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Pectoralis major tendon transfer in reverse total shoulder arthroplasty with irreparable subscapularis: surgical technique and preliminary clinical and radiological results

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Hypothesis/Background: Addressing irreparable subscapularis in conjunction with reverse total shoulder arthroplasty (RTSA) presents challenges. RTSA without subscapularis repair leads to similar clinical results compared to those with a subscapularis repair but with less range of motion in internal rotation (IR). Optimization of IR and anterior stability after RTSA, in the setting of an irreparable subscapularis may be achieved with a pectoralis major (PM) tendon transfer. This study aims to describe a novel surgical technique involving PM transfer in RTSA for irreparable subscapularis and report the initial clinical and radiological outcomes.
Methods: This study included 13 patients with an average of 65.5 years (range, 52-82 years). All patients underwent a lateralized RTSA with concurrent PM transfer, associated to an irreparable subscapularis, performed by a single surgeon (PV). Preoperative and postoperative range of motion, including internal rotation 1, internal rotation 2, external rotation 1 (ER1) and forward elevation, were measured. The absolute Constant score, the age and sex-adjusted Constant Murley score, Visual Analog Scale and subjective shoulder value were evaluated by the same surgeon. Standard X-rays, preoperative magnetic resonance imaging, and computed tomography scan were performed for all patients.
Results: With an average follow-up of 37 months, the mean Constant score improved from 17.7 preoperatively to 61 postoperative ($P < .05$). Postoperative clinical outcomes significantly improved across the study group. Mean internal rotation 2 increased from 44.6° to 61.5° ($P < .05$), while internal rotation 1 improved from 2.6 to 5 ($P < .05$). The Gerber test yielded positive results for all patients, while the belly press test was negative for eleven patients. Postoperative imaging assessment of the transferred PM tendon transfer showed intact repair, a good cicatrization on the lesser tuberosity with excellent trophicity of the muscle without any fatty infiltration in all patients.
Conclusion: PM transfer combined with a lateralized RSTA in cases of irreparable subscapularis leads to improved shoulder range of motion, particularly in IR, increased strength and pain relief.

Deficits in internal rotation (IR) and anterior instability after Reverse Total Shoulder Arthroplasty (RTSA) continue to be a functional problem for patients, especially in cases where the subscapularis is irreparable. The role of subscapularis in this context remains controversial, and the impact of an irreparable subscapularis on RTSA outcomes is not well-established. The term “irreparable” is defined by a fatty infiltration stage 3-4, a medial retraction to the glenoid process and the inability to anatomically repair it during surgery.[11]

Recent studies and meta-analysis confirm the benefits of subscapularis repair in terms of joint stability and IR.[2,4] While certain studies have highlighted significant increases in dislocation rates

This study was classified as observational (noninterventional) by the authors' local ethics committee Statutory and ethical obligations of observational (noninterventional) studies in France: According to the past Huriet law on biomedical research, and to the current regulation that went into effect in August 2006 (law n°2004-806), such studies do not require prior submission or approval to/from an IRB, and they do not require written consent. There is a current discrepancy on observational studies between the French legal requirements, and the editors' requirements. This observational research on data fulfils current French regulatory and ethical obligations.

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when the subscapularis is not repaired, there is scarcity of studies investigating the outcome of using pectoralis major (PM) tendon transfer to restore IR after RTSA in cases of irreparable subscapularis.[34]

Various theories have been proposed to explain the loss of IR following RTSA, encompassing factors such as rotator cuff deficiency, alteration in the rotator cuff's moment arm, deficient scapulothoracic control and mechanical impingement.[32] Among these, the most widely acknowledged is the excessive medialization creates mechanical impingement between the scapular pillar and the humerus and decreases tension of the residual rotator cuff.[32] Having said this, lateralization also plays an important role improving IR, as it also is associated with increased deltoid wrapping and more anatomic rotator cuff tensioning, both of which contribute to stability.[21] A recent computed tomography (CT)-based study by Huish et al shows that a combination of lateralization, increased glenosphere overhang, and enhanced humeral anteversion can also contribute to improved IR.[13]

A recent cadaveric biomechanical analysis conducted by Werthel et al shows that a PM tendon transfer for irreparable subscapularis during RTSA may increase IR mobility compared to a native shoulder.[32] In the native shoulder, the force vector from the transferred PM results in anterior translation of the humeral head; with a semi-constrained joint such as the RTSA, the applied forces are converted into rotational forces.[32]

Considering the outcomes of a lateralized RTSA with a good subscapularis and the findings of Werthel et al biomechanical study, the transfer of PM tendon may be a strong option to restore active IR in combination with a lateralized glenosphere in cases of an irreparable subscapularis.[32]

No clinical studies have been conducted yet to confirm this hypothesis. The aim of this study is to describe a novel technique of PM tendon transfer in a lateralized RTSA with an irreparable subscapularis and to report the preliminary clinical and radiological results.

