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Comparison of survivorship and performance of a platform shoulder system in anatomic and reverse total shoulder arthroplasty

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Background: Contemporary studies note sustained clinical benefit and decreasing complications after reverse total shoulder arthroplasty (RTSA), which warrant a comparison with the standard anatomic total shoulder arthroplasty (ATSA). The purpose of this study is to evaluate and compare differences in midterm survivorship between ATSA and RTSA patients treated with a single platform shoulder prosthesis. Secondary objectives include a comparison of the clinical outcomes and complication profile for each procedure.

Methods: A prospective analysis of all primary ATSA and RTSA performed by 3 surgeons between 2007 and 2012 was conducted. Selection of the ATSA or RTSA implant configuration was determined by the surgeons per their clinical understanding of each individual patient's glenoid morphology, rotator cuff, and patient expectations. All 778 procedures were performed using a single platform shoulder system.

Results: Survivorship for ATSA was similar to that for RTSA at all time points; ATSA at 2 and 8 years was 98.5% and 96.0%, whereas RTSA at 2 and 8 years was 98.7% and 96.0%, respectively ($P = .392$). All postoperative range of motion scores for ATSA patients were greater than those for RTSA patients. The overall rate of complications between the ATSA and RTSA groups was similar (6.3% vs. 4.9%, $P = .414$).

Conclusions: On the basis of this cohort comparison, both ATSA and RTSA demonstrated similar survivorship at 8 years after surgery with multiple surgeons practicing in different countries. Our results demonstrate that the RTSA and ATSA implants have comparable results and can be expected to provide similar implant longevity over the midterm with excellent functional outcomes.

Modern studies demonstrate a sustained clinical benefit and decreasing complication rate after reverse total shoulder arthroplasty (RTSA), prompting a comparison with the standard anatomic total shoulder arthroplasty (ATSA).[23,28,37,38,40] In the setting of rotator cuff compromise or significant glenoid deformity, the benefits of RTSA are apparent.[11,23,34] However, as the indications for RTSA have widened, patients may be considered candidates for either RTSA or ATSA based on age, preoperative function, glenoid bone loss, retroversion, and rotator cuff disease without full thickness rotator cuff tears.[16,22,37]

Given the option of 2 different shoulder arthroplasty surgical procedures (RTSA and ATSA) for overlapping patient indications, the orthopedic surgeon must consider the differences in postoperative outcomes in relation to each patient's individual goals and requirements. Differences in postoperative range of motion (ROM) and complication rates have been previously reported between ATSA and RTSA. Because of the unconstrained design of the ATSA and an intact rotator cuff, it is reported to have a greater ROM than RTSA.[2,35]

Historically, RTSA complication and revision rates have exceeded the rates for ATSA causing some surgeons trepidation regarding

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the procedure.[23] However, with modern implant designs, RTSA complications and revision rates have decreased[4] such that these rates are similar to those of ATSA.[8,18,33,39] The most frequent complications for ATSA remain aseptic glenoid loosening and rotator cuff tears,[10,12,13,15,24] which lead to an increased rate of revision surgery at midterm follow-up.[29] The most frequent complication for RTSA is scapula notching, but this rarely results in the need for revision. Other complications after RTSA are glenoid component failure and instability both of which typically result in the need for revision surgery.[6] With modern implants and techniques, it is important to continually re-evaluate the survivorship curves of ATSA and RTSA as differences may exist. Previous reports have evaluated revision rates of ATSA and RTSA at midterm or longer follow-up, but these have failed to evaluate the survivorship over time using more traditional survivorship analyses.[8,18,19,37] The primary purpose of this study is to evaluate and compare differences in midterm survivorship between ATSA and RTSA patients treated with a single platform shoulder prosthesis. Secondary objectives include a comparison of the clinical outcomes and complication profile for each procedure.

Methods

A retrospective analysis of all primary ATSA and RTSA performed on prospectively collected data by 3 fellowship-trained high-volume surgeons between 2007 and 2012 was conducted. Data were collected through a multinational shoulder arthroplasty registry operated by the sponsor (WIRB approved #20091701), using standardized data collection forms. Patients were excluded if they had a preoperative diagnosis of infection, revision arthroplasty, humeral fracture, neuromuscular disorders, brachial plexopathy, and alcohol/substance abuse.

