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Clinical Outcomes Do Not Deteriorate Over Time Following Primary Reverse Total Shoulder Arthroplasty

Minimum 10-Year Follow-up of 135 Shoulders

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Background: Reverse total shoulder arthroplasty (RTSA) offers satisfactory mid-term outcomes for a variety of pathologies, but long-term follow-up data are limited. This study demonstrates the long-term clinical and radiographic outcomes as well as the predictive factors for an inferior outcome following RTSA.

Methods: Using the prospective database of a single, tertiary referral center, we included all primary RTSAs that were performed during the study period and had a minimum 10-year follow-up. Clinical outcomes included the absolute Constant-Murley score (CS), relative CS, Subjective Shoulder Value (SSV), range of motion, pain, complication rate, and reintervention rate. Radiographic measurements included the critical shoulder angle (CSA), lateralization shoulder angle (LSA), distalization shoulder angle (DSA), reverse shoulder angle (RSA), acromiohumeral distance (ACHD), center of rotation, glenoid component height, notching, radiolucent lines, heterotopic ossification, and tuberosity resorption.

Results: A total of 135 shoulders (133 patients) were available for analysis at a mean follow-up of 10.9 ± 1.6 years. The mean age was 69 ± 8 years, and 76 shoulders (76 patients; 56%) were female. For most of the clinical outcomes, initial improvements were observed in the short term and were sustained in the long term without notable deterioration, with >10-year follow-up values of 64 ± 16 for the absolute CS, 79% ± 18% for the relative CS, 79% ± 21% for the SSV, and 14 ± 3 for the CS for pain. However, after initial improvement, deterioration was seen for flexion and external rotation, with values of 117° ± 26° and 25° ± 18°, respectively, at the final follow-up. Scapular notching, heterotopic ossification, and radiolucent lines of <2 mm progressed during the study period. Younger age (p = 0.040), grade-II notching (p = 0.048), tuberosity resorption (p = 0.015), and radiolucent lines of <2 mm around the glenoid (p = 0.015) were predictive of an inferior outcome. The complication rate was 28%, with a reintervention rate of 11%.

Conclusions: RTSA provided improved long-term results that did not significantly deteriorate over time for most of the clinical parameters. Negative clinical outcome predictors were younger age, grade-II notching, tuberosity resorption, and radiolucent lines of <2 mm around the glenoid.

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

Reverse total shoulder arthroplasty (RTSA) is utilized in the management of a variety of pathologies[1], including cuff tear arthropathy[2], massive rotator cuff tear[2], osteoarthritis[3], rheumatoid arthritis, and fracture[4], and as a revision option[5]. RTSA prostheses are being implanted at an increasing rate[6,7] as a result of expanding indications and an aging population[8,9]. Satisfactory results have been reported up to at least mid-term follow-up in several studies[10-13]. However, long-term follow-up studies are limited and have not included comprehensive radiographic evaluations or analyses of the predictors of a poor outcome[14-17]. Given that the utilization of RTSA is rapidly increasing[6] and growth rates are projected to exceed those of total hip and knee replacements[18], it is becoming important for surgeons and patients to know the predictors

Disclosure: No external funding was received for this work. The Article Processing Charge for open access publication was funded internally by the Department of Orthopaedics. The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJSOA/A671).

