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ORIGINAL PAPER

The role of the subscapularis tendon in a lateralized reverse total shoulder arthroplasty: repair versus nonrepair

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Abstract

Purpose The reverse shoulder prost hesis (rTSA) is now implanted by the same percentage of anatomic shoulder prosthesis in the USA. Scapular notching and loss of extrarotation have been underlined as complication at long-term follow-up due to the Grammont design. The current trend to reduce those limits is to position both components lateralized. As the role of the subscapularis tendon in this new rTSA design is unclear, the purpose of this study is to quantify rTSA outcomes in patients with or without subscapularis tendon suture.

Methods The surgery was performed by the same orthopaedic surgeon (F.F.), using a Aequalis Ascend™ Flex prosthesis (Tornier, Montbonnot, France) with a bone autograft.

Forty-four patients underwent surgery with the tendon sutured, whereas 40 patients underwent the same surgery without repairing it.

Patients were evaluated pre-operatively and at the last follow-up using Constant score, VAS, and ROM. The minimum and mean follow-ups were six and 16.6 months, respectively.

Results All patients showed statistically significant improvement in pain and joint function following surgery. This study highlighted significant higher values in intrarotation and abduction, respectively, with and without suturing the subscapularis tendon.

However, no significant differences were underlined in Constant score, VAS, forward flexion, extrarotation at 0° and 90° of abduction, and rate of instability.

Conclusions As predicted, significant clinical improvements were observed in both groups with some differences.

These clinical results showed that the use of rTSA with lateralized humerus and bony increase offset leads to realistic clinical improvements with a low risk of instability without the need for compression and stabilization of the tendon.

Keywords Reverse total shoulder arthroplasty · Subscapularis tendon · Cuff tear arthropathy

Introduction

The reverse total shoulder arthroplasty (rTSA) was developed to improve the treatment of cuff tear arthropathy [1–11].

t is currently effectively used to treat many pathological conditions with good results in the vast majority of patients [3, 4, 9, 11–21].

The common feature of all types of rTSA available in the global market is the reversal of anatomy, unlike the position of the humerus and the centre of rotation (CoR) that may vary among different designs [8, 10, 11, 22–25].

The biomechanic of the shoulder may be altered by rTSA due to a medial shift and distomedial shift, respectively, of the CoR and the humerus [4, 6, 8, 10, 12, 15, 25].

Insertion, resting lengths, and momentum are modified by this new articular configuration, compared to an anatomical shoulder [6, 8, 16, 22–25].

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Different from deltoid muscle, which has been shown to increase efficiency in a rTSA [8, 22–24], the impact on the rotator cuff, especially the subscapularis muscle, is still unclear [9, 17].

The first role of the subscapularis muscle is intrarotation, but it also actively contributes to abduction, adduction, extension, and flexion of the shoulder. The subscapularis tendon rotates the humerus differently, depending on the position of the upper extremity in the space during the contraction: it acts as an abductor whether the muscle traction vector F is located above the CoR; otherwise, it acts as adductor. In a physiological shoulder, the contraction of the upper two thirds of the subscapularis tendon will lead to abduction, whereas the lower third will lead to adduction [17].

Furthermore, the balance between forces produced by posterior rotator cuff and the subscapularis tendon increases the stability of the glenohumeral joint through a compression-concavity mechanism [9, 17].

Controversial is the importance of the subscapularis tendon in avoiding articular instability and modifying the ROM and therefore whether to suture or not the subscapularis tendon in a rTSA [3–7, 9–13, 15–17, 26].

Scapular notching and loss of extrarotation have been underlined as complications at long-term follow-up due to the Grammont design. The concept of humeral and bony or metal lateralization of the glenosphere has been observed to decrease the risk of scapular notching and increase ROM [27–29].

The current trend to reduce the limits of Grammont's design is to position both lateralized components. But what will be the role of the subscapularis tendon?

To our knowledge, no studies have reported the influence of the subscapularis tendon in prosthetic designs with both a bony increased offset and a lateralized humerus.

Materials and methods

This retrospective study with patients enrolled prospectively has been approved by the local ethics committee.

