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Original article

Influence of preoperative rotational shoulder stiffness on rate of motion restoration after anatomic and reverse total shoulder arthroplasty for glenohumeral osteoarthritis with an intact rotator cuff

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ABSTRACT

Background: A subset of patients undergoing anatomic and reverse total shoulder arthroplasty (aTSA and rTSA) lag behind their peers in regaining overhead range of motion (ROM) after surgery. The primary purpose of this study was to compare the rate of recovery of ROM after aTSA and rTSA performed in stiff (preoperative passive external rotation [ER] ≤0 °) versus non-stiff (preoperative passive ER >0°) shoulders with RCI-GHOA.
Hypothesis: We hypothesized that preoperatively stiff shoulders (preoperative passive ER ≤0 °) would have slower recovery in ROM postoperatively with lower postoperative motion compared to non-stiff shoulders.
Methods and materials: A retrospective review of a multi-institution shoulder arthroplasty database was performed between 2001 and 2021. We identified 1,164 aTSAs and 539 rTSAs performed for RCI-GHOA with a minimum of 2-year clinical follow-up along with follow-up between 3–6 months and a third visit at any other time point. Primarily, the rate of recovery in ROM and time to maximum ROM was evaluated. Secondarily, we assessed six outcome scores and the influence of subscapularis repair during rTSA. Recovery in each outcome was modeled using continuous two-phase segmented linear regression models with random effects. Rate of recovery was defined as the slope of the first segment. Patients were considered to have recovered after surgery at the timepoint corresponding to the inflection point between piecewise segments.
Results: Of the 1,164 aTSAs and 539 rTSAs included, 172 aTSAs (15%) and 80 rTSAs (15%) were stiff preoperatively, respectively. Compared to preoperatively stiff aTSAs, non-stiff aTSAs regained ER, abduction, internal rotation (IR), and forward elevation (FE) faster over a shorter duration. Similarly, non-stiff rTSAs regained ER, abduction, and FE faster and over a shorter duration compared to stiff rTSAs, but regained IR more slowly over a longer duration. Stiff rTSAs performed with subscapularis repair did not have any appreciable gain in ER after the immediate postoperative period. Although non-stiff and stiff rTSAs performed without subscapularis repair regained ER at a similar rate (4.4 vs. 4.2 °/month), stiff rTSAs continued to regain ER 1.9-times longer (11.9 vs. 6.4 months). When the subscapularis was repaired, non-stiff rTSAs regained abduction and IR faster over a short duration compared to stiff rTSAs.
Conclusions: Preoperative stiffness is associated with slower recovery of active ROM over a longer duration in patients undergoing shoulder arthroplasty for RCI-GHOA.
Level of evidence: III; Retrospective Cohort Comparison; Treatment Study.

1. Introduction

Anatomic total shoulder arthroplasty (aTSA) is a reliable operation to improve pain and function in patients with rotator cuff-intact primary glenohumeral osteoarthritis (RCI-GHOA). Prior studies have shown that most improvement in ROM, strength, and functional scores occurs

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within the first 6 months following aTSA [1,2]. However, there remains a subset of patients who lag behind their peers in the rate at which they regain functional overhead motion.

Although not previously demonstrated, patients with shoulder stiffness may limit use of their shoulder preoperatively which may increase the rates of disuse atrophy of the rotator cuff. Additionally, the extensive intraoperative soft-tissue releases that are necessary to achieve adequate glenoid exposure in stiff patients may contribute to greater pain and functional limitations postoperatively, necessitating a more gradual rehabilitation course. Furthermore, repair of the subscapularis tendon is often more challenging in shoulders with longstanding stiffness; excess tension on a stiff subscapularis tendon during postoperative rehabilitation may predispose to nonhealing or post-surgical repair failure [3]. As a result, many surgeons have begun to consider reverse total shoulder arthroplasty (rTSA) in stiff patients with RCI-GHOA, and particularly those with severe glenoid deformity and in patients with lower functional demands [3–6]. For example, Wright et al. [7] compared aTSA and rTSA in Patients older than 70 with RCI-GHOA and found no differences in rates of complications, revision surgery, postoperative outcome scores, or range of motion. Given the critical role of the rotator cuff on outcomes of aTSA, patients with preoperative rotational stiffness may gain ROM after aTSA more gradually compared to their non-stiff peers. Characterizing the postoperative shoulder function improvement in these patients will enable surgeons to counsel these patients more effectively and potentially tailor their postoperative rehabilitation protocols.

