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Clinical outcomes of anatomic vs. reverse total shoulder arthroplasty in primary osteoarthritis with preoperative rotational stiffness and an intact rotator cuff: a case control study

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Background: Reverse total shoulder arthroplasty (rTSA) has begun to challenge the place of anatomic total shoulder arthroplasty (aTSA) as a primary procedure for certain indications. One purported benefit of aTSA is improved postoperative range of motion (ROM) compared to rTSA especially in internal rotation; however, it is unclear whether aTSA can provide patients with significant preoperative stiffness superior ROM compared to rTSA. Our purpose was to compare clinical outcomes of aTSA and rTSA performed in stiff vs. non-stiff shoulders for rotator cuff intact (RCI) glenohumeral osteoarthritis (GHOA).
Methods: A retrospective review of an international shoulder arthroplasty database identified 1608 aTSAs and 600 rTSAs performed for RCI GHOA with minimum 2-year follow-up. Defining preoperative stiffness as $\leq 0°$ of passive external rotation (ER), we matched: (1) stiff aTSAs (n = 257) 1:3 to non-stiff aTSAs, (2) stiff rTSAs (n = 87) 1:3 to non-stiff rTSAs, and (3) stiff rTSAs (n = 87) 1:1 to stiff aTSAs. We compared ROM, outcome scores, and the rate of complications and revision surgery at latest follow-up.
Results: Despite stiff aTSAs having poorer preoperative ROM and functional outcome scores for all measures assessed ($P < .001$ for all), only poorer postoperative active abduction (113 ± 27° vs. 128 ± 35°; $P < .001$), active ER (39 ± 18° vs. 50 ± 20°; $P < .001$), and passive ER (45 ± 17° vs. 56 ± 18°; $P < .001$) persisted postoperatively compared to the non-stiff cohort. Similarly, stiff rTSAs had poorer preoperative ROM and functional outcome scores for all measures assessed compared to non-stiff rTSAs ($P \leq .044$), but only poorer active abduction (108 ± 24° vs. 128 ± 29°, $P < .001$), active ER (28 ± 17° vs. 42 ± 17°, $P < .001$), and passive ER (36 ± 15° vs. 48 ± 17°, $P < .001$) persisted. When comparing stiff rTSAs to matched stiff aTSAs, no significant differences in preoperative ROM or functional outcome scores were found. However, stiff aTSAs had greater postoperative active internal rotation score (4.8 ± 1.5 vs. 4.2 ± 1.7, $P = .022$), active ER (40 ± 19° vs. 28 ± 17°, $P < .001$), and passive ER (46 ± 18° vs. 36 ± 15°, $P = .001$). Postoperative outcome scores were similar across all matched cohort comparisons despite motion differences. The rate of complications and need for revision surgery did not differ between any group comparisons.

Approval for this study was received from WCG Institutional Review Board (#20091701).

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Conclusions: Patients with RCI GHOA who have preoperative rotational stiffness have poorer postoperative ROM compared with non-stiff patients following both aTSA and rTSA, but similar functional outcome scores. Notably, preoperative limitations in passive ER do not appear to be a limitation to utilizing aTSA. Indeed, patients with limited preoperative ER treated with aTSA had greater postoperative internal rotation and ER compared to those treated with rTSA.

Level of evidence: Level III; Retrospective Cohort Comparison Using Large Database; Treatment Study

Keywords: External rotation stiffness; passive external rotation; glenohumeral arthritis; stiff shoulder; versus; TSA; RSA; ER

The popularization of reverse total shoulder arthroplasty (rTSA) has begun to challenge the place of anatomic total shoulder arthroplasty (aTSA) as a primary procedure for certain indications, including primary osteoarthritis (OA) with an intact rotator cuff.[19,22,23,28,48] Traditional indications for rTSA have included rotator cuff tear arthropathy, massive irreparable rotator cuff tear, failed primary arthroplasty, tumor, and proximal humerus fracture.[3,9,10,15,21] A recent meta-analysis comparing aTSA and rTSA for primary rotator cuff intact (RCI) glenohumeral osteoarthritis (GHOA) found more favorable external rotation (ER) after aTSA, but equivalent outcome scores.[28] At present, commonly cited indications for rTSA over aTSA in the setting of RCI GHOA include rotator cuff insufficiency, glenoid bone loss, and stiffness, with the latter being seldom studied.[23,26,35]

Both aTSA and rTSA are more technically challenging in patients with preoperative shoulder stiffness. First, obtaining adequate glenoid exposure intraoperatively can be more difficult in stiff shoulders, which can subsequently result in glenoid component malpositioning. Given the reliance on the rotator cuff and unconstrained mechanics of aTSA, the consequences of glenoid component malpositioning are potentially more severe. Second, stiff shoulders often require extensive soft tissue traction and/or release, potentially increasing the risk of nerve injury and postoperative instability. Third, patients with significant preoperative stiffness may limit use of their shoulder preoperatively, which has been shown to increase the rates of disuse atrophy of the rotator cuff.[2,20,36] Lastly, subscapularis repair in a shoulder with longstanding stiffness may lead to excess tension on the subscapularis repair during the postoperative rehabilitation phase and may increase the risk of failure, leading some surgeons to consider rTSA for these patients given that subscapularis healing postoperatively is not critical for good function following rTSA.