Material & methods

Study design

This study presents a retrospective analysis of 13 patients who underwent RTSA with a concomitant PM tendon transfer between 2015 and 2020. A consistent prothesis was used in all cases, and the patients were subjected to a minimum of 1-year follow-up by the same treating surgeon. Intraoperatively, the indication for tendon transfer was confirmed by the inability to anatomically repair the subscapularis.

Patient demographics

The study cohort consisted of 7 males and 6 females, with an average age of 65.5 years (range, 52-82). Eight left shoulders and five right shoulders.

Four patients without prior surgical history and five patients with prior arthroscopic rotator cuff repairs; one of the five patients with a diagnosis of obstetrical brachial plexus palsy, two patients with prior osteosynthesis procedures for fracture (one nail and one plate), two patients with prior prosthesis; one conversion from anatomic total shoulder arthroplasty to RTSA and one revision of an unstable RTSA (Table I).

Clinical assessment

The preoperative clinical assessment included determination of pain by a visual analogue scale (VAS) ranging from 0 (no pain) to 10 (severe pain),[15] functional outcome was determined according to the Constant shoulder subjective scores preoperatively and postoperatively at follow-up.[3,16] The subjective shoulder value was determined by asking the patient to estimate the percentage of normal shoulder function which they thought that they had in the involved shoulder.[10] The subjective functional outcome was determined by asking the patients if they were very satisfied, satisfied (S) or disappointed (D) compare the preoperative status. Range of motion measurements were made during consultation by a single surgeon (PV) of the following ROM's using a goniometer for standardization: Forward elevation, abduction strength, external rotation 1 (ER1) with the elbow by the side, internal rotation 1 (IR1) with the elbow by the side, internal rotation 2 (IR2) with the arm abducted at 90º. IR1 was assessed according to the Constant Score[3,16] (Table I). The belly press test and Gerber test [8,9] were always assessed preoperatively and postoperatively, but frequently the pain and the stiffness did not permit the proper assessment of the Gerber test.[8,9]

Radiological assessment

Standard X-rays (anteroposterior view in Neutral, External, IR and axillary views) were taken preoperatively and postoperatively. Additionally, the classifications of Thomazeau et al[24] and Goutallier et al[11] were used for the preoperative magnetic resonance imaging and CT scans to assess the degree of muscles atrophy and fatty infiltration of the remaining posterosuperior cuff (Infraspinatus, Teres minor), in particularly the subscapularis muscle. The CT scan and X-Rays were also employed to grade glenoid deformity[1] and postoperative periimplant radiolucency.[19,23] Preoperatively, the atrophy and fatty infiltration of the subscapularis were graded and specifically recorded for those with grade 3-4 (Table I). Follow-up CT-Scans were performed to assess the integrity and fatty infiltration of the PM tendon transfer in all patients.[31]

Surgical technique

All surgical procedures were performed by the senior author (PV), all patients underwent lateralized RTSA with PM transfer. Two patients underwent clavicular head transfer, one a sternal head transfer and ten an entire PM transfer.

All patients were positioned in the beach chair position under general anesthesia with interscalene block.

An extended deltopectoral approach was used in all cases. After identifying the cephalic vein and the conjoin tendon, the deltoid muscle was mobilized laterally and protected. With a retractor it was possible to maintain retraction of the deltoid and PM. A soft tissue biceps tenodesis was performed in all cases above the insertion of the PM with two nonabsorbable sutures. In all patients, efforts were made to mobilize the subscapularis musculotendinous units by releasing adhesions and attempting to repair the subscapularis. However, it was determined that the subscapularis was not amenable to repair in any of the cases. The axillary and musculo-cutaneous nerve were always identified and protected.