The primary purpose of this study was to compare the rate of recovery of ROM after aTSA and rTSA performed in stiff (preoperative passive external rotation [ER] $\leq 0°$) versus non-stiff (preoperative passive ER $>0°$) shoulders with RCI-GHOA. Secondarily, we assessed the rate of recovery of outcome scores and assessed the influence of subscapularis management (repair vs. no repair) on rTSA recovery. We hypothesized that preoperatively stiff shoulders would have slower recovery in ROM postoperatively with lower postoperative motion compared to non-stiff shoulders.

2. Materials and methods

A retrospective review of a multicenter international shoulder arthroplasty database was performed between 2001 and 2021. We initially identified 8,028 postoperative visits from 2,239 aTSAs and 3,496 postoperative visits from 1,121 rTSAs performed for RCI-GHOA with minimum 2-year follow-up. Shoulders were excluded for a preoperative diagnosis of nerve injury, infection, or fracture. Postoperative complications that would affect ROM were also eliminated (postoperative rotator cuff tear after aTSA, subscapularis failure after aTSA, fracture, infection, Lazarus grade 4 or 5 glenoid radiolucency after aTSA, revision surgery and neurological injury). To be included for analysis, patients had to have a minimum of three follow-up visits meeting the following criteria: (1) one between 3 and 6 months, (2) one at minimum 2-year follow-up, and (3) one follow-up at any other time. In total, 5,704 postoperative visits from 1,164 aTSAs (mean 4.9 visits per aTSA) and 2,337 visits from 539 rTSAs (mean 4.3 visits per rTSA) were included for analysis. A single shoulder arthroplasty system was used for all procedures (Equinoxe; Exactech, Inc., Gainesville, FL, USA). All procedures were performed by one of 36 senior shoulder surgeons.

2.1. Clinical outcomes

ROM and outcome scores were evaluated at preoperative and postoperative visits using a standardized protocol by the surgeon, trained research assistant, or physical therapist. Measures assessed included active abduction, active forward elevation (FE), and active and passive external rotation (ER) measured in degrees. Internal rotation (IR) was assessed as the most cephalad vertebral level reached by the thumb behind the patient's back and scored as previously described: 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 [8]. 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.

2.2. Statistical analysis

Patient demographic and surgical characteristics were summarized descriptively and compared between preoperative stiffness groups. Continuous measures were compared using two-sided unpaired t-tests and Wilcoxon rank-sum tests, where appropriate. Fisher's Exact test was used to compare count data. Stiffness was defined as preoperative passive ER $\leq 0°$ based on our prior work, which demonstrated that this threshold best differentiated outcomes when fitted with a two-segment piecewise linear regression model [9].

Our primary outcome was the rate of recovery in postoperative ROM in abduction, FE, IR, and ER compared between preoperatively stiff and non-stiff shoulders. Secondarily, we evaluated the rate of recovery in postoperative outcome scores (SST, Constant, ASES, UCLA, SPADI, and SAS). To assess the relationship between outcome measure data and follow-up time, we first plotted postoperative ROM and outcome scores versus time using locally-estimated scatterplot smoothing (Supplementary Figs. S1–S4). Based on the trends visualized, continuous two-phase segmented linear regression models with random effects were fitted to the data separately for each postoperative outcome measure and preoperative stiffness group using the chngpt package [10]. Rate of improvement in each outcome was defined as the slope of the first segment. Patients were considered to have recovered after surgery at the timepoint corresponding to the inflection point between piecewise segments. Patients were modeled with random intercepts to account for the correlation between repeated measures from the same individuals in the analysis of longitudinal outcome data [1,2]. The mean, standard deviation (SD), and 95% confidence intervals (CI) of regression model estimates were computed from 500 bootstrap replicates. Statistical analyses were performed using R Software (version 4.2.0; R Core Team, Vienna, Austria) using an α of 0.05.