The purpose of this study was to compare the functional outcomes of aTSA and rTSA in patients with preoperative shoulder stiffness with an intact rotator cuff to further evaluate the role of aTSA in this difficult patient population. We hypothesized that utilization of rTSA in patients with preoperative stiffness would have superior outcomes and fewer complications compared to aTSA.

Materials and methods

A retrospective review of a multicenter international shoulder arthroplasty database was performed between 2001 and 2021. We initially identified 1608 aTSAs and 600 rTSAs performed for RCI GHOA with minimum 2-year follow-up. Shoulders with a preoperative diagnosis of post-traumatic arthritis, oncologic indication, or preoperative nerve injury were excluded because prior reports have demonstrated poorer clinical performance in these populations.[9-11] A single shoulder arthroplasty system was used for all procedures (Equinoxe; Exactech, Inc., Gainesville, FL, USA). This system comprises a lateralized humerus design with a 145° neck-shaft angle.[47] Shoulder arthroplasties were performed by 1 of 36 senior shoulder surgeons.

Clinical outcomes

Range of motion (ROM) and outcome scores were evaluated at preoperative and postoperative visits. ROM measures assessed included active abduction, active forward elevation (FE), active and passive ER, and active internal rotation (IR) and were standardized across study sites. IR was assessed as the most cephalad vertebral level reached by the thumb behind the patient's back and scored as follows: no IR, 0; hip, 1; buttocks, 2; sacrum, 3; L5-L4, 4; L3-L1, 5; T12-T8, 6; and T7 or higher, 7.[16] Clinical outcome scores evaluated 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, the Shoulder Pain and Disability Index (SPADI), and the Shoulder Arthroplasty Smart (SAS) score.[39]

Matched cohort comparisons

The influence of preoperative rotational stiffness on clinical outcomes of aTSA and rTSA was assessed based on a 0° threshold value of passive ER to divide cohorts. The methodology used to choose this threshold of passive ER is detailed in the Supplementary Materials. Four cohorts were created and matched as follows: (1) all available stiff aTSAs (n = 257) were matched 1:3 to non-stiff aTSAs (n = 771), (2) all available stiff rTSAs (n = 87) were matched 1:3 to non-stiff rTSAs (n = 261), and (3) all available stiff rTSAs (n = 87) were matched 1:1 to stiff aTSAs (n = 87). Given the known effect of subscapularis repair on rTSA function, a subset of group 2 was created (2b) comparing stiff rTSAs without subscapularis repair (n = 32) to 1:1 matched stiff rTSAs with subscapularis repair (n = 32).[7,8,13,17,25,33] The decision to repair the subscapularis and the technique used was left to

Table I Demographics and clinical outcomes of all aTSAs with preoperative passive ER $\leq 0°$ matched 1:3 to a cohort of aTSAs with preoperative passive ER $> 0°$ based on age, sex, and follow-up

Outcome measure	Pre-op passive ER > 0 (n = 771)	Pre-op passive ER ≤ 0 (n = 257)	*P* value
Age at surgery (y)	66.9 ± 7.4	66.7 ± 8.6	.698
Female sex (% [n])	53.7% (414)	53.7% (138)	1
Follow-up (mo)	61.6 ± 35.9	66.2 ± 43.9	.130
Preoperative			
Active abduction (°)	88 ± 31	69 ± 24	**<.001**
Active FE (°)	103 ± 33	88 ± 29	**<.001**
Active IR score	3.2 ± 1.6	2.5 ± 1.4	**<.001**
Active ER (°)	26 ± 17	−5 ± 9	**<.001**
Passive ER (°)	32 ± 17	−3 ± 7	**<.001**
SST score	4.4 ± 3.0	3.2 ± 2.5	**<.001**
Constant score	41.1 ± 14.7	33.3 ± 11.6	**<.001**
ASES score	37.4 ± 16.3	33.3 ± 14.9	**<.001**
UCLA score	14.8 ± 4.0	13.2 ± 3.6	**<.001**
SPADI score	79.8 ± 23.6	86.8 ± 20.8	**<.001**
SAS score	48.6 ± 10.8	40.0 ± 8.5	**<.001**
Postoperative			
Active abduction (°)	128 ± 35	113 ± 27	**<.001**
Active FE (°)	146 ± 31	145 ± 26	.705
Active IR score	5.0 ± 1.5	4.8 ± 1.5	.216
Active ER (°)	50 ± 20	39 ± 18	**<.001**
Passive ER (°)	56 ± 18	45 ± 17	**<.001**
SST score	10.2 ± 2.5	10.1 ± 2.5	.729
Constant score	70.7 ± 15.6	70.4 ± 14.1	.826
ASES score	83.7 ± 20.5	83.7 ± 18.5	.991
UCLA score	30.3 ± 6.1	30.4 ± 5.4	.709
SPADI score	19.1 ± 24.7	19.5 ± 24.9	.802
SAS score	79.1 ± 13.3	77.2 ± 12.6	.063
Improvement			
Active abduction (°)	40 ± 41	43 ± 35	.392
Active FE (°)	42 ± 37	53 ± 34	**<.001**
Active IR score	1.7 ± 1.9	2.3 ± 1.9	**<.001**
Active ER (°)	24 ± 21	45 ± 20	**<.001**
Passive ER (°)	23 ± 21	48 ± 19	**<.001**
SST score	5.9 ± 3.3	6.9 ± 3.2	**<.001**
Constant score	29.9 ± 17.7	36.1 ± 17.6	**<.001**
ASES score	47.1 ± 23.7	50.3 ± 22.5	.067
UCLA score	15.4 ± 6.2	17.4 ± 6.5	**<.001**
SPADI score	−60.9 ± 30.0	−67.4 ± 30.3	**.008**
SAS score	30.2 ± 14.1	37.5 ± 14.6	**<.001**
Complications (% [n])	6.1% (47)	8.6% (22)	.221
Required revision surgery (% [n])	4.5% (35)	6.6% (17)	.250

