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Does lateralizing the glenosphere center of rotation by 4 mm decrease scapular notching in reverse shoulder arthroplasty with a 135° humeral component?

Samuel M. Harmsen, MD[a,b,*], Joey Robaina, MD[b], David Campbell, MD[b], Patrick J. Denard, MD[c,d], Reuben Gobezie, MD[e], Evan S. Lederman, MD[b,f]

[a]TOCA at Banner Health, Phoenix, AZ, USA
[b]The University of Arizona College of Medicine, Phoenix, AZ, USA
[c]Southern Oregon Orthopedics, Medford, OR, USA
[d]Department of Orthopedics and Rehabilitation, Oregon Health & Science University, Portland, OR, USA
[e]The Cleveland Shoulder Institute, Cleveland, OH, USA
[f]Banner Health, Phoenix, AZ, USA

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Background: Scapular notching continues to be associated with reverse shoulder arthroplasty (RSA) and is thought to lead to fewer outcomes. Decreasing the humeral neck-shaft angle (NSA) has been associated with decreased incidence of scapular notching. Lateralizing the glenosphere center of rotation (COR) has also been proposed to decrease notching; however, its effect in lower NSA RSA is less understood. The purpose of this study was to compare the impact of the medial (0 mm) and lateral (4 mm) COR on the incidence of scapular notching and clinical outcomes after RSA with a 135° NSA humeral component.

Methods: We performed a multicenter retrospective comparative cohort of 82 patients with cuff tear arthropathy (41 in each cohort) who underwent RSA with a 135° NSA humeral component and a glenosphere COR of either 0 mm (medialized COR [MCOR]) or 4 mm (lateralized COR [LCOR]) of lateralization. RSA was performed using the same 135° humeral system and baseplate design. All patients had 2-year radiographic and clinical follow-up. Postoperative radiographs were evaluated for scapular notching. Clinical outcomes included American Shoulder and Elbow Surgeons scores, visual analog pain scale, Simple Assessment Numeric Evaluation, and active range of motion.

Results: The overall incidence of scapular notching was 22.0%. There was no significant difference in scapular notching between cohorts: 24.4% in the MCOR and 19.5% in the LCOR ($P = .625$). Both cohorts had significant improvements in American Shoulder and Elbow Surgeons scores, visual analog pain scale, Simple Assessment Numeric Evaluation, and active range of motion postoperatively ($P < .005$). Improvements did not significantly differ between cohorts. The presence of scapular notching did not have a significant negative effect on any clinical outcome measure. Complications occurred in 5 patients (2 MCORs and 3 LCORs), none of which occurred in patients with scapular notching.

Discussion and conclusion: Lateralizing the glenosphere COR by 4 mm does not significantly affect the incidence of scapular notching in RSA when using a 135° NSA humeral component at short-term follow-up. Furthermore, such offset does not significantly improve functional outcome scoring systems or range of motion when compared with the MCOR (0 mm). Scapular notching did not have a negative impact on any clinical outcome measure or complication rate in this series.

Reverse shoulder arthroplasty (RSA) has proven to be a safe and effective treatment for patients with cuff tear arthropathy.[4-6,9,31] Pain relief and improved patient function have been established as predictable outcomes in most patients after RSA and appear to be maintained through long-term follow-up.[4,6,9,31] Improvements in implant design and surgical techniques are thought to have decreased complication rates and improved patient outcomes;

This study was approved by the Salus Institutional Review Board under protocol #608 and SOS #1.

*Corresponding author: Samuel M. Harmsen, MD, TOCA at Banner Health, 2222 E. Highland Ave. Suite 300, Phoenix, AZ 85016, USA.
E-mail address: gwsharmsen@gmail.com (S.M. Harmsen).

