

Subscapularis Tendon Repair Improves Functional Internal Rotation after Onlay Design Reverse Shoulder Arthroplasty

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Background: A major challenge of the reverse shoulder arthroplasty (RSA) is to restore postoperative range of motion, especially internal and external rotation. Attempting to address this issue, several modifications to the prosthesis design have been made.

Purpose: This study aimed to compare functional internal rotation (fIR) outcomes following RSA with different humeral implant designs.

Methods: We conducted a retrospective comparative analysis of data from 384 patients, each with a minimum of two years of follow-up, who underwent RSA with two distinct implant models: an inlay 155° neck-shaft angle and an onlay 145° neck-shaft angle. We assessed the postoperative progress of fIR based on type I IR (with the hand blocked against the buttock), type II IR (involving lumbar sliding), and type III IR (characterized by smooth motion). We categorized type I as non-fIR, while types II and III were considered as fIR. To analyze the influence of subscapularis repair on fIR, both groups were further categorized into two subgroups: those with repaired subscapularis (subgroup R) and those without repaired subscapularis (subgroup NR).

Results: No statistically significant difference was observed when comparing postoperative fIR between the two groups. Within the entire cohort, patients in subgroup R exhibited superior fIR outcomes compared to subgroup NR (40% type III vs. 19% type III, respectively; $p < 0.0001$). In the inlay group, no statistically significant difference in fIR was found among subgroups. Conversely, patients in the onlay subgroup R demonstrated better fIR than those in the group NR (42% type III vs. 17% type III, respectively; $p < 0.0001$).

Conclusion: There was no significant difference in fIR following RSA based on humeral design. However, in subgroup R, there was an improvement in fIR for group onlay, but no significant impact was observed in the inlay group. These results suggest that subscapularis repair should be attempted in lateralized designs whenever possible. Patients with higher preoperative IR were more likely to experience a decrease in IR after surgery.

Keywords: Prosthesis; Onlay; Inlay; Prosthetic design; Range of motion; Complications; PROMs.

Level of Evidence: Level III; Retrospective Cohort Comparison; Treatment Study.

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Introduction

The Grammont reverse shoulder arthroplasty (RSA) design exhibits certain limitations, one of which is the medialized inlay system, which reduces tension on the subscapularis and infraspinatus, resulting in incomplete restoration of active external/internal rotation (IR) [1].

In response to these challenges, newer designs have been introduced. On the humeral component, the neck-shaft angle (NSA) was reduced to a more anatomical alignment, and the polyethylene was positioned above the metaphysis, adopting an onlay configuration. These modifications notably lateralized the humerus, increasing tension on the remaining anteroposterior rotator cuff [2].

While there has been considerable attention given to restoring active external rotation [2], less emphasis has been placed on IR, despite its significance in daily activities [3][4][5]. The latter is indeed indispensable for a range of tasks, including buttoning a shirt, fastening a belt, dressing, bathing, or performing personal hygiene [6][7][8]. Therefore, enhancing IR in RSA seems necessary to achieve more favorable functional outcomes and ensure patient satisfaction [9]. Several studies, primarily of a biomechanical nature, have identified factors associated with improved IR [10]. However, most of these factors have not been corroborated in clinical studies [11].

The objective of this study was to compare functional rotational improvement (fRI) after RSA using various designs. Our hypothesis proposed that the previously described design alterations would result in improved postoperative clinical fIR.

Materials and Methods

Study Design, Data Collection, and Ethical Committee Approval

A retrospective comparative analysis of data was conducted on a consecutive series of RSAs performed by the senior surgeon (P.C.) between January 2012 and July 2021. Data were extracted from a prospective database (Follow Health, Rennes, France). The study involved 476 consecutive patients who underwent RSA with two distinct humeral component implant models: an inlay 155° neck-shaft angle (Aequalis Reversed II, Wright Medical, Memphis, TN, USA) and an onlay 145° neck-shaft angle (Aequalis Ascend Flex, Wright Medical, Memphis, TN, USA).

