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Subscapularis Repair Is Unnecessary After Lateralized Reverse Shoulder Arthroplasty

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Background: Controversy exists as to whether the subscapularis should be repaired after reverse shoulder arthroplasty. The purpose of the present study was to evaluate the utility of repairing the subscapularis after reverse shoulder arthroplasty with regard to complications, objective findings, and patient-reported outcome measures.

Methods: We retrospectively reviewed the records for 99 patients who had undergone a lateralized reverse shoulder arthroplasty with (n = 58) or without (n = 41) subscapularis repair. Outcomes were compared with the Single Assessment Numeric Evaluation (SANE), Penn shoulder score (PSS), Veterans RAND (VR)-12, and American Shoulder and Elbow Surgeons (ASES) score at a minimum of 2 years of follow-up. Demographics, range of motion, and complications were also compared. A 1-way analysis of variance was performed to determine differences in performance and outcome scores, and a chi-square analysis was performed to compare the frequency of complications between groups.

Results: There were no significant differences between the repair and no-repair groups in terms of SANE, PSS, ASES, or VR-12 scores. There also were no significant differences between the 2 groups in terms of postoperative ranges of forward elevation (128° versus 123°; p = 0.44) and external rotation (33° versus 29°; p = 0.29), the dislocation rate (5% versus 2%; p = 0.49), or the overall complication rate (9% versus 5%; p = 0.47).

Conclusions: The results of the present study suggest that repair of the subscapularis tendon after lateralized reverse shoulder arthroplasty may not be necessary.

Level of Evidence: Therapeutic Level III. See Instructions for Authors for a complete description of levels of evidence.

The current use of reverse shoulder arthroplasty essentially parallels that of anatomical total shoulder arthroplasty[1]. The acceptance of this trend has been fueled largely by an evolution of design modifications and increased understanding of technical aspects of the procedure. Following poor results of early attempts at reverse shoulder arthroplasty[2], this procedure became commonly accepted with the introduction of the Grammont-style prosthesis in the late 1980s. This design transferred the humeral center of rotation medially and lengthened the humerus, with a theoretical increase in deltoid tension and more-efficient deltoid lever arm[3]. This design lead to improved clinical outcomes[4-6], but new issues, such as scapular notching[7-9] and limited external rotation requiring muscle transfers, were encountered[4,10,11]. Additionally, as the humerus is lengthened, the vector of pull changes[12], frequently resulting in instability of the glenohumeral joint. The role of subscapularis repair in preventing this complication has been investigated. Using a medialized reverse shoulder arthroplasty design, Edwards et al.[13] reported a 9% dislocation rate following procedures in which a subscapularis repair was not achieved, compared with a 0% rate following procedures in which subscapularis repair was achieved (relative risk, 1.9), and therefore advocated attempted repair in every case.

It is unclear, however, whether this recommendation should apply to other prosthetic designs. An alternative

Disclosure: There was no external funding source for this project. On the **Disclosure of Potential Conflicts of Interest** forms, *which are provided with the online version of the article*, one or more of the authors checked "yes" to indicate that the author had a relevant financial relationship in the biomedical arena outside the submitted work (http://links.lww.com/JBJSOA/A51).

prosthetic design, with a relatively lateralized center of rotation (compared with Grammont-style prostheses), has been advocated as a response to the above concerns[14,15]. Gutiérrez et al.[16] showed that lateralization of the center of rotation was the most important factor in maximizing the overall arc of motion. Lateralization in conjunction with inferior placement of the glenosphere and a varus humeral neck-shaft angle best avoids impingement in adduction, thus lessening the concern of scapular notching[17]. Furthermore, the lateralized design retensions the remaining rotator cuff musculature, allowing a potentially more normal moment arm for these muscles[18,19] as well as a more anatomical vector of pull for the deltoid as it wraps around the humeral component. This normalized vector is the theoretical basis for the improved range of motion, particularly in external rotation, seen in association with lateralized designs[15,19-22]. Additionally, these factors, combined with the increased jump distance associated with lateralized designs[23], theoretically impart improved inherent stability compared with medialized designs. A review of large series in which component design and dislocation rates were reported indicted that the dislocation rates for lateralized designs ranged from 0% to 4.2% (average, 3%)[20,21,24,25], whereas those for medialized designs ranged from 0% to 8.6% (average, 5%)[7,26-30].