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however, scapular notching continues to be a commonly reported radiographic finding with RSA.[1,12,16,18,19,21,22,23,24]

Scapular notching is a term used to describe the erosive changes seen at the axillary boarder of the scapular neck in RSA. This is a multifactorial phenomenon that is most commonly attributed to mechanical impingement of the humeral component on the inferior scapular neck and lateral scapular pillar.[21,22] The literature suggests that notching can increase over time, which is thought to be attributed to polyethylene wear resulting in osteolysis.[4,5] The clinical impact of scapular notching shows disagreement, with some studies suggesting no negative impact on outcomes.[1-3,21,31,33] However, recent studies suggest that decreased clinical outcomes and increased complication rates are associated with scapular notching.[22,22,23,29,30]

The rate of scapular notching varies widely, reported from 0% to 96% in the literature.[21,22,23,28] Certain anatomic, hardware-related, and technique-dependent factors have been implicated with higher rates.[1,7,8,13,16,18,21,22,23,28,34] As a result, changes in implant design and surgical technique have been recommended to decrease notching, two of which include lateralizing the center of rotation (COR) and decreasing the humeral neck-shaft angle (NSA).[1,8,11,13-16,18,25,26,32,34] Lateralizing the COR has been shown to significantly decrease notching rates in traditional Grammont-style RSA with a 155° NSA.[1,16,19] Decreasing the NSA has also been associated with significantly lower rates of scapular notching compared with traditional 155° NSA designs.[7,20] In many of these studies, however, RSA was performed with both a decreased NSA humeral implant and a lateralized COR. As a result, the effect of lateralizing the COR in RSA with a lower NSA on scapular notching is less understood.

The purpose of this study was to compare the rates of scapular notching in patients who had undergone RSA with a 135° NSA and either a lateralized (4 mm) or neutral (0 mm) COR. In addition, functional outcome scores, ranges of motion (ROM), and complications would also be compared. We hypothesized that a lateralized COR would result in a lower rate of scapular notching; however, no differences in functional outcome scores or ROM would be identified.

Methods

A retrospective comparative cohort study was designed to evaluate the effect of lateralizing the COR in RSA with a 135° humeral component on the rate of scapular notching. Patient data and imaging were obtained from a larger, institutional review board–approved, prospectively gathered registry intended for outcome analysis of shoulder replacement surgery. All patients provided informed consent for inclusion in the registry before surgical intervention. All RSAs performed between June 2015 and June 2017 using the same 135° humeral component design were reviewed. Inclusion criteria included primary RSA, surgical indication of cuff tear arthropathy, and complete clinical and radiographic follow-up at 2-year follow-up. Exclusion criteria included surgical indication other than cuff tear arthropathy, revision surgery, prior open shoulder surgery, significant glenoid and/or humeral bone loss that would require bone grafting or augmented implants, baseplate malposition (superior inclination and/or inferior glenosphere edge higher than native glenoid), humeral component version outside of 0-30 degrees of retroversion, and the use of an eccentric glenosphere.

Patients were divided as per glenosphere lateralization. The first cohort consisted of patients who underwent RSA with a standard glenosphere (0 mm of the COR offset), equivalent to a traditional medialized COR (MCOR) configuration. The second cohort consisted of patients who underwent RSA with a lateralized glenosphere (+4 mm of the COR offset), resulting in a lateralized COR (LCOR) configuration. All patients who underwent RSA with an MCOR and met inclusion criteria were included in the study. The LCOR cohort was then developed by matching cases in consecutive order based on age and indication. A priori power analysis determined that 38 patients would be required in each cohort to see a 25% decrease in the notching rate ($\alpha = .05$).

Implant design and surgical technique

All RSAs were performed with the Arthrex Univers Revers humeral stem and Universal Glenoid Baseplate (Arthrex, Inc., Naples, FL, USA). The humeral implant in this system allows the surgeon to orient the metaphyseal cup at either a 135° or 155° NSA in a universal stem body. The baseplate is anatomically shaped with 3 sizes to best match the native glenoid. Lateralization options of the glenosphere include a neutral (0 mm offset) or lateralized (+4 mm lateralized offset) glenosphere in 36 mm, 39 mm, and 42 mm sizes.

All RSAs were performed by fellowship-trained shoulder surgeons following the official technique guide through a deltopectoral approach. All humeral components were oriented at a 135° NSA. Baseplates were sized based on the patient's anatomy and placed with the goal of restoring the version and inclination of the native glenoid. Glenospheres were selected based on surgeon preference. Postoperative rehabilitation was not standardized.