Inclusion criteria were as follows: (1) a preoperative diagnosis of an irreparable rotator cuff tear (IRCT), (2) primary osteoarthritis (OA) or cuff tear arthropathy (CTA), and (3) a minimum follow-up of 24 months. Exclusion criteria were as follows: (1) proximal humeral fracture, (2) revision surgery, (3) postoperative complications after RSA (fracture, instability, or infection) [12], or (4) concomitant transfer.

Patients underwent complete subscapularis repair at the time of surgery only if they met the following criteria: (1) fatty degeneration of grade 1 or 2 on preoperative computed tomography (CT) scans or magnetic resonance imaging (MRI) according to the Goutallier classification [13], (2) intact subscapularis without attenuation or rupture at the time of surgery, and (3) tendon amenable to repair without significant tension or tendon gapping following prosthesis implantation. To analyze the influence of subscapularis repair on fRI, both groups were further categorized into two subgroups: those with repaired subscapularis (subgroup R) and those without repaired subscapularis (subgroup NR).

Institutional review board approval (CERC-VS-2020-11-1) was obtained before commencing the study, and all patients provided informed consent for participation.

Equity, Diversity and Inclusion Statement

The studied population included women and men from various countries in Southern Africa, North America, Oceania, and Europe, reflecting the usual distribution for this pathology. Additionally, the cohort represented a wide range of ages, backgrounds, and demographics.

Our research team comprised two women and four men at different stages of their careers and clinical disciplines. One author is South American, another is from the Middle East, and the remaining authors are from Central Europe. We did not collect or present data on race, socioeconomic status, or other social determinants.

Surgical Technique and Implant Design

All surgeries were performed with patients in the beach chair position under general anesthesia, supplemented by interscalene block. A standard deltopectoral approach was employed to access the shoulder. The long head of the biceps tendon was routinely tenodesed to the pectoralis major tendon insertion. A mid-substance subscapularis tenotomy was executed approximately one cm medial to the tendon insertion at the lesser tuberosity. The humeral head was cut with a 20° humeral retroversion.

The preparation of the baseplate was identical for both groups. The component was positioned at the level of the lower edge of the glenoid and tilted downward by 10°. It was implanted with seven mm of increased bony offset, using autogenous bone graft obtained from the humeral head, and secured with four peripheral screws in all cases. The size of the glenosphere and its eccentricity were determined based on preoperative planning.

In the inlay group, a Grammont-style RSA (Aequalis Reversed II, Tornier, Wright Medical, Memphis, TN, USA) with a 155° neck-shaft angle was implanted. In the onlay group, a short stem with a curved design and a 145° NSA (Aequalis Ascend Flex, Tornier, Wright Medical, Memphis, TN, USA) was implanted.

In cases involving subscapularis repair, before inserting the final humeral stem implant, three bone tunnels were drilled through the bicipital groove, through which three nonabsorbable sutures were passed in preparation for subscapularis repair. Intraoperative stability and range of motion were assessed before inserting the final humeral implant. The subscapularis was then repaired using a side-to-side and transosseous repair technique [14].

Postoperative Protocol

Postoperatively, the operative arm was immobilized with a simple sling in IR for four weeks. Patients were allowed to remove the sling only for hygiene and to use the hand and elbow for simple daily activities. Lifting was not permitted. Pendulum exercises were initiated three days after surgery. The sling was discontinued at four weeks, and activities were subsequently allowed as tolerated [15].

Study Variables

The primary outcome was the impact of different humeral designs on IR following RSA. Additionally, the effect of subscapularis repair was assessed. The following baseline

characteristics were evaluated: age, sex, and diagnosis (IRCT, OA or CTA).

Clinical Evaluation

Patients were assessed both preoperatively and at the final follow-up using the Constant score [16] and the fIRI, which were evaluated by an independent and blinded observer (S.G.).

We assessed IR using the functional classification, as previously described [17]:

Type I: Unable to perform - the patient could not reach their ipsilateral hand behind their back.