These trends support the proposed advantage of lateralized reverse shoulder arthroplasty in terms of stability, and one of the previously mentioned studies, which specifically examined the role of subscapularis repair on dislocation rates associated with lateralized designs, demonstrated no difference between repair and no-repair groups[24]. That finding stands in contrast to the finding, reported by Edwards et al.[13], that procedures performed with medialized prostheses without subscapularis repair were associated with increased rates of dislocation, further highlighting the need to understand the difference in designs when discussing technical points of reconstruction. To our knowledge, those 2 investigations[13,24] remain the only studies that have specifically examined the role of subscapularis repair on dislocation. One recent study[31] demonstrated no difference in functional or patient-reported outcomes after treatment with a medialized design with or without subscapularis repair, yet little work has been done to evaluate the effect of subscapularis repair on outcomes after reverse shoulder arthroplasty with a lateralized prosthesis, to our knowledge. Therefore, the present study was designed to further clarify the rates of complications, including dislocation, after lateralized reverse shoulder arthroplasty and to compare the functional outcomes after reverse shoulder arthroplasty performed with a lateralized design with or without subscapularis repair. On the basis of the aforementioned information, we hypothesized that subscapularis repair would have no effect on complication rates or clinical outcomes associated with the lateralized design.

Materials and Methods

As part of an ongoing institutional review board-approved outcomes database that does not receive any funding, a retrospective review was performed on all reverse shoulder arthroplasties that were performed at a single institution over a 7-year period (from 2007 to 2014). One hundred and thirty-four patients with >2 years of follow-up were identified. Revision procedures were excluded, leaving 124 primary reverse shoulder arthroplasties that were performed by 4 fellowship-trained shoulder surgeons with use of a lateralized prosthesis, including 102 that were performed with the Reverse Shoulder Prosthesis (DJO) and 22 that were performed with the Trabecular Metal Reverse Shoulder (Zimmer-Biomet). Primary procedures that were performed for the treatment of rotator cuff tear arthropathy and irreparable rotator cuff tears were included, whereas those performed for the treatment of proximal humeral fractures were excluded, yielding 99 reverse shoulder arthroplasties for the final analysis.

Medical records were reviewed with regard to patient comorbidities, body mass index (BMI), age, sex, preoperative diagnosis, and preoperative range of motion. Resiliency, a measure of an individual's ability to cope with adversity, was also recorded. Operative reports were reviewed in detail for intraoperative complications, confirmation of lateralization of the prosthesis, and repair (or lack of repair) of the subscapularis. The decision to repair the subscapularis was made by the treating physician on the basis of the quality of available tendon and whether repair would be achieved without undue tension. When performed, subscapularis repair was carried out with bone tunnels in the bicipital groove in patients managed with the subscapularis peel approach and via the Mason-Allen technique with use of nonabsorbable sutures in those managed with tenotomy. All reverse shoulder arthroplasties were performed through a deltopectoral approach with layered closure, regardless of the performance of a subscapularis repair or the use of a drain at the discretion of the surgeon. Postoperatively, patients who did not undergo subscapularis repair were initially immobilized in a sling for comfort, with progression to passive and active range of motion as tolerated under the direction of formal physical therapy. Patients who underwent subscapularis repair were restricted to passive external rotation to neutral for 6 weeks, with progression of active and passive range of motion as tolerated thereafter. Both groups were permitted to return to full activity without restriction at 3 months.

