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Does preoperative forward elevation weakness affect clinical outcomes in anatomic or reverse total shoulder arthroplasty patients with glenohumeral osteoarthritis and intact rotator cuff?

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Background: This study sought to determine if preoperative forward elevation (FE) weakness affects outcomes of anatomic (aTSA) and reverse total shoulder arthroplasty (rTSA) for patients with rotator cuff-intact glenohumeral osteoarthritis (RCI-GHOA).
Methods: A retrospective review of a single institution's prospectively collected shoulder arthroplasty database was performed between 2007 and 2020, including 333 aTSAs and 155 rTSAs for primary RCI-GHOA with a minimum 2-year follow-up. Defining preoperative weakness as FE strength ≤4.9 lb (2.2 kg), three cohorts were matched 1:1:1 by age, sex, and follow-up: weak (n=82) to normal aTSAs, weak (n=44) to normal rTSAs, and weak aTSAs (n=61) to weak rTSAs. Compared outcomes included range of motion, outcome scores, and complication and revision rates at latest follow-up.
Results: Weak aTSAs and weak rTSAs achieved similar postoperative outcome measures to normal aTSAs and normal rTSAs, respectively (P>0.05). Compared to weak rTSAs, weak aTSAs achieved superior postoperative passive (P=0.006) and active external rotation (ER) (P=0.014) but less favorable postoperative Shoulder Pain and Disability Index (P=0.032), American Shoulder and Elbow Surgeons (P=0.024), and University of California, Los Angeles scores (P=0.008). Weak aTSAs achieved the minimal clinically important difference and substantial clinical benefit at a lower rate for abduction (P=0.045 and P=0.003) and FE (P=0.011 and P=0.001). Weak aTSAs had a higher revision rate (P=0.025) but a similar complication rate (P=0.291) compared to weak rTSAs.
Conclusions: Patients with RCI-GHOA and preoperative FE weakness obtain postoperative outcomes similar to patients with normal preoperative strength after either aTSA or rTSA. Preoperatively, weak aTSAs achieved greater ER but lower rates of clinically relevant improvement in overhead motion compared to weak rTSAs.
Level of evidence: III.

Keywords: Shoulder joint; Arthroplasty; Shoulder replacement; Inverted shoulder; Joint range of motion

INTRODUCTION

The utilization of total shoulder arthroplasty (TSA), in both the reverse (rTSA) and anatomic (aTSA) configurations, is increasing in the United States [1]. Conventionally, aTSA has been the procedure of choice for rotator cuff-intact glenohumeral osteoar-

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thritis (RCI-GHOA) with purported superior rotational motion; however, rTSA is beginning to gain popularity, with recent investigations demonstrating similar outcomes for this indication [2,3].

Overhead motion and strength in forward elevation (FE) are critical to functional outcome [4]. Poor FE strength preoperatively may indicate supraspinatus pathology or insufficiency and portend a poor prognosis after aTSA [5]. Given that the success of aTSA relies on an intact rotator cuff, patients with RCI-GHOA and poor preoperative FE strength undergoing aTSA may have a better outcome with rTSA. Additionally, modern lateralized rTSA implant designs have been shown to improve strength in other planes applicable to the posterior cuff, such as the external rotation (ER), though results directly applicable to FE are few and vary [6-9]. Trammell et al. [10] found superior outcomes in patients undergoing rTSA compared to aTSA in the context of limited preoperative FE range of motion (ROM). Hao et al. [11] demonstrated pre- to postoperative improvements in FE strength in patients undergoing either aTSA or rTSA. In the context of weak FE with the rotator cuff intact, there may be incomplete supraspinatus tears or insufficiency below the threshold of visibility, in which case rTSA may portend more of an advantage with less reliance on the supraspinatus for overhead motion compared to aTSA [12], though aTSA has been shown to have acceptable outcomes in this context [13].

To further refine the indications for aTSA versus rTSA in patients with RCI-GHOA, the purpose of this study was to compare clinical outcomes of patients with RCI-GHOA and preoperative FE weakness undergoing aTSA versus rTSA. We hypothesized that patients undergoing rTSA for this indication would have improved functional outcomes and a lower complication rate compared to those undergoing aTSA.