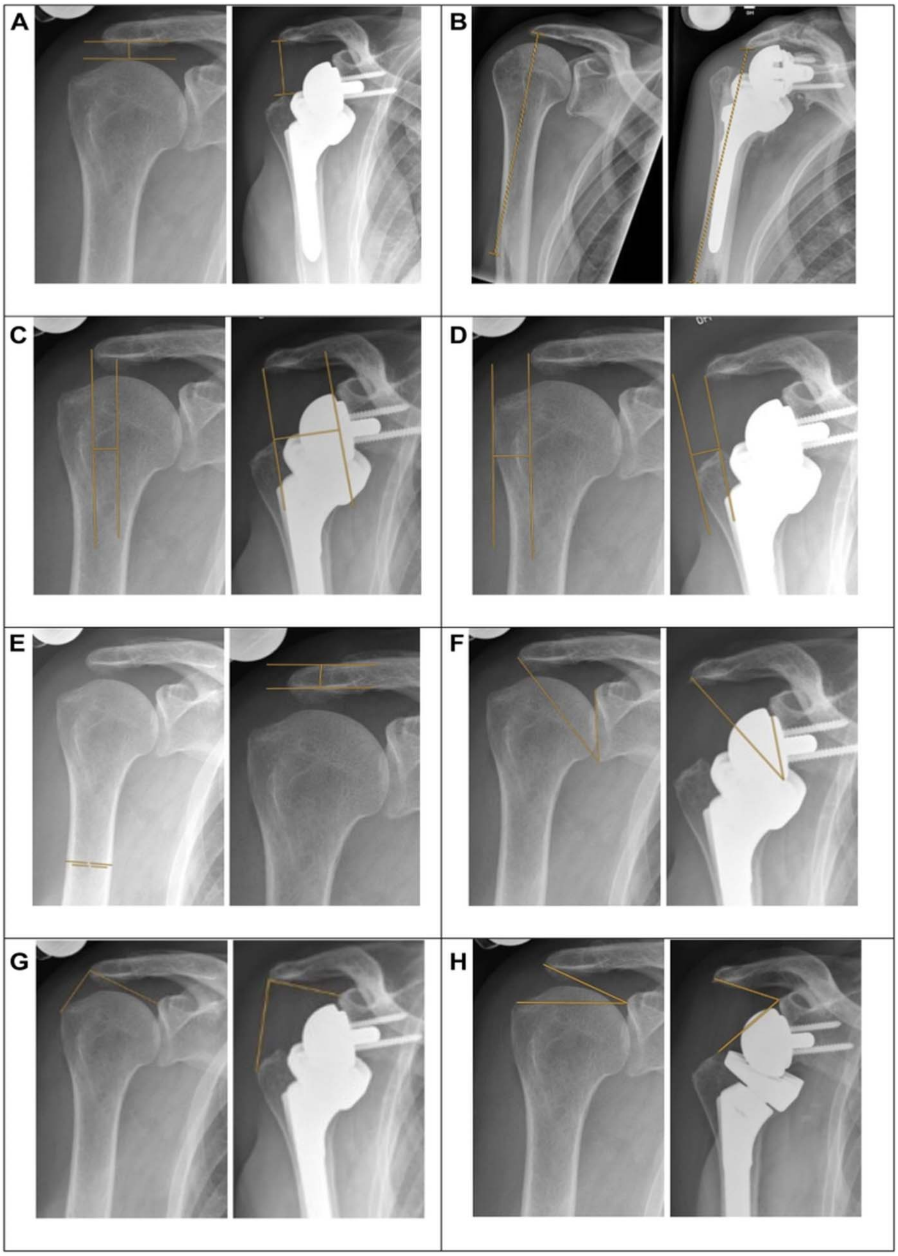

Fig. 1

Figs. 1-A through 1-H Visualizations of the measurement of predictive preoperative and postoperative radiographic parameters on an anteroposterior view. The method for each measurement is shown as a yellow line. Reproduced from: Kriechling P, Hodel S, Paszicsnyek A, Schwihla I, Borbas P, Wieser K. Incidence, radiographic predictors, and clinical outcome of acromial stress reaction and acromial fractures in reverse total shoulder arthroplasty. J Shoulder Elbow Surg. 2022 Jun;31(6):1143-53, an open access article under the CC-BY-NC-ND 4.0 license (https://creativecommons.org/licenses/by-nc-nd/4.0/)[36]. **Fig. 1-A** Acromiohumeral distance (ACHD). **Fig. 1-B** Deltoid length. **Fig. 1-C** Distance from the center of rotation to the lateral acromion (COR-LA). **Fig. 1-D** Distance from the lateral acromion to the most lateral tip of the greater tuberosity (LA-GT). **Fig. 1-E** Deltoid tuberosity index (DTI) and acromial thickness. **Fig. 1-F** Critical shoulder angle (CSA). **Fig. 1-G** Lateralization shoulder angle (LSA). **Fig. 1-H** Distalization shoulder angle (DSA).

of clinical outcome. A previous shoulder surgery has been associated with impaired outcomes in most studies[19-22]. However, the influences of most other factors, including age, gender, body mass index, preoperative American Society of Anesthesiologists (ASA) class, and the indication for arthroplasty, remain unclear[19-25]. Apart from the fact that contrary findings have been reported regarding the influences of some factors, none of those analyses were based on long-term data[14-17].

The present study aimed to evaluate the clinical and radiographic outcomes and predictors of outcome at a