Complications were defined as infection, dislocation, neurological injury, and fracture (including periprosthetic and acromial fracture). Outcome measures included the postoperative range of motion as well patient-reported outcome measures—specifically, the Penn shoulder score (PSS), American Shoulder and Elbow Surgeons (ASES) score, visual analog scale (VAS) score for pain, and Single Assessment Numeric Evaluation (SANE) score at >2 years of follow-up. The Veterans RAND (VR)-12 score, a measure of health-related quality of life, were also determined. Statistical analysis was performed with use of 1-way analysis of variance (ANOVA) to determine the difference between the repair and no-repair groups in terms of performance and outcome scores. Chi-square analysis was performed to compare the frequency of complications between groups. The level of significance was set at $p < 0.05$. All statistical analyses were performed by a PhD research scientist with advanced statistical training.

Results

The study group included 99 patients (including 58 patients who underwent subscapularis repair and 41 who did not) who were followed for an average of 49 months (range, 25 to 104 months). The average age was 68 years (range, 52 to 87 years), with no difference between the repair and no-repair groups (67 compared with 70 years, respectively; p = 0.08). There were no significant differences between the groups in term of the length of follow-up (p = 0.85), sex distribution (p = 0.17), BMI (p = 0.58), smoking status (p = 0.11), resiliency (p = 0.31), or Charlson comorbidity index (p = 0.31) (Table I).

The overall complication rate was 9% in the subscapularis repair group, compared with 5% in the no-repair group (p = 0.47). The complications in the repair group included 3 dislocations and 2 deep infections. The complications in the no-repair group included 1 dislocation and 1 deep infection. The dislocation rate in the repair group was not significantly different from that in the no-repair group (5% compared with 2%; p = 0.49) (Table II). There were no periprosthetic or acromial fractures in the follow-up period.

There was no significant difference between the repair and no-repair groups in terms of the preoperative range of forward flexion (75° versus 80°; p = 0.66) or external rotation (21° versus 19°; p = 0.81). Likewise, there was no significant difference between the groups in terms of the postoperative range of forward flexion (128° versus 123°; p = 0.44) or external rotation (33° versus 29°; p = 0.29). There was no difference between the groups in terms of the VAS score either preoperatively (6.3 versus 5.9; p = 0.59) or postoperatively (3.0 versus 3.2; p = 0.72). Postoperatively, there was a maximum 7-point difference in the patient-reported outcome measures, with no significant differences between the groups in terms of the PSS (68 versus 67; p = 0.71), ASES score (72 versus 65; p = 0.18), or SANE score (73 versus 70; p = 0.62). Likewise, there was no difference between the groups in terms of the VR-12 score (89 versus 84; p = 0.25).

Of the 58 patients in the repair group, 38 had the repair after a subscapularis peel technique; 18, after a subscapularis tenotomy; and 2, after a lesser tuberosity osteotomy. The 2 patients who underwent lesser tuberosity osteotomy were excluded from further analysis. There was no significant difference between the peel and tenotomy groups terms of the dislocation rate (3% versus 11%; p = 0.16) or the overall complication rate (5% versus 17%; p = 0.19) (Table III). There was no difference between the peel and tenotomy groups in terms of the preoperative range of forward flexion (72° versus 85°; p = 0.28) or external rotation (21° versus 21°; p = 0.93). Postoperatively, the peel group demonstrated significantly greater forward elevation compared with the tenotomy group (136° versus 117°; p = 0.03) but there was no significant difference between the groups in terms of external rotation (34° versus 34°; p = 0.90). There were no significant differences between the groups in terms of the PSS (67 versus 72; p = 0.53), ASES score (72 versus 72; p = 0.97), SANE score (74 versus 70; p = 0.69), or VR-12 score (91 versus 89; p = 0.76).

TABLE I Patient Demographics

	No Repair (N = 41)	Repair (N = 58)	P Value
Duration of follow-up* *(mo)*	49	49	0.85
Age* *(yr)*	70	67	0.08
Male	46%	33%	0.17
Body mass index* *(kg/m²)*	30	31	0.58
Tobacco use *(no. of patients)*	8 (20%)	5 (9%)	0.11
Resiliency* *(points)*	22	23	0.31
Charlson comorbidity index* *(points)*	1.0	0.78	0.31

*The values are given as the mean.