ASES, American Shoulder and Elbow Surgeons; *aTSA*, anatomic total shoulder arthroplasty; *ER*, external rotation; *FE*, forward elevation; *IR*, internal rotation; *rTSA*, reverse total shoulder arthroplasty; *SAS*, Shoulder Arthroplasty Smart; *SPADI*, Shoulder Pain and Disability Index; *SST*, Simple Shoulder Test; *UCLA*, University of California, Los Angeles.
Values represent mean ± standard deviation unless otherwise noted. Bold indicates statistical significance.

the operating surgeon's discretion and was not available for most shoulders. Similarly, whether the subscapularis repair was intact at follow-up was not ubiquitously assessed. All matching was performed based on age (matches within 2 years), sex (exact match), and follow-up. In addition, matches 2b and 3 were further constrained by preoperative passive ER (matches within 5°). Matched cohorts were conceived using the MatchIt package.[24] Outcomes compared among matched cohorts included ROM, functional outcome scores, patient-reported pain, and the rate of complications and revision surgery.

Statistical analysis

Two-sided unpaired Welch's t-tests were used to compare continuous measures between cohorts. Fisher's exact test was used

Table II Demographics and clinical outcomes of all rTSAs with preoperative passive ER $\leq 0°$ matched 1:3 to a cohort of rTSAs with preoperative passive ER $> 0°$ based on age, sex, and follow-up

Outcome measure	Pre-op passive ER > 0 (n = 261)	Pre-op passive ER ≤ 0 (n = 87)	*P* value
Age at surgery (y)	72.8 ± 8.0	72.7 ± 8.6	.884
Female sex (% [n])	59.8% (156)	59.8% (52)	1
Subscapularis repaired (% [n])	60.9% (159)	60.9% (53)	1
Follow-up (mo)	42.6 ± 24.5	41.8 ± 21.1	.760
Preoperative			
Active abduction (°)	79 ± 35	60 ± 28	**<.001**
Active FE (°)	94 ± 36	80 ± 31	**<.001**
Active IR score	2.9 ± 1.8	2.5 ± 1.6	**.044**
Active ER (°)	21 ± 18	−8 ± 11	**<.001**
Passive ER (°)	30 ± 17	−4 ± 8	**<.001**
SST score	4.0 ± 2.8	3.1 ± 2.4	**.004**
Constant score	37.6 ± 13.8	31.2 ± 12.3	**<.001**
ASES score	37.0 ± 16.8	30.9 ± 15.0	**.002**
UCLA score	14.1 ± 4.2	12.2 ± 3.6	**<.001**
SPADI score	82.6 ± 24.1	93.5 ± 20.4	**<.001**
SAS score	46.6 ± 11.9	38.2 ± 8.6	**<.001**
Postoperative			
Active abduction (°)	122 ± 31	108 ± 24	**<.001**
Active FE (°)	142 ± 27	142 ± 25	.823
Active IR score	4.4 ± 1.7	4.2 ± 1.7	.358
Active ER (°)	41 ± 18	28 ± 17	**<.001**
Passive ER (°)	47 ± 17	36 ± 15	**<.001**
SST score	9.8 ± 2.6	9.9 ± 2.6	.761
Constant score	70.7 ± 13.6	69.5 ± 15.1	.580
ASES score	83.6 ± 18.5	83.8 ± 19.1	.929
UCLA score	30.8 ± 4.5	30.6 ± 5.5	.831
SPADI score	21.2 ± 23.8	19.8 ± 26.5	.651
SAS score	76.8 ± 11.2	75.3 ± 10.5	.325
Improvement			
Active abduction (°)	43 ± 37	47 ± 32	.386
Active FE (°)	48 ± 39	59 ± 36	**.022**
Active IR score	1.4 ± 1.9	1.5 ± 2.0	.773
Active ER (°)	20 ± 21	36 ± 18	**<.001**
Passive ER (°)	17 ± 21	40 ± 15	**<.001**
SST score	5.8 ± 3.3	6.8 ± 2.9	**.008**
Constant score	32.0 ± 15.6	40.0 ± 14.6	**.001**
ASES score	46.4 ± 21.1	52.6 ± 22.0	**.025**
UCLA score	16.7 ± 5.8	18.5 ± 5.8	**.029**
SPADI score	−61.8 ± 27.9	−73.8 ± 27.9	**.002**
SAS score	30.6 ± 14.4	36.9 ± 12.3	**.001**
Complications (% [n])	2.3% (6)	2.3% (2)	1
Required revision surgery (% [n])	1.1% (3)	1.1% (1)	1

