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The influence of preoperative teres minor muscle fatty degeneration on active external rotation following reverse total shoulder arthroplasty

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A R T I C L E I N F O

Keywords:
Reverse shoulder
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Teres minor
Rotator cuff

A B S T R A C T

Background: Reverse total shoulder arthroplasty (rTSA) improves shoulder elevation in patients treated for cuff tear arthropathy (CTA) or irreparable massive cuff tears. Patient satisfaction can be limited by reduced active external rotation (AER). Rotator cuff muscles that externally rotate the shoulder are infraspinatus and teres minor (TM).
Aim: The purpose of this study was to assess the correlation between preoperative TM fatty degeneration and postoperative AER after rTSA performed for CTA or irreparable cuff tears.
Methods: Constant scores and active range of motion were consecutively collected for 109 shoulders in 97 patients (mean: 75.73 ± 8.94 years; 31 male, 66 female) over a 10-year period. AER was evaluated with the humerus in adduction (AER1) and in abduction. TM muscle atrophy was scored according to Goutallier's classification, assessed on preoperative computed tomography scans.

The Institution Review and Audit Board and the Clinical Quality Assurance office at the Royal Berkshire NHS Foundation Trust approved this study (approval no. N3114).
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Results: Multivariate analysis showed that TM fatty infiltration was a predictor of AER1. AER1 decreased by 4.9 degrees preoperatively and by 6.4 degrees at the final follow-up, for each increment in Goutallier grade ($P = .02$). Postoperatively, AER evaluated with humerus in abduction improved significantly ($P < .001$), but did not correlate with TM Goutallier grade. At a mean follow-up of 38 months (range: 24 to 96), mean Constant score improved from 20.5 ± 11.1 to 68.4 ± 14.9 ($P < .001$), as did shoulder active range of motion in all planes including AER1 ($P < .001$).

Conclusion: This is the first study to quantify the inverse correlation between AER and TM Goutallier grade, both preoperatively and after rTSA; this information guides prognosis for patients with TM degeneration undergoing rTSA. Further studies are necessary to have a better understanding and find reliable solutions.

Level of evidence: Level III; Case Series

Reverse total shoulder arthroplasty (rTSA) is widely utilized in the treatment of patients with massive irreparable cuff tears, with or without cuff tear arthropathy (CTA).[48] Large cuff tears inevitably involve the tendons of infraspinatus and teres minor (TM): the rotator cuff muscles that reside in the posterior portion and are involved in assisting external rotation of the shoulder in both humeral adduction and abduction (ABD). TM provides approximately 40% of external rotation strength.[54]

With 4 powerful internal rotator muscles (subscapularis, pectoralis major, latissimus dorsi, and teres major), the rotational forces acting on the shoulder joint are inherently unbalanced. Therefore, dysfunction of the posterior cuff, which can affect infraspinatus and TM at varying degrees, may irrevocably compromise the already fragile balance in the sagittal plane.[5]

The loss of active external rotation (AER) particularly disables activities of daily living (ADLs),[34] with tasks such as tending to personal hygiene, feeding, and dressing oneself being particularly problematic, or even impossible.

Existing studies evaluating rTSA function have reported excellent postoperative shoulder elevation[3,6,14,15,18,20,27,28,32,39,45,55,57]; however, a satisfactory restoration of AER continues to represent a challenge in patients with pre-existing dysfunction of the posterior cuff.[8,26,46,56]

The aim of this study was to investigate the role of pre-existing TM cuff dysfunction in the degree of post-operative AER after rTSA. We hypothesized that increased levels of preoperative fatty degeneration within the TM muscle, indicating the chronicity of a tear, would inversely correlate with the amount of AER after rTSA.

Materials and methods

Study design

Our study was approved by the hospital's Audit and Research Review Board (Assigned reference N3114). This was a consecutive cohort study of 109 rTSAs implanted into 97 patients, for whom objective outcome data were prospectively collected and retrospectively analyzed. All operations were performed between 2005 and 2015, utilizing the same agreed upon operative technique. Procedures were performed by fellowship-trained shoulder surgeons under direct supervision of the senior author.