The hospital database has been analyzed to quantify the outcomes of rTSA (with BIO-RSA and lateralized humerus) in patients with and without suture of the subscapularis, with a minimum and mean follow-up of, respectively, six and 16.6 months (mean 15.9 ± 1.29 for the S group and 16.92 ± 1.92 for the NS group), with the aim to determine whether the suture had any impact on the clinical outcomes of modern reverse shoulder prosthesis.

Inclusion criteria were the following: cuff tear arthropathy, age range from 65 to 85 aa, patients undergoing first rTSA implantation, data regarding suture of the subscapularis available, use of bony increased offset (BIO-RSA) [30], absence of neoplastic diseases at the treated site, and low-grade fatty infiltration of the subscapularis (Goutallier < grade 3) [31].

The exclusion criteria were the following: follow-up less than six months, previous implantation, post-traumatic avascular necrosis, cervical radiculitis (cervical spine MRI was performed in the case of a related neck disease suspected), psychiatric disease, and fatty infiltration (Goutallier ≥ 3).

One hundred and nine patients have been operated by the senior author (F.F.) from January 2015 to February 2017. Eleven of those were excluded for the criteria outlined above, and 14 did not continue the follow-up.

The pre-operative and post-operative data of 84 patients (mean BMI of 26.03 and mean age of 70.27) treated using rTSA were divided into two groups: group S in which the subscapularis was sutured and group NS in which the subscapularis was not sutured (Table 1).

Forty-four patients (mean BMI of 25.72 and mean age of 70.18) underwent primary rTSA intervention with Aequalis Ascend™ Flex (Tornier, Montbonnot, France) for the treatment of OA and cuff tear arthropathy suturing the subscapularis tendon. In 40 patients (mean BMI 26.4 and mean age 69.7), primary rTSA, Aequalis Ascend™ Flex (Tornier, Montbonnot, France), was implanted for treatment of OA and cuff tear arthropathy, without suturing the subscapularis tendon.

Table 1 Demographics and perioperative data of the two groups of patients. SS subscapularis tendon, ns $p > 0.05$, BMI body mass index, mo months

Variable	Group S	Group NS	*p* value
Shoulders	44	40	0.372
Follow-up duration mo (mean ± SD)	15.9 ± 1.29	16.92 ± 1.92	0.074
Age (mean ± SD)	70.18 ± 10.63	69.71 ± 6.14	0.797
Gender M/F	10/34	11/29	0.613
BMI (mean ± SD)	25.72 ± 4.52	26.4 ± 3.42	0.442
SS fatty infiltration			
Stade 1	12	9	
Stade 2	32	31	

Pre-operative imaging

Pre-operative imaging included plain radiographs and computed tomography scans [32]. Fatty infiltration was graded according to Goutallier et al [31].

Surgical technique

A single physician (F.F.) has carried out all the surgeries. Under general anaesthesia, patient is placed in the beach chair position with the arm in a limb holder (TRIMANO® by Arthrex—Naples). Deltopectoral approach [33]. Subscapularis tendon is prepared with resorbable suture, and then, tenotomy is performed (Fig. 1). Capsulotomy and humeral dislocation. Introduction of humeral intramedullary guide with cutting guide. Resection of the humeral head approximately 2 mm below the articular cartilage, after execution of bone removal of 29 mm in diameter and 10 mm in height for the BIO-RSA, using a dedicated guide. Starting with the smallest rasp, the humeral medullary cavity is gradually extended until the last rasp fits tightly. Glenoid exposure through dedicated retractors. Excision of the glenoid cercine and preparation for the glenoid component removing the damaged cartilage and subchondral bone. The bone augment previously taken from the humeral head is placed on the glena and fixed through a long post "aequalis reversed" metaglene with two compression screws, upper and lower, and two locking screws, on front and back. Choice of the glenosphere and the humeral component sizes and reduction (Fig. 2).

The health of the subscapularis tendon was evaluated preoperatively, clinically and/or radiologically (RMN), and intraoperatively by the surgeon.