ASES, American Shoulder and Elbow Surgeons; *aTSA*, anatomic total shoulder arthroplasty; *ER*, external rotation; *FE*, forward elevation; IR, internal rotation; *rTSA*, reverse total shoulder arthroplasty; *SAS*, Shoulder Arthroplasty Smart; *SPADI*, Shoulder Pain and Disability Index; *SST*, Simple Shoulder Test; *UCLA*, University of California, Los Angeles.
Values represent mean ± standard deviation unless otherwise noted. Bold indicates statistical significance.

to compare categorical measures. Additionally, stiff aTSAs vs. stiff rTSAs were further evaluated by comparing the proportion of patients exceeding the minimal clinically important difference (MCID) and substantial clinical benefit (SCB) from prior reports utilizing the same database.[43,44] All statistical analyses were performed using R Software (version 4.2.0; R Core Team, Vienna, Austria) with a defined $\alpha = 0.05$.

Results

Stiff vs. non-stiff aTSA

Age, sex, and time to follow-up are shown in Table I. The mean preoperative passive ER was 35° less in the stiff vs.

Table III Demographics and clinical outcomes of stiff rTSAs that did not undergo subscapularis repair matched 1:1 to a cohort of stiff rTSAs with subscapularis repair based on age, sex, follow-up, and preoperative passive ER

Outcome measure	No repair (n = 32)	Subscapularis repair (n = 32)	*P* value
Age at surgery (y)	70.7 ± 8.2	70.8 ± 6.8	.921
Female sex (% [n])	53.1% (17)	53.1% (17)	1.000
Follow-up (mo)	41.0 ± 23.7	41.6 ± 19.9	.903
Preoperative			
Active Abduction (°)	62 ± 25	58 ± 32	.543
Active FE (°)	78 ± 30	81 ± 35	.732
Active IR score	2.4 ± 1.5	2.5 ± 1.7	.850
Active ER (°)	−8 ± 12	−8 ± 10	.936
Passive ER (°)	−6 ± 10	−4 ± 7	.497
SST score	3.2 ± 2.4	3.0 ± 2.6	.798
Constant score	30.3 ± 11.2	32.9 ± 14.4	.471
ASES score	32.7 ± 16.2	30.6 ± 16.5	.614
UCLA score	12.4 ± 3.9	11.9 ± 3.9	.578
SPADI score	91.0 ± 18.3	97.0 ± 25.3	.342
SAS score	37.7 ± 7.1	38.0 ± 10.5	.898
Postoperative			
Active Abduction (°)	112 ± 22	107 ± 28	.454
Active FE (°)	140 ± 19	146 ± 29	.419
Active IR score	3.4 ± 1.9	4.4 ± 1.4	.053
Active ER (°)	28 ± 18	32 ± 15	.324
Passive ER (°)	35 ± 15	37 ± 14	.668
SST score	9.7 ± 2.7	10.2 ± 2.7	.438
Constant score	68.1 ± 13.9	73.3 ± 15.8	.228
ASES score	84.2 ± 15.8	85.1 ± 21.2	.842
UCLA score	31.3 ± 3.9	30.4 ± 6.3	.551
SPADI score	19.8 ± 23.3	18.1 ± 29.0	.795
SAS score	73.1 ± 10.4	77.2 ± 9.2	.140
Improvement			
Active Abduction (°)	49 ± 27	48 ± 37	.908
Active FE (°)	62 ± 34	63 ± 36	.911
Active IR score	1.0 ± 1.9	1.7 ± 2.0	.212
Active ER (°)	37 ± 17	39 ± 15	.716
Passive ER (°)	42 ± 15	40 ± 15	.664
SST score	6.5 ± 2.9	7.2 ± 3.1	.378
Constant score	38.7 ± 13.1	43.6 ± 16.8	.307
ASES score	50.8 ± 20.6	54.6 ± 23.3	.502
UCLA score	19.0 ± 5.5	18.4 ± 6.2	.709
SPADI score	−69.5 ± 26.0	−80.6 ± 29.8	.165
SAS score	35.5 ± 11.3	38.3 ± 12.8	.439
Complications (% [n])	3.1% (1)	3.1% (1)	1.000
Required revision surgery (% [n])	0.0% (0)	3.1% (1)	1.000

ASES, American Shoulder and Elbow Surgeons; *ER*, external rotation; *FE*, forward elevation; *IR*, internal rotation; *rTSA*, reverse total shoulder arthroplasty; *SAS*, Shoulder Arthroplasty Smart; *SPADI*, Shoulder Pain and Disability Index; *SST*, Simple Shoulder Test; *UCLA*, University of California, Los Angeles.