Inclusion/exclusion criteria

Inclusion criteria for the study were patients with irreparable massive rotator cuff tears with, or without, CTA undergoing primary rTSA. A preoperative computed tomography (CT) scan must have been available, as well as a minimum of two years of postoperative follow-up.

We excluded patients undergoing rTSA as a result of trauma or its sequelae, rheumatoid arthritis, arthropathy resulting from glenohumeral instability, and revision arthroplasty (Table I).

Data collection

All patients were assessed preoperatively (T0) and post-operatively at 3 months (T1), 6 months (T2), 1 year (T3), and yearly until the final follow-up (T4). Patient sex, age, and the operated side were recorded, as well as functional outcome using the Constant score (CS)[11] at each dedicated shoulder arthroplasty clinic. The range of motion (ROM) was also assessed using a goniometer for accuracy by a member of the shoulder team. (AER1) and in ABD (AER2).

For AER1, the patients were examined while sitting on a chair. They were instructed to externally rotate the shoulder with the humerus held in adduction, maintaining contact with their torso throughout. A photograph was taken with a camera set up directly overhead (Fig. 1); this allowed standardized and accurate measurements of the movement arc in the axial plane.

In AER2, the rotation was scored according to CS criteria. For a maximum of 10 points, the patient required the ability to perform sequential movements, with increased demands placed on the stability of the shoulder in space. The starting point is assessed by whether the patient could reach the back of the head. If the elbow is pointing forward, the patient scores

Table I – Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
Irreparable RCT with or without GHJ degeneration	Repairable RCT
Cuff tear arthropathy	Acute trauma and fracture sequela
Primary arthroplasty	Instability arthropathy
Available preoperative CT scan	Rheumatoid arthritis
2-year minimum follow-up	Revision arthroplasty

CTA, cuff tear arthropathy; *GHJ*, glenohumeral joint; *OA*, osteoarthritis; *CT*, computed tomography; *RCT*, rotator cuff tear.

2 points; ability to flare the elbow back in this position scores a further 2 points. Following this, placing the hand on top of the head with the elbow forward scores 2 more points, and then flared back scores another 2 points. At no point can the patient touch or rest the hand on the head. A maximum of 10 points is scored if the patient can then go on to fully elevate their arm overhead. Inability to reach the head scores 0 points. This scoring system is displayed in Figure 2.

Radiologic evaluation

All patients underwent a preoperative CT scan which was used to assess the TM for fatty degeneration, measured using soft-tissue viewing modalities on the sagittal images according to Goutallier's classification (Fig. 3).[22] All CT scans were formally reported by a consultant musculoskeletal radiologist and were also independently assessed by two fellowship-trained shoulder surgeons (P.C. and L.P.). Assessors were blinded by noninvolvement in the patients' treatment and clinical outcome. If consensus was not reached, a third observer (G.S.) arbitrated.

Surgical technique

All operations were carried out by the senior author (O.L.) using a standardized technique to implant a Verso (Innovative Design Orthopaedics, London, UK) short metaphyseal rTSA prosthesis[3]: a stemless implant system with a lateralized glenoid and medialized humerus. Patients received a general anesthetic as well as a regional nerve block (Interscalene) and were placed in a beach-chair position on the operating table.

An anterosuperior deltoid-splitting approach to the shoulder (Neviaser-MacKenzie approach)[37,42] was used. Acromioplasty and acromioclavicular joint excisions were sequentially performed to enhance exposure. If present, the tendon of long head of biceps was tenodesed, and subscapularis, if intact, was incised with a thin sliver of bone. A jig was used to make a 155° humeral cut, and the triple-finned humeral component (porous titanium with hydroxyapatite coating) was press-fitted with 30° of retroversion.

The glenoid was prepared next to accept the baseplate and affixed with a central screw (also hydroxyapatite coated porous titanium) and two antirotation screws. The baseplate was positioned in a 10° downward inclination, flush to the inferior border of the glenoid to reduce scapular notching.[8] Either a 36- or 41-mm-diameter glenosphere was fixed to the baseplate with a Morse taper.