TABLE I Basic Demographic Data*

No. of shoulders	135
No. of patients	133
Mean age *(yr)*	69 ± 8
Female *(no. of shoulders)*	76 (56%)
Right side *(no. of shoulders)*	86 (64%)
Right-dominant *(no. of shoulders)*	91 (67%)
Mean BMI *(kg/m²)*	27 ± 5
Smoking	
Never smoked	99 (73%)
Stopped	17 (13%)
Active	14 (10%)
Unknown	5 (4%)
Alcohol consumption *(no. of shoulders)*	
Rarely	58 (43%)
None	52 (39%)
Regularly	18 (13%)
Unknown	7 (5%)
ASA classification *(no. of shoulders)*	
I	12 (9%)
II	97 (72%)
III	24 (18%)
IV	0 (0%)
V	1 (1%)
Unknown	1 (1%)
Indication *(no. of shoulders)*	
RCT without OA	46 (34%)
RCT with OA	39 (29%)
CTA	14 (10%)
Fracture, acute	7 (5%)
Fracture, conversion from plate	6 (4%)
Instability	9 (7%)
OA	7 (5%)
Osteonecrosis	7 (5%)
No. of previous surgeries *(no. of shoulders)*	
0	74 (55%)
1	34 (25%)
2	15 (11%)
3	11 (8%)
4	1 (1%)

*Values are given as the mean ± standard deviation for numerical data or as the absolute number, with the percentage in parentheses, for categorical data. ASA = American Society of Anesthesiologists, BMI = body mass index, CTA = cuff tear arthropathy, RCT = rotator cuff tear, OA = osteoarthritis.

minimum follow-up of 10 years. We hypothesized that the initial clinical improvements following RTSA would be maintained over a course of at least 10 years.

Materials and Methods

The study received ethical approval from the University of Zurich (ID 2018-01494) and was conducted in accordance with the Declaration of Helsinki[26]. Data analysis followed the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines[27].

Using the database of a single tertiary referral center, we included all prospectively followed patients with a primary RTSA performed between September 2005 and July 2012 and a minimum follow-up of 10 years. Primary RTSA was defined as the first implantation of any arthroplasty prosthesis at the shoulder joint, excluding all patients with a previous implantation of any arthroplasty prosthesis in that location. The indications for surgery were an irreparable rotator cuff tear with or without arthritis, cuff tear arthropathy, a proximal humeral fracture, osteoarthritis, instability or dislocation arthropathy, or osteonecrosis of the humeral head. Cuff tear arthropathy was defined in accordance with Neer et al.[28] and Hamada et al.[29] as an end-stage rotator cuff tear with osteoarthritis. Patients who declined to participate in the study or were unable to attend a clinical appointment were excluded.

An RTSA prosthesis (Zimmer Biomet Anatomical Shoulder Inverse/Reverse) with a neck-shaft angle of 155° and an onlay design was implanted with use of a standardized, previously reported technique[8]. The implant lateralizes predominantly on the humeral side[30]. If possible, the tuberosities were repaired in patients with a fracture. Each RTSA was performed by 1 of 9 surgeons. Postoperatively, the arm was immobilized in a sling for comfort for a duration of 4 to 6 weeks. All patients underwent clinical and radiographic follow-up at 1 and/or 2 years postoperatively and every 2 to 4 years thereafter. Routine clinical follow-up included measurements of range of motion using a handheld goniometer (external rotation was measured in adduction), Subjective Shoulder Value (SSV)[31], the Constant-Murley score (CS), the CS for pain, and abduction strength[32]. Radiographic follow-up included anteroposterior, lateral scapular view, and axillary view radiographs. All scores were also evaluated for the contralateral side and were included if no operation was performed on the contralateral shoulder. The clinical appointment was undertaken by a study nurse under the supervision of 1 orthopaedic consultant specializing in shoulder surgery.

The radiographic analysis included the critical shoulder angle (CSA)[33], lateralization shoulder angle (LSA)[34], distalization shoulder angle (DSA)[34], reverse shoulder angle (RSA)[35], acromiohumeral distance (ACHD), and the position of the implant, which was measured as the distance between the center of rotation and the lateral acromion (COR-LA), the distance between the lateral acromion and the greater tuberosity (LA-GT), and the distance between the center of rotation and the greater tuberosity (COR-GT) (Fig. 1). Those measurements have previously been described in detail[36]. Further analysis included notching, as defined by Sirveaux et al.[37]; glenoid component height, which was measured to evaluate inferior overhang of the glenosphere in reference to the inferior glenoid rim[38]; glenoid bone wear, as defined by Bercik et al. (a modification of the original Walch system)[39]; glenoid version; radiolucent lines of <2

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TABLE II Clinical Function of All Shoulders That Underwent RTSA (N = 135) Compared with the Contralateral Shoulders of All Patients Without Any Operation on That Side (N = 86)*