3. Results

3.1. Cohort characteristics

Of the 1,164 aTSAs and 539 rTSAs included, 172 (15%) aTSAs and 80 (15%) rTSAs were stiff preoperatively (Table 1**)**. Overall, the age at surgery for aTSAs was 66.3 ± 8.1 years and 73.1 ± 7.5 years for rTSAs ($P < .001$). For aTSAs, the mean preoperative passive ER was -2.4 ± 5.8° in the stiff group and 33.4 ± 17.9° in the non-stiff group. For rTSAs, the mean preoperative passive ER was -3.8 ± 6.4° in the stiff group and 29.2 ± 16.9° in the non-stiff group. The subscapularis was repaired in 52% of rTSAs; stiff rTSAs had the subscapularis repaired at a higher rate (63% vs. 50%, $P = .034$). Patient characteristics did not differ between stiff and non-stiff patients when stratified by whether the subscapularis was repaired; the only exception was older age among non-stiff rTSAs compared to stiff rTSAs in the groups without subscapularis repair (73.0 ± 7.0 vs. 69.1 ± 8.0 years, $P = .020$).

3.2. Range of motion

3.2.1. aTSA

Non-stiff aTSAs regained ROM faster over a shorter period of time compared to stiff aTSAs for all ROM measures. Non-stiff aTSAs regained ER 3.1-times faster (9.0 vs. 2.9 °/month), abduction 2.0-times faster (12.5 vs. 6.3 °/month), IR 1.3-times faster (0.4 vs. 0.3 points/month), and FE 1.2-times faster (16.7 vs. 13.7 °/month) (Fig. 1 and Supplementary Table S1). However, stiff aTSAs continued to regain ER 2.4-

Table 1
Characteristics of included aTSAs and rTSAs.

Characteristic	aTSA			rTSA		
	Non-stiff (n = 992)	Stiff (n = 172)	*P*	Non-stiff (n = 459)	Stiff (n = 80)	*P*
Age at surgery (years)	66.3 ± 8.0	65.9 ± 8.7	.579	73.2 ± 7.4	72.5 ± 7.9	.452
BMI (kg/m^2)	30.3 ± 6.4	31.1 ± 6.9	.145	29.3 ± 6.1	29.4 ± 6.4	.924
Follow-up (months)	50.2 ± 32.5	62.7 ± 43.2	**<.001**	38.8 ± 26.2	36.4 ± 24.1	.420
Female sex	48.9% (485)	47.1% (81)	.680	59.5% (273)	63.8% (51)	.537
Dominant side surgery	54.7% (543)	58.7% (101)	.361	56.2% (258)	55.0% (44)	.903
Comorbidities						
Hypertension	49.4% (471)	43.1% (72)	.154	55.3% (245)	56.3% (45)	.903
Heart disease	12.8% (122)	7.8% (13)	.071	15.8% (70)	12.5% (10)	.504
Diabetes	13.5% (129)	13.2% (22)	1.000	14.4% (64)	13.8% (11)	1.000
Tobacco use	8.1% (77)	7.8% (13)	1.000	5.0% (22)	2.5% (2)	.559
Received shoulder injections	50.1% (495)	49.4% (85)	.934	41.6% (188)	40.0% (32)	.807
Analgesic use	62.7% (609)	64.9% (109)	.605	66.6% (295)	68.5% (50)	.790
Cemented humeral component	12.3% (122)	23.3% (40)	**<.001**	7.2% (33)	2.5% (2)	.142
Previous surgery on shoulder	15.4% (153)	15.7% (27)	.909	16.6% (76)	22.5% (18)	.204
Estimated blood loss (mL) (IQR)	200 (150–300)	200 (110–300)	.368	200 (120–250)	200 (128–300)	.364

aTSA, anatomic total shoulder arthroplasty; BMI, body mass index; IQR, interquartile range; rTSA, reverse total shoulder arthroplasty. P values were computed using two-sided unpaired Welch's t-tests and Fisher's exact tests, where appropriate. Bold values indicate statistical significance.