METHODS

We performed a retrospective review and case-control study of one tertiary referral institution's shoulder arthroplasty database for patients undergoing aTSA or rTSA for primary RCI-GHOA between 2007 and 2020 after University of Florida Institutional Review Board approval was obtained (IRB No. 202202385). Informed consent was obtained from patients prior to enrolling in the shoulder arthroplasty database. The diagnosis of an intact rotator cuff was based on preoperative imaging and examination and confirmed intraoperatively. In addition, computed tomography (CT) scans were commonly obtained preoperatively. Low-grade partial tears were considered to be intact based on surgeon discretion, while high-grade partial and full-thickness tears were not included. Patients lacking preoperative clinical data or with less than 2 years of clinical follow-up were excluded. Additionally, patients with a preoperative diagnosis of acute proximal humerus fracture, posttraumatic glenohumeral arthritis, oncologic-related diagnoses, or preoperative nerve palsy were excluded, given the demonstration of worse clinical outcomes in these populations [14,15]. All TSAs were performed by one of four fellowship-trained shoulder surgeons. Initially, 716 primary TSAs were ascertained, from which we excluded 90 for missing preoperative clinical information including strength measurements. Thus, we had clinical information on 626 shoulders (413 aTSAs and 213 rTSAs). Of this cohort, 488 had a minimum of 2 years of clinical follow-up and were included in subsequent analyses of ROM, strength, outcome scores, and postoperative complications (332 aTSAs and 153 rTSAs). The choice between aTSA and rTSA was made by the surgeon intraoperatively. Generally, rTSA was used in the following cases, all based on surgeon discretion: Walsh B2 and B3 glenoids that could not be corrected to within 10 degrees of retroversion with augments and eccentric reaming, patients with a good result with an rTSA for any reason on the contralateral side, low-grade partial thickness cuff tears, and patients who were considered to have a low chance of healing from subscapularis takedown for an aTSA.

Surgical Technique

All shoulder arthroplasties were performed through a deltopectoral approach. This study included multiple implant designs for rTSA; 85% were the medialized-glenoid lateralized-humerus design with a 145° neck-shaft angle [16]. During rTSA, the supraspinatus was left intact and was only tenotomized sequentially if there was concern for soft tissue tension preventing glenohumeral joint reduction. The subscapularis tendon was repaired based on surgeon discretion but was commonly left as a tenotomy given the lateralized implant design commonly used in this study. For aTSA, the subscapularis was either peeled or a lesser tuberosity was performed based on surgeon preference.

Rehabilitation

Postoperatively, all patients completed a standard rehabilitation protocol consisting of a physical therapist-directed home exercise program. A sling was used for 2 weeks, and patients were allowed to begin pendulum exercises, with motion limited to passive FE and ER, to neutral for a total of 3 weeks postoperatively. Active ROM was initiated without limitations at 6 weeks. Strengthening exercises were initiated at 12 weeks, with gradual return to activities.

Clinical Outcomes

ROM, shoulder strength, and outcome scores were obtained at preoperative and postoperative clinical visits, including annual postoperative visits with clinical exam and standard radiographic views after the first year postoperatively. ROM measures were evaluated using a handheld goniometer, including active and passive FE, active and passive ER, active abduction, and active internal rotation (IR). Active IR was assessed as the most cephalad vertebral level reached by the thumb behind the patient's back and scored according to the following scale: no IR, 0; hip, 1; buttocks, 2; sacrum, 3; L5 to L4, 4; L3 to L1, 5; T12 to T8, 6; and T7 or higher, 7 [17]. ER and FE strength were measured using a hand-held dynamometer (Lafayette Instrument Company). ER strength was assessed with the shoulder in 0° ER and 0° abduction with the elbow in 90° flexion. FE strength was measured at 30° of shoulder flexion and 30° of abduction. All measurements were executed using standardized methods by a research coordinator. Outcome scores recorded included the Simple Shoulder Test (SST), the Constant score, the American Shoulder and Elbow Surgeons (ASES) score, the University of California, Los Angeles (UCLA) score, and the Shoulder Pain and Disability Index (SPADI) as previously described [18]. Pre- and postoperative radiographs at annual follow-up visits were obtained for diagnosis and evaluation of implant positioning, loosening, and periprosthetic fractures postoperatively. Postoperative advanced imaging (e.g., CT) was not standardly obtained.

Matched Cohort Comparisons

We dichotomized preoperative FE strength using the 30th percentile among aTSAs (Fig. 1) to create weak (preoperative FE strength ≤4.9 lb [2.2 kg]) and normal (>4.9 lb) cohorts. The 30th percentile was selected as it best approximated the mode of preoperative FE strength among aTSAs. Three cohorts were generated and matched: (1) weak aTSAs (n=82) to normal aTSAs (n=82), (2) weak rTSAs (n=44) to normal rTSAs (n=44), and (3) weak rTSAs (n=61) to weak aTSAs (n=61). All matching was completed based on age (within 3 years), sex, and follow-up. In addition, the third match set was further constrained by preoperative FE strength (matched within 2 lb). Matched cohorts were conceived using the MatchIt package [19]. Outcomes compared between matched cohorts included ROM, strength, functional outcomes, and pain.