	Preop.	1 Year	2-4 Years	>4-7 Years	>10 Years	P Value, >10 Years vs. 2-4 Years†	Postop. ANOVA P Value‡
CS, absolute							
RTSA group	32 ± 14	64 ± 15	64 ± 15	66 ± 16	64 ± 16	0.934	0.962
Contralateral group	77 ± 11	76 ± 12	77 ± 12	76 ± 15	73 ± 12	0.018	0.068
P value§	<0.01	<0.01	<0.01	<0.01	<0.01		
CS, relative *(%)*							
RTSA group	40 ± 17	75 ± 18	77 ± 17	79 ± 18	79 ± 18	0.355	0.303
Contralateral group	89 ± 13	88 ± 14	90 ± 13	89 ± 16	88 ± 13	0.256	0.418
P value§	<0.01	<0.01	<0.01	<0.01	<0.01		
SSV *(%)*							
RTSA group	28 ± 18	73 ± 21	77 ± 20	77 ± 21	79 ± 21	0.508	0.65
Contralateral group	94 ± 9	92 ± 14	93 ± 12	92 ± 15	88 ± 18	0.140	0.077
P value§	<0.01	<0.01	<0.01	<0.01	<0.01		
CS for pain#							
RTSA group	7 ± 4	13 ± 3	13 ± 3	14 ± 3	14 ± 3	0.016	0.02
Contralateral group	14 ± 2	14 ± 2	14 ± 2	14 ± 2	14 ± 2	0.440	0.492
P value§	<0.01	<0.01	0.011	0.234	0.758		
Flexion *(deg)*							
RTSA group	77 ± 43	128 ± 29	130 ± 26	121 ± 28	117 ± 26	<0.01	<0.01
Contralateral group	154 ± 23	150 ± 23	150 ± 22	145 ± 28	135 ± 23	<0.01	<0.01
P value§	<0.01	<0.01	<0.01	<0.01	<0.01		
Abduction *(deg)*							
RTSA group	69 ± 40	124 ± 35	126 ± 32	127 ± 36	125 ± 35	0.935	0.923
Contralateral group	148 ± 29	147 ± 26	149 ± 24	147 ± 29	139 ± 35	<0.01	0.035
P value§	<0.01	<0.01	<0.01	<0.01	<0.01		
External rotation *(deg)*							
RTSA group	22 ± 27	29 ± 16	30 ± 19	24 ± 19	25 ± 18	0.025	0.016
Contralateral group	48 ± 22	47 ± 20	48 ± 16	46 ± 18	45 ± 19	0.446	0.211
P value§	<0.01	<0.01	<0.01	<0.01	<0.01		
Internal rotation** *(deg)*							
RTSA group	5 ± 3	5 ± 3	5 ± 3	5 ± 2	5 ± 3	0.922	0.979
Contralateral group	8 ± 3	8 ± 3	8 ± 2	8 ± 2	8 ± 3	0.757	0.921
P value§	<0.01	<0.01	<0.01	<0.01	<0.01		
Abduction strength *(kg)*							
RTSA group	1 ± 1	3 ± 2	3 ± 2	3 ± 2	2 ± 2	0.198	0.389
Contralateral group	4 ± 3	4 ± 3	4 ± 3	4 ± 3	3 ± 3	<0.01	<0.01
P value§	<0.01	<0.01	<0.01	<0.01	0.403		
Follow-up *(mo)*	–	12 ± 1	33 ± 6	81 ± 11	130 ± 19	–	–

*Values are given as the mean± standard deviation, except as noted. RTSA = reverse total shoulder arthroplasty, ANOVA = analysis of variance, CS = Constant-Murley score, SSV = Subjective Shoulder Value. †The result of testing that compared values at short-term (2-4 year) follow-up with those at long-term (>10-year) follow-up. ‡Analysis of the change over the postoperative course. §The result of testing that compared the RTSA group with the contralateral shoulder group. #The CS for pain was rated from 0 to 15, with 15 as the best result. **Internal rotation was rated from 0 to 10, with 10 as the best result.

or ≥2 mm in width around the glenoid[40] or humerus[41]; stress shielding and stem subsidence, as described by Melis et al.[42]; heterotopic ossification[43]; and tuberosity resorption[42]. Radiolucent lines around the glenoid were categorized according to the classification utilized by Bogle et al.[40]. The radiographs were analyzed by 1 fellowship-trained orthopaedic surgeon with a