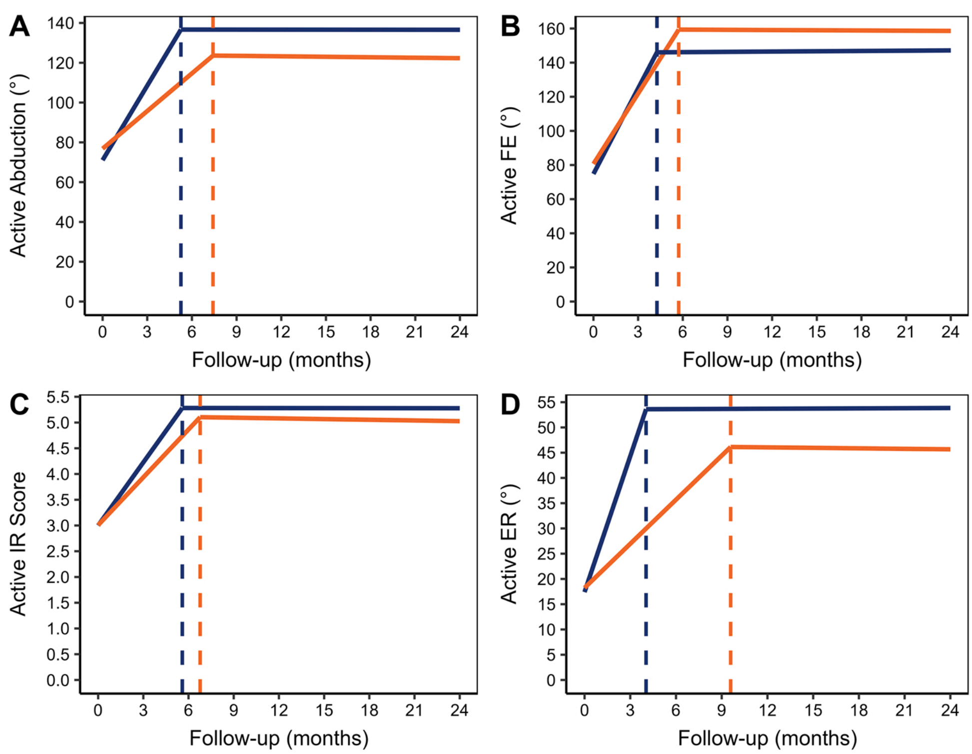

Fig. 1. Two-segment linear regression models for stiff (orange) and non-stiff (blue) aTSAs depicting the relationship between follow-up time and postoperative active abduction (A), active FE (B), IR score (C), and active ER (D). Changepoints are depicted by dashed lines. ER, external rotation; FE, forward elevation; IR, internal rotation.

times longer (9.6 vs. 4.0 months), abduction 1.4-times longer (7.4 vs. 5.3 months), FE 1.3-times longer (5.7 vs. 4.3 months), and IR 1.2-times longer (6.8 vs. 5.6 months).

3.2.2. rTSA

Non-stiff rTSAs regained ROM in ER, abduction, and FE faster over a shorter period of time compared to stiff rTSAs, but regained IR slower over a longer period of time. Non-stiff rTSAs regained ER 3.8-times faster (4.2 vs. 1.1 °/month), abduction 2.7-times faster (12.4 vs. 4.6 °/month), and FE 1.4-times faster (12.9 vs. 8.9 °/month) (Fig. 2 and Supplementary Table S1). However, stiff rTSAs continued to regain ER 2.6-times longer (16.1 vs. 6.3 months), abduction 1.9-times longer (8.0 vs. 4.2 months), FE 1.3-times longer (6.0 vs. 4.6 months). In contrast, stiff rTSAs regained IR 1.3-times faster (0.25 vs. 0.19 points/month) and non-stiff rTSAs regained IR 1.1-times longer (8.9 vs. 7.8 months).

3.2.3. rTSA: subscapularis repair

When the subscapularis was repaired, non-stiff and stiff rTSAs were similar with regard to IR (Fig. 3 and Supplementary Table S2); while non-stiff rTSAs regained ER at 3.6 °/month until 7.3 months, stiff rTSAs with subscapularis repair did not regain any meaningful ER during the postoperative period. When the subscapularis was not repaired, stiff rTSAs regained IR 3.2-times faster (0.41 vs. 0.13 points/month), but non-stiff rTSAs regained IR 1.8-times longer (13.3 vs. 7.5 months) (Fig. 4 and Supplementary Table S2). While non-stiff and stiff rTSAs regained ER at similar rates (4.4 vs. 4.2 °/month), stiff rTSAs continued to regain