Figure 1 – Active external rotation in adduction: Photograph taken in outpatient clinic during a follow-up appointment, with a camera held above the patient to record the active external rotation in the E1 position with the arm in adduction. A goniometer was then used to calculate the shoulder external rotation using the forearm rotation in the axial plane.

The Verso prosthesis has the unique feature of a 10° inclined polyethylene liner that can be "dialed" to further adjust both offset and version, in addition to its original purpose of lowering medial profile to reduce the incidence of liner impingement and scapular notching. The ability to dial the liner allows for adjustments in rotation, even after the metal prostheses have been implanted. The liner gives the implant a final combined angle of 145°.

Before closure, the torn posterior cuff was released from the metaphysis. It was then repaired and retensioned with a transosseous double-row repair using 5-Ethibond (Ethicon, Inc. Johnson & Johnson NJ, USA). This step restored cuff tension and the force couple between the subscapularis (which was also repaired in all cases) and the infraspinatus/TM.

All patients were placed into a polysling, to be worn at all times to protect the shoulder until the regional Interscalene block wore off (usually within 48 hours). Patients followed a standardized postoperative deltoid rehabilitation protocol, which aimed to maintain glenohumeral range of movement as well as to progressively recruit and strengthen deltoid fibers.[38] The polysling was retained by the patient as an analgesic adjunct for up to one week, unless they were part of an "Accelerated Rehabilitation Trial" where their polysling was removed completely as soon as the block had worn off.[35]

Statistical analysis

Normal distribution of data was assessed using the Shapiro-Wilk test. Multicomparison tests were performed with analysis of variance (ANOVA) for repeated measures within groups. The Bonferroni correction (B) of *P* value was used in pairwise comparison within groups to assess differences in the CS at different time points (T0, T1, T2, T3, and T4).

Preoperative (T0) and the final follow-up (T4) values for forward flexion (FF), ABD, internal rotation (IR), and AER1 were

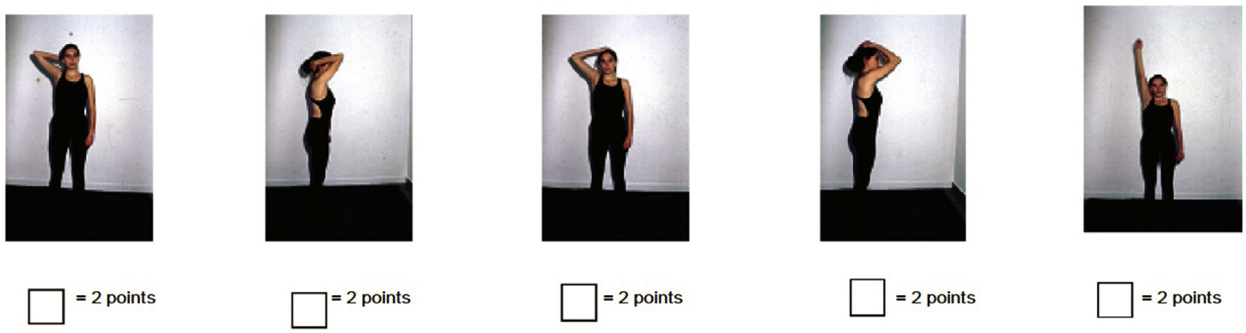

Figure 2 – Constant score: specific parameters assessing the shoulder movement with the arm in abduction and external rotation.

