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Impact of scapular notching on reverse total shoulder arthroplasty midterm outcomes: 5-year minimum follow-up

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Background: The impact of scapula notching on reverse total shoulder arthroplasty (rTSA) clinical outcomes is controversial. The purpose of this study was to conduct a sufficiently statistically powered analysis to quantify the impact of scapular notching on midterm rTSA outcomes.

Methods: There were 324 rTSA patients with 5 years of minimum follow-up evaluated. Patients were stratified according to the presence of a scapular notch at latest follow-up; radiographs were also assessed at each time point for patients with notching to determine the time for notch grade development. A 2-tailed, unpaired *t*-test compared preoperative, postoperative, and preoperative to postoperative outcomes between cohorts.

Results: There were 324 patients having an average follow-up of 75.1 months assessed; 47 (14.5%) patients had scapular notching. For scapular notching patients, the average notching grade was 1.7 ± 0.8 (24 grade 1, 15 grade 2, and 8 grade 3). The average time to notch development was 51.4 ± 24.1 months; grade 1, grade 2, and grade 3 notches developed at 49.0 ± 22.1 months, 57.5 ± 22.6 months, and 71.6 ± 15.8 months, respectively. No preoperative differences were observed between cohorts. At latest follow-up, scapular notching patients had significantly worse outcome scores and significantly less active abduction, forward flexion, and strength. Finally, scapular notching patients had significantly more complications, revisions, and humeral radiolucent lines.

Conclusions: Scapular notching patients had significantly worse clinical outcomes and less range of motion than patients without scapular notching; these differences exceeded the minimal clinically important difference threshold for several outcome metrics. Based on these results, we recommend minimizing scapular notching through patient and implant selection and technique modification.

Western Institutional Review Board approval was obtained for this outcome study (Tracking #20091701; Protocol #CR09-005).

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The indications of reverse total shoulder arthroplasty (rTSA) have evolved substantially since Paul Grammont introduced his medialized center of rotation design in the 1980s to treat patients with rotator cuff tear arthropathy.[3,5,31] Over the years, indications have grown to include irreparable rotator cuff dysfunction,[3,5,10] acute fractures,[1,19,39] fracture sequelae,[5,39] tumors around the shoulder,[6] inflammatory arthropathy with an irreparable rotator cuff tear,[24] and revision arthroplasty.[5,31] Whereas clinical results have been good, complications and survivorship continue to be a concern. Favard et al[8] reported on rTSA survivorship and demonstrated survivorship (using removal of the prosthesis or conversion to a hemiarthroplasty as an end point) of 89% at 10 years with a break in the curve at 2 years and 9 years; however, 10-year survivorship was only 72% using a drop to a Constant-Murley score <30 points. They also reported an 18% complication rate. Other studies have cited complication rates between 3% and 22%.[11,15]

One rTSA complication that is documented throughout the literature is scapular notching. This phenomenon is unique to rTSA and results from the mechanical impingement of the polyethylene humeral liner against the inferior glenoid and lateral scapula, causing bone loss and polyethylene wear. Notching can be progressive and extend beyond the most inferior screw, suggesting that an osteolytic response can occur in addition to the mechanical impingement. Previous studies have demonstrated that prosthesis design parameters, patient attributes, and surgical technique predispose to scapular notching.[7,16,23,25,26,33] As a result, surgeons often use specific implantation methods, even employing glenoid bone grafting techniques to minimize notching in designs that are prone to notching.[4,14]

The precise effect of scapular notching is unclear. One biomechanical study demonstrated that scapular notching can impair baseplate fixation, which may limit glenoid baseplate bone ingrowth.[28] Another study raised concerns about instability and failure due to notching of the polyethylene.[22] The clinical effect of scapular notching after rTSA has been controversial; some studies identified a negative clinical impact,[18,21,29,33,34,37] whereas others concluded that it has no effect on clinical outcomes.[5,17,36,40] However, a study by Mollon et al[21] demonstrated that the majority of these studies were insufficiently powered to detect the clinical impact of scapular notching. This study builds on the work by Mollon et al,[21] which analyzed the impact of scapular notching in patients with 2 years of minimum follow-up. This appropriately powered study retrospectively reviewed the same database to determine whether scapular notching negatively affects clinical outcomes at 5 years of minimum follow-up.