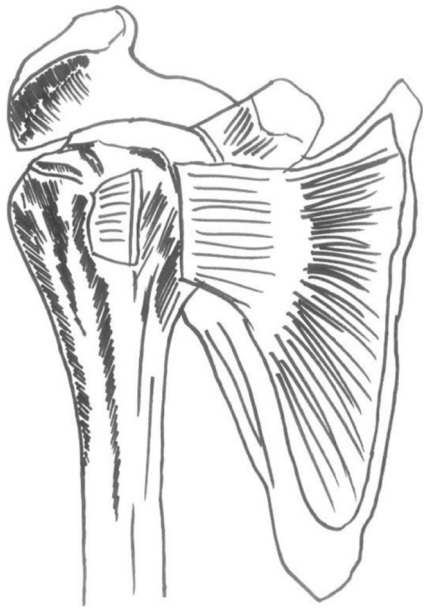

Fig. 1 The tenotomy of the subscapularis is carried out

Whether the subscapularis tendon was present, not degenerate, and able to reach its anatomical footprint, a tenodesis was performed at the end of surgery; otherwise, a simple tenotomy without suturing was carried out (Fig. 3).

Clinical evaluation and outcome measures

Patients were evaluated pre-operatively and at the latest follow-up through Constant score [34], VAS, active abduction, forward flexion, extrarotation at 0° and 90° of abduction, and intrarotation.

The ROM was measured in all patients by the same examiner (E.G.S.) through a goniometer. The spinal segments were used as reference points to calculate the intrarotation and were associated to the following scores: 0°, 0; hip, 1; buttocks, 2; sacrum, 3; L4–L5, 4; L1–L3, 5; T8–T12, 6; and T7 or higher, 7 [12].

Statistical analysis

After assessment of the distribution with the Kolmogorov–Smirnov test, unpaired *t* tests and Mann–Whitney *U* tests were, respectively, used to compare parametric and nonparametric variables. Mean and standard deviation (SD) were calculated. A p value of 0.05 was regarded as statistically significant. SPSS version 17.0 (SPSS, Chicago, IL) was used to analyze the data.

Results

The two groups did not differ for demographic and preoperative clinical and imaging features (Table 1).

A significant improvement in pain and functions after rTSA treatment has been showed in all patients regardless of the suture of the subscapularis tendon. However, differences could be highlighted between the two groups (Table 2).

Comparing the post-operative results, no significant correlation was found between the two groups regarding Constant score and VAS (Fig. 4).

The abduction value was significantly higher in the NS group. Both groups achieved a similar post-operative forward flexion value (Table 2) (Fig. 5).

Differences in both extrarotation values (0° and 90° of abduction) between the two groups were not significant, with higher values in the NS group. The intrarotation value was significantly higher in the S group.

Only one complication (instability) was reported in the NS group (2.5%) and none in the S group without being a significant difference ($p = 0.32$).

Fig. 2 Evaluation of the subscapularis tendon

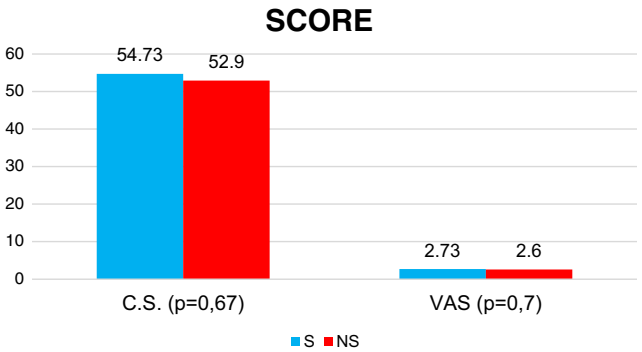

Fig. 4 Comparison of score outcomes after rTSA. CS constant score, VAS visual analog scale, S suture, NS nonsuture

Discussion

The role of subscapularis in the setting of rTSA is still debated. Some authors believe that an intact or reattached tendon could modify ROM and post-operative scores by increasing intrarotation, force applied on the joint, and force generated by the posterior rotator cuff and by decreasing abduction and extrarotation, whereas others cannot find any significant correlation between reattachment and range of motion [10–13, 25, 35].

In rTSA, the humerus is moved inferiorly; consequently, the subscapularis tendon is shifted inferiorly to the CoR, becoming an adductor for almost the entire range of motion, losing its biphasic effect [12, 15, 25, 35]. It would counteract the function of the deltoid muscle, increasing both the effort required to elevate the arm and the resultant force acting on the glenohumeral joint, which could reduce the life of the device [8, 11, 12, 15, 17, 22, 24, 25, 35–37].