Type II: The patient could reach their hand behind their back to at least waist level but required assistance by rolling, sliding, or walking their hands up their back/backside.

Type III: The patient could reach their hand behind their back to at least waist level in a fluid, uninterrupted fashion.

Type I was categorized as non-fIR, while types II and III were considered as fIR.

Statistical Analyses

Data were analyzed using R software v. 4.1.2. Descriptive statistics summarized patients' demographics in the sample, including mean, standard deviation, median, minimum, and maximum for continuous variables, and counts and percentages for discrete variables. To compare pre-operative and post-operative characteristics between inlay and onlay prosthesis, t-tests were performed for continuous variables, and chi-square tests were conducted for discrete variables. For the subgroups, two-way ANOVAs were used for continuous variables such as age or the Constant score, and chi-square tests were employed for discrete variables. Boxplot figures were generated to illustrate the improvement in the Constant score between groups and subgroups.

Results

From an initial cohort of 476 patients, 384 were included after excluding 72 lost to follow-up, 15 who experienced complications, and 5 who passed away (Figure 1). The final cohort comprised 153 patients in the inlay group and 231 in the onlay group, with a mean follow-up of 24 months (range: 24 to 60 months). Patients in the inlay group were significantly older (mean age: 74±8 years) compared to the onlay group (mean age: 71±8 years, p<0.0001). A higher proportion of patients in the inlay group were diagnosed with CTA, whereas the onlay group exhibited a more balanced distribution of diagnoses (p<0.0001, Table 1).

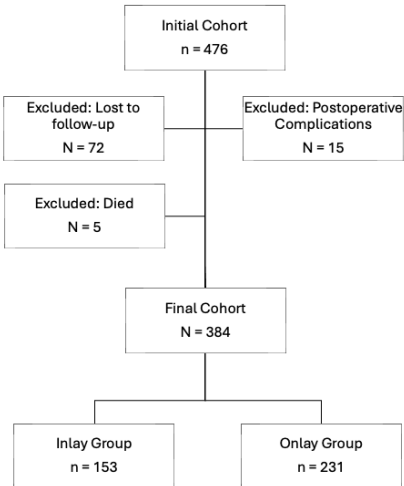


Figure 1: Flow chart of study cohort.

Table 1. Group demographic and perioperative characteristics

	Inlay group	Onlay group
Shoulders, n (%)	153 (40)	231 (60)
Age in years, means±SD	74±8	71±8
Age in years, p-value	p<0,0001 (Student t-test)	
Sex, n (%)		
Male	58 (38)	96 (42)
Female	95 (62)	135 (58)
Etiology, n (%)		
OA	37 (24)	91 (40)
CTA	96 (63)	60 (26)
IRCT	20 (13)	80 (34)
Etiology p-value	p=0, 0317 (Chi square test)	p=<0,0001 (Chi square test)
FU in months means±SD	24.08±0.97	24.72±4.11

CTA: cuff tear arthroplasty, IRCT: irreparable rotator cuff tear, OA: osteoarthritis, FU: follow-up

Subscapularis Repair and Patient Demographics

Subscapularis repair was performed in 75% of inlay patients and 61% of onlay patients. NR patients were generally older and more likely to have an IRCT, particularly in the onlay NR subgroup (44% IRCT, p<0.0001, Table 2).

Clinical Outcomes

The onlay group demonstrated superior postoperative Constant scores compared to the inlay group (74±11 vs. 72±11, p=0.0403, Table 3). However, no significant differences

were observed in the improvement of Constant scores between groups (p=0.4461, Table 3).

fIR did not differ significantly between the onlay and inlay groups postoperatively (p=0.9035, Table 3). Subgroup analysis, however, revealed that subscapularis repair significantly improved fIR outcomes. In the onlay R subgroup, 42% of patients achieved type III fIR, compared to only 17% in the onlay NR subgroup (p<0.0001, Table 4). In contrast, no significant difference in fIR was observed between the inlay R and inlay NR subgroups (p=0.4659, Table 4).