Materials and methods

An international multicenter database composed of operations performed by 9 shoulder fellowship–trained surgeons collected from 2007 through the present time was used in this midterm outcome study. The database records patient demographics, indications, surgical technique and implant information, preoperative and postoperative functional scores and other patient-reported outcome measures, radiographic outcomes, and intraoperative and postoperative complications. All patients within the database had an rTSA using the same platform prosthesis (Equinoxe; Exactech, Inc., Gainesville, FL, USA). To limit this study to patients with midterm (5-year minimum) follow-up, only patients entered into the database before 2014 were included. Patients with a revision arthroplasty, history of infection, acute fracture, and fracture sequelae were excluded. Patients with a diagnosis of osteoarthritis, osteoarthritis or inflammatory arthritis with rotator cuff tear, and cuff tear arthropathy were included. These criteria yielded 324 rTSA cases (67.6% [219/324] female patients and 32.4% [105/324] male patients), having a mean follow-up of 75.1 ± 16.9 months (range, 60-132 months) and a mean age at the time of surgery of 72.0 ± 7.0 years (range, 38-89 years).

All operations were performed through a deltopectoral approach. Intraoperatively, each surgeon made a decision to cement or to press-fit the humerus, depending on preference and evaluation of bone quality; 84.6% of humeral stems were press-fit and 15.4% were cemented. Similarly, glenosphere size was determined on the basis of preoperative templating and intraoperative trialing. Specifically, 191 patients (170 women and 21 men) received a 38×21-mm glenosphere, 3 patients (3 women) received a 38×25-mm glenosphere, 103 patients (37 women and 66 men) received a 42×23-mm glenosphere, 6 patients (2 women and 4 men) received a 42×27-mm glenosphere, and 12 patients (1 woman and 11 men) received a 46×25-mm glenosphere. Glenosphere sizes for 9 patients were not documented. Standard humeral polyethylene liners were implanted in 309 patients (205 women and 104 men), whereas 15 patients (14 women and 1 man) received constrained liners. During implantation, each surgeon placed the glenoid baseplate in an inferiorly biased position to ensure that the lowest portion of the glenosphere was 2 to 3 mm more inferior than the inferior glenoid rim. The authors did not routinely palpate for mechanical impingement between the glenoid component and the inferior glenoid with the arm adducted.

All patients underwent assessment using the same metrics preoperatively and at latest follow-up, which were administered by the treating surgeon or the surgeon's surrogate. These metrics included the shoulder function score (0-10), American Shoulder and Elbow Surgeons score, Constant score, Shoulder Pain and Disability Index, Simple Shoulder Test (SST), and University of

California–Los Angeles (UCLA) score. In addition, patients were evaluated for active range of motion (ROM), including forward flexion, abduction, external rotation, and internal rotation. Forward flexion, abduction, and external rotation were evaluated as continuous variables in 1° increments. Internal rotation was standardized by an 8-point numeric scale[9] with the following discrete assignments based on motion to vertebral segments: 0° = 0; hip = 1; buttocks = 2; sacrum = 3; L5-L4 = 4; L3-L1 = 5; T12-T8 = 6; T7 or higher = 7.

Radiographic assessment was performed at the time of latest follow-up. Anteroposterior (AP), scapular Y, and axillary lateral views were obtained for all patients. Each implanting surgeon identified the presence or absence of a scapular notch and indicated the grade of notching by the Nerot-Sirveaux classification[34]; in addition, humeral radiolucency was scored according to the 8 zones described by Sperling et al.[35] For patients with scapular notching, radiographic data from every postoperative visit were assessed to identify the time of scapular notch development and also to quantify the follow-up duration associated with each scapular notch grade. Statistical analysis was conducted using a 2-tailed unpaired *t*-test to identify differences in preoperative and postoperative outcomes and preoperative to postoperative improvement between cohorts; a P value of $< .05$ was deemed significant. A post hoc power analysis was also conducted for this midterm comparative outcome study.