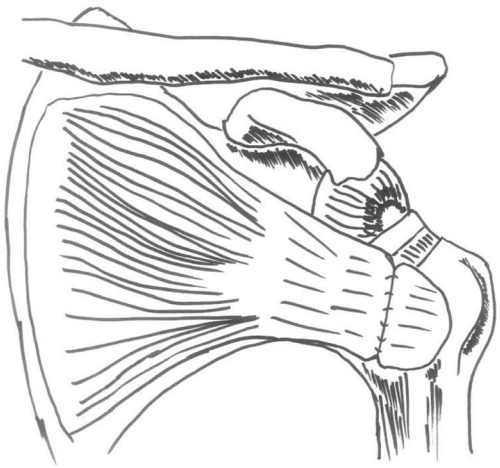

Fig. 3 The tenodesis is performed at the end of the surgery

The change of the joint compression force is due to co-contraction of subcapularis muscle, deltoid muscle, and posterior rotator cuff, and may increase the risk of mobilization and acromial fracture [12, 16, 17, 35].

Multiple studies cite instability as one of the most common complications after rTSA and subscapularis insufficiency as a contribuiting factor [3–7, 16].

However, there are some surgeons believing that the tendon's integrity and suture do not have a significant impact on stability [9, 10, 12, 15, 26].

A large part of the studies demonstrating a correlation between the subscapularis tendon integrity and the instability of rTSA are based on only one type of rTSA design, the Grammont. Conversely, studies showing no correlation, a more lateralized rTSA was used (Table 3).

According to Roche and Co. [36, 37], the most commonly used configuration of this rTSA is composed by lateralized glenoid and medialized humeral component. In their study, three different rTSA configurations are implanted in the same virtual shoulder. It is stated that in a Grammont prosthesis, medialization of both components leads to a decrease in the rotator cuff and deltoid length, reducing the horizontal compression. This design has a greater inclination of dislocating and explains why having the subscapularis as a joint compressor increases stability. Consequently, increasing the lateralization of the Grammont prosthesis increases its stability [18, 24].

This may explain why some studies underline the importance of the subscapularis on stability unlike others.

Therefore, the importance of subscapularis tendon might be design specific and correlates with the lateralization of the architecture.

This study compares the clinical outcomes of rTSA with bone autograft and humeral component lateralization, with or without suturing of the subcapularis tendon.

Table 2 Comparison of the influence of subscapularis tendon suture on range of motion, VAS, and Constant–Murley score pre- and post-operatively

Variable*	Sutured group		Nonsutured group		Comparison (p)	
	Pre-op	Post-op	Pre-op	Post-op	Pre-op	Post-op
Constant score	26.02 ± 11.18	54.73 ± 19.28	25.45 ± 12.93	52.90 ± 20.31	0.83	0.67
VAS	6.91 ± 1.64	2.73 ± 2.44	7.00 ± 1.63	2.60 ± 1.45	0.79	0.77
Abduction	70.68° ± 26.84°	112.27° ± 31.69°	79.10° ± 33.55°	128.15° ± 39.50°	0.21	0.04
Forward flexion	74.91° ± 32.57°	116.36° ± 38.89°	70.80° ± 33.48°	114.15° ± 34.44°	0.57	0.78
Extrarotation at 0° of abduction	9.89° ± 12.08°	25.91° ± 21.22°	16.20° ± 10.89°	28.60° ± 15.35°	0.01	0.51
Extrarotation at 90° of abduction	20.27° ± 14.29°	53.18° ± 29.75°	32.15° ± 12.07°	56.60° ± 18.78°	< 0.0001	0.54
Intrarotation	3.30° ± 1.07°	5.11° ± 1.28°	3.20° ± 1.24°	4.55° ± 0.99°	0.58	0.02

*All values are reported in degrees ± standard deviation

Treating a pathologic shoulder with rTSA significantly increases the values of two analyzed scores and each value of the ROM, regardless of the repair of the tendon.

To our knowledge, this is the first publication on the importance of suturing the subcapularis tendon, including only patients undergoing reverse shoulder arthroplasty performed with both bone autograft (BIO-RSA) and humeral component lateralized.

In scientific literature, clinical studies concerning the role of the subcapularis focus on either designs of Grammont (medial glenosphere–medial humerus), or designs with medial glenoid and lateral humerus. Rarely, patients undergoing bone autograft surgery are evaluated in clinical studies.