RTSA is then performed in a standard fashion. The humeral head cut was performed with 135° of inclination and 20° of retroversion. A lateralized reverse prosthesis was used (Arrow; FH Orthopedics, Mulhouse, France). The glenoid implant with a lateralized center of rotation (8.5mm) was positioned between 0° to 10° of inferior inclination and flush to the inferior edge of the glenoid bone to distalize the prosthesis and avoid scapular notching. After humeral preparation, three 2 mm tunnels were created on the lesser tuberosity for the passage of three nonabsorbable for the reinsertion of the PM (Fig. 1). A cementless or cemented standard humeral stem with an onlay system was implanted. After the reduction of the prosthesis, the tendon of the PM is detached from the humeral insertion, with part of the

Table I
Patients series.

Case	Native/operated shoulder cases	Gender	Age	Side	FU (mo)	Previous surgery	Indication
1	Operated	F	80	R	60	RTSA	Instable RSTA
2	Operated	F	80	L	48	Cuff repair	CTA, obstetrical brachial plexus palsy.
3	Operated	F	52	L	45	Osteosynthesis: Nail	
4	Operated	M	55	L	14	Cuff repair	CTA
5	Operated	F	68	R	12	Cuff repair	CTA
6	Operated	F	46	R	40	ATSA	Deficient subscapularis
7	Native	M	61	R	48	NS	CTA
8	Native	M	72	R	48	NS	CTA
9	Operated	M	60	L	28	Cuff repair	CTA
10	Native	M	69	L	44	NS	CTA
11	Operated	M	67	L	41	Cuff repair	CTA
12	Native	F	82	L	39	NS	Post-traumatic arthritis
13	Operated	M	69	L	10	Osteosynthesis plate	AVN
Average			64.5		37		
Min			52		10		
Max			82		60		
SD			10.5		15.8		

ATSA, anatomic total shoulder arthroplasty; *M*, male; *F*, female; *R*, right; *L*, left; *FU*, follow-up; *NS*, no previous surgery; *CTA*, cuff tear arthropathy; *AVN*, avascular necrosis; *RTSA*, reverse total shoulder arthroplasty.

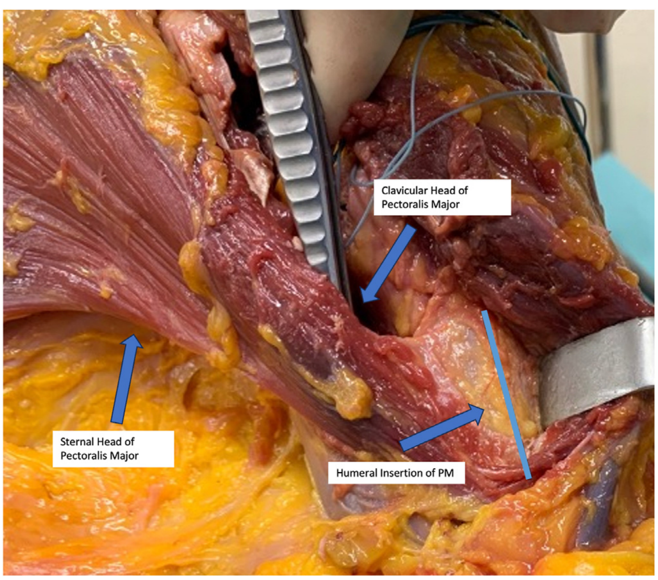

Figure 1 Suture passage for the insertion of pectoralis major (Cadaveric dissection).

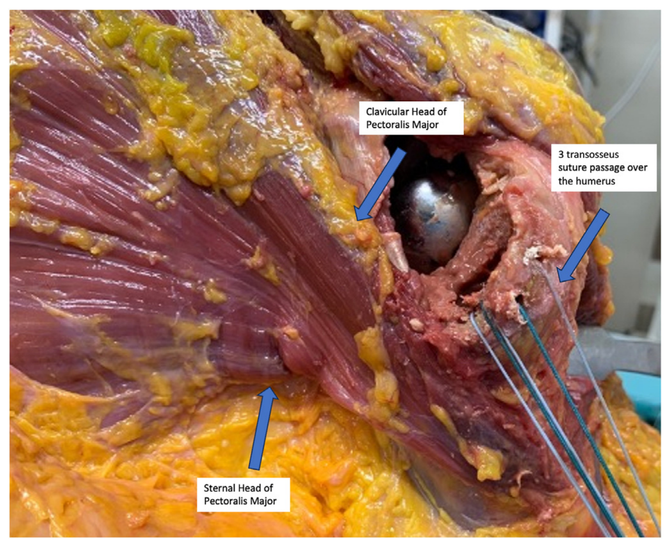

Figure 2 Humeral insertion of pectoralis major (Cadaveric dissection).

periosteum to augment suture purchase, leaving 1-2 cm caudally to avoid damage of the medial pectoralis nerve (Fig. 2). The harvested tendon is then tagged with 2 nonabsorbable sutures (Fig. 3). A release of the superficial and deep part of the PM was done on a length of 8-10 cm with respect of the neuro vascular bundles. Careful hemostasis was performed to avoid a postoperative hematoma. The entire PM tendon is then moved cranially, to the level of lesser tuberosity, anterior to the conjoint tendon without mobilization of the musculocutaneous nerve.