Results

At midterm follow-up, scapular notching was observed in 14.5% (47/324) of rTSA patients. Notching was more likely in patients with a lower body weight (notching, 69 ± 14 kg; no notching, 77 ± 16 kg; $P = .0013$), shorter height (notching, 160 ± 11 cm; no notching, 164 ± 10 cm; $P = .0234$), and lower body mass index (BMI; notching, 26.7 ± 4.3 kg/m^2; no notching, 28.5 ± 5.3 kg/m^2; $P = .0250$). No difference was observed between patient age (notching, 72.2 ± 6.2 years; no notching, 72.0 ± 7.1 years; $P = .8367$), length of follow-up (notching, 77.0 ± 16.2 months; no notching, 74.8 ± 17.1 months; $P = .3999$), or sex ratio (notching, 23% male/77% female; no notching, 34% male/66% female; $P = .1547$).

At latest follow-up, 51% (24/47) of patients with scapular notching had a Nerot-Sirveaux grade 1 notch, 32% (15/47) had a grade 2 notch, and 17% (8/47) had a grade 3 notch; no patients had a grade 4 notch. The average time to notch development was 51.4 ± 24.1 months; grade 1 notches developed at 49.0 ± 22.1 months, grade 2 notches developed at 57.5 ± 22.6 months, and grade 3 notches developed at 71.6 ± 15.8 months. Despite an increase in follow-up duration associated with notching grades, scapular notching was observed to be progressive only in 9 patients; by comparison, scapular notching grade did not progress in 21 patients, and the scapular notch was observed for the first time on the latest follow-up radiograph in 17 patients. Female and male patients were observed to have a similar notching rate (female patients, 36/219 [16.4%]; male patients, 11/105 [10.5%]; $P = .1547$). However, female patients were observed to have a higher scapular notching grade than male patients (female patients, 0.30; male patients, 0.11; $P = .0154$). Sex use differences were observed with implant size; 81.2% of female patients received a 38-mm glenosphere and 79.4% of male patients received a 42-mm glenosphere or larger. Despite these differences in sex use, scapular notching rates were similar across glenosphere sizes. Specifically, 14.7% (28/191 patients; 26/170 women [15.3%]; 2/21 men [9.5%]) who received a 38×21-mm glenosphere notched, 33.3% (1/3 patients; 1/3 women) who received a 38×25-mm glenosphere notched, 16.5% (17/103 patients; 9/37 women [24.3%]; 8/66 men [12.1%]) who received a 42×23-mm glenosphere notched, 0% (0/6 patients; 2 women and 4 men) who received a 42×27-mm glenosphere notched, and 8.3% (1/12 patients; 1/11 men [9.1%]) who received a 46×25-mm glenosphere notched.

No preoperative differences were observed in any outcome metric or ROM measurement between patients who would or would not go on to develop scapular notching (Table I). Analysis of the entire cohort of patients demonstrated that rTSA provided significant mean improvements in every ROM measurement and functional outcome score, regardless of the presence of a scapular notch. However, at latest follow-up, patients with scapular notching had significantly worse outcomes according to 4 of 6 metric scores and significantly less active abduction, forward flexion, and strength compared with patients without scapular notching (Table II). Furthermore, at latest follow-up, patients with scapular notching had significantly less mean improvement in preoperative to postoperative outcomes in the Constant score and strength (Table III).

There were 37 complications (11.4%) reported; 26 complications occurred in patients without scapular notching, and 11 complications occurred in patients with scapular notching. Seven of the 11 complications occurred in patients with a grade 2 or grade 3 notch, whereas only 4 occurred in patients with a grade 1 notch. In addition, 9 patients required revision (2.8%); 4 revisions occurred in patients without scapular notching, and 5 revisions occurred in patients with scapular notching. Of the revisions that occurred in the notching cohort, 4 of the 5 revisions occurred in patients with grade 2 or grade 3 notching, whereas only 1 occurred in a patient with grade 1 notching (Table IV). Patients with scapular notching had a significantly higher complication rate (23.4% vs 9.4%; $P = .0051$) and a significantly higher revision rate (10.6 vs 1.4%; $P = .0004$) compared with patients without scapular notching. Finally, 51 patients had radiolucent humeral lines; 38 radiolucent humeral lines were reported for patients without scapular notching and 13 were reported for patients with scapular notching; patients with scapular notching had a significantly higher radiolucent humeral line rate compared with patients without notching (13.8% vs 27.7%; $P = .0157$).