Selection of the ATSA or RTSA implant configuration was determined by the surgeons per their clinical understanding of each individual patient's glenoid morphology, rotator cuff, and patient expectations. Seven hundred seventy-eight shoulders (286 ATSA [M = 125/F = 160/1 unknown] and 492 RTSA [M = 156/F = 336]) were evaluated in this study. All patients were included for survivorship analysis. However, only patients with a minimum 2-year follow-up (253 ATSA, 382 RTSA) were included in clinical outcomes analysis. ATSA patients had a mean follow-up of 64.0 ± 32.0 months, and RTSA patients had a mean follow-up of 56.4 ± 23.8 months. All ATSA were performed with a hybrid (biologic central cage and 3 peripheral titanium cemented pegs) (n = 144) or keel (n = 142) cemented glenoid component. RTSA surgeries were performed using the same platform stem with nonaugmented glenoid baseplates.

Patients were evaluated preoperatively, through the immediate postoperative period (2-24 weeks), and annually thereafter. At each visit, the surgeons and/or their surrogate evaluated the patient assessing ROM and obtained multiple different patient-reported outcome scores. ROM was measured using a goniometer during active shoulder movements including abduction, forward elevation, and external rotation. Internal rotation was assessed using an 8-point scale ranging from no internal rotation (hip) = 0 to full internal rotation (T7 or higher) = 7.[14] Strength in forward elevation was measured in pounds. Patient outcomes were quantified using the global shoulder function score (0-10), patient satisfaction rating (assessment of their shoulder condition presurgery to postsurgery, with possible responses being worse, unchanged, better, or much better), visual analog scale pain score (0-10), Simple Shoulder Test (SST), Constant-Murley score (CONSTANT), American Shoulder and Elbow Surgeons assessment (ASES), University of California Los Angeles Shoulder Score (UCLA), and the Shoulder Pain and Disability Index (SPADI).[3,7,21,26,27] At each postoperative visit, radiographs were evaluated for humeral radiolucent lines according to Sanchez et al, radiolucent glenoid lines according to Lazarus et al (ATSA only), and scapular notching according to Sirveaux et al (RTSA only).[20,28,32] Postoperative complications and reoperations were also recorded at each visit.

A survivorship analysis was performed using the Kaplan-Meier method. The survivorship analysis (Kaplan-Meier, complication rates, and revision rates) included all patients (N = 778). Patients undergoing any operation requiring explant of any component were classified as revised or failed.

Statistical analysis

Statistical analyses compared outcome measures between ATSA and RTSA patients. Numeric outcome measure comparisons were performed using a Student's *t*-test. Gender, diagnosis, patient satisfaction ratings, and complication rates were analyzed with the χ^2 analysis. A comparison of the survivorship curves was performed with the log-rank test. Depending on the observed frequencies, the complication and revision rates were evaluated with the Fisher exact test or the χ^2 test.

Results

The majority of patients had a diagnosis of osteoarthritis (ATSA = 93%, RTSA = 58%). RTSA patients were significantly older (74 vs. 68, $P < .001$) and more commonly female (68% vs. 56%, $P < .001$). See Table I for full demographic details.

RTSA shoulders had similar preoperative active forward elevation and external rotation ROM scores to ATSA patients, as well as similar preoperative ASES and SPADI patient-reported outcome measures. RTSA shoulders did have greater internal rotation than ATSA patients (RTSA = 3.6, ATSA = 3.1, $P = .003$) but significantly less preoperative active abduction (RTSA = 77°, ATSA = 83°, $P = .04$). Furthermore, the RTSA preoperative scores SST, CONSTANT, and UCLA were lower than those for ATSA patients, and the preoperative RTSA max strength was much lower (RTSA = 1.0 kg, ATSA = 2.9 kg, $P < .001$).

All postoperative ROM scores for ATSA patients were greater than those for RTSA patients ([active abduction ATSA = 131, RTSA = 114, $P < .001$], [forward elevation ATSA = 150, RTSA = 141, $P < .001$], [external rotation ATSA = 48, RTSA = 36, $P < .001$], and [internal rotation ATSA = 5.2, RTSA = 4.7, $P < .001$]). Furthermore, the postoperative max strength for ATSA patients was significantly higher (ATSA = 4.1 kg, RTSA = 3.5 kg, $P = .002$) (Table II). ATSA patient–reported outcome measure (SST) was greater than RTSA (ATSA = 10.9, RTSA = 10.0, $P = .022$), whereas no differences were observed in the CONSTANT, ASES, UCLA, and SPADI postoperative scores between RTSA and ATSA patients.