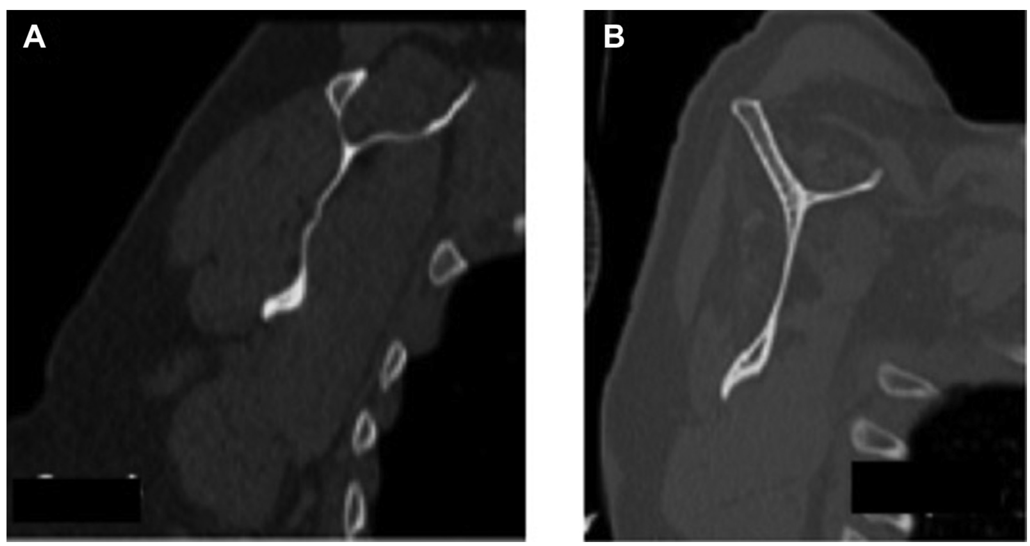

Figure 3 – (A) Computed tomography scan showing teres minor fatty degeneration Goutallier grade 0: sagittal cut; (B) Fatty degeneration Goutallier grade 4: sagittal cut.

compared using the Student's t test or the Wilcoxon rank-sum test, depending on normality testing.

Univariate analyses (Table II) were performed to assess the association of age (Pearson's correlation), Goutallier grade (Kruskal-Wallis test), sex, and operated side (Wilcoxon rank-sum analysis) for the following continuous variables: 1) CS at times T0 and T4; 2) the improvement in CS at T4 (delta = T4-T0); 3) AER1 at T0 and T4; 4) the improvement in AER1 at T4 (delta = T4-T0).

Variables found to be independently significant in the univariate analyses were then included in a multivariate linear regression to determine predictors of clinical outcome. Similarly, a simple ordered logistic regression model was used to assess the association between the aforementioned independent variables and AER2, followed by a multiple ordered logistic regression model including variables significant in the univariate analyses. Analysis was performed using STATA statistical software package (version 12.0, StataCorp, College Station, TX, USA; 2011). The P value for statistical significance was set at .05.

Results

A total of 109 consecutive shoulders in 97 patients (31 males and 66 females) were included, with a mean age of 75.7 ± 8.9 years. Mean follow-up was 38 months (range: 24 to 96 months). There were 74 right and 35 left shoulders. A 36-mm-diameter glenosphere was implanted in 93 shoulders, and a 41-mm-diameter glenosphere in 16 shoulders.

Review of preoperative CT scans for Goutallier grading (for the degree of TM fatty degeneration) revealed 4 shoulders at grade 0, 20 at grade 1, 44 at grade 2, 31 at grade 3, and 10 at grade 4.

AER1

AER1 significantly improved in all patients from 22.4 ± 21.6 degrees preoperatively to 37.8 ± 19.9 degrees at the time of the final follow-up ($P < .001$) (Table III). At T0, age and Goutallier grade appeared to be negatively

Table II – Univariate analysis of the effect of age, teres minor fatty infiltration, sex, and operative side on the Constant score at T0 (preoperatively) and at T4 (final follow-up, 38 months, range: 13 to 96).

Variable	N		CS T0		CS T4		CS improvement (delta = T4-T0)	
			PCC	*P* value	PCC	*P* value	PCC	*P* value
Age, y*	109		−0.14	.13	−0.13	.15	−0.03	.73
			χ^2	*P* value	χ^2	*P* value	χ^2	*P* value
Teres minor fatty infiltration (GS)†	109		4.83	.3	3.28	.5	6.22	.18
			Mean ± SD	*P* value	Mean ± SD	*P* value	Mean ± SD	*P* value
Sex‡	34	M	22 ± 11.3	.23	68.3 ± 20.4	.07	46.3 ± 22.1	.89
	75	F	19.8 ± 11		67.5 ± 13.6		47.7 ± 16.1	
Side‡	74	R	20.7 ± 11.4	.89	66.5 ± 16.4	.11	45.8 ± 17.7	.12
	35	L	20 ± 10.6		70.4 ± 14.8		50.3 ± 18.8	

CS, Constant score; *PCC*, Pearson's Correlation Coefficients; *GS*, Goutallier's Score; *SD*, standard deviation.
* Pearson's Correlation Coefficients.
† Kruskal-Wallis Tests.
‡ Wilcoxon Rank-Sum Tests.