Table I Comparison of overall preoperative outcomes for reverse total shoulder arthroplasty patients who would and would not go on to develop scapular notching

Preoperative outcomes	Shoulder function	ASES score	Constant score	New SPADI	SST score	UCLA score	Active abduction (°)	Active forward flexion (°)	Active external rotation (°)	Internal rotation score	Strength (lb)
No notching	3.8 ± 2.2	36.4 ± 17.2	35.1 ± 14.5	82.5 ± 25.0	3.6 ± 3.0	13.7 ± 4.4	77 ± 36	90 ± 42	21 ± 24	3.4 ± 1.8	1.5 ± 2.7
Notching	3.5 ± 1.8	33.6 ± 14.9	34.2 ± 14.7	81.4 ± 20.1	3.0 ± 2.0	13.2 ± 4.2	70 ± 31	90 ± 43	16 ± 19	3.3 ± 1.9	1.3 ± 2.8
P value	.4505	.3530	.7397	.8107	.2890	.5798	.2555	.9378	.2328	.6036	.7472

ASES, American Shoulder and Elbow Surgeons; *SPADI*, Shoulder Pain and Disability Index; *SST*, Simple Shoulder Test; *UCLA*, University of California Los Angeles.

Table II Comparison of overall postoperative outcomes at midterm follow-up after reverse total shoulder arthroplasty for shoulders with and without scapular notching

Postoperative outcomes	Shoulder function	ASES score	Constant score	New SPADI	SST score	UCLA score	Active abduction (°)	Active forward flexion (°)	Active external rotation (°)	Internal rotation score	Strength (lb)
No notching	7.9 ± 2.1	79.0 ± 20.6	66.8 ± 14.7	28.5 ± 29.7	9.5 ± 2.8	29.2 ± 5.8	116 ± 29	132 ± 27	33 ± 20	4.5 ± 1.7	6.5 ± 4.8
Notching	6.9 ± 2.5	72.6 ± 25.6	58.8 ± 18.2	38.0 ± 37.9	8.4 ± 3.7	26.4 ± 7.7	96 ± 30	122 ± 39	34 ± 20	4.6 ± 1.8	4.7 ± 4.5
P value	**.0049**	.0625	**.0012**	.0584	**.0249**	**.0041**	**< .0001**	**.0403**	.6563	0.6856	**.0198**

ASES, American Shoulder and Elbow Surgeons; *SPADI*, Shoulder Pain and Disability Index; *SST*, Simple Shoulder Test; *UCLA*, University of California Los Angeles.
Bold values indicate a significant difference denoted by a *P* value < .05.

Table III Comparison of midterm clinical improvements after reverse total shoulder arthroplasty for shoulders with and without scapular notching

Preoperative to postoperative improvement	Shoulder function	ASES score	Constant score	New SPADI	SST score	UCLA score	Active abduction (°)	Active forward flexion (°)	Active external rotation (°)	Internal rotation score	Strength (lb)
No notching	+3.9 ± 2.8	+42.9 ± 22.2	+31.6 ± 17.4	-52.9 ± 31.2	+6.1 ± 3.6	+15.2 ± 6.4	+37 ± 41	+40 ± 44	+10 ± 27	+1.1 ± 2.1	+4.8 ± 4.4
Notching	+3.5 ± 2.8	+43.1 ± 23.6	+24.9 ± 16.9	-49.5 ± 33.8	+5.8 ± 3.6	+13.5 ± 6.8	+26 ± 40	+32 ± 42	+17 ± 22	+1.5 ± 1.9	+2.9 ± 3.4
P value	.3490	.9587	**.0466**	.5536	.6257	.1319	.0935	.2644	.1205	.2272	**.0204**

ASES, American Shoulder and Elbow Surgeons; *SPADI*, Shoulder Pain and Disability Index; *SST*, Simple Shoulder Test; *UCLA*, University of California Los Angeles.
Bold values indicate a significant difference denoted by a *P* value < .05.