Handling of Missing Data

To avoid the selection bias introduced by complete case analysis [20], missing ROM, strength, and outcome score data were alleviated using a two-step process. First, patients missing outcome data at the latest follow-up had their previous clinical visits reviewed in reverse chronological order to identify outcomes recorded at earlier time points that qualified for the minimum 2-year follow-up. If data were present at a qualifying previous clinical time point, they were used for analysis. Additionally, for patients that still had missing data, multiple imputation by pre-

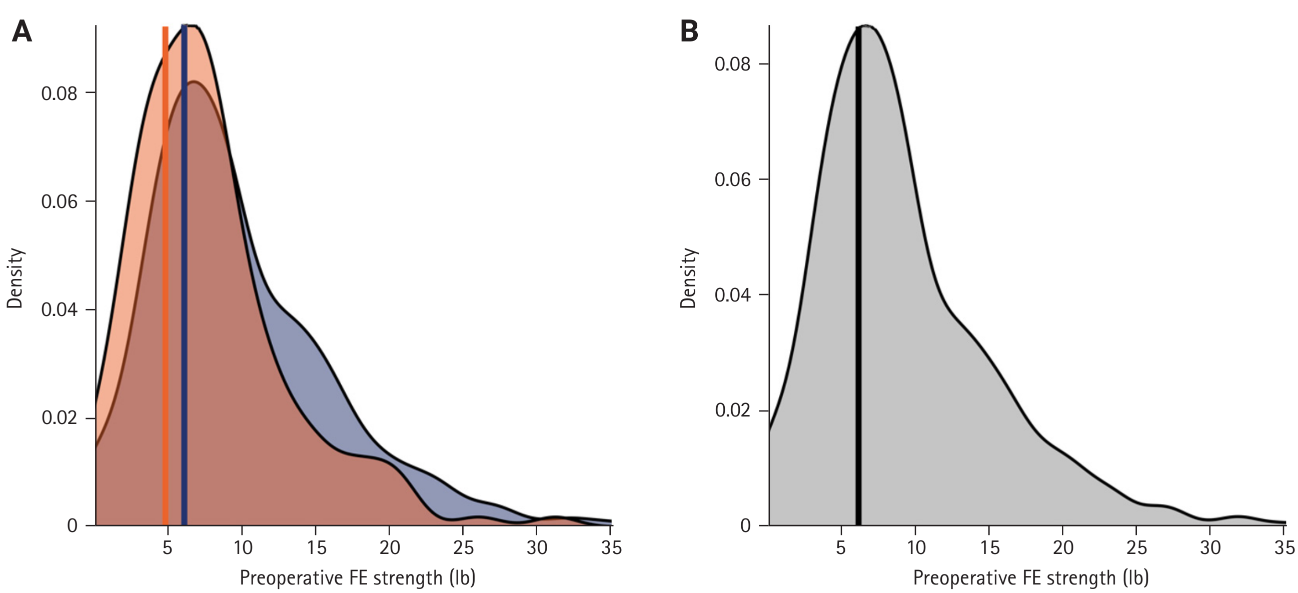

Fig. 1. Density plots depicting the distribution of preoperative forward elevation (FE) strength with lines indicating the 30th percentile for anatomic total shoulder arthroplasty (aTSA; blue, 4.9 lb [2.2 kg]) and reverse total shoulder arthroplasty (orange, 4.9 lb) separately (A) and the 30th percentile for aTSA (4.9 lb) overlayed on the overall cohort (B).

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dictive mean matching was used to impute data for variables with missing values. Multiple imputation utilizes existing data to reproduce conclusions that likely would have been present in a complete dataset and has been progressively more applied in shoulder surgery studies [21,22]. We set the number of imputed datasets (M) to 20 as endorsed by the literature [23]. Estimates of standard errors among these datasets were calculated using Rubin's rules [24]. Multiple imputation was performed using the mice package [25].

Statistical Analysis

Toward our primary aim, we compared pooled ROM, strength, and outcome scores between matched cohorts. Two-sided unpaired Welch's t-tests were used to compare continuous measures. Fisher's Exact test was used to compare categorical measures. Additionally, weak aTSAs vs. weak rTSAs were further evaluated by comparing the proportion of patients exceeding the minimal clinically important difference (MCID) and substantial clinical benefit (SCB) derived for primary aTSA from prior reports utilizing the same prosthesis and including many patients from our institution [18,26,27]. All statistical analyses were performed using R Software (version 4.2.0, R Core Team) with a defined $P<0.05$.

RESULTS

Overall Characteristics

Patients undergoing aTSA were significantly younger (65.2±7.7 vs. 71.3±7.0 years, $P<0.001$) and had a longer average follow-up period (5.9±3.2 vs. 3.7±1.8 years, $P<0.001$) compared to those undergoing rTSA. Patients who underwent aTSA also had a significantly increased average preoperative Constant score ($P=0.031$), active FE ROM ($P=0.001$), active abduction ROM ($P=0.005$), ER strength ($P=0.005$), and FE strength ($P=0.005$) compared to those undergoing rTSA. Postoperatively, patients who underwent aTSA exhibited significantly lower SST score ($P=0.008$), ASES score ($P=0.001$), and Constant score ($P=0.001$) and significantly higher SPADI ($P=0.001$), active ER ROM ($P=0.001$), passive ER ROM ($P=0.003$), and active IR score ($P=0.009$) compared to those who underwent rTSA. Patients who underwent aTSA showed significantly larger pre- to postoperative improvement in passive ER ROM ($P=0.026$) and significantly smaller pre- to postoperative improvement in SPADI ($P=0.001$), SST score ($P=0.015$), ASES score ($P=0.004$), UCLA score ($P=0.001$), Constant score ($P=0.001$), active FE ROM ($P<0.001$), passive FE ROM ($P<0.001$), active abduction ROM ($P=0.006$), and FE strength ($P=0.015$) compared to those who underwent rTSA.