Radiographic analysis

Standardized shoulder radiographs (Grashey [AP], scapular Y, and axillary views) were obtained for all patients at set time points throughout their follow-up. For purposes of this study, the 24-month follow-up AP radiographs were reviewed and assessed for scapular notching as per the Sirveaux grading system[30]: grade 0, no visible notching; grade 1, notching limited to the lateral pillar; grade 2, notching is confluent with the inferior glenoid baseplate screw; grade 3, notching the extends beyond the inferior screw; and grade 4, notching that involves the central post/screw. Reviewers also were instructed to review the immediate postop AP for comparison. Three fellowship-trained shoulder surgeons performed an independent radiographic review. If a discrepancy arose, the majority assessment was taken. Reviewers were blinded to the surgeon of record, date of surgery, and the other reviewer's grading. Rates of notching between cohorts were compared.

Clinical analysis

All patients were evaluated preoperatively and at set time points throughout their follow-up. Validated functional outcome scoring systems (FOSs) were administered at each visit and included the American Shoulder and Elbow Surgeons score, Simple Assessment Numeric Evaluation, and visual analog pain scale. Standard active ROM (AROM) were also measured at each time point using a goniometer. These included forward flexion and external rotation with the arm held at 0° of abduction. FOS and AROM at 24-month follow-up were compared with preoperative values.

Statistical analysis

Statistical comparisons for interval-scale variables within cohorts were performed with the paired Student t-test. Comparisons between cohorts were performed using the independent samples t-test for interval-scale variables and the Mann-Whitney U test for ordinal-scale variables. A mean κ value was calculated to test agreement between reviewers for scapular notching.

Results

Forty-two RSAs performed with an MCOR glenosphere were identified, 1 of which was excluded for need of glenoid bone grafting. This left 41 RSAs for inclusion in the MCOR cohort. Subsequently, 41 RSAs performed with an LCOR glenosphere were matched to create the LCOR cohort. For all patients, the average age at the time of surgery was 70.3 +/- 6. There was no significant age difference between cohorts (MCOR = 70.7 +/- 7.4 vs. LCOR = 70.0 +/- 5.8, $P = .571$).

Scapular notching was identified in 18 patients (22.0%). There was no significant difference in scapular notching between the MCOR and LCOR cohorts ($P = .62$): 10 patients in the MCOR cohort (24.4%) and 8 patients in the LCOR cohort (19.0%). Notching with MCOR RSA included 6 patients with grade 1 (60.0%), 2 patients with grade 2 (20.0%), 1 patient with grade 3 (10.0%), and 1 patient with grade 4 (10.0%) notching. In the LCOR cohort, there were 7 patients with grade 1 (87.5%), 1 patient with grade 2 (12.5%), and no patients with grade 3 or 4 notching (Table I). There was substantial interobserver agreement between the reviewers with a mean κ value of .68.

Significant improvements in all FOS and AROM were observed in both groups ($P < .001$), with no significant difference in any clinical parameter between them (Table I). Similarly, when comparing patients with notching with those without notching, there were no significant differences observed in any FOA or AROM (Table II). Five complications occurred in 5 patients (6.1%), with 2 occurring in the MCOR group (4.8%) and 3 in the LCOR group (7.3%). Complications included 3 scapular spine fractures (all in the LCOR), 1 dislocation, and 1 superficial infection. All were treated conservatively with nonoperative measures. No complications occurred in patients with scapular notching and as such could not be attributed to the presence of notching.

Table I
Comparison of MCOR and LCOR at 2-year follow-up.

	MCOR (n = 41)	LCOR (n = 41)	*P* value
Age, yr	70 ± 7	70 ± 6	.571
Indication			
Cuff tear arthropathy	41	41	
Scapular notching (%)	10 (24.4%)	8 (19.5%)	.652
Grade 1 (%)	5 (50%)	7 (87.5%)	
Grade 2 (%)	3 (30%)	1 (12.5%)	
Grade 3 (%)	1 (10%)	0 (0%)	
Grade 4 (%)	1 (10%)	0 (0%)	
ASES			
Pre-op	39.6 ± 20.5	40.3 ± 21.0	.889
Post-op	83.3 ± 15.0	81.9 ± 15.5	.682
Change	43.7	41.6	.698
SANE			
Pre-op	26.8 ± 17.5	26.6 ± 16.5	.969
Post-op	83.6 ± 14.9	78.6 ± 16.9	.154
Change	56.9	51.9	.316
VAS			
Pre-op	6 ± 2.6	5.4 ± 2.6	.279
Post-op	0.8 ± 1.7	0.7 ± 1.4	.624
Change	−5.2	−4.7	.439
AFF			
Pre-op	81.5 ± 38.0	95.9 ± 37.0	.089
Post-op	133.6 ± 23.9	134.9 ± 23.7	.809
Change	52.1	39.0	.129
AER			
Pre-op	21.4 ± 12.8	24.3 ± 13.9	.371
Post-op	33.7 ± 12.2	38.3 ± 19.9	.113
Change	12.3	14.0	.665
Complications			
Total	2	3	.644