Values represent mean ± standard deviation unless otherwise noted. Bold indicates statistical significance.

non-stiff aTSA cohorts (−3 ± 7° vs. 32 ± 17°; $P < .001$). Stiff aTSAs had significantly lower preoperative ROM in all planes and outcome scores for all measures assessed ($P < .001$ for all). Postoperatively, the mean passive ER was only 11° less in stiff vs. non-stiff aTSAs (45 ± 17° vs. 56 ± 18°; $P < .001$). Stiff aTSAs had poorer postoperative active abduction (113 ± 27° vs. 128 ± 35°; $P < .001$) and active ER (39 ± 18° vs. 50 ± 20°; $P < .001$) compared to non-stiff aTSAs, but comparable active FE (145 ± 26° vs. 146 ± 31°; $P = .705$) and IR score (4.8 ± 1.5 vs. 5.0 ± 1.5; $P = .216$). Postoperative outcome scores were not significantly different between cohorts. Preoperative to postoperative improvement was greater for stiff vs. non-stiff aTSAs for 4 of 5 ROM measures (active FE, IR score, and active and passive ER) and 5 of 6 outcome scores (SST, Constant, UCLA, SPADI, and SAS). Stiff and non-stiff

Table IV Demographics and clinical outcomes of all rTSAs with preoperative passive ER $\leq 0°$ matched 1:1 to a cohort of aTSAs with preoperative passive ER $\leq 0°$ based on age, sex, follow-up, and preoperative passive ER

Outcome measure	Stiff aTSA (n = 87)	Stiff rTSA (n = 87)	*P* value
Age at surgery (yr)	71.2 ± 7.1	72.7 ± 8.6	.210
Female sex (% [n])	59.8% (52)	59.8% (52)	1.000
Follow-up (mo)	40.1 ± 22.2	41.8 ± 21.1	.606
Preoperative			
Active abduction (°)	65 ± 21	60 ± 28	.211
Active FE (°)	85 ± 28	80 ± 31	.259
Active IR score	2.3 ± 1.4	2.5 ± 1.6	.251
Active ER (°)	−5 ± 10	−8 ± 11	.087
Passive ER (°)	−4 ± 8	−4 ± 8	.765
SST score	2.7 ± 2.6	3.1 ± 2.4	.384
Constant score	30.3 ± 12.3	31.2 ± 12.3	.638
ASES score	29.6 ± 14.9	30.9 ± 15.0	.568
UCLA score	12.9 ± 3.4	12.2 ± 3.6	.194
SPADI score	89.2 ± 22.6	93.5 ± 20.4	.244
SAS score	38.9 ± 8.8	38.2 ± 8.6	.623
Postoperative			
Active abduction (°)	109 ± 28	108 ± 24	.754
Active FE (°)	142 ± 30	142 ± 25	.880
Active IR score	4.8 ± 1.5	4.2 ± 1.7	**.022**
Active ER (°)	40 ± 19	28 ± 17	**<.001**
Passive ER (°)	46 ± 18	36 ± 15	**.001**
SST score	9.8 ± 2.7	9.9 ± 2.6	.728
Constant score	71.2 ± 14.6	69.5 ± 15.1	.519
ASES score	84.0 ± 18.2	83.8 ± 19.1	.939
UCLA score	30.9 ± 5.0	30.6 ± 5.5	.714
SPADI score	19.8 ± 25.6	19.8 ± 26.5	.984
SAS score	78.1 ± 12.8	75.3 ± 10.5	.156
Improvement			
Active abduction (°)	43 ± 35	47 ± 32	.472
Active FE (°)	53 ± 32	59 ± 36	.272
Active IR score	2.4 ± 1.9	1.5 ± 2.0	**.006**
Active ER (°)	46 ± 21	36 ± 18	**.002**
Passive ER (°)	50 ± 19	40 ± 15	**.002**
SST score	7.0 ± 3.3	6.8 ± 2.9	.738
Constant score	39.1 ± 17.1	40.0 ± 14.6	.762
ASES score	53.8 ± 21.2	52.6 ± 22.0	.739
UCLA score	18.0 ± 6.2	18.5 ± 5.8	.584
SPADI score	−71.1 ± 31.2	−73.8 ± 27.9	.596
SAS score	39.4 ± 14.4	36.9 ± 12.3	.301
Complications	6.9% (6)	2.3% (2)	.278
Required revision surgery	5.7% (5)	1.1% (1)	.213

ASES, American Shoulder and Elbow Surgeons; *aTSA*, anatomic total shoulder arthroplasty; *ER*, external rotation; *FE*, forward elevation; *IR*, internal rotation; *rTSA*, reverse total shoulder arthroplasty; *SAS*, Shoulder Arthroplasty Smart; *SPADI*, Shoulder Pain and Disability Index; *SST*, Simple Shoulder Test; *UCLA*, University of California, Los Angeles.
Values represent mean ± standard deviation unless otherwise noted. Bold indicates statistical significance.

aTSAs had similar rates of complications (8.6% vs. 6.1%; $P = .221$) and revision surgery (6.6% vs. 4.5%; $P = .250$).