TABLE II Outcomes After Reverse Shoulder Arthroplasty According to Subscapularis Repair Status

	No Repair (N = 41)	Repair (N = 58)	P Value
No. of complications	2 (5%)	5 (9%)	0.47
No. of dislocations	1 (2%)	3 (5%)	0.49
Preop. range of motion* *(°)*			
Forward flexion	80	75	0.66
External rotation	19	21	0.81
Postop. range of motion* *(°)*			
Forward flexion	123	128	0.44
External rotation	29	33	0.29
Change in range of motion* *(°)*			
Forward flexion	53	46	0.58
External rotation	10	9	0.93
Outcome scores*			
PSS			
Pain	21	22	0.70
Function	38	39	0.65
Satisfaction	7	8	0.33
Total	67	69	0.71
ASES			
Function	27	31	0.09
Pain	38	41	0.43
Total	65	72	0.18
VR-12			
Physical component	35	38	0.19
Mental component	49	51	0.51
Total	84	89	0.25
VAS	3.2	3.0	0.72
SANE	70	73	0.62

*The values are given as the mean.

TABLE III Outcomes After Reverse Shoulder Arthroplasty According to Repair Type*

	Peel (N = 38)	Tenotomy (N = 18)	P Value
No. of complications	2 (5%)	3 (17%)	0.19
No. of dislocations	1 (3%)	2 (11%)	0.16
Preop. range of motion† *(°)*			
Forward flexion	72	85	0.28
External rotation	21	21	0.93
Postop. range of motion† *(°)*			
Forward flexion	136	117	0.03
External rotation	34	34	0.90
Change in range of motion† *(°)*			
Forward flexion	56	30	0.09
External rotation	12	6	0.54
Outcome scores†			
PSS			
Pain	22	22	0.97
Function	39	41	0.65
Satisfaction	8	8	0.54
Total	67	72	0.53
ASES			
Function	31	32	0.85
Pain	41	40	0.82
Total	72	72	0.97
VR-12			
Physical component	37	42	0.23
Mental component	52	49	0.53
Total	89	91	0.76
VAS	2.9	3.3	0.67
SANE	74	70	0.69

*Two lesser tuberosity osteotomies were excluded from analysis. †The values are given as the mean.

Discussion

The current study, one of the first to evaluate the effect of subscapularis repair on the results of lateralized reverse shoulder arthroplasty, demonstrated no difference between the repair and no-repair groups in terms of functional or patient-reported outcomes. We also found that the dislocation rates were similar in both groups and also were similar to the rates reported in previous studies[7,20,21,24-26,28,30], suggesting that repair is not critical to stability following procedures involving a lateralized design.

One of the most notable advantages of a relatively lateralized center of rotation is restoration of external rotation postoperatively[15,18-22]. A potential downside of subscapularis repair could be its antagonistic effect on restoring external rotation, which has an influential effect on activities of daily living. A previous biomechanical study with a lateralized design prosthesis showed that an increased force of between 262% and 460% was required to maintain external rotation with abduction of the arm in a model with subscapularis repair versus a non-repaired subscapularis[32]. Additionally, the inherent biomechanical advantage of a reverse prosthesis allows an advantageous moment arm for the deltoid to act in abduction. However, 1 report summarized that, at low levels of abduction, the subscapularis acts as an adductor[33] antagonistically against the deltoid, with a 132% increase in deltoid force being required for abduction when the subscapularis was intact versus released. Furthermore, a 426% increase in the joint-reaction force was noted when the subscapularis was intact, raising concern over the potential impact on implant longevity[33]. These findings raise concern that subscapularis repair in patients managed with a lateralized design not only may have no beneficial effect but actually may be detrimental. Our study did not demonstrate a difference in active external rotation at an average of just over 4 years of follow-up. It remains to be seen whether external rotation and implant longevity may be negatively impacted in the long term by subscapularis repair in patients managed with a lateralized reverse shoulder arthroplasty prosthesis.

Another potential disadvantage of subscapularis repair is the presumed alteration in postoperative rehabilitation. A repaired subscapularis requires protection for healing, with a delay in aggressive external rotation. As external rotation has a major impact on activities of daily living, delaying this motion at least temporarily may negatively affect patients receiving repair. Reverse shoulder arthroplasty is most commonly performed in the elderly, who may particularly feel this adverse effect in the early postoperative period. For these reasons, additional study may be warranted on the return to activities of daily living and self-care in the early postoperative period following subscapularis repair.