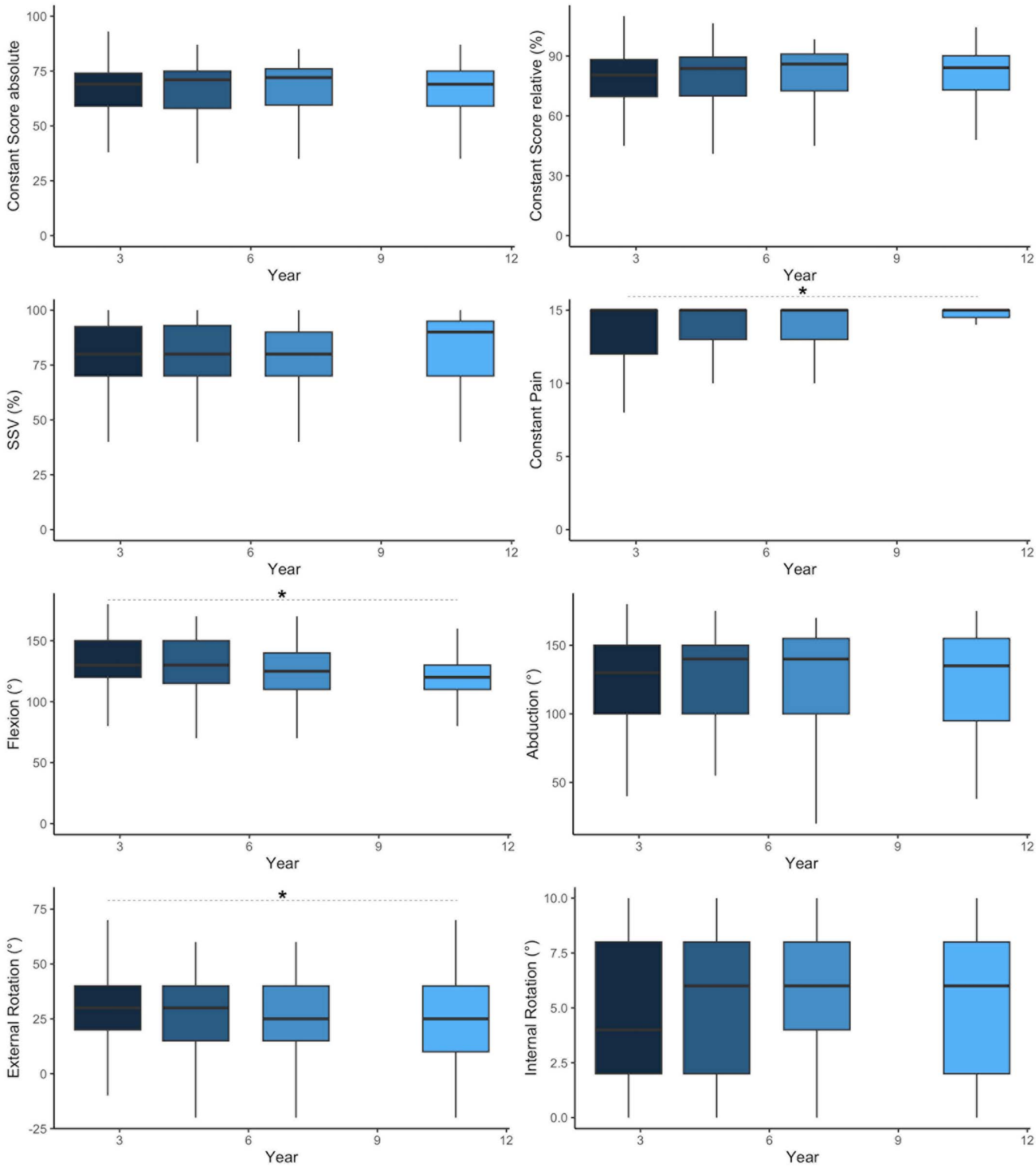

Fig. 2

Clinical outcomes measured as the absolute and relative CS, the SSV, the CS for pain, flexion, abduction, external rotation, and internal rotation. Data are visualized in box plots, with the horizontal line representing the median value, the upper and lower bounds of the box representing the interquartile range, and the whiskers representing the minimum and maximum values. Internal rotation is given on a scale from 0 to 10, with 10 as the best result. The CS for pain is given on a scale from 0 to 15, with 15 as the best result. Significant differences between 2 and 10 years were evaluated with use of ANOVA testing and marked with a dotted line and an asterisk.