MCOR, 0 mm offset of the center of rotation; *LCOR*, 4 mm offset of the center of rotation; *ASES*, American Shoulder and Elbow Surgeons; *SANE*, Simple Assessment Numeric Evaluation; *VAS*, visual analog pain score; *AFF*, active forward flexion; *AER*, active external rotation.
All clinical outcome improvements were significant in both cohorts ($P < .001$).

Discussion

The effect of lateralizing the COR with a 135° RSA on scapular notching is unclear. In this study, there was no significant difference in scapular notching between the +4-mm LCOR and the MCOR using a 135° RSA at 2-year follow-up, disproving our hypothesis. To our knowledge, this is the first study to directly compare notching rates between the MCOR and the LCOR with a 135° RSA. Similar findings, however, were noted by Mollen et al when looking at the clinical impact of scapular notching in 145° RSA.[23] Although they did not directly compare the MCOR vs. the LCOR, when extrapolating from their data, no significant difference in notching is identified when an expanded glenosphere (+4-mm LCOR) was used compared with a standard glenosphere.

The effect of the LCOR on scapular notching in Grammont-style prosthesis with a 155° NSA has been well established. Boileau et al reported scapular notching in 19% of patients with BIO-RSA.[3] Athwal et al showed significantly lower notching rates in patients with BIO-RSA than with standard RSA, 40% to 75%, respectively.[1] Similarly, Kirzner et al reported scapular notching in 33% of patients with BIO-RSA compared with 68% with standard RSA.[19] The BIO-RSA techniques used in these studies provided up to 10 mm of the LCOR. Metallic lateralization has also shown to decrease notching in 155° NSA designs. Katz et al reported scapular notching in 29% of RSAs performed with 8.5 mm of metallic LCOR.[16] The lateralized CORs in these studies are all greater than 8 mm. In our series, we were limited to lateralizing the COR by 4 mm. It is possible that further lateralization of the COR is required to protect against scapular notching in 135° RSA as well.

Previous studies have established that decreasing the NSA in comparison with the original Grammont-style NSA of 155° is associated with significantly lower notching rates.[1,19,20,24,25,27] Gobezie et al demonstrated reduction of scapular notching from 58% to 21% when using a 155° vs a 135° RSA with an MCOR in a randomized controlled trial using an implant that can be implanted with either NSA.[10] The overall scapular notching rate in our series (22.0%) is consistent the reported rates in lower NSA studies. Many 135° RSA designs have an inherent LCOR; however, the decreased incidence of scapular notching seen with these designs has not been directly attributed to the presence or amount of the LCOR. Many studies have shown very low rates of scapular notching when using an RSA design with a 135° NSA and 6-10 mm of the lateralized COR. Zitkovsky et al reported notching rates of 14.7% at 2-year follow-up in patients with 6-10 mm of the LCOR with a 135° RSA; however, they did not differentiate between the 6- and 10-mm LCOR.[34] Other authors have reported 0.0%-15.0% scapular notching rates with the same implant design, with Cuff et al reporting only 15% notching at 10-year follow-up.[5] These rates are consistently lower than other designs and would suggest that an increased LCOR greater than 6 mm is protective against scapular notching.

The clinical impact of scapular notching remains variable within the literature. Some studies show no difference, whereas others show significant impact on functional outcome scores, ROM, and complication rates. Mollen et al reported lower American Shoulder and Elbow Surgeons scores, active abduction, and increased complication rates (<0.05) in patients with scapular notching than in those without scapular notching. Interestingly, however, they did not see a significant difference in the mean change from preoperative values in FOS or ROM between cohorts.[23] In our study, we found no significant negative clinical effects of scapular notching. FOS scores and ROM showed similar improvements from

Table II
Comparison of patients with and without notching at 2-year follow-up.