Similarly to the studies written by Hansen et al. [35], Wall et al. [10], and Friedman et al. [12], suturing the subscapularis induces a significant increase and reduction, respectively, of intrarotation and active abduction ($p = 0.02$ and $p = 0.04$).

This contradicts authors stating that there is no significant difference in range of motion among the two groups [9, 14, 15].

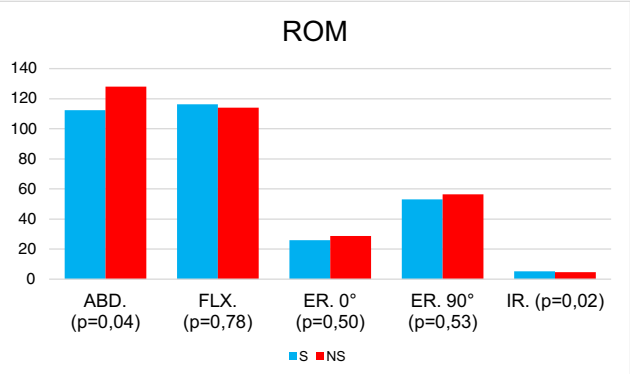

Fig. 5 Comparison of ROM outcomes after rTSA. Abd abduction, FLX flexion, ER. 0° extrarotation at 0° of abduction, ER. 90° extrarotation at 90° of abduction, S suture, NS nonsuture

Although not statistically significant, the NS group has higher results in terms of extrarotation at 0° and 90° of abduction.

It does not seem to have any correlation between active forward flexion and the suture of the subscapularis tendon.

Clinical results of Friedman et al. [12] and Hansen et al. [35], concerning a significant extrarotation decrease in patients with the subcapularis tendon repaired, do not correlate with ours.

No significant differences in Constant score and VAS, between the two groups, were pointed out. VAS was not significantly increased in the S group. The tension of the sutured tendon could cause an increase in pain, especially in the very early post-operative period as it is healing.

In our study, the NS group did not significantly increase the risk of joint instability ($p = 0.32$). However, it should be noted that the percentage of instability, total and both groups separately evaluated, is lower than previous studies in scientific literature.

The modern rTSAs, including the one used in this study, lateralizing humerus/glenoid component or both, as in our case, bring biomechanical benefits when compared to the traditional Grammont design.

Lateralizing the construct increases the deltoid winding and tension of the remaining fibers of the damaged rotator cuff, leading to a greater compression and preventing dislocation. Additionally, it decreases the risk of impingement [3, 4, 9, 12, 15–17, 24].

Even for the subscapularis tendon, the lateralization of the footprint compared to the design of Grammont would increase its tension.

Those recommendations should not be taken into account for designs with glenoid/humerus or both components medialized. In these types of prosthesis, as the retraction force is lower, the suture is easier to perform, but the lower deltoid tension and the greater risk of impingement increase the need for a tenodesis of the subcapularis to stabilize the prosthesis, preventing a dislocation. The decision whether or not to repair it may be based on the type of prosthetic design.

Table 3 Literature review. GM–HL medial glenosphere–lateral humeral design, GL–HL lateral glenosphere–lateral humeral design, n/a not applicable, n/e not evaluated

First author	Prosthesis design	No. of patients	Level of evidence	Impact on stability
Edwards et al.	Grammont	138	IV	S
Gallo et al.	Grammont	57	IV	S
Chalmers et al.	Grammont	11	IV	S
Trappey et al.	Grammont	284	III	S
Wall et al.	Grammont	240	II	NS
de Boer et al.	Grammont*	127	III	n/e
Grassi et al.	Grammont	19	IV	NS
Boileau et al.	Grammont	45	III	S
Oh et al.	GM–HL	Cadaver	n/a	S
Clark et al.	GL–HL	120	III	NS
Friedman et al.	GM–HL	591	III	NS
Vourazeris et al.	GM–HL	202	III	NS
Onstot et al.	GM–HL	Cadaver	n/a	n/e
Ladermann et al.	GM–HL	20	IV	n/e

*BIO-RSA used in 6/65 patients

Our results demonstrate that positive outcomes in terms of range of motion and scores can be achieved regardless of the suture of the subcapularis, using a lateralized implant.