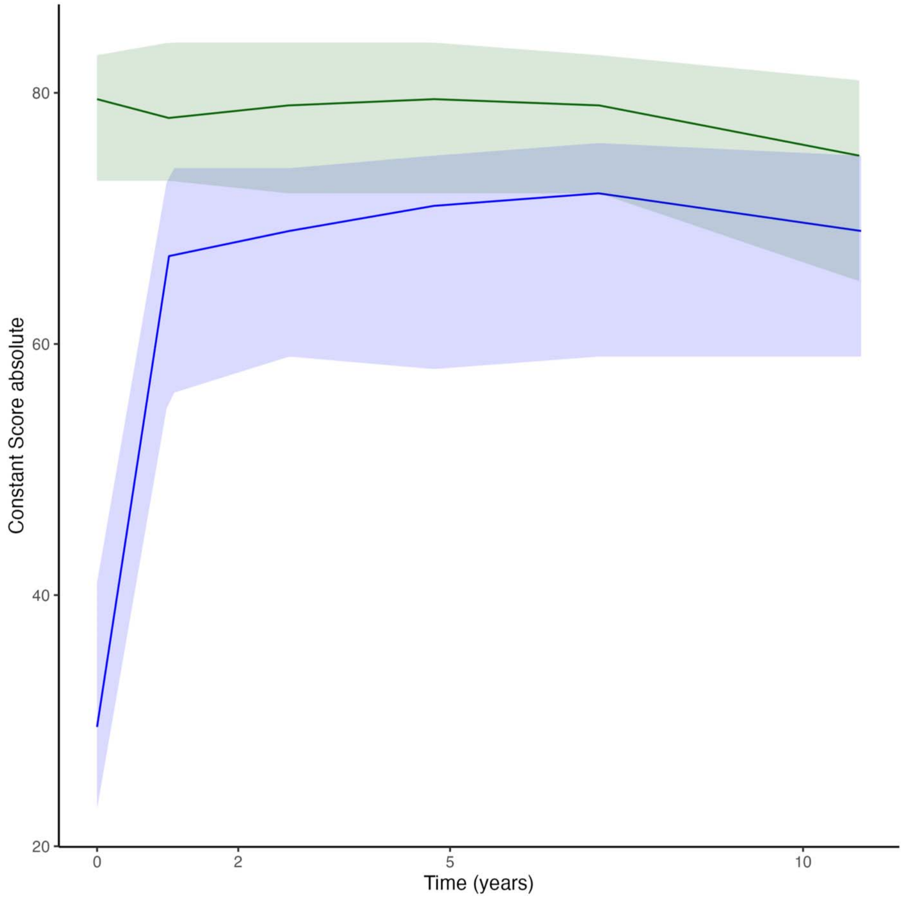

Fig. 3
Comparison of clinical outcome, measured as the absolute CS over time (in years), between shoulders that underwent RTSA (blue) and contralateral shoulders without any shoulder surgery (green). The line represents the median, and the shading represents the interquartile range.

special interest in shoulder surgery. All radiographs were made in a standardized position by a radiographer specializing in musculoskeletal imaging.

As previously described[9] using the definition by Zumstein et al.[44], complications were defined as those negatively affecting the outcome. All patients with pain at the acromion and no signs of fracture on radiographs underwent computed tomography (CT) to rule out fractures. All additional reinterventions, including revisions (i.e., surgeries with a change to the implant) and reoperations (i.e., surgeries without a change to the implant), were recorded. All closed procedures (e.g., closed reductions) were excluded.

All study data were collected and managed with use of REDCap (Vanderbilt University) electronic data capture tools[45,46]. Statistical analyses were performed with use of RStudio (version 2022.12; Posit). Differences between 2 time points were analyzed with use of the chi-square test or the paired Student t test, as appropriate. Differences between multiple postoperative time points were calculated with use of analysis of variance (ANOVA) testing. The paired Student t test was utilized to compare shoulders that underwent RTSA with contralateral shoulders that did not undergo RTSA. Predictive demographic and radiographic parameters were identified with use of linear regression modeling or the t test, as appropriate. The level of significance was set at $p < 0.05$.

Results

A total of 396 shoulders across 375 patients underwent primary RTSA between September 2005 and July 2012. Minimum 10-year clinical and radiographic follow-up data were available for 135 shoulders (133 patients; 34% of shoulders) at a mean follow-up duration (and standard deviation) of 10.9 ± 1.6 years. The reasons for loss to follow-up were death (96 of 396 shoulders; 24%), which occurred at a mean of 5.9 ± 3.1 years; inability to travel or frailty (150 shoulders; 38%); an unknown cause (13 shoulders; 3%); or choosing not to participate (2 shoulders; 1%). In the overall cohort, the mean age was 73 ± 9 years, and 259 (65%) of the 396 shoulders were in female patients. In the analyzed group, the mean age was 69 ± 8 years, and 76 (56%) of the 135 shoulders were in female patients. At the time of surgery, the lost-to-follow-up group was markedly older than the included group: patients >80 years old constituted 9 (7%) of 135 shoulders in the analyzed group and 77 (30%) of 261 shoulders in the lost-to-follow-up group, and patients