Weak vs. Normal aTSA

Patients undergoing weak aTSAs had similar age ($P=0.106$), sex ($P=1.000$), prior surgery rates ($P=0.350$), and body mass index (BMI) ($P=0.318$) compared to normal aTSAs (Table 1). Weak aTSA patients had longer average follow-up than normal aTSAs (6.4±3.4 vs. 5.1±3.0 years, $P=0.012$) and had poorer preoperative outcome scores, strength, and active FE and abduction compared to patients undergoing normal aTSA.

Postoperatively, ROM, strength, and outcome scores were comparable between the weak and normal aTSA cohorts ($P>0.05$) (Table 1). Compared to normal aTSA patients, those undergoing weak aTSAs demonstrated significantly greater pre- to postoperative improvement in ER strength (4±6 vs. 1±6 lb, $P=0.008$) and FE strength (4±6 vs. 1±6 lb, $P=0.001$). Weak aTSA and normal aTSA patients demonstrated comparable all-cause complication rates (14% and 13%, respectively; $P=1.000$) and revision rates (12% each, $P=1.000$) (Table 2).

Weak vs. Normal rTSA

Weak rTSAs had similar age ($P=0.487$), sex ($P=1.000$), prior surgery rates ($P=0.446$), and BMI ($P=0.754$) compared to normal rTSAs (Table 1). Weak rTSAs had shorter follow-up (2.8±1.2 vs. 3.5±1.5 years, $P=0.011$) and poorer preoperative outcome scores, strength, and active FE compared to normal rTSAs.

Postoperatively, ROM, strength, and outcome scores were comparable between the weak and normal rTSA cohorts ($P>0.05$) (Table 1). Compared to normal rTSAs, weak rTSAs demonstrated significantly greater improvements in active FE (64°±25° vs. 45°±29°, $P=0.002$) and active abduction (55°±30° vs. 39°±36°, $P=0.035$). Weak rTSAs and normal rTSAs demonstrated similar all-cause complication rates (8.9% and 7.3%, respectively; $P=0.799$) and revision rates (3.8% and 3.0%, respectively; $P=1.000$) (Table 2).

Weak aTSA vs. Weak rTSA

Weak aTSAs and weak rTSAs had similar sex proportions, prior surgery rates, BMI, and follow-up (Table 3). Weak aTSAs were younger than weak rTSAs (68.7±7.8 vs. 72.0±8.0 years, $P=0.021$). Weak aTSAs and weak rTSAs had similar preoperative outcome scores, strength, and ROM, but weak aTSAs had superior preoperative active FE (88°±25° vs. 74°±28°, $P=0.004$) and abduction (82°±26° vs. 69°±26°, $P=0.013$).

Postoperatively, compared to weak aTSAs, weak rTSAs demonstrated significantly better SPADI (19.7±16.5 vs. 27.3±22.7, $P=0.032$), ASES (81.1±16.3 vs. 73.4±21.7, $P=0.024$), and UCLA scores (29.6±5.6 vs. 26.1±7.3, $P=0.008$), while weak aTSAs

Table 1. Demographics and clinical outcomes of aTSAs and rTSAs with preoperative FE strength ≤6.1 lb