The ATSA patients had significantly greater improvements in all ROM measurements over RTSA. Although the RTSA improvement of max shoulder strength was significantly greater than ATSA, the postoperative value was still smaller. No differences were noted in improvement for the patient-reported outcome measures (SST, CONSTANT, ASES, UCLA, and SPADI).

Although increased complications and associated revisions in the ATSA cohort at midterm follow-up resulted in a lower mean survivorship compared with RTSA, it was not statistically significant (ATSA = 96.0%, RTSA = 97.3%, $P = .392$). The overall rates of complication (excluding notching) between the ATSA and RTSA groups were similar (6.3% vs. 5.3%, $P = .414$). The most common complications for RTSA were acromial/scapula fractures and aseptic glenoid loosening, whereas the most common complications for ATSA were aseptic glenoid loosening and rotator cuff tear/subscapularis repair failure, as shown in Table III. When analyzing the

Table I
Patient demographics, indications for surgery, and duration of postoperative follow-up for each study group

Study demographics	ATSA group	RTSA group	*P* value
Group size	286	492	–
Gender			
Female	160 (56%)	336 (68%)	$\chi^2 = 12$
Male	126 (44%)	156 (32%)	$P < .001$
Age at surgery			
Average ± SD	67.8 ± 9.6	74.2 ± 7.4	<.001
Demographic characteristics			
Height (cm)	165.9 ± 12.4	157.7 ± 30.0	<.001
Weight (kg)	79.4 ± 17.6	71.4 ± 21.0	<.001
BMI	29.4 ± 15.0	28.1 ± 12.5	.236
Diagnosis			
Osteoarthritis	261 (91.3 %)	138 (28.0%)	$\chi^2 = 194$
Osteoarthritis and rotator cuff insufficiency	8 (2.8%)	150 (30.5%)	$P < .001$
Rotator cuff insufficiency	0 (0%)	136 (27.6%)	
Other	17* (5.9%)	68† (13.8%)	

SD, standard deviation; *BMI*, body mass index; *ATSA*, anatomic total shoulder arthroplasty; *RTSA*, reverse total shoulder arthroplasty.
* Other diagnoses are post-traumatic arthritis (7), osteonecrosis (4), fracture (2), rheumatoid arthritis (1), psoriatic arthropathy (1), and not documented (2).
† Other diagnoses are fracture (26), post-traumatic arthritis (8), rheumatoid arthritis (4), osteonecrosis (3), instability (3), pseudoparalysis (2), bicep synovectomy (2), neuropraxia (1), and not documented (19).

Table II
Average and standard deviation of the preoperative and postoperative performance metrics for each patient group

Clinical metric	Time of measure	ATSA	RTSA	*P* value
Active abduction	Preop	83 ± 30	77 ± 33	.038
	Last postop	131 ± 36	114 ± 32	<.001
	Delta	53 ± 44	34 ± 43	<.001
Active forward elevation	Preop	107 ± 36	103 ± 43	.215
	Last postop	150 ± 34	141 ± 29	<.001
	Delta	51 ± 44	39 ± 45	.003
Active external rotation	Preop	15 ± 23	16 ± 24	.529
	Last postop	48 ± 21	36 ± 20	<.001
	Delta	35 ± 26	19 ± 27	<.001
Active internal rotation	Preop	3.1 ± 1.6	3.6 ± 1.9	.003
	Last postop	5.2 ± 1.4	4.7 ± 1.6	<.001
	Delta	2.1 ± 1.9	1.2 ± 2.2	<.001
Forward flexion max strength (kg)	Preop	2.9 ± 2.8	1.0 ± 1.5	<.001
	Last postop	4.1 ± 2.6	3.5 ± 2.3	.002
	Delta	1.3 ± 2.9	2.5 ± 2.2	<.001
Shoulder function	Preop	3.6 ± 1.7	2.9 ± 1.5	<.001
	Last postop	8.2 ± 2.0	7.9 ± 2.0	.018
	Delta	4.6 ± 2.6	4.7 ± 2.3	.650
VAS daily pain	Preop	6.2 ± 1.9	6.1 ± 1.8	.589
	Last postop	1.3 ± 2.1	1.2 ± 2.1	.526
	Delta	−4.6 ± 3.1	−4.8 ± 2.6	.553
Patient satisfaction rating	Not recorded	17	33	$\chi^2 = 6.8$
	Worse	7	9	$P = .079$
	Unchanged	13	9	
	Better	43	94	
	Much better	206	347	
SST	Preop	4.3 ± 3.0	3.6 ± 2.6	.012
	Last postop	10.9 ± 5.5	10.0 ± 2.5	.022
	Delta	6.9 ± 7.5	7.0 ± 3.5	.945
CONSTANT	Preop	43 ± 16	38 ± 14	.003
	Last postop	74 ± 16	69 ± 15	.445
	Delta	32 ± 19	31 ± 16	.620
ASES	Preop	37 ± 15	36 ± 14	.581
	Last postop	83 ± 20	82 ± 19	.445
	Delta	46 ± 23	45 ± 22	.507
UCLA	Preop	14 ± 4	13 ± 4	<.001
	Last postop	30 ± 6	30 ± 5	.594
	Delta	16 ± 7	17 ± 6	.486
SPADI	Preop	79 ± 21	82 ± 21	.100
	Last postop	19 ± 25	22 ± 24	.154
	Delta	−60 ± 29	−59 ± 29	.781