Discussion

This retrospective clinical study represents the largest midterm analysis evaluating the impact of scapular notching on rTSA clinical outcomes. Our results demonstrate several factors associated with a statistically significant increase in scapular notching, including shorter stature, lower body weight, and lower BMI; sex and glenosphere size did not influence the rate of notching. Scapular notching was associated with significantly worse postoperative outcomes as it relates to shoulder function score, Constant score, SST score, UCLA score, active abduction, forward flexion, and strength. However, scapular notching was associated with significantly less improvement only in the Constant score and strength. Scapular notching was also associated with a significantly increased rate of complications, revisions, and humeral radiolucent lines compared with patients without notching at midterm follow-up.

The scapular notching rate in this series was 14.5% after a mean follow-up of 75.1 months. This rate is a departure from the 35%-96%[3,5,12,13,17,18,29,33,34,36,37,40] range of notching rates reported for other rTSA designs with a medialized center of rotation; however, this rate at midterm is consistent with other studies reporting the notching rates of this particular prosthesis.[20,21,26,27] This low notching rate is probably due to a combination of specific surgical techniques (ie, inferiorly shifting the glenosphere position to obtain inferior overhang) and prosthesis design attributes, as described previously by Roche et al.[25-28]

Scapular notching has been previously reported to be progressive and radiographically observable as early as 6 weeks after surgery with the Grammont reverse shoulder.[18] Our radiographic analysis demonstrated the average time for scapular notch development to be 51.4 ± 24.1 months. We also observed that larger grade notches took longer on average to develop (grade 1, 49.0 ± 22.1 months; grade 2, 57.5 ± 22.6 months; and grade 3, 71.6 ± 15.8 months), although only one-third of scapular notching patients experienced notching that was progressive in grade. Just as different reverse shoulder prosthesis designs have different inherent scapular notching rates,[25] our findings relative to Levigne[18] suggest that the time for scapular notch formation also varies between prosthesis designs, where prostheses with lower scapular notching rates are also associated with longer follow-up duration for notch development.

Shorter body stature, lower body weight, and lower BMI were associated with a significant increase in notching rate. A possible explanation for the increased notching rate is that patients with a lower body weight and BMI are generally more active, and this activity may result in more frequent mechanical impingement during adduction, coupled with smaller stature and lower body weight predisposing to more neutral adduction angles with the arm at the side. A previous study by Lévigne et al[18] also documented higher notching rates in more active individuals, which would lend some credence and corroboration to this theory. Previous studies of the effect of BMI on notching rate and clinical outcomes after rTSA[2,20,30,38] have been variable in their conclusions. However, these studies have grouped patients into 3 BMI subgroups instead of analyzing BMI as a continuous variable as we did. Future works should compare notching rate of different rTSA designs and account for differences in patients' weight and height as these variables can influence the rate of notching.

Table IV Comparison of complications for shoulders with and without scapular notching

Complication	No scapular notching, No. (%)	Scapular notching, No. (%)
Humeral fracture/ periprosthetic fracture	9 (3.2)	2 (4.3)
Fractured scapula/ stress fracture	6 (2.2)	2 (4.3)
Infection	3 (1.1)	1 (2.1)
Persistent pain	3 (1.1)	1 (2.1)
Aseptic glenoid loosening	2 (0.7)	3 (6.4)
Dislocation/ instability	2 (0.7)	1 (2.1)
Aseptic humeral loosening	1 (0.4)	1 (2.1)
Complication rate	9.4%	23.4%

Based on the analysis of 324 rTSA patients with 5 years of minimum follow-up, we found that patients with scapular notching had significantly lower postoperative patient-reported outcome measures, significantly less strength and ROM, and significantly higher complication and revision rates compared with patients without scapular notching. Whereas these statistical differences were small, the observed mean differences met or exceeded the minimal clinically important difference (MCID) thresholds previously established by Simovitch et al[32] for rTSA for the Constant score (MCID threshold, −0.3; observed mean difference, 8.0), global shoulder function score (MCID threshold, 1.0; observed mean difference, 1.0), active abduction (MCID threshold, −1.9°; observed mean difference, 20.0°), and active forward flexion (MCID threshold, −2.9°; observed mean difference, 10.0°), thereby objectively demonstrating that these outcome differences are clinically meaningful.