Stiff vs. non-stiff rTSA

Age, sex, and time to follow-up are shown in Table II. The rate of subscapularis repair was 61% in both groups. The mean preoperative passive ER was 35° less in the stiff vs. non-stiff rTSA cohort (−4 ± 8° vs. 31 ± 17°; $P < .001$). Stiff rTSAs had significantly lower preoperative ROM and outcome scores for all measures assessed. Postoperatively, the difference in mean passive ER decreased to 12° less in stiff vs. non-stiff rTSAs (36 ± 15 vs. 48 ± 17; $P < .001$). Postoperatively, stiff rTSAs had poorer active abduction (108 ± 24° vs. 128 ± 29°; $P < .001$) and active ER (28 ± 17° vs. 42 ± 17°; $P < .001$), but comparable active

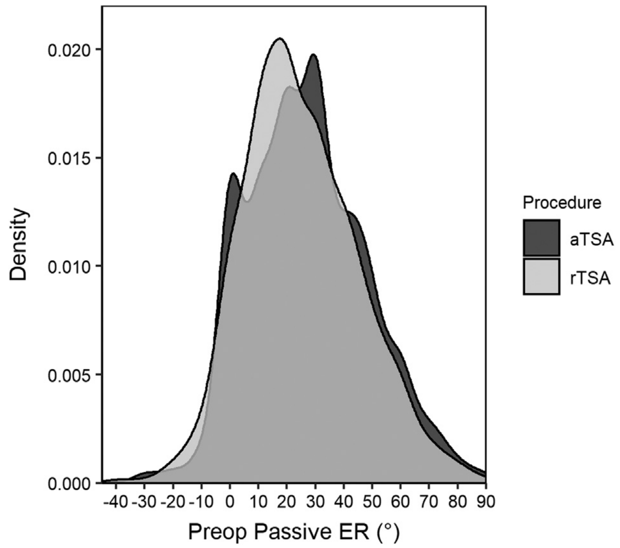

Figure 1 Density plot depicting similar distributions of preoperative passive external rotation in patients that underwent anatomic total shoulder arthroplasty and reverse total shoulder arthroplasty. *aTSA*, anatomic total shoulder arthroplasty; *ER*, external rotation; *rTSA*, reverse total shoulder arthroplasty.

FE (142 ± 25° vs. 144 ± 45°; *P* = .548) and identical IR scores (4.2 ± 1.7 for both). Postoperative outcome scores were not significantly different between stiff and non-stiff rTSAs. Preoperative to postoperative improvement was greater for stiff vs. non-stiff rTSAs for active and passive ER and 3 of 6 outcome scores (Constant, SPADI, and SAS). Stiff and non-stiff rTSAs had identical rates of complications (2.3% vs. 2.3%; *P* = 1) and similar rates of revision surgery (0.8% vs. 1.1%; *P* = 1).

Stiff rTSA with vs. without subscapularis repair

Age, sex, time to follow-up, and mean preoperative passive ER are shown in Table III. Both groups had comparable preoperative passive ER (−4 ± 7° vs. −6 ± 10°; *P* = .497), active ER (−8 ± 10° vs. −8 ± 12°; *P* = .936), and IR score (2.5 ± 1.7 vs. 2.4 ± 1.5; *P* = .850). Postoperatively, there were no significant differences in ROM measures or outcome scores. The mean improvement preoperatively to postoperatively was similar with and without subscapularis repair for active ER (39 ± 15° vs. 37 ± 17°; *P* = .716) and IR score (1.7 ± 2.0 vs. 1.0 ± 1.9; *P* = .212). The rates of complications and revision surgery did not differ based on whether the subscapularis was repaired.

Stiff aTSA vs. stiff rTSA

Age, sex, mean preoperative passive ER, and time to follow-up are shown in Table IV. The mean preoperative passive ER was identical in both groups (−4 ± 8°). The distribution of preoperative passive ER was similar in patients undergoing aTSA and rTSA (Fig. 1). The subscapularis was repaired in 61% of rTSAs, which did not affect outcomes in this cohort. No significant differences in preoperative ROM or outcome scores were present. Postoperatively, stiff aTSAs had greater active IR score (4.8 ± 1.5 vs. 4.2 ± 1.7; *P* = .022), active ER (40 ± 19° vs. 28 ± 17°; *P* < .001), and passive ER (46 ± 18° vs. 36 ± 15°; *P* = .001), but similar active abduction (109 ± 28° vs. 108 ± 24°; *P* = .754) and FE (142 ± 30° vs. 142 ± 25°; *P* = .880) compared to stiff rTSAs. Postoperative outcome scores were not significantly different between stiff aTSAs and stiff rTSAs; in fact, the mean ASES score was the same in stiff aTSAs vs. stiff rTSAs (84.0 vs. 83.8). Preoperative to postoperative improvement was greater in stiff aTSAs vs. stiff rTSAs for IR score (2.4 ± 1.9 vs. 1.5 ± 2.0; *P* = .006), active ER (46 ± 21° vs. 36 ± 18°; *P* = .002), and passive ER (50 ± 19° vs. 40 ± 15°; *P* = .002), whereas improvement in overhead motion and outcome scores was not significantly different. There were no statistically significant differences when comparing the proportion of stiff aTSAs vs. stiff rTSAs that exceeded the MCID and SCB for primary aTSA (Table V).[43,44] Stiff aTSAs trended toward a greater rate of complications (6.9% vs. 2.3%; *P* = .278) and revision surgery (5.7% vs. 1.1%; *P* = .213), but these differences were not statistically significant. Complications in the stiff aTSA cohort included infection (n = 3), aseptic glenoid loosening (n = 2), and unexplained pain (n = 1); a rotator cuff tear was not attributed to any complication. Complications in the stiff rTSA cohort included infection (n = 1) and unexplained pain (n = 1).