Outcome measure	aTSA			rTSA		
	Normal (n=82)	Weak (n=82)	P-value	Normal (n=44)	Weak (n=44)	P-value
Age at surgery (yr)	65.9±7.0	67.8±7.5	0.106	70.8±6.9	71.9±7.9	0.487
Female	75.6 (62)	75.6 (62)	1.000	61.4 (27)	61.4 (27)	1.000
Prior surgery	15.9 (13)	9.8 (8)	0.350	27.3 (12)	18.2 (8)	0.446
BMI (kg/m^2)	31.7±6.8	30.6±7.4	0.318	30.5±6.1	30.1±5.8	0.754
Follow-up (yr)	5.1±3.0	6.4±3.4	0.012	3.5±1.5	2.8±1.2	0.011
Preoperative						
SPADI score	62.5±13.7	72.1±13.2	<0.001	61.2±14.7	73.4±13.3	<0.001
SST score	4.5±2.5	3.2±2.2	0.001	5.0±2.2	3.2±2.1	<0.001
ASES score	42.3±14.4	33.0±14.7	<0.001	41.6±15.4	32.2±13.7	0.004
UCLA score	15.5±4.0	12.8±4.4	0.002	14.8±3.3	11.9±3.8	<0.001
Constant score	46.4±14.1	37.2±13.0	<0.001	44.9±12.7	31.9±12.4	<0.001
Active ER (°)	22.6±17.0	19.9±20.0	0.351	22.0±20.2	15.7±19.7	0.140
Active FE (°)	98±24	84±25	0.001	94±27	69±29	<0.001
Passive ER (°)	35±18	32±19	0.248	34±22	31±19	0.548
Passive FE (°)	125±25	111±24	0.248	118±26	98±25	0.548
Active IR score	3.1±1.7	2.9±1.7	0.438	2.6±1.5	2.6±1.6	0.891
Active abduction (°)	91±27	77±25	0.002	89±26	67±26	<0.001
ER strength (lb)	12±6	6±3	<0.001	11±6	6±3	<0.001
FE strength (lb)	10±4	4±2	<0.001	9±3	4±2	<0.001
Postoperative						
SPADI score	26.2±25.9	32.1±24.6	0.145	16.4±19.0	19.6±17.6	0.429
SST score	9.1±3.5	8.2±3.6	0.114	10.3±2.5	9.8±2.4	0.362
ASES score	73.5±24.3	68.3±24.1	0.173	83.1±19.8	79.8±18.1	0.426
UCLA score	27.1±7.4	25.5±8.2	0.299	30.5±5.5	29.6±5.8	0.499
Constant score	72.2±20.5	66.8±21.6	0.138	81.5±15.9	75.5±16.4	0.145
Active ER (°)	47±17	42±19	0.160	40±19	39±13	0.789
Active FE (°)	127±32	118±33	0.157	139±16	133±18	0.176
Passive ER (°)	55±18	53±19	0.490	48±17	49±14	0.700
Passive FE (°)	147±22	137±29	0.053	153±14	147±18	0.140
Active IR score	4.9±1.5	4.7±1.8	0.437	4.7±1.7	4.4±1.6	0.405
Active abduction (°)	118±33	111±34	0.213	127±26	122±27	0.356
ER strength (lb)	12±7	11±7	0.284	15±8	12±7	0.117
FE strength (lb)	10±6	8±6	0.077	15±7	12±6	0.108
Improvement						
SPADI score	-	–40.0±23.4	0.336	-	-	0.073
SST score	4.6±3.5	5.0±3.5	0.458	5.3±2.9	6.5±3.4	0.074
ASES score	31.2±25.6	35.3±24.5	0.312	41.6±22.1	47.7±23.2	0.225
UCLA score	11.7±8.1	12.7±8.8	0.489	15.9±5.7	17.9±6.6	0.148
Constant score	26.2±21.4	29.9±22.5	0.339	37.2±17.7	43.8±17.8	0.112
Active ER (°)	24.2±17.4	22.6±23.1	0.640	17.8±22.4	22.7±19.3	0.311
Active FE (°)	29±35	34±40	0.449	45±29	64±25	0.002
Passive ER (°)	20±22	21±22	0.723	14±22	18±23	0.440
Passive FE (°)	22±27	27±32	0.326	38±33	50±30	0.123
Active IR score	1.8±2.1	1.8±2.1	0.937	2.1±2.0	1.8±2.1	0.512
Active abduction (°)	28±39	33±40	0.404	39±36	55±30	0.035
ER strength (lb)	1±6	4±6	0.008	4±7	6±5	0.181
FE strength (lb)	1±6	4±6	0.001	5±7	8±6	0.094

Values are presented as mean±standard deviation or percent (number). Normal: based on age, sex, and follow-up, Weak: matched 1:1 to a cohort with preoperative FE strength >4.9 lb (2.2 kg).
aTSA: anatomic total shoulder arthroplasty, rTSA: reverse total shoulder arthroplasty, FE: forward elevation, BMI: body mass index, SPADI: Shoulder Pain and Disability Index, SST: Simple Shoulder Test, ASES: American Shoulder and Elbow Surgeons, UCLA: the University of California, Los Angeles, ER: external rotation, IR: internal rotation.

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Table 2. Incidence of surgical complications and revision surgery amongst all shoulder arthroplasties performed during the study period