The tendon was inserted onto the lesser tuberosity following decortication, using a double row repair technique. The three sutures already passed from the humerus were attached through the tendon with Mason Allen technique and fixed on the lesser tuberosity (medial row) (Fig. 4). The two nonabsorbable sutures used to tag the harvested tendon (Fig. 3) were fixed transosseous at the level of the bicipital groove (lateral row) (Fig. 5). The fixation of the tendon was always done at 0° to 30° of external rotation.

Seven transfers were made with the whole clavicular and sternal head, five clavicular heads and one sternal head because the muscle belly of these heads was hypertrophic, this was sufficient to achieve the desired results. The dissection of the five heads was performed through the interval, separating them as described by Jennings et al,[14] the sternal head was passed below the clavicular head and all harvested tendons were passed anterior of the conjoint tendon.

The decision was based on the surgeon's assessment of each patient's specific anatomical conditions, particularly the trophicity of the PM muscle heads. The choice between using the clavicular head, the sternal head, or both for the transfer was determined by evaluating the muscle's quality and size. For instance, if the clavicular head was judged to be atrophic or of inadequate quality, the sternal head was added/favored for the transfer, and vice versa.

Postoperative treatment

The patient was immobilized with a brace in neutral position for 6 weeks. Passive range of motion started immediately

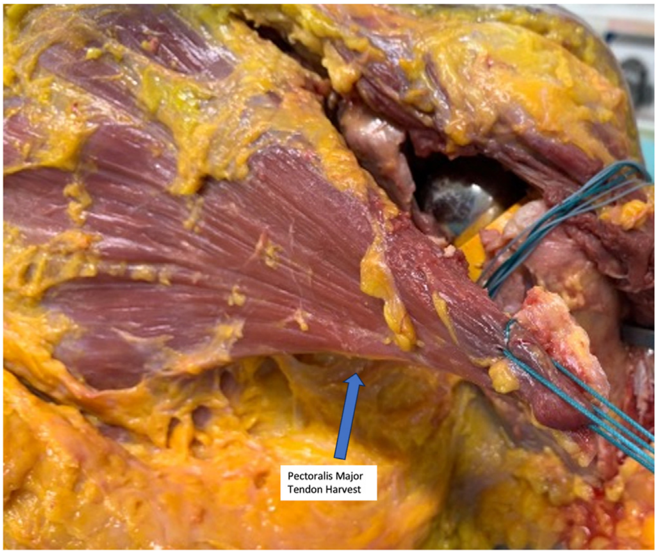

Figure 3 Harvest and detachment of pectoralis major (Cadaveric dissection).

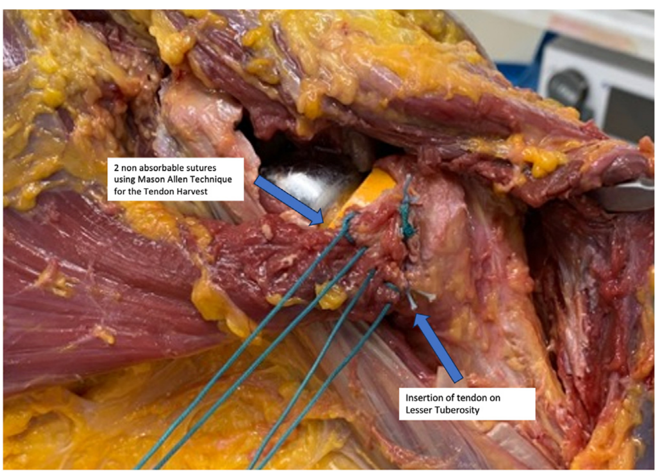

Figure 4 Medial row sutures (Cadaveric dissection).

with the exception of external rotation that was commenced after 4 weeks. Once the 6 weeks passed, the brace was discontinued and replaced by active-assisted range of motion with pool therapy for another 6 weeks. Three months later, a gentle strengthening program started for 8 weeks. Passive stretching of the shoulder in any direction should be avoided for at least 5 months postoperatively to avoid injury to the muscle transfer.