The negative impact of scapular notching on clinical outcomes is corroborated by previous studies.[18,21,29,33,34,37] Specifically, these studies have reported a negative effect of scapular notching on the Constant score,[21,29,33,34] global function score,[21] American Shoulder and Elbow Surgeons score,[21] Shoulder Pain and Disability Index,[21] SST

score,[21] UCLA score,[21] ROM,[18,21,29,33,34,37] strength,[18,21,33] and pain.[21] Other studies[5,36,40] have failed to demonstrate any effect of scapular notching on clinical outcomes; however, these studies by Boileau et al,[5] Stechel et al,[36] and Werner et al[40] reported a study power of only 41.6%, 37.1%, and 17%, respectively, according to Mollon et al.[21] The study power for this study was calculated to be 89%. The low study power of the studies[5,36,40] that failed to show an effect was due to the small number of patients in the overall cohort coupled with the high overall notching rate, leaving an insufficiently small "no notching" cohort for comparison. By comparison, our midterm outcome study relied on a large sample of patients with a low overall notching rate; this permitted a high study power with sufficient numbers in each cohort, thereby improving our ability to detect an effect of scapular notching on midterm clinical outcomes.

There are several limitations to this study. First, this is a database study composed of 9 surgeons. Therefore, by definition, there are differences between subsets of patients enrolled by different surgeons, including differences in characteristics of the patient population, subtly different implantation methods, and differences in data acquisition (ie, who interacts with the patient for data collection). However, these acquisition concerns were mitigated by standardizing format of data acquisition with use of the same forms between study sites. Second, the identification of scapular notching is the cornerstone of this study; whereas every attempt was made to standardize the identification of notching and properly grade each notch, a single AP radiograph was used and fluoroscopy was not employed. This could allow some inaccuracy in identification as Lévigne et al[18] reported that only 89% of the scapular notches were observable in an AP radiograph because of imprecision in positioning of the patient. Also, the implanting surgeons reviewed their own radiographs to evaluate notching; this introduced a potential for bias. Finally, this database did not record preoperative glenoid erosion or version and did not identify humeral version. Previous studies have demonstrated that glenoid erosion[18,34] and version[16] can predispose to notching. Future studies should attempt to record preoperative radiographic attributes that may predispose to notching and also affect clinical results.

Conclusion

This midterm clinical outcome study demonstrates that patients with scapular notching had significantly worse clinical outcomes and significantly greater complication and revision rates compared with patients without scapular notching. These statistical differences are demonstrated to be clinically meaningful as they exceeded the MCID threshold for the Constant and global shoulder function outcome metrics and also for active abduction and forward flexion. Based on these midterm clinical outcome results, we recommend that surgeons minimize the risk of scapular notching through appropriate patient and implant selection and technique modification.

Disclaimer

Ryan Simovitch is a consultant for Exactech, Inc.

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References

1. Acevedo DC, VanBeek C, Lazarus MD, Williams GR, Abboud JA. Reverse shoulder arthroplasty for proximal humeral fractures: update on indications, technique, and results. J Shoulder Elbow Surg 2014;23:279-89. https://doi.org/10.1016/j.jse.2013.10.003
2. Anakwenze O, Fokin A, Chocas M, Dillon MT, Navarro RA, Yian EH, et al. Complications in total shoulder and reverse total shoulder arthroplasty by body mass index. J Shoulder Elbow Surg 2017;26:1230-7. https://doi.org/10.1016/j.jse.2016.11.055
3. Boileau P, Gonzalez JF, Chuinard C, Bicknell R, Walch G. Reverse total shoulder arthroplasty after failed rotator cuff surgery. J Shoulder Elbow Surg 2009;18:600-6. https://doi.org/10.1016/j.jse.2009.03.011
4. 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;469:2558-67. https://doi.org/10.1007/s11999-011-1775-4
5. 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;15:527-40. https://doi.org/10.1016/j.jse.2006.01.003
6. De Wilde LF, Plasschaert FS, Audenaert EA, Verdonk RC. Functional recovery after a reverse prosthesis for reconstruction of the proximal humerus in tumor surgery. Clin Orthop Relat Res 2005:156-62.
7. Falaise V, Levigne C, Favard L, SOFEC. Scapular notching in reverse shoulder arthroplasties: the influence of glenometaphyseal angle. Orthop Traumatol Surg Res 2011;97:S131-7. https://doi.org/10.1016/j.otsr.2011.06.007
8. Favard L, Levigne C, Nerot C, Gerber C, De Wilde L, Mole D. Reverse prostheses in arthropathies with cuff tear: are survivorship and function maintained over time? Clin Orthop Relat Res 2011;469:2469-75. https://doi.org/10.1007/s11999-011-1833-y
9. Flurin PH, Marczuk Y, Janout M, Wright TW, Zuckerman J, Roche CP. Comparison of outcomes using anatomic and reverse total shoulder arthroplasty. Bull Hosp Jt Dis (2013) 2013;71(Suppl 2):101-7.
10. Gerber C, Canonica S, Catanzaro S, Ernstbrunner L. Longitudinal observational study of reverse total shoulder arthroplasty for irreparable rotator cuff dysfunction: results after 15 years. J Shoulder Elbow Surg 2018;27:831-8. https://doi.org/10.1016/j.jse.2017.10.037