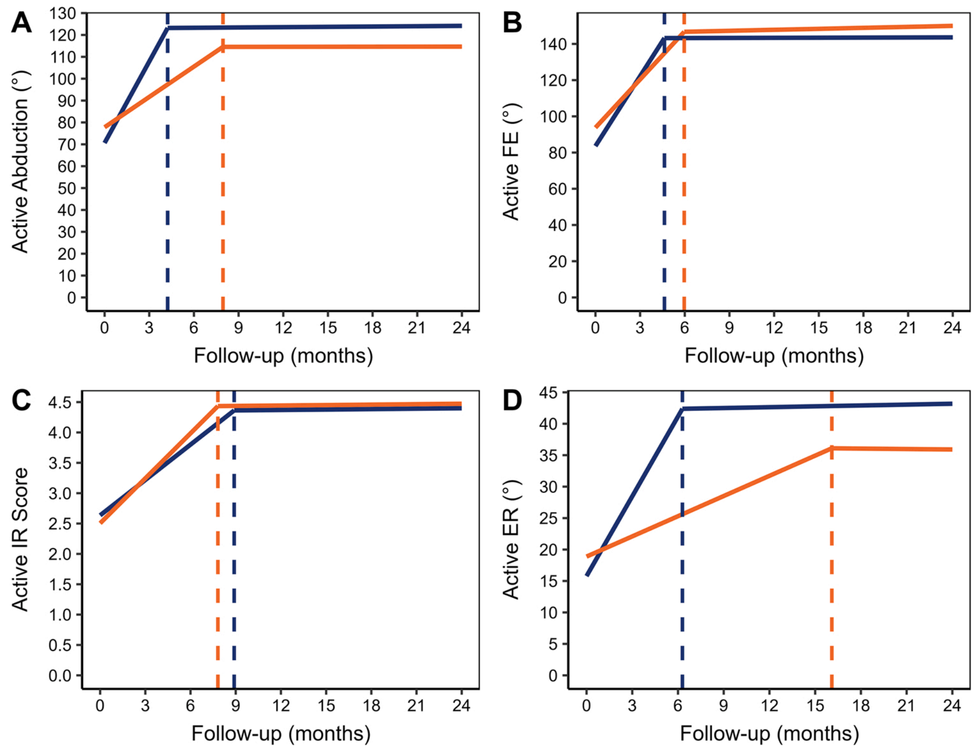

Fig. 2. Two-segment linear regression models for stiff (orange) and non-stiff (blue) rTSAs regardless of subscapularis management depicting the relationship between follow-up time and postoperative active abduction (A), active FE (B), IR score (C), and active ER (D). Changepoints are depicted by dashed lines. ER, external rotation; FE, forward elevation; IR, internal rotation.

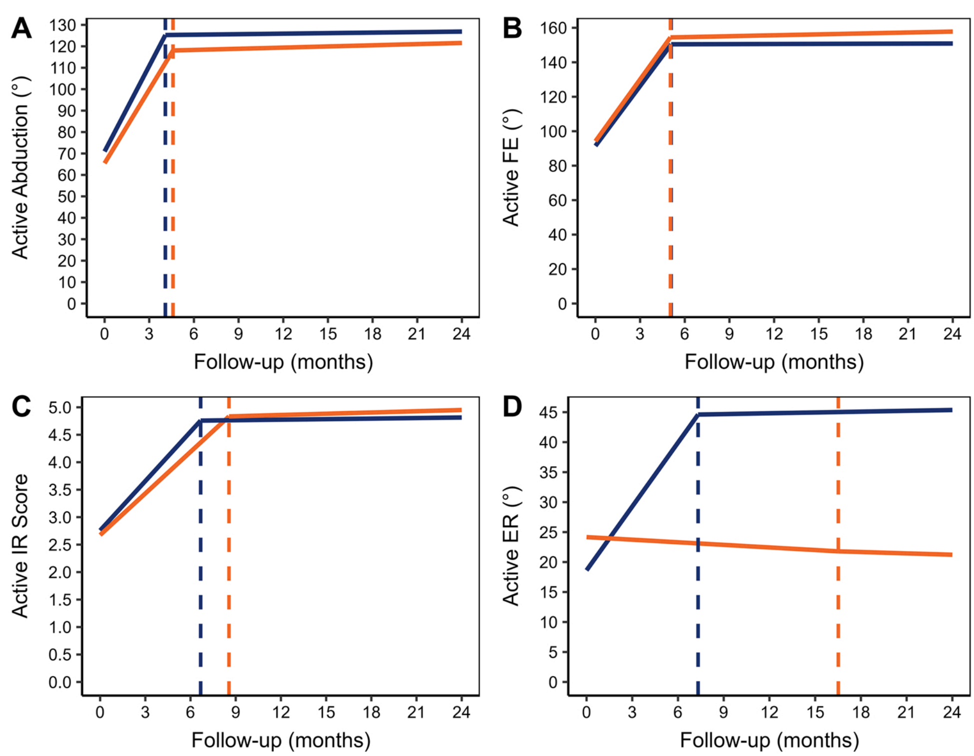

Fig. 3. Two-segment linear regression models for stiff (orange) and non-stiff (blue) rTSAs with subscapularis repair depicting the relationship between follow-up time and postoperative active abduction (A), active FE (B), IR score (C), and active ER (D). Changepoints are depicted by dashed lines. ER, external rotation; FE, forward elevation; IR, internal rotation.