We are aware of only 2 studies that have analyzed instability in relation to subscapularis repair, regardless of prosthetic design[13,24]. Those studies revealed conflicting results in terms of instability rates but did not evaluate patient outcomes. Friedman et al. performed what we believe to be the first study evaluating the effect of subscapularis repair on patient-reported outcomes following treatment with a lateralized prosthesis[34]. That study demonstrated a significant improvement for both groups, similar to the findings of the current study. Although that study demonstrated significant improvement in several patient-reported outcomes in association with repair, the authors conceded that the improvements were so small that they were unlikely to be clinically meaningful. The rate of recurrent instability was low in both the study by Friedman et al. (1.2%) and the current study (4%).

One difference between the study by Friedman et al.[34] and the current study was the prosthetic design. While both prostheses had a lateralized center of rotation, the prostheses in the study by Friedman et al. were lateralized on the humeral side whereas those in the current study were lateralized on the glenoid side. Lateralization on the humeral side may provide for a longer lever arm of deltoid action, but it is not yet clear whether or how these 2 methods of lateralization affect clinical outcomes. Nevertheless, both studies demonstrated that there is no clinically meaningful benefit to repairing the subscapularis in the setting of reverse shoulder arthroplasty.

The present study had several limitations. First, as it was a retrospective study, the patients were not randomized to groups according to subscapularis handling. This limitation may have led to a performance or selection bias, although we did not find a difference in outcomes according to surgeon. Second, as in other studies that have evaluated the effect of repair of the subscapularis on outcomes after reverse shoulder arthroplasty[13,34], the decision to repair was based on the surgeon's assessment of whether or not the tendon was of sufficient quality and excursion to be successfully repaired. This limitation also introduces a possible selection bias. However, this surgeon-based decision may reflect the everyday clinical decision-making of surgeons who perform this procedure. Third, we did not evaluate the postoperative integrity of the subscapularis at the time of the latest follow-up. It is possible that some of the subscapularis repairs failed, which may have altered the outcomes in the repair group overall. However, this clinical scenario would likely be generalizable as well and would not necessarily affect a surgeon's decision whether to repair the subscapularis (as he or she would likely expect a similar, although undefined, retear rate). To our knowledge, no other study has evaluated the structural results after reverse shoulder arthroplasty to determine the effect of an intact and healed subscapularis on outcomes.

Overall, the results of the current study indicate that repair of the subscapularis affords no advantage in terms of patient outcomes, range of motion, or complication rates in the setting of a lateralized reverse shoulder arthroplasty design. We therefore no longer routinely recommend subscapularis repair for patients undergoing a lateralized reverse shoulder arthroplasty. These results should not be generalized to medialized (Grammont-style) designs as the mechanics are not interchangeable. Longer-term study is warranted to further investigate what role the subscapularis may play in determining the outcomes of reverse shoulder arthroplasty. ■

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References

1. Day JS, Paxton ES, Lau E, Gordon VA, Abboud JA, Williams GR. Use of reverse total shoulder arthroplasty in the Medicare population. J Shoulder Elbow Surg. 2015 May;24(5):766-72. Epub 2015 Feb 18.

2. Flatow EL, Harrison AK. A history of reverse total shoulder arthroplasty. Clin Orthop Relat Res. 2011 Sep;469(9):2432-9.

3. Nyffeler RW, Werner CM, Gerber C. Biomechanical relevance of glenoid component positioning in the reverse Delta III total shoulder prosthesis. J Shoulder Elbow Surg. 2005 Sep-Oct;14(5):524-8.

4. Gerber C, Pennington SD, Lingenfelter EJ, Sukthankar A. Reverse Delta-III total shoulder replacement combined with latissimus dorsi transfer. A preliminary report. J Bone Joint Surg Am. 2007 May;89(5):940-7.