Predictors of IR

A linear regression analysis showed no significant association between graft size and postoperative IR (coefficient = -0.0497, $p=0.161$) or between glenosphere size and postoperative internal rotation, though a trend toward significance was observed (coefficient = -0.0369, $p=0.084$, **Table 5**). Additionally, a binomial logistic regression identified preoperative IR as a strong predictor of postoperative IR outcomes. Patients with higher preoperative IR were more likely to experience a decrease in IR postoperatively, whereas those with higher postoperative IR were less likely to show a decrease (**Table 6**).

Subgroup Differences in IR

Subscapularis repair had no significant effect on postoperative Constant scores across subgroups ($p=0.7781$, Table 4). However, postoperative fiR outcomes were significantly better in repaired subgroups compared to non-repaired subgroups (40% type III vs. 19% type III, $p<0.0001$, **Table 7**).

Table 2. Subgroups demographic and perioperative characteristics

Groups/subgroups	Inlay R	Inlay NR	Onlay R	Onlay NR
Shoulders, n (%)	115 (75)	38 (25)	141 (61)	90 (39)
Age in years, means $\pm$ SD	73 $\pm$ 7	78 $\pm$ 9	70 $\pm$ 8	72 $\pm$ 8
Sex, n (%)				
Male	44 (38)	14 (37)	55 (39)	49 (54)
Female	71 (62)	24 (63)	86 (61)	41 (46)
Etiology, n (%)				
OA	32 (28)	5 (13)	73 (52)	18 (21)
CTA	72 (63)	24 (63)	29 (20)	31 (35)
IRCT	11 (9)	9 (24)	39 (28)	41 (44)
Etiology p-value	$p=0.0317$ (Chi square test)		$p=<0.0001$ (Chi square test)	
Follow-up in months, means $\pm$ SD	24 $\pm$ 0	24.32 $\pm$ 1.95	24.85 $\pm$ 4.2	24.53 $\pm$ 3.96

CTA: cuff tear arthroplasty, IRCT: irreparable rotator cuff tear, NR: non repair, OA: osteoarthritis, R: repair.

Table 3. Humeral design clinical outcomes

IR Type, n (%)	Onlay group	Inlay group	Onlay group	Inlay group
	Preoperative		Postoperative	
I	59 (26)	53 (34)	69 (30)	46 (30)
II	112 (48)	66 (43)	85 (36)	58 (38)
III	60 (26)	34 (22)	80 (34)	49 (32)
MD IR Type			p = 0,9035*	
Cs means±SD	43±15	39±16	74± 11	72±11
Cs p-value	p=0,0233**		p=0,0403**	
MD Group	Comparison onlay-inlay =3.75***		Comparison onlay-inlay = 2.37***	
Cs improvement	p=0,4461****			

IR: Internal Rotation, Pre: preoperative, Post: postoperative, Cs: Constant score, MD: Mean difference. * Chi square test, **ANOVA analysis, ***Post Hoc Tests (ANOVA) comparison are based on estimated marginal means, **** Student T-test.

Table 4. Subscapularis repair clinical outcomes

Group IR Type	PREOPERATIVE				POSTOPERATIVE			
	INLAY		ONLAY		INLAY		ONLAY	
	R	NR	R	NR	R	NR	R	NR
I	38 (33%)	15 (39%)	40 (29%)	19 (21%)	35 (30%)	11 (29%)	26 (19%)	42 (47%)
II	49 (43%)	17 (45%)	66 (46%)	46 (52%)	40 (35%)	18 (47%)	51 (36%)	32 (36%)
III	28 (24%)	6 (16%)	35 (25%)	25 (27%)	40 (35%)	9 (24%)	64 (42%)	16 (17%)
Total n (%)	115 (100%)	38 (100%)	141 (100%)	90 (100%)	116 (100%)	38 (100%)	141 (100%)	90 (100%)
p-value	$p=0.5188$		$p=0.4659$		$p=0.3146$		$p<0.0001$	
Cs, means $\pm$ SD	40 $\pm$ 16	35 $\pm$ 15	42 $\pm$ 16	44 $\pm$ 14	72 $\pm$ 11	70 $\pm$ 11	75 $\pm$ 11	73 $\pm$ 11
Mean Difference	$p=0.7781$				$p=0.0842$			

ShapelR: Internal rotation, R: repaired subscapularis, NR: non repaired subscapularis, Cs: Constant score.