Table III – Comparison of preoperative range of motion with the final follow-up.

Parameter	T0		T4		P value
	Mean ± SD	Range	Mean ± SD	Range	
FF*	65 ± 28.7	10-160	150.7 ± 34.5	30-160	<.001*
ABD*	57.3 ± 23.3	10-120	144.4 ± 37.9	30-180	<.001*
IR*	42.6 ± 32.6	0-90	74.1 ± 23.3	0-90	<.001*
AER1*	22.4 ± 21.6	0-80	37.8 ± 19.9	0-90	<.001*
AER2†	91 at 0-2		9 at 0-2		<.00001†
	11 at 4-6		10 at 4-6		
	7 at 8-10		90 at 8-10		

Range of motion at T0 (preoperatively) and T4 (final follow-up, 38 months, range 13 to 96) for forwards flexion (FF), abduction (ABD), internal rotation (IR), active external rotation in adduction (AER1), and active external rotation in abduction (AER2). Results are expressed in degrees.
* Wilcoxon rank-sum test.
† Chi-Squared

Table IV – Univariate analysis of the effect of age, teres minor fatty infiltration, sex, and operative side on active external rotation with the arm in adduction (AER1) at T0 (preoperatively) and at T4 (final follow-up, 38 months, range: 13 to 96).

Variable	N		AER1 T0		AER1 T4		AER1 improvement (delta = T4-T0)	
			PCC	*P* value	PCC	*P* value	PCC	*P* value
Age*	109		−0.18	.06	−0.11	.23	0.07	.45
			χ^2	*P* value	χ^2	*P* value	χ^2	*P* value
TM fatty infiltration (GS)*	109		9.62	.04	11.1	.02	3.48	.47
			Mean ± SD	*P* value	Mean ± SD	*P* value	Mean ± SD	*P* value
Sex†	34	M	23.9 ± 21.3	.5	38 ± 20.8	.86	14.1 ± 20.2	.74
	75	F	21.7 ± 21.9		37.8 ± 19.7		16 ± 23.4	
Side†	11	R	23.4 ± 22.3	.52	38.5 ± 19.2	.35	15.1 ± 23.6	.67
	11	L	20.2 ± 20.3		36.4 ± 21.6		16.1 ± 19.8	

PCC, Pearson's Correlation Coefficients; *GS*, Goutallier's Score; *SD*, standard deviation.
* Pearson's Correlation Coefficients.
† Wilcoxon Rank-Sum Tests.

correlated with AER1 (Table IV). However, multivariable analysis revealed that only TM fatty infiltration was a significant predictor of preoperative AER1; it demonstrated that with each increment in Goutallier grade, AER1 decreased by 4.9 degrees (Table V). Similarly, at T4, Goutallier grade negatively correlated with AER1 (Table IV), decreasing by 6.4 degrees of AER for each increment in Goutallier grade.

Table V – Multiple linear regression model for external rotation (ER) at preoperative T0.

Variable	Parameter estimate	Standard error	P value*
Age, y	−0.32	0.23	.16
TM fatty infiltration, GS	−4.91	2.12	.02

GS, Goutallier's Score.
* P values < .05 were considered to indicate significance.

Table VI – Univariate analysis of the effect of age, teres minor fatty infiltration, sex, and operative side on active external rotation with the arm in abduction (AER2) at T0 (preoperatively) and at T4 (final follow-up, 38 months, range: 13 to 96).

Variable	N	AER2 T0		AER2 T4	
		Coef.	P value	Coef.	P value
Age*	109	0.02	.31	−0.07	.002
TM fatty infiltration (GS)*	109	−0.22	.27	−0.21	.28
Sex*	109	0.22	.59	−0.41	.33
Side*	109	−0.38	.36	0.63	.13

GS, Goutallier's Score.
* Ordered logistic regression.