VAS, visual analog scale; *SST*, Simple Shoulder Test; *CONSTANT*, Constant-Murley score; *ASES*, American Shoulder and Elbow Surgeons assessment; *UCLA*, University of California Los Angeles Shoulder score; *SPADI*, Shoulder Pain and Disability Index; *ATSA*, anatomic total shoulder arthroplasty; *RTSA*, reverse total shoulder arthroplasty.
Last postop is the postoperative score collected at the last postoperative visit. Delta is the difference in the preoperative score to the last postoperative score.

Table III
Postoperative complications, revisions, and survivorship

Complications	Anatomic (ATSA), number (%)	Reverse (RTSA), number (%)	*P* value
Acromial/scapular fracture	0 (0)	6 (1.2)	.091
Humeral fracture	0 (0)	3 (0.6)	.302
Clavicle fracture	0 (0)	1 (0.2)	1.000
Aseptic glenoid loosening	6 (2.1)	5 (1.0)	.137
Aseptic humeral loosening	1 (0.3)	0 (0)	.368
Rotator cuff tear/subscapularis repair failure	7 (2.4)	0 (0)	.001
Instability/dislocation	2 (0.7)	2 (0.4)	.628
Total orthopedic-related complications	18 (6.3)*	26 (5.3)†	.557
Scapular notching	NA	27 (5.5)	NA
Revisions	12 (4.2)	11 (2.2)	.129
Survivorship			
2 yr [95% CI]	98.5% [97.0-100.0]	98.7% [97.7-99.7]	.392
5 yr [95% CI]	96.0% [93.3-98.6]	97.3% [95.7-99.0]	
8 yr [95% CI]	96.0% [93.3-98.6]	97.3% [95.7-99.0]	

CI, confidence interval; *ATSA*, anatomic total shoulder arthroplasty; *RTSA*, reverse total shoulder arthroplasty.
* Other ATSA complications include pain (2).
† Other RTSA complications include pain (5), infection (2), stiffness (1), and hematoma (1).

rate of revision relative to orthopedic-related complications for both ATSA and RTSA, we identified that the odds ratio for revision for RTSA relative to ATSA is 0.367 (95% confidence interval [CI] = 0.10-1.28, $P = .109$). This implied that complications were more often revisions in the ATSA group, but the difference was not statistically significant.

Survivorship for ATSA was similar to that for RTSA at all time points (Fig. 1). At 2 years, survivorship for ATSA was 98.5% (95% CI = 97-100) compared with 98.7% (95% CI = 97.7-99.7) for RTSA. Survivorship remained similar at 8 years for both ATSA (96.0%, 95% CI = 93.3-98.6) and RTSA (97.3%, 95% CI = 95.7-99.0). When comparing the 3 participating surgeons individually, survivorship remained similar at all time points, as shown in Table IV, suggesting good generalizability of outcomes at each clinical site in the 3 different countries analyzed in this study.