Table 5. Linear Regression : postoperative IR

Model Fit Measures				
Model	R	R²		
1	0.174	0.0303		
Model Coefficients - postoperative IR				
Predictor	Estimate	SE	t	p
Intercept *	3.7482	0.8088	4.643	<0.001
Graft size	-0.0497	0.0354	-1.405	0.161
Glenosphere size	-0.0369	0.0213	-1.730	0.084
Diagnosis:				
OA-CTA	0.1756	0.0988	1.778	0.076
IRCT-CTA	-0.0997	0.1084	-0.920	0.358
Inlay/onlay:				
Inlay-onlay	0.0293	0.0933	0.314	0.754

* Represents reference level; IR: internal rotation, R: Correlation Coefficient, R²: Coefficient of Determination, SE: Standard Error, t: t-Statistic, p: p-value, CTA: cuff tear arthroplasty, OA: osteoarthritis, IRCT: irreparable rotator cuff tear.

Table 6. Binominal logistic regression

Model Fit Measures				
Model	Deviance	AIC	R ² McF	
1	72.2	94.2	0.835	
Model Coefficients - Decrease IR				
Predictor	Estimate	SE	Z	p
Intercept	1.6150	6.341	0.2547	0.799
Sphere size	-0.1351	0.152	-0.8905	0.373
Graft size	0.0404	0.340	0.1186	0.906
Preoperative IR	6.8138	1.135	6.0019	<0.001
Postoperative IR	-7.8564	1.312	-5.9876	<0.001
Prosthesis type:				
Onlay-inlay	-0.0762	0.839	-0.0909	0.928
Diagnosis:				
OA-CTA	0.2416	1.002	0.2410	0.810
IRCT-CTA	-0.3332	0.762	-0.4375	0.662
SSC repaired:				
yes-no	-0.0201	0.934	-0.0215	0.983
SSC healed:				
yes "healed"-NA "no US done"	-0.1439	0.960	-0.1499	0.881
no "non healed"-NA "no US done"	0.0341	1.177	0.0290	0.977

Note: Estimates represent the log odds of "Decrease IR = 1 "Decrease in IR" vs "Decrease IR = 0 "No decrease in IR"; AIC: Akaike Information Criterion, R² McF: McFadden's R-squared, SE: Standard Error, Z: Z-Statistic, p: p-value, IR: internal rotation, CTA: cuff tear arthroplasty, OA: osteoarthritis, IRCT: irreparable rotator cuff tear, SSC: subscapularis, NA: not applicable, US: ultrasound.

Table 7. Postoperative IR according to subgroups

IR Type, n (%)	R	NR
I	61 (24)	54 (42)
II	93 (36)	50 (39)
III	104 (40)	25 (19)

NR: non repair, R: repair.

Discussion

The primary objective of this study was to compare fRI outcomes after RSA using two different humeral component designs. Our findings indicate that there was no significant difference in fRI between the two designs, invalidating our hypothesis. However, it is noteworthy that the repair of the subscapularis tendon had a positive impact on the functional internal rotation in the lateralized design. Our study is aligned with the current literature, as previous clinical studies have also failed to identify a relationship between humeral component variations and IR [18][19][20][21][22].