Discussion

Utilization of rTSA over aTSA in the setting of RCI GHOA is increasing, particularly in patients with a suspected nonfunctional rotator cuff, severe posterior humeral head subluxation, severe glenoid retroversion, and poor glenoid bone stock. While rTSA is sometimes considered in stiff patients due to concerns over the functional status of the subscapularis, prior to this study it was unclear whether rTSA provides equivalent outcomes to aTSA in the setting of RCI GHOA in stiff patients. In this study, patients with preoperative rotational stiffness had superior postoperative rotational ROM when treated with aTSA vs. rTSA, thus disproving our hypothesis. However, postoperative overhead ROM and clinical outcome scores were not significantly different and the proportion of patients exceeding the MCID and SCB were similar. Notably, the rate of complications in stiff shoulders after aTSA was 3 times greater than after rTSA, although this did not reach statistical significance (6.9% vs. 2.3%; *P* = .278); however, none of the complications in the stiff aTSA cohort were attributed to rotator cuff failure.

Table V Proportion of stiff aTSAs and stiff rTSAs that exceeded the MCID and SCB for active ROM and outcome scores after primary aTSA

Outcome measure	Ref.*	Stiff aTSA (n = 78)	Stiff rTSA (n = 78)	*P* value
MCID				
Abduction (°)	13.9	82.2%	80.6%	.834
FE (°)	23.1	82.4%	83.3%	1.000
ER (°)	14.5	94.6%	90.3%	.364
SST	1.7	90.2%	93.0%	.584
Constant	8.6	93.1%	98.2%	.364
ASES	14.2	93.7%	92.9%	1.000
UCLA	8.1	91.4%	92.9%	1.000
SPADI	−19.7	95.4%	94.4%	1.000
SAS	8.5	95.5%	96.7%	1.000
SCB				
Abduction (°)	36.1	56.2%	65.3%	.309
FE (°)	45.5	66.2%	62.5%	.730
ER (°)	20.1	87.8%	77.8%	.127
SST	3.5	81.7%	84.9%	.680
Constant	20.4	86.2%	89.5%	.777
ASES	33.2	84.8%	83.5%	.835
UCLA	12.6	84.3%	84.3%	1.000
SPADI	−44.3	83.1%	88.9%	.459
SAS	19.2	89.4%	86.9%	.785

ASES, American Shoulder and Elbow Surgeons; *ER*, external rotation; *FE*, forward elevation; *MCID*, minimal clinically important difference; *rTSA*, reverse total shoulder arthroplasty; *SAS*, Shoulder Arthroplasty Smart; *SCB*, substantial clinical benefit; *SPADI*, Shoulder Pain and Disability Index; *SST*, Simple Shoulder Test; *UCLA*, University of California, Los Angeles; *ROM*, range of motion; *aTSA*, anatomic total shoulder arthroplasty.
* Reference values adopted from Roche et al and Simovitch et al.

Clinical outcomes of primary rTSA have been previously compared between stiff and non-stiff shoulders on the basis of preoperative passive ER.[6] Carofino et al[6] compared stiff (passive ER $\leq$ 20° and lag $\leq$ 10°) and normal (passive ER $\geq$ 30° and a lag $<$ 10°) shoulders undergoing lateralized primary rTSA with a preoperative diagnosis of cuff tear arthropathy or a combination of OA and rotator cuff insufficiency. Lag was defined as a difference between active ER and passive ER, and provided a measure of weakness. Preoperatively, stiff patients in their study had poorer ROM in all planes. However, stiff and normal patients had equivalent postoperative active FE (142 $\pm$ 21° vs. 139 $\pm$ 28°, P = .329) and IR (4.4 $\pm$ 1.7 vs. 4.6 $\pm$ 1.5, P = .611), similar to the present study (Table III). In their study, stiff patients experienced a significant improvement in active ER of 36° (35 $\pm$ 16° vs. −1 $\pm$ 19°) exceeding both the SCB for rTSA (3.6°) and aTSA (20.1°),[44] but still had poorer ER postoperatively compared to normal patients (30 $\pm$ 17° vs. 44 $\pm$ 18°; P < .001). These findings agree with our study despite using a different threshold for stiffness (preoperative passive ER of 0° vs. 20°) and differing surgical indications. Carofino et al[6] attributed the substantial improvements in rotation to the removal of mechanical restrictions to motion such as osteophytes, capsular contractures, and impingement. Taken together, primary rTSA can provide substantial improvements in rotational ROM even in stiff shoulders, but postoperative rotation will not be comparable to patients without preoperative stiffness.