One of the strengths of our study is to compare the outcomes of a single prosthesis design (lateral humerus and glenosphere) in patients with first surgery performed by a single surgeon.

This study has some limitations: it retrospectively reports clinical outcomes of prosthesis with a follow-up from six months to two years. Also, as this study is not randomized, there might be a bias in the selection of patients.

Clinical results change with time, and longer follow-ups of rTSA with and without the subscapularis tendon are needed.

It could be interesting to evaluate what would be the best treatment in order to return to sport [38].

The decision to repair the subscapularis was taken by the surgeon (F.F.) according to his judgment preference, based on the quality of the tendon, easiness in reaching the original footprint, and the quality of the lesser tubercle.

Certainly, there were some patients where the tendon was not supposed to be sutured, and others having a suturable tendon, not re-attached to the lesser tubercle.

Other weaknesses of our study are the lack of knowledge of the tendon integrity post-operatively during the follow-up.

The suture integrity after rTSA is doubtful, due to the frequent involvement of subscapularis tendon in the pathology [13]. From the study of de Boer et al. [14], it comes up that after a 36-month follow-up ultrasound examination, only 40% of the sutured tendon remained attached to the humerus.

Probably, some of the sutured tendons never healed; working as nonsutured implant but appearing in S group altered the results.

Acknowledgements Suturing the subscapularis tendon does not lead to inferior clinical results as predicted by biomechanical models [25, 35].

Likewise, not repairing the tendon with a lateralized humerus does not result in higher scores or greater range of motion.

Moreover, no difference was observed in the rates of complications between patients with or without suture.

The difference of the designs (lateral versus medial) used can partially explain the contradictory results in the scientific literature.

Longer follow-ups, greater number of patients, and multiple score use are important to confirm our results.

A potential future study on the role of the subscapularis in the rTSA should stratify all patients undergoing surgery performed by the same surgeon in four groups according to the prosthetic design (Grammont design, medial glenosphere and lateral humerus, lateral glenosphere and medial humerus, both lateral).

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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References

1. Valenti P, Maqdes A, Werthel JD (2017) Clinical and radiological outcomes after reverse shoulder arthroplasty in patients with failed deltoid or latissimus dorsi transfers. A review of ten cases. Int Orthop 41(10):2143–2148. https://doi.org/10.1007/s00264-017-3520-4
2. Ladermann A, Denard PJ, Collin P (2015) Massive rotator cuff tears: definition and treatment. Int Orthop 39(12):2403–2414. https://doi.org/10.1007/s00264-015-2796-5
3. Gallo RA, Gamradt SC, Mattern CJ, Cordasco FA, Craig EV, Dines DM, Warren RF, Sports M Shoulder Service at the Hospital for Special Surgery NYNY (2011) Instability after reverse total