Statistical analysis

All statistical analyses were executed using Statistical Package for the Social Science (SPSS) Statistics software (IBM Corp., Armonk, NY, USA). Descriptive statistics are described as minimum, maximum, mean and standard deviation for continuous measures and number (percentage) for discrete variables. A two-tailed Student t-test, assuming normal distribution and equal variances as verified by Shapiro-Wilk and Levene's tests, respectively, was utilized to compare preoperative and postoperative states. The difference between preoperative and postoperative is considered as significant when P is < 0.05.

Figure 5 Final construct (Cadaveric dissection).

Results

Results are shown in Table II and Table III, no patients were lost at the follow-up. The mean follow-up was 37 months (range, 12-60).

Function

The mean preoperative Constant Score significantly increased from 17.7 preop to 61 in postop ($P < .05$). The mean adjusted Constant Score increased from 22 to 79 ($P < .05$) for daily living activities. The mean VAS decreased from 6 to 1 postoperatively ($P < .05$) and the mean subjective shoulder value increased from 30% to 72% ($P < .05$) (Fig. 6). Eight patients were very satisfied with the outcome, three patients were satisfied, and two patients were not satisfied.

Range of motion

The mean forward elevation improved from 69° to 132° ($P < .05$), the mean IR 1 calculated by the constant score increased from 2.6 to 5 ($P < .05$), the mean IR 2 increased from 44.6° to 61.5° ($P < .05$). The mean external rotation in position 1 improved from an average of 8.4° to 22° ($P < .05$). The abduction strength improved from an average of 1kg (range, 0-3) preoperatively to an average of 3 kg (range, 1-5) at the latest follow-up ($P < .05$).

The Gerber test was positive in all patients, but the belly press test was negative postoperatively in eleven patients (84.61%). However, the Gerber and the belly press sign were reported postoperatively but not used as diagnostic tests to assess failure after tendon transfer, because these tests may remain positive even after a successful tendon transfer.

We did not find any difference in clinical results between the entire PM tendon transfer (7) and the clavicular head (5) or the sternal head (1) tendon transfer.

Radiological control

At the last follow-up, a CT-scan control was performed for all the patients. An excellent trophicity, no fatty infiltration and good integrity and function of the tendon transfer was reported in all patients. Retearing of the PM tendon transfer was not observed on postoperative CT-scan control (Fig. 7).

Table II
Scores results.

Cases	Constant score Preop postop		Adjusted constant score Preop postop		SSV Preop postop		VAS Preop postop		Satisfaction
1	6	33	9,4	52	0	50	7	3	S
2	15	40	21	57	30	50	5	1	S
3	15	50	21	69	30	50	4	2	S
4	18	61	20	68	20	80	4	1	VS
5	18	71	26	100	20	80	2	1	VS
6	21	34	26	43	30	50	8	5	D
7	24	79	29	95	50	90	5	0	VS
8	12	80	16	100	30	90	8	0	VS
9	14	46	16	55	30	50	6	2	D
10	26	79	31	100	30	80	5	0	VS
11	28	74	33	98	40	90	6	1	VS
12	16	71	25	100	40	100	5	0	VS
13	18	76	22	92	50	80	7	1	VS
Average	17.7	61	22.7	79	30.7%	72%	5.5	1	
Min	6	33	9.4	52	0	50	2	0	
Max	28	80	33	100	50	100	8	5	
SD	17.77	18.04	6.6	22.17	13.21	19.22	1.71	1.43	
Student test (*P*)	<.001		<.001		<.001		<.001		

VS, very satisfied; *D*, disappointed; *S*, satisfied; *SSV*, subjective shoulder value; *VAS*, visual analog scale.

Table III
Range of motion results.