	Notching (n = 18)	No notching (n = 64)	*P* value
ASES			
Pre-op	43.1 ± 23.4	38.8 ± 20.0	.488
Post-op	87.3 ± 9.8	81.1 ± 16.3	.129
Change	44.2	42.3	.795
SANE			
Pre-op	25.9 ± 20.3	27 ± 16.1	.826
Post-op	86.1 ± 10.1	79.7 ± 17.3	.141
Change	60.2	52.6	.271
VAS			
Pre-op	5.3 ± 3.2	5.9 ± 2.4	.442
Post-op	0.3 ± 0.7	0.9 ± 1.7	.146
Change	−5	−5	.971
AFF			
Pre-op	90.0 ± 38.6	87.8 ± 38.2	.834
Post-op	133.4 ± 25.8	134.4 ± 23.4	.883
Change	43.4	46.6	.71
AER			
Pre-op	20.3 ± 11.6	23.1 ± 15.3	.402
Post-op	37.6 ± 11.7	35.3 ± 13.7	.499
Change	17.3	12.2	.106
Complications			
Total	0	5	.581

MCOR, 0 mm offset of the center of rotation; *LCOR*, 4 mm offset of the center of rotation; *ASES*, American Shoulder and Elbow Surgeons; *SANE*, Simple Assessment Numeric Evaluation; *VAS*, visual analog pain score; *AFF*, active forward flexion; *AER*, active external rotation.
All clinical outcome improvements were significant in both cohorts ($P < .001$).

preoperative scores, and final outcomes were not inferior in patients with notching compared with those without notching at 2-year follow-up. In addition, we did not appreciate an increase in complications in patients with scapular notching. Longer-term follow-up is needed to better understand the potential clinical effects of scapular notching over time.

Lateralization of the COR has a number of potential effects that may influence prosthesis performance, scapular notching, and clinical outcomes. The results of several nonclinical studies have suggested that additional lateralization of the COR may have beneficial effects in lateralized prostheses. A cadaveric study by Ferle et al noted that lateralization and a smaller NSA may improve glenohumeral stability.[8] A computer modeling study by Werner et al using patient computed tomography scans found that decreasing the humeral NSA from 145° to 135° improved impingement-free ROM in adduction, external rotation, and extension.[32] A similar study using computed tomography scans with posterior glenoid erosion noted that lateralization provided the most significant benefits to ROM.[17]

However, the same studies also suggest that abduction can be limited with increased lateralization. In addition, the increased soft tissue tension associated with increased lateralization theoretically promotes other potential complications. Excessive lateralization of the COR increases the deltoid force required for active ROM and places added stress on the acromion. Additional stress on the baseplate fixation also raised concerns for higher failure rates in these designs. However, the heterogeneity of previously reported data makes definitive conclusions on the relationship between prosthesis failure and lateralization unclear. What is apparent is that more modern designs with less vertical NSAs and a more lateralized COR have lower rates of notching than the original design.

A systematic review examining the clinical effects of lateralization in patients with traditional Grammont-style and decreased NSA humeral prostheses noted improvements in postoperative external rotation and decreased scapular notching with lateralized designs.[13] Although the benefits of an overall lateralized design are apparent, the heterogeneity of these comparisons makes it difficult to identify what the optimal amount of the lateral offset in a lateralized prosthesis might be. For the 82 patients in our study treated with a 135° NSA implant, lateralization of the COR by 4 mm did not have any significant effects on clinical outcomes at 2 years. Complication rates were similar between the cohorts, regardless of notching (2 MCORs and 3 LCORs). However, it should be noted that all 3 complications in the LCOR cohort were scapular spine fracture, which were not observed in the MCOR cohort. It is also possible that further lateralization beyond 4 mm is needed to see significant differences in clinical outcomes in addition to increased scapular notching protection. Further studies are needed to understand the clinical and radiographic effects of lateralization in 135° RSA.