AER2

AER2 also improved at the final follow-up, with 91 (83%) shoulders scoring at 0-2 points before surgery and 90 shoulders (82%) scoring at 8-10 points after surgery ($P < .001$). The univariate analysis revealed that only age was significant in negative correlation with AER2 at T4 ($P = .002$) (Table VI).

Constant score

We found a significant and progressive improvement in the CS which increased from 20.5 ± 11.1 preoperatively to 69.5 ± 12.2 at 12-month follow-up ($P < .001$) and then stabilized at 68.4 ± 14.9 at the final follow-up (Table VII) ($P < .001$).

Range of motion

ROM improved (Fig. 4) in FF, ABD, IR, and external rotation at the final follow-up (Table III) ($P < .001$).

Complications

Reported complications were four. Three were fractures: one periprosthetic fracture after a fall, a fracture of the acromion, and a scapula spine fracture; one was a nerve palsy involving the axillary nerve. The periprosthetic fracture and acromion fracture were treated conservatively, while the scapula spine fracture underwent open reduction internal fixation. All patients regained function even if not at the preinjury level. The axillary nerve palsy was treated conservatively; the patient was pain free but had limited function.

Discussion

Improved FF is a reliably replicable outcome in rTSA; however, restoration of AER is not. Poor AER function and its concerns have been shared in numerous previous studies.[18,19,21,26,30,50] AER is critical for the vast majority of ADLs that most people take for granted,[34] such as using utensils to feed oneself, personal hygiene and grooming routines such as brushing teeth and combing hair, and tasks requiring overhead activity. Loss of AER in patients after rTSA can be disappointing for patients,[19,26,30] inevitably leading to some degree of disability.[3,7,23,26,50,51]

Although many authors[2,7,12,24,49,50,55] have shared their concerns regarding rTSA outcomes in patients with a preoperatively deficient posterior cuff, few have analyzed the effect of muscle degeneration on postoperative clinical outcomes.

At the time of writing, only Simovitch et al[50] have reported on the association between TM muscle fatty infiltration and rTSA outcomes. Their series did not quantify the effect of each TM Goutallier grade. However, they did investigate 42 shoulders and observed better postoperative AER1 in patients with lower preoperative Goutallier grades. They reported that the mean postoperative AER1 improved by 9° in 30 shoulders with a preoperative Goutallier's grade of 0, 1, or 2 (minimal to moderate TM fatty degeneration) but deteriorated with a loss of 7° in 12 shoulders with a preoperative Goutallier's grade of 3 or 4 (severe TM fatty degeneration).

The aforementioned study had a number of limitations influencing the results, some of which were discussed by the authors. The study analyzed a small cohort of patients (42) and included only 12 patients with a Goutallier's grade >2. Furthermore, inclusion criteria were less stringent with the sequelae of shoulder instability not being excluded. AER was only assessed with the humerus in adduction, AER1 in our study. Fatty degeneration was analyzed inconsistently on either CT or magnetic resonance imaging (MRI) modalities for different patients; unfortunately, there is no interobserver reliability in their grading of rotator cuff fatty infiltration comparing CT and MRI images.[17]

The results of our study confirmed our initial hypothesis and are generally consistent with the observations of Simovitch et al.[50] We too confirmed a significant improvement in the CS and ROM in patients after rTSA, in keeping with the previous published literature.[16,40,41,44,47,51] Furthermore, we are confident that this study is the first to quantify the correlation between reduction in AER relative to the degree of TM fatty infiltration.

In our cohort, we found that the degree of fatty infiltration of the TM muscle in 109 shoulders, assessed through the Goutallier's classification on preoperative CT images, correlated with a decreased AER1 both preoperatively and also at the final follow-up after rTSA. More specifically, for each increment in the Goutallier grade, there was a loss of AER1 by approximately 5-6 degrees.

Increasing patient age inversely correlated to preoperative AER, but no correlation was observed in postoperative results. Interestingly, in AER2 at the last follow-up, more than 80% of patients reached a score of at least 8 (hand on top of the head with the elbow flared back), thereby obtaining a respectable

Table VII – Comparison of Constant scores.