Discussion

As RTSA continues to gain popularity with an expansion of viable indications, it is important for surgeons to understand the performance and complication profile of the RTSA prosthesis relative to ATSA. On the basis of this cohort comparison, both ATSA and RTSA demonstrated similar survivorship at 8 years after surgery with multiple surgeons practicing in different countries. Both operations also performed similarly regarding patient-reported outcome measures, patient satisfaction ranking, complication, and revision rates. Considering the differences in indications, our results demonstrate that the RTSA and ATSA implants have comparable results with this platform shoulder system.

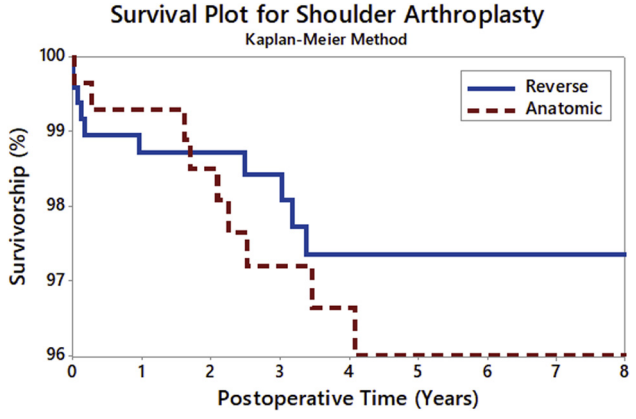

Figure 1 Kaplan-Meier survivorship curve for anatomic total shoulder arthroplasty and reverse total shoulder arthroplasty.

Although not significantly different, we observed that RTSA patients had a lower mean revision rate than ATSA patients at similar follow-up (RTSA = 2.2%, ATSA = 4.2%, $P = .129$). This finding is similar to the results reported by Wright et al,[39] who compared 102 ATSA and 33 RTSA and reported a reoperation rate of 6.9% for ATSA compared with a 3.0% rate for RTSA patients. In addition, Kiet et al[18] also found a slightly higher reoperation rate for ATSA patients (11%) than RTSA patients (9%) at 2-year follow-up. Smith et al[33] asserted that with modern implants, the rate of complications and revisions for RTSA are now similar to those for ATSA. Continued follow-up is necessary to determine if differences in revision rate between ATSA and RTSA patients will be maintained in the long term, especially because rotator cuff disease likely progresses with age.[17] Thus, long-term survivorship studies are needed to assess the effect of rotator cuff disease progression on ATSA.

Despite differences in the revision rate, both implant configurations performed similarly when assessed using a Kaplan-Meir survivorship analysis. The performance of both ATSA and RTSA was similar amongst study sites location, indicating that the results can be generalized across geographic locations and between surgeons. Although cultural and governmental differences exist between each of the sites, similar surgical techniques and study protocol were followed.

Clinically, ATSA demonstrated superior ROM compared with RTSA patients. Specifically, greater postoperative active abduction, active forward elevation, and active external rotation measures were observed after ATSA. When evaluating improvements in ROM from preoperatively to postoperatively, ATSA outperformed RTSA for all ROM measures in a statistically significant manner. This finding is consistent with other studies comparing ROM between RTSA and ATSA.[35] However, the findings can be interpreted differently when analyzed according to whether or not the differences between ATSA and RTSA meet the thresholds for minimal clinically important difference (MCID) or substantial clinical benefit (SCB) as previously reported by Simovitch et al.[30,31] The difference in improvement for active abduction between ATSA and RTSA exceeded MCID but did not meet the threshold for SCB. The difference in improvement for active forward elevation between ATSA and RTSA did not meet the threshold for MCID or SCB. The difference in improvement for active external rotation between ATSA and RTSA exceeded both

Table IV
Survivorship calculations for each geographical area of sites

Cohort	US site		UK site		EU site	
	ATSA (N = 107)	RTSA (N = 161)	ATSA (N = 84)	RTSA (N = 77)	ATSA (N = 95)	RTSA (N = 254)
Survivorship						
Year 2	98.8	99.2	98.8	95.9	97.8	99.2
Year 5	97.4	98.2	97.6	95.9	93.1	97.3
Year 8	97.4	98.2	97.6	95.9	93.1	97.3

ATSA, anatomic total shoulder arthroplasty; *RTSA*, reverse total shoulder arthroplasty.