Limitations to this study include those inherent to a retrospective review of prospectively gathered data and multicenter studies. Although we matched cohorts by age and diagnosis and our inclusion/exclusion criteria help to reduce certain anatomic variables, glenosphere selection was based on surgeon preference and not controlled. As a result, there may be some inherent selection bias. In addition, although we were powered to see a significant difference between groups, the lower incidence seen in patients treated with newer prosthesis designs unfortunately decreases the power of studies seeking to demonstrate a significant difference between groups. A larger sample size would be needed to demonstrate a difference if one exists. The follow-up period we report is commonly accepted in studies of this kind, although a midterm and long-term follow-up would be beneficial in determining any long-term consequences of COR lateralization that are not evaluated by this study. Finally, we were only able to compare the MCOR and 4 mm of the LCOR with the system used during the study period. More recent design from the same company allows for up to 8 mm of lateralization (Modular Glenoid System). Further lateralizing the COR may show differences or similarities in scapular notching rates and clinical outcomes. This study also has several strengths. To our knowledge, this is the first study to directly evaluate the effect of lateralization on scapular notching with a 135° RSA with a control cohort. All patients underwent RSA with the same implant. In addition, we showed a high interobserver reliability when evaluating scapular notching.

Conclusion

This comparative cohort study demonstrated no significant difference in scapular notching rates in patients who underwent RSA with a 135° NSA implant design with 4 mm of the lateralized COR compared with the standard (0 mm) COR at 2-year follow-up. All patients saw significant improvements in functional outcome scores and ROM. Lateralizing the COR by 4 mm did not have a significant effect on any patient outcome compared with 0 mm of lateralization. In addition, at short-term follow-up, the presence of scapular notching did not have a negative effect on clinical outcomes. Based on these short-term results, lateralization of 4 mm in patients with a 135° RSA does not have a radiographic or clinically significant impact at 2-year follow-up. Further studies evaluating higher amounts of lateralization are needed to determine if lateralization beyond 4 mm is associated with improved radiographic and clinical outcomes.