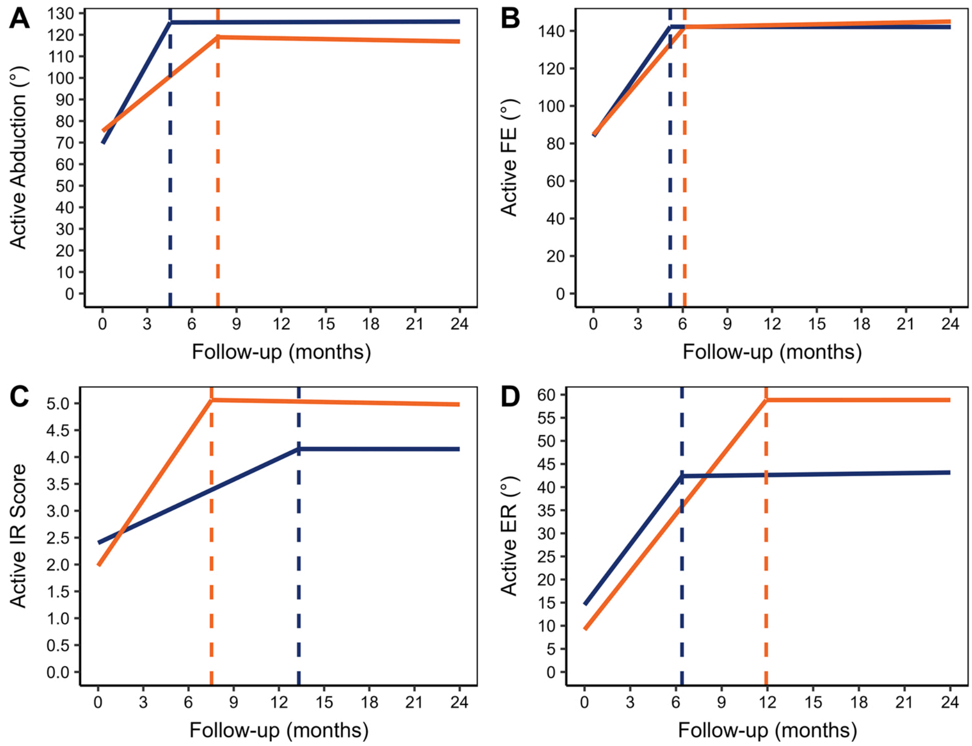

Fig. 4. Two-segment linear regression models for stiff (orange) and non-stiff (blue) rTSAs without subscapularis repair depicting the relationship between follow-up time and postoperative active abduction (A), active FE (B), IR score (C), and active ER (D). Changepoints are depicted by dashed lines. ER, external rotation; FE, forward elevation; IR, internal rotation.

ER 1.9-times longer (11.9 vs. 6.4 months).

3.3. Outcome scores

3.3.1. aTSA

Non-stiff aTSAs improved clinically faster than stiff aTSAs for all outcome scores except the SST score (Supplementary Figure S5 and Supplementary Table S3). However similar to ROM, stiff aTSAs continued to improve all outcome scores over a longer period compared to non-stiff aTSAs.

3.3.2. rTSA

While non-stiff rTSAs had faster improvement in the Constant and SAS scores compared to stiff rTSAs (Supplementary Figure S6 and Supplementary Table S3), they had slower or equivalent improvement in the SST, ASES, UCLA, and SPADI. Again, stiff rTSAs improved outcome scores over a longer period for all scores compared to non-stiff rTSAs. Rate and duration of improvement of rTSAs depending on subscapularis management is presented in Supplementary Figure S7 and Supplementary Figure S8; data is available is Supplementary Table S4).

4. Discussion

While most patients rapidly regain ROM after aTSA and rTSA during the first 6 months postoperatively, a subset of patients lag behind their peers. In this study, we found that patients with RCI-GHOA and limited preoperative passive ER undergoing aTSA have a slower recovery of active ROM over a longer duration compared with preoperatively non-stiff shoulders. Similarly, stiff rTSAs regained ER, abduction, and FE slower and over a longer duration, but regained IR more quicky over a shorter duration. Notably, stiff rTSAs with subscapularis repair did not regain any meaningful ER during the postoperative period. Our findings confirm our hypothesis and inform patient counseling and suggest more prolonged postoperative rehabilitation protocols in preoperatively stiff patients may be needed.