MCID and SCB thresholds. In addition to ROM, our results demonstrated that ATSA patients were associated with greater max strength and shoulder function postoperatively than RTSA patients. The significant difference is likely secondary to the preoperative diagnosis of cuff tear arthropathy and patients treated with RTSA having significantly lower preoperative max strength and shoulder function. In addition, this significant difference might be an artifact of the demographic differences (gender and age) between the groups.

Our study has limitations, primarily related to the study design. Of particular note, this is an industry-funded study, including a sponsor-funded registry and results analyzed by sponsor statisticians. Although the sample size is large and the participating surgeons are highly experienced in using this shoulder implant, the ATSA study population remains different than the RTSA study population (Table I). We anticipate that the different patient populations are a major study limitation; although ATSA and RTSA are specific to different diagnoses, a more accurate comparison of ATSA and RTSA would be for patients only with osteoarthritis. These patient differences (age, gender ratios, height, weight, and preoperative diagnoses) could impact the postoperative measures. Specifically, the lower rate of revision for the RTSA patient cohort might be biased because of their older age as older patients may be less likely to choose to undergo revision surgery due to increased risks of doing so. Furthermore, the RTSA cohort has a much higher rate of rotator cuff insufficiency compared with the ATSA cohort, which might impact the ROM differences seen independent of implant type.[5] A second limitation of the study is the lack of preoperative radiographic status, because the glenoid type could also impact postoperative outcomes. A third potential limitation of this study is that the comparison of the rate of revision may be biased because of the platform nature of the shoulder system used, which facilitates revision of an ATSA to an RTSA (most commonly) without humeral stem removal.[1] Surgeons may have been more inclined to revise an ATSA due to ease in doing so because of the ability to retain the stem, whereas they may have been more disinclined to revise an RTSA as the outcomes of RTSA revisions are generally less predictable.[1,25,36] This may be illustrated by our finding that 67% of ATSA patients with an orthopedic-related complication, as defined, underwent a revision, whereas only 42% of RTSA patients with an orthopedic-related complication, as defined, underwent a revision surgery. Therefore, surgeon-patient considerations and requirements that lead to ATSA revisions may be different than RTSA revisions.[9]

Conclusion

Our results indicate that both ATSA and RTSA can be expected to provide similar implant longevity over the midterm with excellent functional outcomes. ATSA patients can expect greater postoperative ROM and max strength compared with RTSA patients.

Based on these results, surgeons should feel confident indicating a patient for the appropriate polarity of shoulder arthroplasty based on their clinical judgment without concerns for survivorship at 8-year follow-up.

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References

1. Abdel MP, Hattrup SJ, Sperling JW, Cofield RH, Kreofsky CR, Sanchez-Sotelo J. Revision of an unstable hemiarthroplasty or anatomical total shoulder replacement using a reverse design prosthesis. Bone Joint J 2013;95-B:668–72. https://doi.org/10.1302/0301-620X.95B5.30964.
2. Alta TD, de Toledo JM, Veeger HE, Janssen TW, Willems WJ. The active and passive kinematic difference between primary reverse and total shoulder prostheses. J Shoulder Elbow Surg 2014;23:1395–402. https://doi.org/10.1016/j.jse.2014.01.040.
3. Amstutz HC, Sew Hoy AL, Clarke IC. UCLA anatomic total shoulder arthroplasty. Clin Orthop Relat Res 1981:7–20.
4. Bohsali KI, Bois AJ, Wirth MA. Complications of shoulder arthroplasty. J Bone Joint Surg Am 2017;99:256–69. https://doi.org/10.2106/JBJS.16.00935.
5. Boileau P. Complications and revision of reverse total shoulder arthroplasty. Orthop Traumatol Surg Res 2016;102:S33–43. https://doi.org/10.1016/j.otsr.2015.06.031.
6. Braun BJ, Holstein J, Fritz T, Veith NT, Herath S, Mörsdorf P, et al. Polytrauma in the elderly: a review. EFORT Open Rev 2016;1:146–51. https://doi.org/10.1302/2058-5241.1.160002.
7. Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. Clin Orthop Relat Res 1987:160–4.
8. Cox RM, Padegimas EM, Abboud JA, Getz CL, Lazarus MD, Ramsey ML, et al. Outcomes of an anatomic total shoulder arthroplasty with a contralateral reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2018;27:998–1003. https://doi.org/10.1016/j.jse.2017.12.005.
9. Crosby LA, Wright TW, Yu S, Zuckerman JD. Conversion to reverse total shoulder arthroplasty with and without humeral stem retention: the role of a convertible-platform stem. J Bone Joint Surg Am 2017;99:736–42. https://doi.org/10.2106/JBJS.16.00683.
10. Dillon MT, Ake CF, Burke MF, Singh A, Yian EH, Paxton EW, et al. The Kaiser Permanente shoulder arthroplasty registry: results from 6,336 primary shoulder arthroplasties. Acta Orthop 2015;86:286–92. https://doi.org/10.3109/17453674.2015.1024565.
11. Donohue KW, Ricchetti ET, Iannotti JP. Surgical management of the biconcave (B2) glenoid. Curr Rev Musculoskelet Med 2016;9:30–9. https://doi.org/10.1007/s12178-016-9315-1.
12. Fevang BT, Lie SA, Havelin LI, Skredderstuen A, Furnes O. Risk factors for revision after shoulder arthroplasty: 1,825 shoulder arthroplasties from the Norwegian Arthroplasty Register. Acta Orthop 2009;80:83–91. https://doi.org/10.1080/17453670902805098.