Cases	Forward elevation (°) Preop postop		Internal rotation 1 (X/10) Preop postop		Internal rotation 2 Preop postop		External rotation 1 (°) Preop postop		Mean abduction strength (X/20) Preop postop	
1	30	90	2	2	40	60	0	10	0	4
2	60	60	2	6	60	80	−60	−40	0	0
3	60	90	2	6	20	60	0	20	0	0
4	30	160	2	4	60	70	30	40	0	8
5	30	170	2	4	60	70	40	40	0	6
6	90	90	2	2	40	30	20	10	0	2
7	110	160	8	4	40	60	30	40	0	10
8	80	160	2	8	40	60	40	30	0	9
9	70	90	2	4	60	60	20	30	0	2
10	80	170	6	6	60	60	−30	40	6	12
11	100	160	6	6	60	60	40	30	4	16
12	80	160	2	6	30	60	−20	20	0	2
13	80	160	4	8	10	70	0	20	2	10
Average	69.2	132.3	2.6	5	44.6	61.5	8.4	22	0.9	6
Min	30	60	2	2	10	30	−60	−40	0	0
Max	110	170	8	8	60	80	40	40	6	16
SD	26.3	40.65	2.08	1.93	17.1	11,4	30.8	21.7	1.9	5
Student test (*P*)	000		000		.007		000		000	

Complications

One complication was reported of an unstable RTSA due to repetitive falls, the prothesis and the transfer was revised with a change of the humeral insert for a 36 + 5, the PM transfer was torn, it was not repaired again. Good results and no further dislocations were reported after the revision.

Discussion

This main finding of this study is that a lateralized RTSA combined with a PM transfer in case of irreparable subscapularis is an effective treatment option to restore IR.

Restoring and rebalancing the musculotendinous forces in all planes around the shoulder joint in a RTSA is of great importance and crucial for better functional outcomes.[6] With the previous studies published it has remained unclear what the best treatment is when the subscapularis tendon is deficient or irreparable; the reconstruction options available to restore its function as an IR are limited.[29]

Our preliminary results show an increase in forward elevation, IR in position (IR1 & IR2), strength, and relief of pain. The Constant Score increased from 17.7 preop to 61 postop ($P < .05$). The mean Constant Score for activities of daily living increased from 22 to 79, and the VAS decreased from 6 to 1 ($P < .05$). It is also important to mention that IR1 increased from 2.6 to 5 ($P < .05$) and IR2 increased from 44.6° to 61.5°. One patient presented a clinical history of obstetrical brachial plexus palsy, with a limited range of motion, especially in external rotation. A combined transfer of the latissimus dorsi and teres major tendons (L'Episcopo Technique) for external rotation and PM tendon transfer for IR with a lateralized RTSA were performed. The last follow-up of this patient showed an improvement in IR2 from 60° to 80° and an ER1 from −60° to 40°. In the last clinical and radiological follow-up via CT-Scan, good trophicity, no fatty infiltration and the good integrity and function of the tendon transfer was reported in all patients.[31] No atraumatic dislocations were reported during this study.