shoulder replacement. J Shoulder Elbow Surg 20(4):584–590. https://doi.org/10.1016/j.jse.2010.08.028
4. Boileau P, Watkinson D, Hatzidakis AM, Hovorka I (2006) Neer Award 2005: the Grammont reverse shoulder prosthesis: results in cuff tear arthritis, fracture sequelae, and revision arthroplasty. J Shoulder Elb Surg 15(5):527–540. https://doi.org/10.1016/j.jse.2006.01.003
5. Trappey GJ, O'Connor DP, Edwards TB (2011) What are the instability and infection rates after reverse shoulder arthroplasty? Clin Orthop Relat Res 469(9):2505–2511. https://doi.org/10.1007/s11999-010-1686-9
6. Oh JH, Shin SJ, McGarry MH, Scott JH, Heckmann N, Lee TQ (2014) Biomechanical effects of humeral neck-shaft angle and subscapularis integrity in reverse total shoulder arthroplasty. J Shoulder Elb Surg 23(8):1091–1098. https://doi.org/10.1016/j.jse.2013.11.003
7. Edwards TB, Williams MD, Labriola JE, Elkousy HA, Gartsman GM, O'Connor DP (2009) Subscapularis insufficiency and the risk of shoulder dislocation after reverse shoulder arthroplasty. J Shoulder Elb Surg 18(6):892–896. https://doi.org/10.1016/j.jse.2008.12.013
8. Ackland DC, Roshan-Zamir S, Richardson M, Pandy MG (2010) Moment arms of the shoulder musculature after reverse total shoulder arthroplasty. J Bone Joint Surg Am 92(5):1221–1230. https://doi.org/10.2106/JBJS.I.00001
9. Clark JC, Ritchie J, Song FS, Kissenberth MJ, Tolan SJ, Hart ND, Hawkins RJ (2012) Complication rates, dislocation, pain, and postoperative range of motion after reverse shoulder arthroplasty in patients with and without repair of the subscapularis. J Shoulder Elb Surg 21(1):36–41. https://doi.org/10.1016/j.jse.2011.04.009
10. Wall B, Nove-Josserand L, O'Connor DP, Edwards TB, Walch G (2007) Reverse total shoulder arthroplasty: a review of results according to etiology. J Bone Joint Surg Am 89(7):1476–1485. https://doi.org/10.2106/JBJS.F.00666
11. Zumstein MA, Pinedo M, Old J, Boileau P (2011) Problems, complications, reoperations, and revisions in reverse total shoulder arthroplasty: a systematic review. J Shoulder Elb Surg 20(1):146–157. https://doi.org/10.1016/j.jse.2010.08.001
12. Friedman RJ, Flurin PH, Wright TW, Zuckerman JD, Roche CP (2017) Comparison of reverse total shoulder arthroplasty outcomes with and without subscapularis repair. J Shoulder Elb Surg 26(4):662–668. https://doi.org/10.1016/j.jse.2016.09.027
13. Ladermann A, Lo EY, Schwitzguebel AJ, Yates E (2016) Subscapularis and deltoid preserving anterior approach for reverse shoulder arthroplasty. Orthop Traumatol Surg Res 102(7):905–908. https://doi.org/10.1016/j.otsr.2016.06.005
14. de Boer FA, van Kampen PM, Huijsmans PE (2016) The influence of subscapularis tendon reattachment on range of motion in reversed shoulder arthroplasty: a clinical study. Musculoskelet Surg 100(2):121–126. https://doi.org/10.1007/s12306-016-0401-8
15. Vourazeris JD, Wright TW, Struk AM, King JJ, Farmer KW (2017) Primary reverse total shoulder arthroplasty outcomes in patients with subscapularis repair versus tenotomy. J Shoulder Elb Surg 26(3):450–457. https://doi.org/10.1016/j.jse.2016.09.017
16. Chalmers PN, Rahman Z, Romeo AA, Nicholson GP (2014) Early dislocation after reverse total shoulder arthroplasty. J Shoulder Elb Surg 23(5):737–744. https://doi.org/10.1016/j.jse.2013.08.015
17. Routman HD (2013) The role of subscapularis repair in reverse total shoulder arthroplasty. Bull Hosp Jt Dis 71(Suppl 2):108–112
18. Greiner S, Schmidt C, Konig C, Perka C, Herrmann S (2013) Lateralized reverse shoulder arthroplasty maintains rotational function of the remaining rotator cuff. Clin Orthop Relat Res 471(3):940–946. https://doi.org/10.1007/s11999-012-2692-x
19. Mansat P, Bonnevialle N (2015) Treatment of fracture sequelae of the proximal humerus: anatomical vs reverse shoulder prosthesis. Int Orthop 39(2):349–354. https://doi.org/10.1007/s00264-014-2651-0
20. Schwartz BE, Savin DD, Youderian AR, Mossad D, Goldberg BA (2015) National trends and perioperative outcomes in primary and revision total shoulder arthroplasty: trends in total shoulder arthroplasty. Int Orthop 39(2):271–276. https://doi.org/10.1007/s00264-014-2614-5