13. Fox TJ, Cil A, Sperling JW, Sanchez-Sotelo J, Schleck CD, Cofield RH. Survival of the glenoid component in shoulder arthroplasty. J Shoulder Elbow Surg 2009;18:859–63. https://doi.org/10.1016/j.jse.2008.11.020.
14. 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.
15. Gowd AK, Garcia GH, Liu JN, Malaret MR, Cabarcas BC, Romeo AA. Comparative analysis of work-related outcomes in hemiarthroplasty with concentric glenoid reaming and total shoulder arthroplasty. J Shoulder Elbow Surg 2019;28:244–51. https://doi.org/10.1016/j.jse.2018.07.026.
16. Hartzler RU, Steen BM, Hussey MM, Cusick MC, Cottrell BJ, Clark RE, et al. Reverse shoulder arthroplasty for massive rotator cuff tear: risk factors for poor functional improvement. J Shoulder Elbow Surg 2015;24:1698–706. https://doi.org/10.1016/j.jse.2015.04.015.
17. Keener JD, Galatz LM, Teefey SA, Middleton WD, Steger-May K, Stobbs-Cucchi G, et al. A prospective evaluation of survivorship of asymptomatic degenerative rotator cuff tears. J Bone Joint Surg Am 2015;97:89. https://doi.org/10.2106/JBJS.N.00099.
18. Kiet TK, Feeley BT, Naimark M, Gajiu T, Hall SL, Chung TT, et al. Outcomes after shoulder replacement: comparison between reverse and anatomic total shoulder arthroplasty. J Shoulder Elbow Surg 2015;24:179–85. https://doi.org/10.1016/j.jse.2014.06.039.
19. Latif V, Denard PJ, Young AA, Liotard JP, Walch G. Bilateral anatomic total shoulder arthroplasty versus reverse shoulder arthroplasty. Orthopedics 2012;35:e479–85. https://doi.org/10.3928/01477447-20120327-25.
20. Lazarus MD, Jensen KL, Southworth C, Matsen FA III. The radiographic evaluation of keeled and pegged glenoid component insertion. J Bone Joint Surg Am 2002;84:1174–82. https://doi.org/10.2106/00004623-200207000-00013.
21. Lippitt SB, Harryman DT, Matsen FA. A practical tool for evaluating function: the Simple Shoulder Test. In: Matsen FA, Fu FH, Hawkins RJ, editors. The shoulder: a balance of mobility and stability. Rosemont, IL: American Academy of Orthopaedic Surgeons; 1992. p. 501–18.
22. Mahony GT, Werner BC, Chang B, Grawe BM, Taylor SA, Craig EV, et al. Risk factors for failing to achieve improvement after anatomic total shoulder arthroplasty for glenohumeral osteoarthritis. J Shoulder Elbow Surg 2018;27:968–75. https://doi.org/10.1016/j.jse.2017.12.018.
23. Matsen FA III, Boileau P, Walch G, Gerber C, Bicknell RT. The reverse total shoulder arthroplasty. J Bone Joint Surg Am 2007;89:660–7. https://doi.org/10.2106/00004623-200703000-00027.
24. McLendon PB, Schoch BS, Sperling JW, Sánchez-Sotelo J, Schleck CD, Cofield RH. Survival of the pegged glenoid component in shoulder arthroplasty: part II. J Shoulder Elbow Surg 2017;26:1469–76. https://doi.org/10.1016/j.jse.2016.12.068.
25. Melis B, Bonnevialle N, Neyton L, Lévigne C, Favard L, Walch G, et al. Glenoid loosening and failure in anatomical total shoulder arthroplasty: is revision with a reverse shoulder arthroplasty a reliable option? J Shoulder Elbow Surg 2012;21:342–9. https://doi.org/10.1016/j.jse.2011.05.021.