Complication	aTSA (n = 413)			rTSA (n = 213)			P-value (weak aTSA vs. weak rTSA)
	Weak (n = 123)	Normal (n = 290)	P-value	Weak (n = 90)	Normal (n = 123)	P-value	
All-cause complication	17 (13.8)	38 (13.1)	1.000	8 (8.9)	9 (7.3)	0.799	0.291
Rotator cuff tear and subscapularis failure	1 (0.8)	0	-	0	0	-	-
Rotator cuff tear	0	5 (1.7)	-	0	0	-	-
Subscapularis failure	1 (0.8)	2 (0.7)	-	0	0	-	-
Combined humeral and glenoid loosening	2 (1.6)	1 (0.3)	-	0	0	-	-
Humeral stem loosening	1 (0.8)	1 (0.3)	-	0	0	-	-
Glenoid loosening	4 (3.3)	8 (2.8)	-	1 (1.3)	4 (3.0)	-	-
Glenosphere loosening	1 (0.8)	2 (0.7)	-	0	0	-	-
Component failure	1 (0.8)	7 (2.4)	-	0	3 (2.2)	-	-
Infection	1 (0.8)	10 (3.4)	-	0	0	-	-
Glenoid fracture	0	0	-	1 (1.3)	0		-
Periprosthetic fracture	2 (1.6)	1 (0.3)	-	4 (5.0)	0	-	-
Unexplained pain	2 (1.6)	0	-	0	1 (0.7)	-	-
Nerve injury	1 (0.8)	0	-	0	0	-	-
Intraoperative fracture: humeral shaft cortex	0	1 (0.3)	-	2 (2.5)	1 (0.7)	-	-
Re-revision rate	15 (12.2)	35 (12.1)	1.000	3 (3.8)	4 (3.0)	1.000	0.025

Values are presented as number (%). This includes procedures that met inclusion criteria and were eligible for 2-year follow-up, stratified by prosthesis (aTSA and rTSA) and whether they had preoperative weakness (preoperative FE strength ≤6.1 lb) (n = 626).
aTSA: anatomic total shoulder arthroplasty, rTSA: reverse total shoulder arthroplasty, FE: forward elevation.

demonstrated superior active (46 ± 16° vs. 38 ± 15°, P = 0.014) and passive ER (59 ± 17° vs. 49 ± 15°, P = 0.006). Compared to weak aTSAs, weak rTSAs demonstrated significantly greater pre- to postoperative improvements in UCLA score (17.5 ± 6.4 vs. 13.8 ± 8.1, P = 0.025), active (59° ± 28° vs. 34° ± 41°, P = 0.002) and passive FE (43° ± 30° vs. 31° ± 38°, P = 0.043), and active abduction (51° ± 31° vs. 31° ± 38°, P = 0.008) (Table 3). Weak rTSAs more frequently exceeded the MCID for abduction (86% vs. 70%, P = 0.045), FE (90% vs. 71%, P = 0.011), and UCLA score (93% vs. 71%, P = 0.002) and the SCB for abduction (70% vs. 42%, P = 0.003) and FE (74% vs. 42%, P = 0.001) (Table 4). Weak aTSAs and weak rTSAs demonstrated comparable all-cause complication rates (14% and 8.9%, respectively; P = 0.291), although weak aTSAs demonstrated higher revision rates than weak rTSAs (12% vs. 3.8%, P = 0.025) (Table 2).

DISCUSSION

This study found that, while patients with RCI-GHOA and preoperative weakness in FE can achieve clinically relevant improvements after both aTSA and rTSA, patients that underwent aTSA achieved greater postoperative ER that did not exceed the MCID or SCB. On the other hand, patients that underwent rTSA achieved greater overhead ROM exceeding clinically-relevant thresholds and had lower rates of revision surgery. In patients with primary RCI-GHOA, aTSA has been purported to offer superior postoperative axial ROM over rTSA [28]. Historically, rTSA has been utilized in patients with non-functional rotator cuffs and severe glenoid bone loss [29,30]. These indications have been expanded with increasing use in RCI-GHOA with good clinical outcomes [31], especially as contemporary designs have demonstrated improved function and strength from the original Grammont design [9].

There are limited data assessing the influence of FE weakness on outcomes after TSA. Hao et al. [11] previously studied 374 primary aTSAs and 601 primary rTSAs and found that aTSA demonstrated significantly greater FE strength than rTSAs at baseline, 6 months, 1 year, and 2 years postoperatively. However, the present study included patients undergoing aTSA and rTSA for a wide variety of indications. rTSA confers certain advantages over aTSA that may enable superior postoperative overhead motion, particularly in patients with poor FE strength preoperatively. First, the improved moment arm of the deltoid after rTSA may provide greater clinical improvement in both ROM and strength in abduction and FE. Biomechanically, contemporary medialized glenoid-lateralized humerus rTSA designs placed with inferior overhang optimize the deltoid moment arm, assisting with overhead ROM [32]. Intraoperatively, the rTSA design allows greater

Table 3. Demographics and clinical outcomes of aTSA and rTSA with preoperative FE strength ≤6.1 lb

