4%	19.2%	0.266		
	Augmented Baseplate	60.7%	69.8%	0.422		
<b>Load (lbf)</b>	Over Head	46.3±16.4	44.6±15.2	0.588		
	Behind Back	53.8±14.9	43.7±16.6	<b>0.002</b>	0.102	0.97 (0.93, 1.01)
	Cross Body	55.9±18.9	48.6±16.6	<b>0.039</b>	0.904	1 (0.97, 1.03)
	IE @ 0°	32.3±15.7	34.9±17.3	0.407		
	IE @ 45°	36.1±14	39.5±16.2	0.242		
	IE @ 90°	51 ± 15.3	45.5 ± 15.6	0.069		
	F/E	60.3±13.5	52.2±16.4	<b>0.008</b>	0.496	0.99 (0.95, 1.02)

**Table 2.** Univariate and multivariate analyses between groups having above and below average active ER.

		Above Average	Below Average	p-value (univariate)	p-value (multivariate)	Odds Ratio (Reference group = above average)
<b>Demographic</b>	Gender	30.6%	36.1%	0.685		
	BMI	27.8 ± 4.2	28.9 ± 4.8	0.212		
<b>Surgical</b>	Paralytic	87.8%	73.8%	0.093		
	Glenosphere size (% 42mm)	64.6%	50.0%	0.172		
	Liner/Tray Offset (% > 0mm)	38.7%	27.6%	0.419		
	Expanded Glenosphere	35.4%	16.7%	<b>0.043</b>	0.157	0.49 (0.18, 1.31)
	Augmented Baseplate	69.4%	61.7%	0.426		
<b>Load (lbf)</b>	Over Head	48.3 ± 15.3	43.1 ± 15.9	0.086		
	Behind Back	52 ± 15.4	46.4 ± 17	0.093		
	Cross Body	52.3 ± 19.4	52.4 ± 17.2	0.968		
	IE @ 0°	34.6 ± 15.6	32.7 ± 17.2	0.553		
	IE @ 45°	40.5 ± 13.9	35.4 ± 15.7	0.080		
	IE @ 90°	53.3 ± 15	44.4 ± 15.1	<b>0.003</b>	0.425	0.99 (0.95, 1.02)
	F/E	60.9 ± 12.6	53.2 ± 16.5	<b>0.009</b>	0.151	0.97 (0.94, 1.01)

**Table 3.** Univariate and multivariate analyses between groups having above and below average ER lag.

		Below Average	Above Average	p-value (univariate)	p-value (multivariate)	Odds Ratio (Reference group = below average)
<b>Demographic</b>	Gender	30.2%	36.8%	0.546		
	BMI	29.2 ± 4.3	27.6 ± 4.7	0.082		
<b>Surgical</b>	Paralytic	81.1%	78.9%	0.815		
	Glenosphere size (% 42mm)	56.6%	56.4%	1.000		
	Liner/Tray Offset (% > 0mm)	27.6%	38.7%	0.419		
	Expanded Glenosphere	17.0%	32.7%	0.076		
	Augmented Baseplate	56.6%	73.2%	0.075		
<b>Load (lbf)</b>	Over Head	46.4 ± 16	44.6 ± 15.6	0.565		
	Behind Back	49.8 ± 15.8	47.8 ± 17.4	0.552		
	Cross Body	55 ± 16.7	49.7 ± 19.2	0.134		
	IE @ 0°	38.6 ± 17.6	29 ± 14.1	<b>0.003</b>	<b>0.004</b>	0.96 (0.94, 0.99)
	IE @ 45°	40.2 ± 17.2	35.5 ± 12.6	0.112		
	IE @ 90°	48.7 ± 16.7	48.1 ± 14.8	0.859		
	F/E	56.8 ± 15.6	56.2 ± 15.4	0.831		