The current study builds upon prior work by Hao et al. [9] assessing the influence of preoperative ER stiffness on outcomes of aTSA and rTSA performed for RCI-GHOA. Non-stiff aTSAs and rTSAs had superior postoperative abduction and active and passive ER compared to matched stiff aTSAs and rTSAs, but similar FE, IR, and outcome scores. When comparing matched stiff aTSAs to stiff rTSAs, stiff aTSAs had superior postoperative active ER ($40 \pm 19^\circ$ vs. $28 \pm 17^\circ$, $P < .001$) and IR (4.8 ± 1.5 vs. 4.2 ± 1.7 points, $P = .022$) with similar overhead motion and outcome scores. Although the results of the current study demonstrate that stiff patients regain ROM more slowly over a longer duration after either aTSA or rTSA, the findings of Hao et al. [9] suggest that stiff and non-stiff patients ultimately attain similar FE, IR, and outcome scores; however, ER and abduction remain poorer in preoperatively stiff shoulders with a longer time to final motion. This highlights a potential area for targeted postoperative rehabilitation strategies.

Given the slower rate of improvement and ultimately poorer abduction and ER in stiff patients undergoing TSA and similar outcomes between stiff aTSA and stiff rTSA [9], surgeons must consider patient desires and activities when considering the utility of rTSA in patients with RCI-GHOA and preoperative stiffness. In contrast to initial reports of early rTSA implants, the modern rTSA offers patients with excellent functional outcomes and we have gained substantial expertise in understanding how to optimize implantation [11–19]. The advantages of rTSA in stiff patients include permitting more extensive release of surrounding soft tissues, easier exposure of the glenoid by allowing for a larger humeral head osteotomy, posterior capsular release, and non-repair of the subscapularis [3]. While aTSA has been consistently shown to provide superior rotational motion compared to rTSA in patients with RCI-GHOA, outcomes scores are similar and we do not believe the poorer ER and abduction in stiff patients would alter these previous findings [4,5,20–22]. Cole et al. [23] compared patients who achieved and failed to achieve the patient acceptable symptomatic state for the ASES and SANE scores after aTSA. The authors found that while pain and FE were different between groups, ROM in ER and IR were similar. Given that stiff patients undergoing aTSA ultimately achieve similar FE and outcome scores compared to non-stiff patients [9], we believe that patients with RCI-GHOA and ER stiffness still have marginally superior ROM when undergoing aTSA versus rTSA. However, the high reported rates of glenoid loosening and rotator cuff failure requiring revision surgery after primary aTSA should be considered when counseling patients [24]. Further study is warranted to directly evaluate outcomes of aTSA and rTSA in these patients.

Whether the subscapularis should be repaired during rTSA remains debated [25–28]. In the context of preoperative ER stiffness, we found that stiff rTSAs performed with subscapularis repair did not have any appreciable gain in ER during the postoperative period. Our model predicted that stiff patients undergoing rTSA with subscapularis repair would have roughly 24 ° of ER in the early postoperative period and have no improvement in the subsequent months (Fig. 3D and Supplementary Table S2). In contrast, stiff patients undergoing rTSA without subscapularis repair were predicted to have 9 ° of ER immediately postoperatively and gain approximately 4 °/month over the first 12 months of the postoperative period and plateauing at 57 ° (Fig. 4D and Supplementary Table S2). Although bootstrapping was performed to improve the accuracy of model estimates, readers should note that the trends reported in these models should be emphasized over the specific values. Nevertheless, these results suggest that the subscapularis should not be repaired in patients with ER stiffness undergoing rTSA. Interestingly, our prior comparison of stiff rTSAs performed with (n = 32) versus without (n = 32) subscapularis repair controlling for age, sex, follow-up (mean: 41.6 and 41.0 months, respectively), and preoperative passive ER demonstrated similar postoperative ROM and outcome scores including in ER (32 ± 15 ° vs. 28 ± 18 °, $P = .324$) [9], although stiff rTSAs with subscapularis repair trended towards superior IR (4.4 ± 1.4 vs. 3.4 ± 1.9 points, $P = .053$). The difference in findings between the present study and our previous case-controlled study may be due to differing follow-up periods (first 24 months herein vs. mean 41 months in Hao et al. [9]) or a difference in baseline characteristics (Hao et al. [9] controlled for age, sex, and preoperative passive ER). Together, these findings suggest that the subscapularis should not be repaired in patients with preoperative ER stiffness undergoing rTSA for RCI-GHOA. In select patients with concerns about limitations in IR postoperatively, transfer of the latissimus dorsi (with or without concomitant transfer of the teres major) should be considered. Patients should additionally be counseled on the expected rate of motion recovery and surgeons may consider targeted rehabilitation.