The results of our study assessing the influence of preoperative stiffness should be considered in the context of the ongoing debate over the optimal management of the subscapularis in rTSA. Specifically with regard to lateralized rTSA designs, some studies have found more favorable IR with subscapularis repair,[13,17,18] whereas others purport no difference in both external and internal rotation.[38,45] Other studies have suggested that the subscapularis should not be repaired in the setting of lateralized rTSA.[30,46] Eno et al[14] constructed biomechanical computer models of lateralized rTSA (Comprehensive rTSA [Zimmer Biomet, Warsaw, IN, USA], 147° neck-shaft angle) and found that greater glenosphere lateralization did not affect the moment arms of the subscapularis in abduction or rotation, but it did lengthen the subscapularis (up to 13 mm of lengthening from its anatomical resting length when a +10 mm glenosphere was used).[14] These results have been translated clinically: Werner et al[46] found greater improvement in the ASES score when either the subscapularis was repaired or the glenoid was lateralized (+3 or +6 mm) compared to when both were performed using the same implant in Eno et al's[14] computer models. Linderman et al[30] demonstrated greatly increased torque requirements for ER in computer models simulating subscapularis stiffness and glenoid lateralization. A noncompliant subscapularis could theoretically limit ER if it cannot be overcome by the opposing force couple (ie, infraspinatus and posterior deltoid). However, improvement in active ER and IR did not differ in our study based on whether the subscapularis was repaired in the setting of stiff lateralized humeral rTSA (Table IV). Furthermore, although we would expect the subscapularis repair to act as an adductor thereby limiting abduction (particularly in the setting of preoperative subscapularis stiffness),[5,17,18,45] improvement in active abduction was similar in patients with and without subscapularis repair (48 ± 37 vs. 49 ± 27; $P = .908$). In the setting of a preoperatively stiff shoulder, increased lengthening of the subscapularis may predispose it to retear. Notably, clinical studies rarely assess whether the intraoperatively-repaired subscapularis remains intact at latest follow-up; greater preoperative stiffness may be associated with higher rates of subscapularis repair failure, and therefore, no gain in IR would be expected at later follow-up. Unfortunately, the retrospective multicenter design of this study prohibited us from assessing the integrity of the subscapularis repair at postoperative follow-up. However, there was a trend towards greater postoperative IR in the subscapularis repair group (4.4 ± 1.4 vs. 3.4 ± 1.9; $P = .053$), suggesting the subscapularis repair remained intact and functioning at follow-up in some patients.

In both the present study and in the findings of Carofino et al,[6] postoperative outcome scores of stiff patients undergoing primary lateralized rTSA were statistically indistinguishable from those of normal patients, despite stiff patients having significantly worse ROM postoperatively (Table III). We also found this same result for aTSA (Table II). The lack of an identifiable difference in functional outcome scores may be due to ceiling effects, which are known to obscure small but clinically important differences in patient outcomes when legacy shoulder outcome scores are used (eg, ASES, SPADI, SST, and UCLA scores).[4,40,42] However, even when evaluating groups based on the SAS score which is not limited by ceiling effects, no differences were found.[29,39] While preoperatively stiff patients may not achieve the same ROM in rotation and abduction compared to non-stiff patients, surgeons can be confident that postoperative outcomes should exceed the SCB in this population (Table V).[44]

Conventionally, stiff shoulders are thought to be associated with significant rotator cuff muscle dysfunction, even in the absence of a full-thickness rotator cuff tear on advanced imaging. In addition, preoperative stiffness has been associated with increased fatty infiltration and muscle atrophy.[12,36] With this knowledge in mind, surgeons might elect to perform an rTSA over an aTSA when they have concern over the long-term function of the rotator cuff, even if there is no evidence of a rotator cuff tear at the time of surgery. Our results call this indication into question. When preoperatively stiff rTSAs were case-control matched to stiff aTSAs (controlling for age, sex, follow-up, and preoperative passive ER), aTSAs outperformed rTSAs in both final postoperative external and internal rotations as well as improvement preoperatively to postoperatively (Table V). Our findings are corroborated by a meta-analysis comparing aTSA and rTSA for primary OA with an intact rotator cuff, which found more favorable ER after aTSA, but equivalent outcome scores.[28] While aTSA may provide superior rotation in stiff patients, surgeons may still wish to consider rTSA in patients with a high risk of rotator cuff insufficiency[41] or older age[27,34,49,50] due to the lower complication profile.[1]

We also recognize that this study has several limitations. First, its retrospective nature limits the conclusions that can be drawn from our results. Although we case-controlled key characteristics, it is possible that other characteristics not anticipated to play a critical role in determining patient outcomes were not controlled for, such as prior surgery.[31,32,37] Second, selection bias may be present—although only patients with an intact rotator cuff were included in this study, surgeons may have elected to perform an rTSA more frequently in patients with fatty infiltration and degeneration of the rotator cuff. The retrospective and multicenter nature of this study prohibited retrospective assessment of rotator cuff status (including whether the subscapularis remained intact when repaired). However, the decision to perform an aTSA vs. rTSA is also dependent on other factors, such as surgeon preference, glenoid deformity, and patient demographics and functional demands which were not considered as independent factors in this analysis. Furthermore, although we controlled for the influence of subscapularis repair on outcomes of rTSA, the technique utilized by the operating surgeon was not available for analysis. Lastly, different surgeons have different treatment preferences, and although a large sample size of multiple surgeons helps to normalize for individual differences, bias from individual surgeon preference and techniques could still be present in the dataset.

Conclusion

Patients with limited preoperative ER and RCI GHOA have lower postoperative ROM compared with non-stiff shoulders when treated with either aTSA or rTSA. Stiff shoulders treated with aTSA had better postoperative IR and ER compared to a matched cohort of stiff shoulder treated with rTSA. All groups, regardless of preoperative stiffness, had similar postoperative clinical outcome scores. Preoperative limitation in passive ER does not appear to be a limitation to utilizing aTSA in patients with RCI GHOA.

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Supplementary Data

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