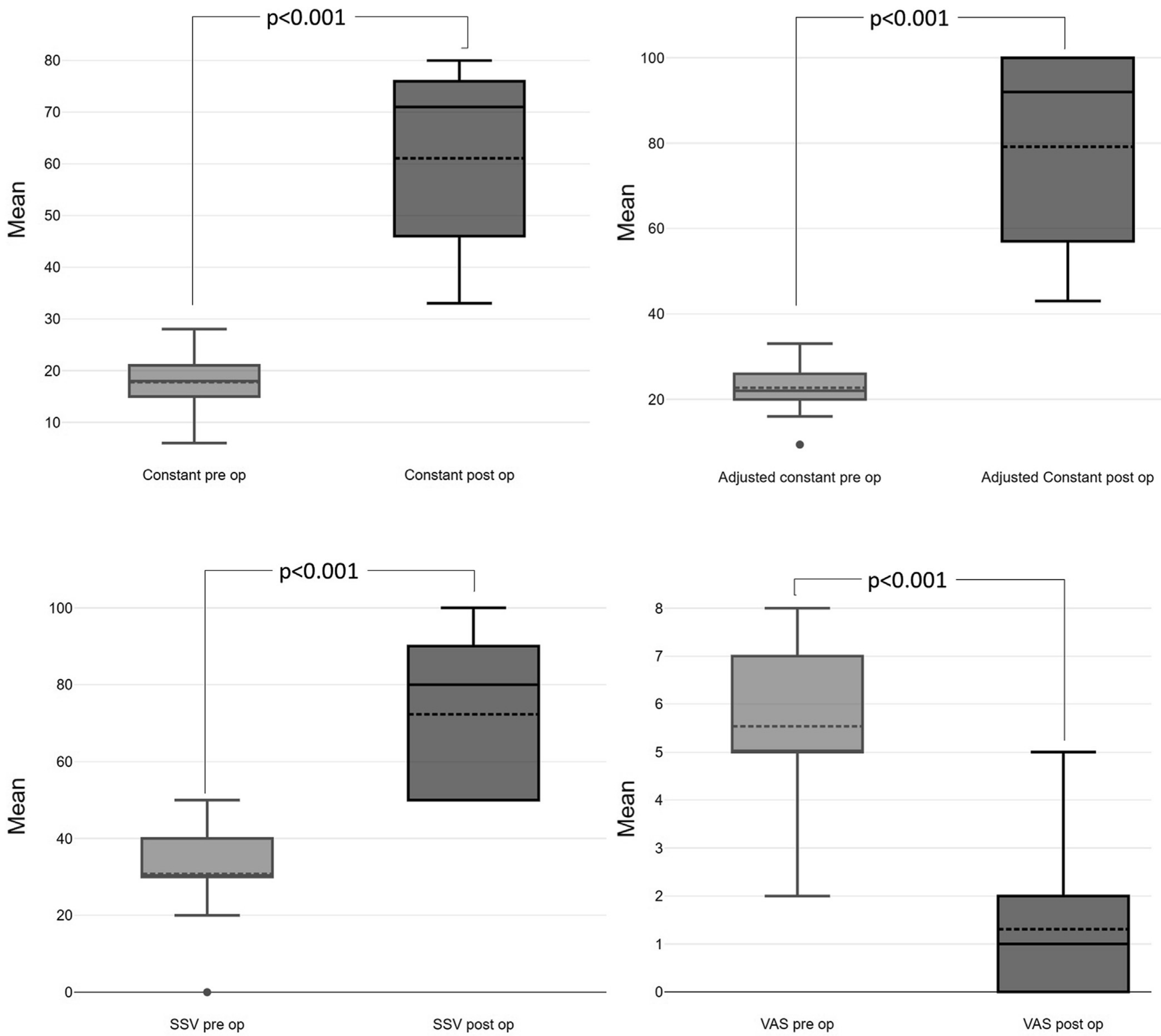

Figure 6 Box plot showing the preoperative and postoperative scores including the Constant Score, the adjusted Constant Score, Visual Analogue Scale (*VAS*) and the Subjective Shoulder Value.

Optimizing IR in RTSA is crucial, with several studies highlighting the role of prosthetic design. Virani et al reported a 14% IR/ER gain when reducing the Humeral Neck-Shaft Angle from 150° to 130°.[27] Werner et al observed IR improvement from 85° ± 9.2° to 93.5° ± 7.7° by lowering Neck-Shaft Angle from 145° to 135°, a parameter we adopted in our study.[30] For glenoid-sided lateralization, studies by Virani et al and Keener et al show increased IR with lateralization, a concept applied in our study with 8.5 mm lateralization.[17,27] Regarding glenosphere diameter, Werner et al found IR enhancements with increased diameters, although evidence here is mixed.[30] However, these improvements are not guaranteed, as most studies above cited studies pertain to scenarios with a repairable subscapularis.[12] This issue becomes more challenging in cases of irreparable subscapularis tendons, a frequent situation in RTSA. The importance of subscapularis repair is also a subject of debate.[12] For instance, Friedman et al observed improved postoperative IR to L1-L3 spinal levels with subscapularis repair compared to L4-L5 levels without repair.[7] Eichinger et al reported significant IR improvement post-RSA with subscapularis repair.[5] On the contrary, Vourazeris et al and Oh et al found no significant difference in IR with or without subscapularis repair.[20,28] These varied findings preclude a clear conclusion on the best practices for optimizing IR in RTSA and further investigation is warranted. This is the context in which we propose our technique.

Werthel et al compared the effectiveness of IR in PM transfer with latissimus dorsi and teres major in their cadaveric biomechanical study. They found that PM transfer had promising results in restoring IR in RTSA.[32] Moreover, Collin et al showed that patients with a healed repair of the Subscapularis after RTSA had significantly better outcomes than those with a ruptured repair after RTSA with a lateralized glenosphere.[2] Therefore, in cases where the subscapularis is irreparable, the transfer of the PM tendon, combined with a lateralized glenosphere in RTSA, may serve as a viable option to restore active IR.