26. Richards RR, An KN, Bigliani LU, Friedman RJ, Gartsman GM, Gristina AG, et al. A standardized method for the assessment of shoulder function. J Shoulder Elbow Surg 1994;3:347–52.
27. Roach KE, Budiman-Mak E, Songsiridej N, Lertratanakul Y. Development of a shoulder pain and disability index. Arthritis Care Res 1991;4:143–9.
28. Sanchez-Sotelo J, O'Driscoll SW, Torchia ME, Cofield RH, Rowland CM. Radiographic assessment of cemented humeral components in shoulder arthroplasty. J Shoulder Elbow Surg 2001;10:526–31.
29. Schoch B, Werthel JD, Schleck CD, Harmsen WS, Sperling J, Sánchez-Sotelo J, et al. Optimizing follow-up after anatomic total shoulder arthroplasty. J Shoulder Elbow Surg 2017;26:997–1002. https://doi.org/10.1016/j.jse.2016.10.024.
30. 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.
31. Simovitch R, Flurin PH, Wright T, Zuckerman JD, Roche CP. Quantifying success after total shoulder arthroplasty: the substantial clinical benefit. J Shoulder Elbow Surg 2018;27:903–11. https://doi.org/10.1016/j.jse.2017.12.014.
32. Sirveaux F, Favard L, Oudet D, Huquet D, Walch G, Mole 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.
33. Smith CD, Guyver P, Bunker TD. Indications for reverse shoulder replacement: a systematic review. J Bone Joint Surg Br 2012;94:577–83. https://doi.org/10.1302/0301-620X.94B5.27596.
34. Smithers CJ, Young AA, Walch G. Reverse shoulder arthroplasty. Curr Rev Musculoskelet Med 2011;4:183. https://doi.org/10.1007/s12178-011-9097-4.
35. Triplet JJ, Everding NG, Levy JC, Moor MA. Functional internal rotation after shoulder arthroplasty: a comparison of anatomic and reverse shoulder arthroplasty. J Shoulder Elbow Surg 2015;24:867–74. https://doi.org/10.1016/j.jse.2014.10.002.
36. Wagner ER, Hevesi M, Houdek MT, Cofield RH, Sperling JW, Sanchez-Sotelo J. Can a reverse shoulder arthroplasty be used to revise a failed primary reverse shoulder arthroplasty? Revision reverse shoulder arthroplasty for failed reverse prosthesis. Bone Joint J 2018;100:1493–8. https://doi.org/10.1302/0301-620X.100B11.BJJ-2018-0226.R2.
37. Walch G, Young AA, Boileau P, Loew M, Gazielly D, Molé D. Patterns of loosening of polyethylene keeled glenoid components after shoulder arthroplasty for primary osteoarthritis: results of a multicenter study with more than five years of follow-up. J Bone Joint Surg Am 2012;94:145–50. https://doi.org/10.2106/JBJS.J.00699.
38. 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.
39. Wright MA, Keener JD, Chamberlain AM. Comparison of clinical outcomes after anatomic total shoulder arthroplasty and reverse shoulder arthroplasty in patients 70 years and older with glenohumeral osteoarthritis and an intact rotator cuff. J Am Acad Orthop Surg 2020;28:e222–9. https://doi.org/10.5435/JAAOS-D-19-00166.
40. Zumstein MA, Pinedo M, Old J, Boileau P. Problems, complications, reoperations, and revisions in reverse total shoulder arthroplasty: a systematic review. J Shoulder Elbow Surg 2011;20:146–7. https://doi.org/10.1016/j.jse.2010.08.001.