The optimal timing of surgery in patients with glenohumeral osteoarthritis with a stiff shoulder should be considered in the context of our findings. Given that non-stiff patients undergoing aTSA had faster recovery in all ROM and outcome scores, patients may benefit from undergoing surgery before their shoulder becomes stiff. Iannotti et al. [29] reviewed 128 shoulders with primary osteoarthritis and found that patients with poor preoperative passive ER (<10 °) was associated with poorer passive ER after both hemiarthroplasty and aTSA. Their findings led the authors to recommend that when nonoperative treatment fails and the patient has sufficient pain to warrant joint replacement, surgery (specifically aTSA) should be performed before there is a progressive loss of passive ROM. Our results suggest that intervention earlier in the disease process may result in a quicker recovery and potentially better motion in abduction and external rotation [9].

This study has several limitations. First, its retrospective nature limits the conclusions that can be drawn from our results. 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. Thus, the patients represented in this sample may not represent the ideal candidate for aTSA with the only exception being preoperative stiffness. Unfortunately, the retrospective and multicenter nature of this study prohibited retrospective assessment of rotator cuff status. Patients that underwent rTSA utilized a single implant design (medialized-glenoid lateralized-humerus per Werthel et al. [30]); it cannot be guaranteed that the results derived from patients that underwent rTSA with this implant design are broadly applicable to rTSA performed with other implants. The definition of preoperative stiffness varies in the literature from 0 to 20 ° of passive ER [9,31], making cross-study comparison difficult. Additionally, although the large sample of patients from multiple surgeons in different practice environments helps to normalize for individual differences and increases the generalizability of our findings, bias from individual surgeon preference and techniques could still be present. Lastly, we chose to model improvement in patient outcomes using a two-segment linear regression model implemented by the chngpt package in R [10]. Our analysis is based upon the underlying assumption that postoperative ROM and outcome scores can be adequately represented by an improvement phase (first segment) and a steady-state phase whereby improvement ceases and outcomes are either maintained or slowly deteriorate (second segment). Given the varying number of follow-up visits per patient, we determined it was necessary to utilize a mixed-effects model that prevents patients with more follow-up visits from having greater influence on model estimates [32,33], However, the mixed-effects models available from the chngpt package do not have error estimation built-in [34]; therefore, we utilized bootstrapping to generate measures of estimate variation (SD and 95% CIs). As a consequence, we encourage readers to focus on the trends in the data as highlighted in our manuscript rather than on the specific estimates generated from our models.

5. Conclusion

Patients with RCI-GHOA and limited preoperative passive ER (≤0 °) undergoing aTSA have a slower recovery of active ROM over a longer duration compared with preoperatively non-stiff shoulders. Similarly, stiff rTSAs regained ER, abduction, and FE more slowly and over a longer duration, but regained IR more quickly over a shorter duration. Our model demonstrated that stiff rTSAs with subscapularis repair do not progressively gain ER during the postoperative period, suggesting the subscapularis should not be repaired in stiff patients undergoing rTSA.

CRediT authorship contribution statement

All authors contributed significantly to the study conception and design. Material preparation, data collection, analysis and interpretation of data were performed by KAH, BSS, and TV. The first draft of the manuscript was written by KAH and all authors were involved in the revision, critical review, and final approval of the submitted manuscript.

Declaration of Generative AI and AI-assisted technologies in the writing process

AI was not used in any capacity to conduct this study or write this manuscript.

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Declaration of competing interest

KAH is a paid consultant for LinkBio Corp. JJK is a paid consultant for Exactech, Inc and LinkBio Corp. TWW receives royalties from Exactech, Inc., and Wolters Kluwer Health—Lippincott Williams & Wilkins. He is also a paid consultant with Exactech, Inc. JDW receives royalties from FH Orthopedics and is a paid consultant for Zimmer. BSS is a paid consultant and receives royalties from Exactech, Inc. BSS receives royalties from Responsive Arthroscopy and Innomed. The other authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.otsr.2024.104036.

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