One important aspect of the presented surgical technique is the lateralization; in fact, the prosthesis used in this study (Arrow; FH

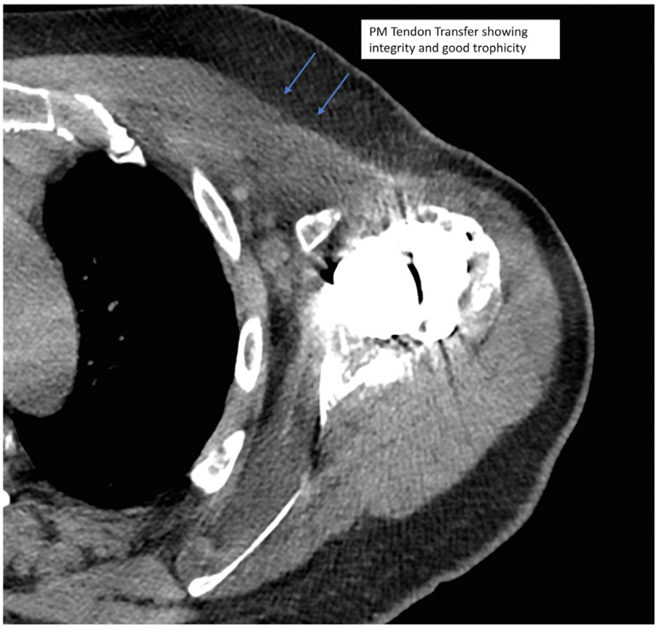

Figure 7 Axial view of CT-SCAN during follow-up, showing the integrity of pectoralis major tendon transfer. (Blue arrows)

Orthopedics, Mulhouse, France) is a very high lateralized RTSA. As described by Werthel et al, implants can be lateralized on the glenoid, on the humeral side, or on both sides.[33] Glenoid lateralization can be achieved by modifying the shape of the glenosphere, lateralizing the baseplate or increasing the length of the scapular neck with a bone graft, decreasing the risk of scapular notching and increasing the impingement-free motion.[33] Furthermore, the humeral bearing may be modified to be either embedded within the metaphysis (inlay) or to rest on the humeral osteotomy (onlay).[33] Specifically, the onlay system achieves lateralization by displacing the stem further from the glenosphere.[33] Additionally, using humeral inserts with a 135° angle has been shown to reduce the risk of scapular notching, without correspondingly increasing the risk of instability.[33]

The PM transfer in a reverse shoulder arthroplasty is a relatively straightforward technique since all the procedure could be performed by a deltopectoral approach. In the context of the native shoulder, transferring the PM tendon below the conjoint tendon typically yields better outcomes compared to routing it underneath the tendon.[18,22,26] This is because the line of pull is closer to the chest wall, which is more anatomically advantageous.[18,22,26] In this series of cases, we did not perform the transfer below the conjoint tendon for two reasons: 1. There is no biomechanical advantage with a RSTA since is a semi-constrained joint; 2. There is a potential compression of the musculocutaneous nerve with the muscle belly and with the distalization of the prosthesis.[26]

To best of our knowledge, outcomes of this technique have been rarely reported in literature in the setting of RTSA. For instance, Wheelwright et al, reported successful use of PM transfer in a patient with anterior deltoid deficiency undergoing RTSA. The authors noted an excellent functional outcome as early as six weeks post-surgery.[34] This highlights the versatility of PM transfer, although our study diverges by focusing on irreparable subscapularis, presenting a different clinical application of this technique. Furthermore, Updegrove et al applied the PM transfer concept in optimizing IR in anatomical shoulder arthroplasty. In their case series, they showed that PM tendon transfer for subscapularis failure after anatomic total shoulder arthroplasty can effectively relieve pain and improve function. However, their findings also indicate instances of recurring instability postprocedure.[25]

Our study has several limitations. It is a retrospective study with a limited sample size. Moreover, the patient population is quite heterogeneous, encompassing both primary and revision cases with varying etiologies such as brachial plexus palsy. This diversity may affect the uniformity and interpretability of our results. There is no comparative group of patients to confirm the functional usefulness of the procedure.

Conclusion

This study shows that a lateralized reverse shoulder total arthroplasty combined with a PM tendon transfer leads to improved shoulder range of motion compared to the preoperative state, particularly in IR in cases of an irreparable subscapularis. The clinical outcomes have shown a significantly improvement in IR and radiological follow-up have proved the integrity of the tendon transfer, making this technique an effective, safe and reproducible procedure to improve IR. Comparative studies are needed as well as long-term follow-up of our present series.

Disclaimers:

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Conflicts of interest: Philippe Valenti received royalties for shoulder prosthesis design from FH Orthopedics. All other authors, their immediate family, and any research foundation with which they are affiliated did not receive any financial payments or other benefits from any commercial entity related to the subject of this article.

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