21. Raiss P, Zeifang F, Pons-Villanueva J, Smithers CJ, Loew M, Walch G (2014) Reverse arthroplasty for osteoarthritis and rotator cuff deficiency after previous surgery for recurrent anterior shoulder instability. Int Orthop 38(7):1407–1413. https://doi.org/10.1007/s00264-014-2325-y
22. Hamilton MA, Diep P, Roche C, Flurin PH, Wright TW, Zuckerman JD, Routman H (2015) Effect of reverse shoulder design philosophy on muscle moment arms. J Orthop Res 33(4):605–613. https://doi.org/10.1002/jor.22803
23. Ackland DC, Richardson M, Pandy MG (2012) Axial rotation moment arms of the shoulder musculature after reverse total shoulder arthroplasty. J Bone Joint Surg Am 94(20):1886–1895. https://doi.org/10.2106/JBJS.J.01861
24. Henninger HB, Barg A, Anderson AE, Bachus KN, Burks RT, Tashjian RZ (2012) Effect of lateral offset center of rotation in reverse total shoulder arthroplasty: a biomechanical study. J Shoulder Elb Surg 21(9):1128–1135. https://doi.org/10.1016/j.jse.2011.07.034
25. Onstot B, Suslak A, Colley R, Jacofsky M, Otis J, Hansen M (2012) Consequences of concomitant subscapularis repair with reverse total shoulder arthroplasty. In: Transaction of the 58th Annual ORS Meeting
26. Grassi FA, Zorzolo I (2014) Reverse shoulder arthroplasty without subscapularis repair for the treatment of proximal humeral fractures in the elderly. Musculoskelet Surg 98(Suppl 1):5–13. https://doi.org/10.1007/s12306-014-0321-4
27. Katz D, Valenti P, Kany J, Elkholti K, Werthel JD (2016) Does lateralisation of the centre of rotation in reverse shoulder arthroplasty avoid scapular notching? Clinical and radiological review of one hundred and forty cases with forty five months of follow-up. Int Orthop 40(1):99–108. https://doi.org/10.1007/s00264-015-2976-3
28. Ladermann A, Denard PJ, Boileau P, Farron A, Deransart P, Walch G (2018) What is the best glenoid configuration in onlay reverse shoulder arthroplasty? Int Orthop 42(6):1339–1346. https://doi.org/10.1007/s00264-018-3850-x
29. Werner BS, Chaoui J, Walch G (2017) The influence of humeral neck shaft angle and glenoid lateralization on range of motion in reverse shoulder arthroplasty. J Shoulder Elb Surg 26(10):1726–1731
30. Boileau P, Moineau G, Roussanne Y, O'shea K (2011) Bony increased-offset reversed shoulder arthroplasty: minimizing scapular impingement while maximizing glenoid fixation. Clin Orthop Relat Res 469(9):2558–2567
31. Goutallier D, Postel J-M, Bernageau J, Lavau L, Voisin M-C (1994) Fatty muscle degeneration in cuff ruptures. Pre-and postoperative evaluation by CT scan. Clin Orthop Relat Res (304):78–83
32. Narasimhan R, Shamse K, Nash C, Dhingra D, Kennedy S (2016) Prevalence of subscapularis tears and accuracy of shoulder ultrasound in pre-operative diagnosis. Int Orthop 40(5):975–979. https://doi.org/10.1007/s00264-015-3043-9
33. Gadea F, Bouju Y, Berhouet J, Bacle G, Favard L (2015) Deltopectoral approach for shoulder arthroplasty: anatomic basis. Int Orthop 39(2):215–225. https://doi.org/10.1007/s00264-014-2654-x
34. Constant C,Murley A (1987) A clinical method of functional assessment of the shoulder. Clin Orthop Relat Res (214):160-164
35. Hansen ML, Nayak A, Narayanan MS, Worhacz K, Stowell R, Jacofsky MC, Roche CP (2015) Role of subscapularis repair on

muscle force requirements with reverse shoulder arthroplasty. Bull Hosp Jt Dis (2013) 73(Suppl 1):S21–S27
36. Roche C, Diep P, Hamilton M, Wright T, Flurin P, Zuckerman J, Routman H Asymmetric tensioning of the rotator cuff by changing humeral retroversion in reverse shoulder arthroplasty. In: Transactions of the 59th Annual ORS Meeting. San Antonio, Texas, p 2013
37. Roche C, Diep P, Hamilton M, Wright T, Flurin P, Zuckerman J, Routman H Biomechanical analysis of 3 commercially available reverse shoulder designs in a normal and medially eroded scapula. In: 59th Annual Orthopaedic Research Society Meeting. San Antonio, Texas, p 2013
38. Kolling C, Borovac M, Audige L, Mueller AM, Schwyzer HK (2018) Return to sports after reverse shoulder arthroplasty-the Swiss perspective. Int Orthop 42(5):1129–1135. https://doi.org/10.1007/s00264-017-3715-8