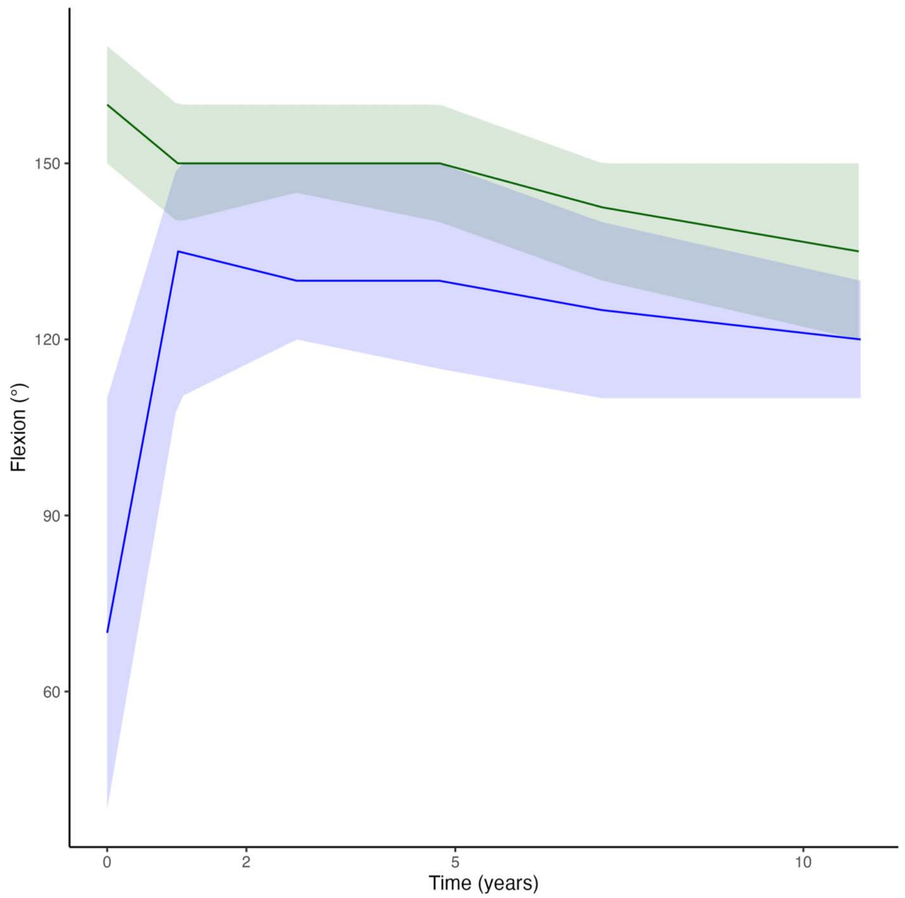

Fig. 4

Comparison of clinical outcome, measured as flexion (in degrees) over time (in years), between shoulders that underwent RTSA (blue) and contralateral shoulders without any shoulder surgery (green). The line represents the median, and the shading represents the interquartile range.

>70 years old constituted 60 (44%) of 135 shoulders in the analyzed group and 201 (77%) of 261 shoulders in the lost-to-follow-up group.

Basic demographic data are included in Table I. A deltopectoral approach was utilized in 125 shoulders (123 patients; 93% of shoulders), and a superolateral approach was utilized in 10 shoulders (10 patients; 7% of shoulders). Additional procedures included a latissimus dorsi transfer in 16 shoulders (16 patients; 12% of shoulders), a combined latissimus dorsi and teres minor transfer (L'Episcopo procedure) in 4 shoulders (4 patients; 3% of shoulders), and refixation of the subscapularis in 72 shoulders (71 patients; 53% of shoulders).

With regard to the clinical outcomes, the absolute and relative CS, the SSV, the CS for pain, flexion, abduction, and abduction strength improved significantly from the preoperative time point to the long-term follow-up ($p < 0.001$ for all; see Appendix Supplemental Table 1). The absolute and relative CS, SSV, abduction, internal rotation, and abduction strength did not change significantly during the study period when the values at different postoperative time points were compared (Table II; see also Appendix Supplemental Table 1). However, flexion and external rotation decreased with time, and pain improved slightly (Fig. 2, Table II; see also Appendix Supplemental Table 1). Of 135 contralateral shoulders, 49 (36%) had a previous shoulder surgery, including arthroplasty (30 shoulders; 22%), rotator cuff repair (17; 13%), debridement (10; 7%), acromioclavicular joint resection (2; 1%), and stabilization surgery (1; 1%). The remaining 86 patients without a previous shoulder surgery were utilized as the control group (Fig. 3). The contralateral shoulder mainly deteriorated with respect to flexion and abduction over time (Fig. 4, Table II). Patients who underwent RTSA for a failed fracture fixation fared significantly worse than patients who underwent RTSA for a rotator cuff tear with arthritis (absolute CS, $p = 0.01$) or without arthritis (absolute CS, $p = 0.02$) (Fig. 5; see also Appendix Supplemental Tables 2 through 11 and Supplemental Figs. 1 through 8).