Humeral Design and IR

Despite its essential role in daily activities and patient satisfaction, most studies have overlooked the restoration of internal rotation, while focusing primarily on achieving functional external rotation [5]. In two systematic reviews [23][24] aiming to evaluate the influence of RSA design on clinical outcomes, no data regarding internal rotation was reported. While Erickson et al. [23] did not mention the results of internal rotation, Larose et al. [24] stated that the analysis of internal rotation was not possible due to variations in measurement methods. Additionally, in another systematic review, Rojas et al. [25] found that one-third of the published clinical studies on reverse total shoulder arthroplasty do not report internal rotation data at all. Kim et al. [9] found that 59% of patients reported IR limitations after RSA. Limited IR was associated with lower patients' subjective rating of RSA and negatively impacted PROMs. The offset lateralization, achieved through the combined effect of the onlay configuration, tray position and, to a lesser extent, an NSA <155° [26], should theoretically address the issue of internal/external rotation, by tensioning the subscapularis and infraspinatus [27][28][29]. However, clinical studies have produced mixed results concerning the relationship between lateralized offset and the improvement of internal/external rotation following RSA [18][19][20][21][26], a finding further confirmed by our study.

To date, to the best of our knowledge, only one biomechanical study has been able to identify humeral component variations positively associated with IR. Huish et al. [30] linked the presence of a more anatomical neck shaft angle (<155°) to increased IR. However, clinical studies have not confirmed this relationship. Our study aligns with the current literature. So far, five clinical studies have compared outcomes following RSA with different humeral designs, and no difference in IR values has been observed [18][19][20][21][22].

Subscapularis Repair and fIR

We also aimed to evaluate the impact of subscapularis repair on IR following RSA. Our results revealed improved IR associated with the repair in the onlay group, while it had no influence in the inlay group. The role of subscapularis tendon repair in RSA remains controversial, with some studies supporting its positive influence on IR and others showing no significant difference [31][32][33][34][35][36][37]. The variability in results may be attributed to the success of subscapularis tendon healing [38]. De Boer et al. [39] showed that in RSA with subscapularis repair, up to 60% of repairs had failed at a mean follow-up of 36 months.

Friedman et al. [34] found that the repair of the subscapularis was associated with statistically significant improvement in active IR, utilizing a 145° NSA onlay design. Wall et al. [37] also demonstrated improved IR associated with the repair of the subscapularis, but in this study, two 155° NSA Inlay design were utilized. Contradicting these findings, Clark et al. [32] and Oak et al. [35] showed equivalent IR results independent of the repair of the subscapularis, with a 135° NSA inlay design. Utilizing a 145° NSA onlay design, Vourazeris et al. [36] found no significant differences regarding IR, between the repair or non-repair of the tendon. Finally, with a 155° NSA inlay design, Boileau et al. [31] found that the tendon repair had no influence on IR.

Our study demonstrated different results related to subscapularis repair depending on the humeral design. This may be related to tendon healing. The need for metaphyseal bone reaming in the inlay design could be associated with impaired local vascularization and subsequent failed tendon healing [24][40][41][42]. Thus, it is likely that our study included failed repairs in the repaired tendon subgroup, acting as a confounding factor in the inlay group results. At the same time, the onlay design preserves the metaphyseal bone stock and this may be associated with a higher rate of tendon healing, explaining the results seen in onlay group.

Predictors of IR

Patients with higher preoperative IR were more likely to experience a decrease in IR following surgery. This finding is particularly important for preoperative counseling, as patients with good preoperative IR should be informed about the potential risk of losing this crucial range of motion postoperatively.

Limitations

This study has several limitations. First, its retrospective nature and lack of randomization. Second, the mid-term follow-up. Clinical results change with time, and results may change at longer follow-up [15]. Third, the technique of subscapularis repair was not consistent during the period analyzed. Fourth, the unknown integrity of the repaired subscapularis tendons. It is likely that a significant number of tendons did not heal properly and functioned similar to non-repaired tendons, despite being included in the repaired group.

Conclusion

There was no significant difference in fIR following RSA based on humeral design. However, in subgroup R, there was an improvement in fIR for group onlay, but no significant impact was observed in the inlay group. These results suggest that subscapularis repair should be attempted in lateralized designs whenever possible. Patients with higher preoperative IR were more likely to experience a decrease in IR after surgery.

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Conflict of interest and disclosure statement

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Institutional Review Board

Comité d'Ethique de Recherche Clinique Vivalto Santé, (CERC-VS-2020-11-1)

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