Parameter	T0	T1	T2	T3	T4	P value
CS	20.5 ± 11.1	53.5 ± 18.9	62.9 ± 15.8	69.5 ± 12.2	68.4 ± 14.9	<.001 (ANOVA test) T0 vs T1: <.001 (B) T1 vs T2: .001 (B) T2 vs T3: .013 (B) T3 vs T4: 1 (B)

ANOVA, analysis of variance.
Comparison of Constant scores (CS) at T0 (preoperatively), T1 (3 months), T2 (6 months), T3 (1 year), and T4 (final follow-up, mean time of 38 months, range: 13 to 96). A multicomparison test was performed with ANOVA, for repeated measures in groups, and the Bonferroni correction (B) of *P* values was used for pairwise comparison. Scores are indicated as mean ± standard deviation.

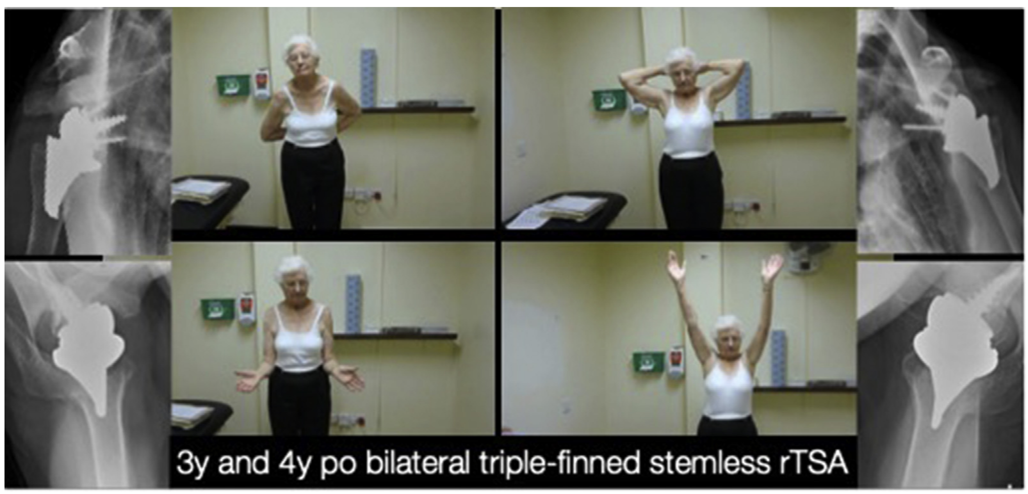

Figure 4 – Postoperative movement and x-rays of bilateral reverse total shoulder arthroplasty (3 and 4 years of follow-up).

and functional ROM, despite their degree of preoperative TM fatty degeneration.

In the current literature, studies that highlight the issue of limited postoperative AER in the presence of TM fatty degeneration[5,7,49-51,56] describe cases where a “Grammont”-type rTSA prosthesis has been implanted, with a medialized center of rotation (COR). The design of these implants creates forces favoring humeral ABD and FF over external rotation. Medialization of the COR results in more anterior and middle deltoid fibers being recruited for ABD and FF. Depression of the humerus, relative to the acromion, restores or increases the tension (and thereby efficiency) of the anterior and middle deltoid muscle fibers.[7] However, this is at the expense of tension in the posterior fibers and may thus detension what remains of the posterior cuff.[7,9,24,56]

Herrmann et al[31] reported that the origin-to-insertion distance values for the TM after medialized rTSA was reduced by 7 mm at 15° of ABD and by 20 mm at 30° of ABD, causing a 25% overall reduction of the rotational moment. Lateralized glenosphere rTSAs have the potential to restore the origin-to-insertion length of the TM, thus improving AER. Several studies of lateralized glenosphere rTSAs have demonstrated improved rotational moments (both active external and IR) compared with medialized rTSA.[4,13,25,53]

The implant used in this study lateralizes the COR on the glenoid side allowing[4,25,30,33] increased recruitment of the most posterior deltoid fibers, which contribute toward external rotation,[1,3,33] and improves the tension in what remains of the posterior cuff. In our series, the humeral component was implanted with 30° retroversion in all cases (including bilateral implants), improving the “impingement-free” passive external rotation movement compared with implantation in zero degrees of retroversion.[29,52]