5. Grammont PM, Baulot E. Delta shoulder prosthesis for rotator cuff rupture. Orthopedics. 1993 Jan;16(1):65-8.

6. Boulahia A, Edwards TB, Walch G, Baratta RV. Early results of a reverse design prosthesis in the treatment of arthritis of the shoulder in elderly patients with a large rotator cuff tear. Orthopedics. 2002 Feb;25(2):129-33.

7. Boileau P, Watkinson D, Hatzidakis AM, Hovorka I. Neer Award 2005: The Grammont reverse shoulder prosthesis: results in cuff tear arthritis, fracture sequelae, and revision arthroplasty. J Shoulder Elbow Surg. 2006 Sep-Oct;15(5):527-40.

8. Lévigne C, Boileau P, Favard L, Garaud P, Molé D, Sirveaux F, Walch G. Scapular notching in reverse shoulder arthroplasty. J Shoulder Elbow Surg. 2008 Nov-Dec;17(6):925-35. Epub 2008 Jun 16.

9. Simovitch RW, Zumstein MA, Lohri E, Helmy N, Gerber C. Predictors of scapular notching in patients managed with the Delta III reverse total shoulder replacement. J Bone Joint Surg Am. 2007 Mar;89(3):588-600.

10. Boileau P, Chuinard C, Roussanne Y, Bicknell RT, Rochet N, Trojani C. Reverse shoulder arthroplasty combined with a modified latissimus dorsi and teres major tendon transfer for shoulder pseudoparalysis associated with dropping arm. Clin Orthop Relat Res. 2008 Mar;466(3):584-93. Epub 2008 Jan 25.

11. Favre P, Loeb MD, Helmy N, Gerber C. Latissimus dorsi transfer to restore external rotation with reverse shoulder arthroplasty: a biomechanical study. J Shoulder Elbow Surg. 2008 Jul-Aug;17(4):650-8. Epub 2008 Apr 21.

12. Boileau P, Watkinson DJ, Hatzidakis AM, Balg F. Grammont reverse prosthesis: design, rationale, and biomechanics. J Shoulder Elbow Surg. 2005 Jan-Feb;14(1)(Suppl S):147S-61S.

13. Edwards TB, Williams MD, Labriola JE, Elkousy HA, Gartsman GM, O'Connor DP. Subscapularis insufficiency and the risk of shoulder dislocation after reverse shoulder arthroplasty. J Shoulder Elbow Surg. 2009 Nov-Dec;18(6):892-6. Epub 2009 Mar 17.

14. Walker M, Brooks J, Willis M, Frankle M. How reverse shoulder arthroplasty works. Clin Orthop Relat Res. 2011 Sep;469(9):2440-51.

15. Greiner S, Schmidt C, Herrmann S, Pauly S, Perka C. Clinical performance of lateralized versus non-lateralized reverse shoulder arthroplasty: a prospective randomized study. J Shoulder Elbow Surg. 2015 Sep;24(9):1397-404. Epub 2015 Jul 7.

16. Gutiérrez S, Levy JC, Lee WE 3rd, Keller TS, Maitland ME. Center of rotation affects abduction range of motion of reverse shoulder arthroplasty. Clin Orthop Relat Res. 2007 May;458(458):78-82.

17. Gutiérrez S, Comiskey CA 4th, Luo ZP, Pupello DR, Frankle MA. Range of impingement-free abduction and adduction deficit after reverse shoulder arthroplasty. Hierarchy of surgical and implant-design-related factors. J Bone Joint Surg Am. 2008 Dec;90(12):2606-15.

18. Greiner S, Schmidt C, König C, Perka C, Herrmann S. Lateralized reverse shoulder arthroplasty maintains rotational function of the remaining rotator cuff. Clin Orthop Relat Res. 2013 Mar;471(3):940-6. Epub 2012 Dec 1.

19. Valenti P, Sauzières P, Katz D, Kalouche I, Kilinc AS. Do less medialized reverse shoulder prostheses increase motion and reduce notching? Clin Orthop Relat Res. 2011 Sep;469(9):2550-7.