11. Groh GI, Groh GM. Complications rates, reoperation rates, and the learning curve in reverse shoulder arthroplasty. J Shoulder Elbow Surg 2014;23:388-94. https://doi.org/10.1016/j.jse.2013.06.002
12. Karelse AT, Bhatia DN, De Wilde LF. Prosthetic component relationship of the reverse Delta III total shoulder prosthesis in the transverse plane of the body. J Shoulder Elbow Surg 2008;17:602-7. https://doi.org/10.1016/j.jse.2008.02.005
13. Kempton LB, Balasubramaniam M, Ankerson E, Wiater JM. A radiographic analysis of the effects of glenosphere position on scapular notching following reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2011;20:968-74. https://doi.org/10.1016/j.jse.2010.11.026
14. Kirzner N, Paul E, Moaveni A. Reverse shoulder arthroplasty vs BIO-RSA: clinical and radiographic outcomes at short term follow-up. J Orthop Surg Res 2018;13:256. https://doi.org/10.1186/s13018-018-0955-2
15. Klein SM, Dunning P, Mulieri P, Pupello D, Downes K, Frankle MA. Effects of acquired glenoid bone defects on surgical technique and clinical outcomes in reverse shoulder arthroplasty. J Bone Joint Surg Am 2010;92:1144-54. https://doi.org/10.2106/JBJS.I.00778
16. Kolmodin J, Davidson IU, Jun BJ, Sodhi N, Subhas N, Patterson TE, et al. Scapular notching after reverse total shoulder arthroplasty: prediction using patient-specific osseous anatomy, implant location, and shoulder motion. J Bone Joint Surg Am 2018;100:1095-103. https://doi.org/10.2106/JBJS.17.00242
17. Lévigne C, Boileau P, Favard L, Garaud P, Molé D, Sirveaux F, et al. Scapular notching in reverse shoulder arthroplasty. J Shoulder Elbow Surg 2008;17:925-35. https://doi.org/10.1016/j.jse.2008.02.010
18. Lévigne C, Garret J, Boileau P, Alami G, Favard L, Walch G. Scapular notching in reverse shoulder arthroplasty: is it important to avoid it and how? Clin Orthop Relat Res 2011;469:2512-20. https://doi.org/10.1007/s11999-010-1695-8
19. Martin TG, Iannotti JP. Reverse total shoulder arthroplasty for acute fractures and failed management after proximal humeral fractures. Orthop Clin North Am 2008;39:451-7. https://doi.org/10.1016/j.ocl.2008.06.006. vi.
20. Mau EM, Roche CP, Zuckerman JD. Effects of body mass index on outcomes in total shoulder arthroplasty. Bull Hosp Jt Dis (2013) 2015;73(Suppl 1):S99-106.
21. Mollon B, Mahure SA, Roche CP, Zuckerman JD. Impact of scapular notching on clinical outcomes after reverse total shoulder arthroplasty: an analysis of 476 shoulders. J Shoulder Elbow Surg 2017;26:1253-61. https://doi.org/10.1016/j.jse.2016.11.043
22. Nam D, Kepler CK, Nho SJ, Craig EV, Warren RF, Wright TM. Observations on retrieved humeral polyethylene components from reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2010;19:1003-12. https://doi.org/10.1016/j.jse.2010.05.014
23. Nyffeler RW, Werner CM, Simmen BR, Gerber C. Analysis of a retrieved Delta III total shoulder prosthesis. J Bone Joint Surg Br 2004;86:1187-91.
24. Rittmeister M, Kerschbaumer F. Grammont reverse total shoulder arthroplasty in patients with rheumatoid arthritis and nonreconstructible rotator cuff lesions. J Shoulder Elbow Surg 2001;10:17-22.
25. 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;18:734-41. https://doi.org/10.1016/j.jse.2008.12.008