In our series, an important surgical step was to perform a thorough release of the subscapularis tendon and the anterior capsule, as well as to repair any posterior cuff remnant, including the TM. The reapproximation and retensioning of the TM remnant may be one element that contributed toward improved AER2. The restoration of force coupling, even if only due to a “tenodesis effect,” may further recruit posterior deltoid fibers to achieve AER2. A technical point that may have contributed to the final results is that all procedures were performed through an anterosuperior (Neviaser-MacKenzie) approach.[37,42] This approach allows better visualization of the posterior aspect of the shoulder and the posterior cuff, which is sometimes challenging through a deltopectoral approach. Logic dictates that the better view allows for ease in performing a sound repair. Furthermore, the "dialable" humeral lipped liner may have further assisted in tensioning the posterior musculature, thereby aiding postoperative AER.

Owing to the difficulty in restoring AER after rTSA, some authors have proposed tendon transfers of the latissimus dorsi in patients with positive clinical signs of TM deficiency[10] and high-grade fatty degeneration on preoperative scans.[22,43] These are carried out through various techniques, but the aim is to transform its action from being an internal rotator to an external rotator.

The L'Episcopo technique[36] is a commonly used technique, where teres major is also transferred with latissimus dorsi; it has provided good clinical results.[8,19,21,46] Boileau et al[5] reported an increase of 34° in AER (17 shoulders, follow-up for minimum 12 months). Costouros et al,[12] using Gerber's technique, showed an improvement of >20° in AER (41 shoulder, mean follow-up of 53 months). Boughebri et al[8] reported an increase of AER from 8.7° ± 21.3° to 27.3° ± 12.2° (14 patients, mean follow-up of 33 months) with the L'Episcopo technique. Shi et al[49] also showed an improvement of 6° ± 16° AER, to 38° ± 14° (21 patients, follow-up for 2 years minimum). However, significant complication rates of between 17 and 42%[5,8,46,49] were reported in these latissimus dorsi transfer studies.

Tendon transfers in the shoulder are time-consuming, require high skill, and constitute high-risk procedures. We have shown that rTSA using a simple double-row transosseous repair of the rotator cuff, with careful retensioning, achieves similar AER movement, while avoiding the additional time spent and the high risk of complications associated with muscle transfers.

Limitations

Although this is the largest study assessing the impact of TM fatty infiltration on AER after rTSA, larger patient numbers would help to improve data accuracy and to reduce the type II error of statistical analysis. In addition, although data were collected prospectively, there are limitations associated with the retrospective nature of data analysis. For example, we did not specifically record preoperative lag signs in AER1 or AER2 (Hornblower's sign) and we did not measure the strength of AER against resistance. AER2 was calculated using data from the CS (Fig. 2). Also, we did not record data for the status of the infraspinatus on CT scan analysis.

Complications are reported in the Results section, but no statistical analysis was possible.

A further limitation is that, for all cases, the operating surgeon reattached and retensioned the remnants of the TM tendon to the humerus. Consequently, there was no specific control group where the TM was purposefully left unrepaired. Furthermore, the integrity of intraoperative repair could not be ascertained because routine postoperative CT scans to assess the TM were not performed owing to financial constraints within the UK's National Health Service. These constraints also factored the choice of CT scanning to ascertain preoperative Goutallier grade as opposed to MRI. However, the imaging modality of choice in modern practice, the original grading system, is based on CT imaging and is therefore sufficient for research practices owing to excellent interobserver reliability.[17]

Conclusion

Numerous studies have reported poor AER after rTSA performed for CTA.[7,9,24,56] This study demonstrated a significant correlation between the preoperative grade of Goutallier fatty atrophy in TM and AER1; each increment in grade of fatty atrophy reduced AER1 by 4.9 degrees preoperatively and by 6.4 degrees at the final follow-up.

Interestingly, AER2 did not correlate with preoperative TM fatty infiltration. Postoperatively, significant improvements occurred in all movements, as well as in the CS.

Implants with a lateralized COR, the use of a deltoid-splitting approach, and achieving optimal implant version may also improve postoperative AER. Although these factors cannot be quantified by this study, they certainly provide avenues for interesting further research.

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