Outcome measure	Weak aTSA (n=61)	Weak rTSA (n=61)	P-value
Age at surgery (yr)	68.7±7.8	72.0±8.0	0.021
Female	48.4 (30)	49.5 (30)	0.558
Prior surgery	73.8 (45)	73.8 (45)	1.000
BMI (kg/m^2)	7.0±0.0	10.0±0.0	0.602
Follow-up (yr)	4.0±1.8	3.5±1.7	0.092
Preoperative			
SPADI score	71.5±12.9	71.5±13.3	0.988
SST score	3.3±2.2	3.4±2.0	0.759
ASES score	32.3±15.4	34.0±13.3	0.546
UCLA score	12.4±4.2	12.2±3.7	0.775
Constant score	37.6±12.5	34.7±13.0	0.283
Active ER (°)	22.4±20.2	16.1±18.0	0.090
Active FE (°)	88±25	74±28	0.004
Passive ER (°)	34±20	31±19	0.495
Passive FE (°)	111±32	102±26	0.495
Active IR score	3.0±1.9	2.9±1.8	0.835
Active abduction (°)	82±26	69±26	0.013
ER strength (lb)	6±3	5±3	0.158
FE strength (lb)	4±2	4±2	0.437
Postoperative			
SPADI score	27.3±22.7	19.2±16.5	0.032
SST score	9.0±3.2	9.8±2.3	0.080
ASES score	73.4±21.7	81.1±16.3	0.024
UCLA score	26.1±7.3	29.6±5.6	0.008
Constant score	71.3±18.6	76.1±15.6	0.221
Active ER (°)	45.9±16.2	37.6±15.1	0.014
Active FE (°)	122±30	132±20	0.086
Passive ER (°)	59±17	49±15	0.006
Passive FE (°)	141±26	145±20	0.351
Active IR score	5.0±1.6	4.6±1.5	0.141
Active abduction (°)	112±33	120±27	0.225
ER strength (lb)	11±6	11±5	0.752
FE strength (lb)	8±6	10±6	0.108
Improvement			
SPADI score	–44.2±23.9	–52.3±21.3	0.075
SST score	5.7±3.6	6.5±3.2	0.259
ASES score	41.1±24.2	47.1±21.3	0.192
UCLA score	13.8±8.1	17.5±6.4	0.025
Constant score	34.6±19.8	41.5±18.2	0.098
Active ER (°)	23.6±21.0	21.5±20.8	0.630
Active FE (°)	34±41	59±28	0.002
Passive ER (°)	25±23	18±23	0.145
Passive FE (°)	31±34	43±30	0.043
Active IR score	2.0±2.2	1.6±2.0	0.328
Active abduction (°)	31±38	51±31	0.008
ER strength (lb)	5±6	6±5	0.220
FE strength (lb)	5±6	7±6	0.064

Values are presented as mean±standard deviation or percent (number). Weak: matched 1:1 to a cohort of rTSAs with preoperative FE strength ≤6.1 lbs.
aTSA: anatomic total shoulder arthroplasty, rTSA: reverse total shoulder arthroplasty, FE: forward elevation, BMI: body mass index, SPADI: Shoulder Pain and Disability Index, SST: Simple Shoulder Test, ASES: American Shoulder and Elbow Surgeons, UCLA: the University of California, Los Angeles, ER: external rotation; IR: internal rotation.

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Table 4. Proportion of weak aTSAs and weak rTSAs that exceeded the MCID and SCB for active ROM and outcome scores after aTSA

Outcome measure	Reference value[a)]	Weak aTSA + rTSA (n = 122)	Weak aTSA (n = 61)	Weak rTSA (n = 61)	P-value
MCID					
Abduction (°)	13.9	78.2 (95)	70.3	86.1	0.045
FE (°)	23.1	80.2 (98)	70.6	89.8	0.011
ER (°)	14.5	70.2 (86)	70.7	69.8	1.000
SST	1.7	91.8 (112)	87.2	96.4	0.095
Constant	8.6	92.9 (113)	89.5	96.3	0.272
ASES	14.2	89.9 (110)	85.2	94.5	0.126
UCLA	8.1	82.0 (100)	71.2	92.7	0.002
SPADI	–19.7	88.2 (108)	83.6	92.7	0.154
SCB					
Abduction (°)	36.1	56.0 (68)	42.0	69.9	0.003
FE (°)	45.5	57.8 (71)	42.0	73.7	0.001
ER (°)	20.1	52.7 (64)	52.6	52.9	1.000
SST	3.5	78.5 (96)	72.5	84.5	0.121
Constant	20.4	80.5 (98)	76.9	84.1	0.495
ASES	33.2	71.6 (87)	68.4	74.8	0.545
UCLA	12.6	70.7 (86)	63.4	78.0	0.109
SPADI	–44.3	60.1 (73)	52.2	68.0	0.099

Values are presented as percent (number).
aTSA: anatomic total shoulder arthroplasty, rTSA: reverse total shoulder arthroplasty, MCID: minimal clinically important difference, SCB: substantial clinical benefit, ROM: range of motion, FE: forward elevation, FE: forward elevation, ER: external rotation, SST: simple shoulder test, ASES: American shoulder and elbow surgeons, UCLA: University of California, Los Angeles, SPADI: shoulder pain and disability index.
[a)]Reference values adopted from Roche et al. [18] and Simovitch et al. [26,27] for aTSA.

soft tissue release, potentially decreasing limitations on ROM. Further, the subscapularis, which acts as an adductor, may not need to be repaired in rTSA, which may allow greater overhead motion [33], although repair is associated with lower rates of postoperative instability [34]. Additionally, multiple techniques for subscapularis repair exist, including tenotomy with tendon-to-tendon repair, tuberosity osteotomy, peel technique, and over-the-top repair, with unclear results concerning the superior technique [35-37]. The greater improvement in active FE observed in weak rTSA compared to weak aTSA cohorts supports these biomechanical principles (59° ± 28° vs. 34° ± 41°, P = 0.002). Furthermore, while not statistically significant, FE strength trended higher after weak rTSA compared to weak aTSA (7 ± 6 vs. 5 ± 6 lb, P = 0.064).