26. Roche CP, Marczuk Y, Wright TW, Flurin PH, Grey S, Jones R, et al. Scapular notching and osteophyte formation after reverse shoulder replacement: radiological analysis of implant position in male and female patients. Bone Joint J 2013;95-B:530-5. https://doi.org/10.1302/0301-620X.95B4.30442
27. Roche CP, Marczuk Y, Wright TW, Flurin PH, Grey SG, Jones RB, et al. Scapular notching in reverse shoulder arthroplasty: validation of a computer impingement model. Bull Hosp Jt Dis (2013) 2013;71:278-83.
28. Roche CP, Stroud NJ, Martin BL, Steiler CA, Flurin PH, Wright TW, et al. The impact of scapular notching on reverse shoulder glenoid fixation. J Shoulder Elbow Surg 2013;22:963-70. https://doi.org/10.1016/j.jse.2012.10.035
29. Sadoghi P, Leithner A, Vavken P, Hölzer A, Hochreiter J, Weber G, et al. Infraglenoidal scapular notching in reverse total shoulder replacement: a prospective series of 60 cases and systematic review of the literature. BMC Musculoskelet Disord 2011;12:101. https://doi.org/10.1186/1471-2474-12-101
30. Savin DD, Frank RM, Sumner S, Richardson C, Nicholson GP, Romeo AA. Good functional outcomes expected after shoulder arthroplasty irrespective of body mass index. J Shoulder Elbow Surg 2018;27(6S):S43-9. https://doi.org/10.1016/j.jse.2018.03.022
31. Shields EJ, Koueiter DM, Maerz T, Schwark A, Wiater JM. Previous rotator cuff repair is associated with inferior clinical outcomes after reverse total shoulder arthroplasty. Orthop J Sports Med 2017;5. https://doi.org/10.1177/2325967117730311. 2325967117730311.
32. Simovitch R, Flurin PH, Wright T, Zuckerman JD, Roche CP. Quantifying success after total shoulder arthroplasty: the minimal clinically important difference. J Shoulder Elbow Surg 2018;27:298-305. https://doi.org/10.1016/j.jse.2017.09.013
33. 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;89:588-600. https://doi.org/10.2106/JBJS.F.00226
34. 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;86:388-95.
35. Sperling JW, Cofield RH, O'Driscoll SW, Torchia ME, Rowland CM. Radiographic assessment of ingrowth total shoulder arthroplasty. J Shoulder Elbow Surg 2000;9:507-13.
36. Stechel A, Fuhrmann U, Irlenbusch L, Rott O, Irlenbusch U. Reversed shoulder arthroplasty in cuff tear arthritis, fracture sequelae, and revision arthroplasty. Acta Orthop 2010;81:367-72. https://doi.org/10.3109/17453674.2010.487242
37. Torrens C, Santana F, Picazo B, Caceres E. Retrospective study of scapular notches in reverse shoulder arthroplasties. Am J Orthop (Belle Mead NJ) 2013;42:362-5.
38. Wagner ER, Houdek MT, Schleck C, Harmsen WS, Sanchez-Sotelo J, Cofield R, et al. Increasing body mass index is associated with worse outcomes after shoulder arthroplasty. J Bone Joint Surg Am 2017;99:929-37. https://doi.org/10.2106/JBJS.15.00255
39. Wall B, Walch G. Reverse shoulder arthroplasty for the treatment of proximal humeral fractures. Hand Clin 2007;23:425-30. https://doi.org/10.1016/j.hcl.2007.08.002. v-vi.
40. Werner CM, Steinmann PA, Gilbart M, Gerber C. Treatment of painful pseudoparesis due to irreparable rotator cuff dysfunction with the Delta III reverse-ball-and-socket total shoulder prosthesis. J Bone Joint Surg Am 2005;87:1476-86. https://doi.org/10.2106/JBJS.D.02342