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References

1. Athwal GS, MacDermid JC, Reddy KM, Marsh JP, Faber KJ, Drosdowech D. Does bony increased-offset reverse shoulder arthroplasty decrease scapular notching? J Shoulder Elbow Surg 2015;24:468-73. https://doi.org/10.1016/j.jse.2014.08.015.
2. Boileau P, Gonzalez J-F, 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.
3. Boileau P, Watkinson DJ, Hatzidakis AM, Balg F. Grammont reverse prosthesis: design, rationale, and biomechanics. J Shoulder Elbow Surg 2005;14(1 Suppl S):147S-61S. https://doi.org/10.1016/j.jse.2004.10.006.
4. Cuff D, Clark R, Pupello D, Frankle M. Reverse shoulder arthroplasty for the treatment of rotator cuff deficiency: a concise follow-up, at a minimum of five years, of a previous report. J Bone Joint Surg Am 2012;94:1996-2000. https://doi.org/10.2106/JBJS.K.01206.
5. 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;90:1244-51. https://doi.org/10.2106/JBJS.G.00775.
6. Cuff DJ, Pupello DR, Santoni BG, Clark RE, Frankle MA. Reverse shoulder arthroplasty for the treatment of rotator cuff deficiency: a concise follow-up, at a minimum of 10 years, of previous reports. J Bone Joint Surg Am 2017;99:1895-9. https://doi.org/10.2106/JBJS.17.00175.
7. Erickson BJ, Frank RM, Harris JD, Mall N, Romeo AA. The influence of humeral head inclination in reverse total shoulder arthroplasty: a systematic review. J Shoulder Elbow Surg 2015;24:988-93. https://doi.org/10.1016/j.jse.2015.01.001.
8. Ferle M, Pastor M-F, Hagenah J, Hurschler C, Smith T. Effect of the humeral neck-shaft angle and glenosphere lateralization on stability of reverse shoulder arthroplasty: a cadaveric study. J Shoulder Elbow Surg 2019;28:966-73. https://doi.org/10.1016/j.jse.2018.10.025.
9. 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;87:1697-705. https://doi.org/10.2106/JBJS.D.02813.
10. Gobezie R, Shishani Y, Lederman E, Denard PJ. Can a functional difference be detected in reverse arthroplasty with 135° versus 155° prosthesis for the treatment of rotator cuff arthropathy: a prospective randomized study. J Shoulder Elbow Surg 2019;28:813-8. https://doi.org/10.1016/j.jse.2018.11.064.
11. 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;24:1397-404. https://doi.org/10.1016/j.jse.2015.05.041.
12. Gutiérrez S, Levy JC, Frankle MA, Cuff D, Keller TS, Pupello DR, et al. Evaluation of abduction range of motion and avoidance of inferior scapular impingement in a reverse shoulder model. J Shoulder Elbow Surg 2008;17:608-15. https://doi.org/10.1016/j.jse.2007.11.010.
13. Helmkamp JK, Bullock GS, Amilo NR, Guerrero EM, Ledbetter LS, Sell TC, et al. The clinical and radiographic impact of center of rotation lateralization in reverse shoulder arthroplasty: a systematic review. J Shoulder Elbow Surg 2018;27:2099-107. https://doi.org/10.1016/j.jse.2018.07.007.
14. Henninger HB, Barg A, Anderson AE, Bachus KN, Burks RT, Tashjian RZ. Effect of lateral offset center of rotation in reverse total shoulder arthroplasty: a biomechanical study. J Shoulder Elbow Surg 2012;21:1128-35. https://doi.org/10.1016/j.jse.2011.07.034.
15. Hettrich CM, Permeswaran VN, Goetz JE, Anderson DD. Mechanical tradeoffs associated with glenosphere lateralization in reverse shoulder arthroplasty. J Shoulder Elbow Surg 2015;24:1774-81. https://doi.org/10.1016/j.jse.2015.06.011.
16. Katz D, Valenti P, Kany J, Elkholti K, Werthel J-D. 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 2016;40:99-108. https://doi.org/10.1007/s00264-015-2976-3.
17. Keener JD, Patterson BM, Orvets N, Aleem AW, Chamberlain AM. Optimizing reverse shoulder arthroplasty component position in the setting of advanced arthritis with posterior glenoid erosion: a computer-enhanced range of motion analysis. J Shoulder Elbow Surg 2018;27:339-49. https://doi.org/10.1016/j.jse.2017.09.011.
18. Kempton LB, Balasubramaniam M, Ankerson E, Wiater JM. A radiographic analysis of the effects of prosthesis design on scapular notching following reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2011;20:571-6. https://doi.org/10.1016/j.jse.2010.08.024.
19. 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.
20. Lawrence C, Williams GR, Namdari S. Influence of glenosphere design on outcomes and complications of reverse arthroplasty: a systematic review. Clin Orthop Surg 2016;8:288-97. https://doi.org/10.4055/cios.2016.8.3.288.
21. 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.
22. 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.
23. 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.
24. Nelson R, Lowe JT, Lawler SM, Fitzgerald M, Mantell MT, Jawa A. Lateralized center of rotation and lower neck-shaft angle are associated with lower rates of scapular notching and heterotopic ossification and improved pain for reverse shoulder arthroplasty at 1 year. Orthopedics 2018;41:230-6. https://doi.org/10.3928/01477447-20180613-01.
25. Nunes B, Linhares D, Costa F, Neves N, Claro R, Silva MR. Lateralized versus nonlateralized glenospheres in reverse shoulder arthroplasty: a systematic review with meta-analysis. J Shoulder Elbow Surg 2020;30:1700-13. https://doi.org/10.1016/j.jse.2020.09.041.
26. Oh JH, Shin S-J, McGarry MH, Scott JH, Heckmann N, Lee TQ. Biomechanical effects of humeral neck-shaft angle and subscapularis integrity in reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2014;23:1091-8. https://doi.org/10.1016/j.jse.2013.11.003.
27. 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.
28. Roche CP, Stroud NJ, Martin BL, Steiler CA, Flurin P-H, 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. 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. https://doi.org/10.1302/0301-620x.86b3.14024.
31. 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;89:1476-85. https://doi.org/10.2106/JBJS.F.00666.
32. Werner BS, Chaoui J, Walch G. The influence of humeral neck shaft angle and glenoid lateralization on range of motion in reverse shoulder arthroplasty. J Shoulder Elbow Surg 2017;26:1726-31. https://doi.org/10.1016/j.jse.2017.03.032.
33. Werner CML, 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.
34. Zitkovsky HS, Carducci MP, Mahendraraj KA, Grubhofer F, Jawa A. Lateralization and decreased neck-shaft angle reduces scapular notching and heterotopic ossification. J Am Acad Orthop Surg 2020;28:e1073. https://doi.org/10.5435/JAAOS-D-19-00808.