Consistent with prior findings [2,28], weak aTSAs obtained greater postoperative active (46° ± 16° vs. 38° ± 15°, P = 0.014) and passive ER (59° ± 17° vs. 49° ± 15°, P = 0.006) compared to weak rTSAs. In a prior study comparing matched aTSA versus rTSA for RCI-GHOA with preoperative ER stiffness (passive ER ≤ 0°), Hao et al. [2] found that stiff aTSAs had greater postoperative active ER (40° ± 19° vs. 28° ± 17°, P < 0.001) compared to stiff rTSAs; however, postoperative outcome scores were similar between groups. Unlike the aforementioned study that showed similar postoperative functional outcome scores between stiff aTSAs and stiff rTSAs, weak aTSAs had inferior postoperative SPADI (27 ± 23 vs. 19 ± 17, P = 0.032), ASES (73 ± 22 vs. 81 ± 6, P = 0.024), and UCLA (26 ± 7.3 vs. 30 ± 5.6, P = 0.008) scores compared to weak rTSAs.

Overall, weak aTSAs were found to have higher revision rates than weak rTSAs in our study (12% vs. 3.8%, P = 0.025) (Table 2), with similar revision rates regardless of preoperative weakness (normal aTSA: 12%, normal rTSA: 3.0%). Previously, Parada et al. [38] reviewed 2224 aTSAs and 4158 rTSAs and found higher revision rates in aTSA compared to rTSA (5.6% and 2.5%, respectively), with aTSAs most commonly requiring revision secondary to cuff failure, aseptic loosening, and infection. This may indicate a clinical benefit of rTSA over aTSA in patients who may be at high risk for revision, including those who may suffer from rotator cuff insufficiency [5] or patients who are older [39]. Notably, glenoid loosening was the most common complication and reason for failure in normal and weak aTSA (3% each). Parada et al. [38] similarly reported a glenoid loosening rate of 2.5% in aTSA. Our aTSA revision rate was higher than theirs, which may reflect the older average age of our matched cohorts and the long-term follow-up (average 5.1 years in normal and 6.4 years in weak aTSAs).

Our study demonstrated that both patients who are preoperatively weak and those with normal preoperative strength can experience postoperative clinical improvements, with no significant differences between groups, further showing that both aTSA and rTSA confer different strengths and weaknesses. However, we recognize that this study has several limitations. By nature, retrospective study designs are subject to bias, which limits the strength of our conclusions. Further, while we matched our aTSA and rTSA cohorts, there are many preoperative characteristics that were not controlled for that could contribute to outcomes, including previous surgery to the ipsilateral shoulder [40], glenoid deformity, and subscapularis repair [33]. While unable to be truly assessed, it is also possible that preoperative strength could be limited secondary to pain and associated with poor effort rather than purely true muscle weakness. Poor FE in patients with an intact rotator cuff may reflect increased fatty degeneration or atrophy of the supraspinatus; unfortunately, preoperative magnetic resonance imaging scans are not routinely acquired in patients undergoing TSA at our institution, and this parameter could not be evaluated in our retrospective investigation. Further, selection bias remains a possible limitation; although we only included patients with RCI-GHOA, surgeon preference and clinical decision-making based on glenoid deformity or intraoperative rotator cuff status may affect the rates at which aTSA versus rTSA were utilized in patients.

CONCLUSIONS

Patients with RCI-GHOA and preoperative FE weakness obtain similar postoperative outcomes to patients with normal preoperative strength after either aTSA or rTSA. While preoperatively weak aTSAs achieved greater postoperative ER compared to weak rTSAs, they had slightly inferior postoperative functional outcome scores and lower rates of clinically relevant improvement in overhead motion. While patients with RCI-GHOA undergoing either aTSA or rTSA benefitted significantly from these operations, rTSA may be advantageous in the setting of poor preoperative FE strength.

NOTES

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Conflict of interest

KAH is a paid consultant for LinkBio Corp. BSS is a consultant and receives royalties from Exactech, Innomed, and Responsive Arthroscopy. JJK is a consultant for Exactech, Inc. and LinkBio Corp. TWW is a consultant and receives royalties from Exactech, Inc. No other potential conflicts of interest relevant to this article were reported.

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Data availability

Contact the corresponding author for data availability.

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