20. Mulieri P, Dunning P, Klein S, Pupello D, Frankle M. Reverse shoulder arthroplasty for the treatment of irreparable rotator cuff tear without glenohumeral arthritis. J Bone Joint Surg Am. 2010 Nov 03;92(15):2544-56.

21. Cuff D, Pupello D, Virani N, Levy J, Frankle M. Reverse shoulder arthroplasty for the treatment of rotator cuff deficiency. J Bone Joint Surg Am. 2008 Jun;90(6):1244-51.

22. Boileau P, Moineau G, Roussanne Y, O'Shea K. Bony increased-offset reversed shoulder arthroplasty: minimizing scapular impingement while maximizing glenoid fixation. Clin Orthop Relat Res. 2011 Sep;469(9):2558-67.

23. Roche C, Flurin PH, Wright T, Crosby LA, Mauldin M, Zuckerman JD. An evaluation of the relationships between reverse shoulder design parameters and range of motion, impingement, and stability. J Shoulder Elbow Surg. 2009 Sep-Oct;18(5):734-41. Epub 2009 Feb 27.

24. Clark JC, Ritchie J, Song FS, Kissenberth MJ, Tolan SJ, Hart ND, Hawkins RJ. Complication rates, dislocation, pain, and postoperative range of motion after reverse shoulder arthroplasty in patients with and without repair of the subscapularis. J Shoulder Elbow Surg. 2012 Jan;21(1):36-41. Epub 2011 Jul 31.

25. Frankle M, Siegal S, Pupello D, Saleem A, Mighell M, Vasey M. The Reverse Shoulder Prosthesis for glenohumeral arthritis associated with severe rotator cuff deficiency. A minimum two-year follow-up study of sixty patients. J Bone Joint Surg Am. 2005 Aug;87(8):1697-705.

26. Guery J, Favard L, Sirveaux F, Oudet D, Mole D, Walch G. Reverse total shoulder arthroplasty. Survivorship analysis of eighty replacements followed for five to ten years. J Bone Joint Surg Am. 2006 Aug;88(8):1742-7.

27. Seebauer L, Walter W, Keyl W. Reverse total shoulder arthroplasty for the treatment of defect arthropathy. Oper Orthop Traumatol. 2005 Feb;17(1):1-24.

28. Sirveaux F, Favard L, Oudet D, Huquet D, Walch G, Molé D. Grammont inverted total shoulder arthroplasty in the treatment of glenohumeral osteoarthritis with massive rupture of the cuff. Results of a multicentre study of 80 shoulders. J Bone Joint Surg Br. 2004 Apr;86(3):388-95.

29. Wall B, Nové-Josserand L, O'Connor DP, Edwards TB, Walch G. Reverse total shoulder arthroplasty: a review of results according to etiology. J Bone Joint Surg Am. 2007 Jul;89(7):1476-85.

30. Wierks C, Skolasky RL, Ji JH, McFarland EG. Reverse total shoulder replacement: intraoperative and early postoperative complications. Clin Orthop Relat Res. 2009 Jan;467(1):225-34. Epub 2008 Aug 7.

31. de Boer FA, van Kampen PM, Huijsmans PE. The influence of subscapularis tendon reattachment on range of motion in reversed shoulder arthroplasty: a clinical study. Musculoskelet Surg. 2016 Aug;100(2):121-6. Epub 2016 Mar 16.

32. Onstot BRSA, Colley R, Jacofsky MC, Otis JC, Hansen ML. Consequences of concomitant subscapularis repair with reverse total shoulder arthroplasty. Read at the Orthopaedic Research Society Annual Meeting; 2012 Feb 4-7; San Francisco, CA.

33. Routman HD. The role of subscapularis repair in reverse total shoulder arthroplasty. Bull Hosp Jt Dis (2013). 2013;71(Suppl 2)(Suppl 2):108-12.

34. Friedman RJ, Flurin PH, Wright TW, Zuckerman JD, Roche CP. Comparison of reverse total shoulder arthroplasty outcomes with and without subscapularis repair. J Shoulder Elbow Surg. 2017 Apr;26(4):662-8. Epub 2016 Oct 27.