The radiographic outcomes are presented in Table III and Appendix Supplemental Table 12. Most of the numeric parameters describing the position of the implant remained unchanged during the postoperative period, including the CSA, LSA, DSA, most of the COR-related parameters, glenoid component height, and RSA. However, the ACHD decreased by 3 mm and the COR-GT decreased by 2 mm from 1 year postoperatively to the latest follow-up, both of which were significant. Furthermore, analyses of notching and heterotopic ossification revealed significant

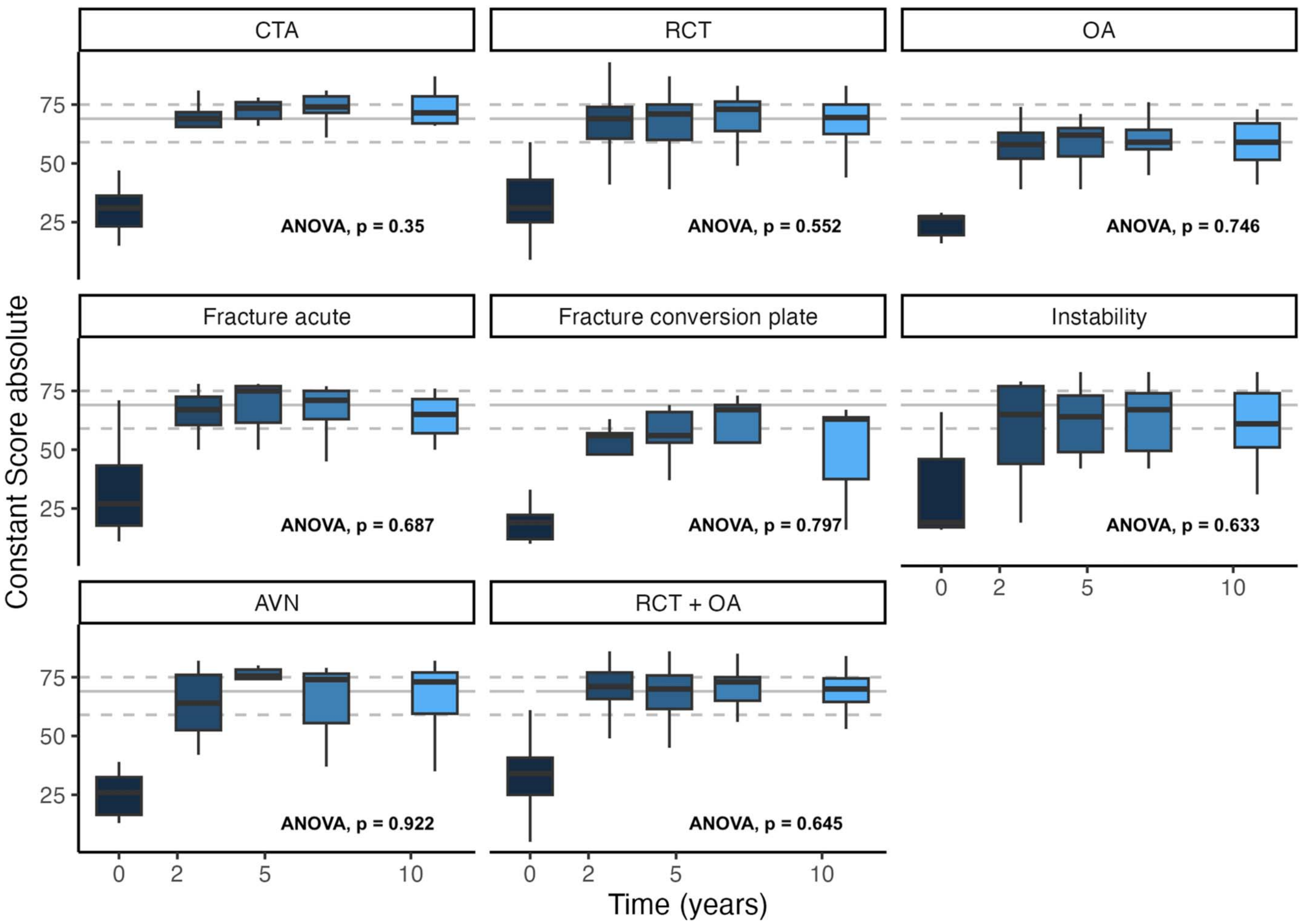

Fig. 5

Box plots showing the clinical outcome, measured as the absolute CS over time, for each indication. The solid gray line represents the overall median of all groups at the latest follow-up, and the dashed gray lines represent the corresponding interquartile range. ANOVA was utilized to test the change from 2 to 10 years of follow-up. CTA = cuff tear arthropathy, RCT = rotator cuff tear, OA = osteoarthritis, fracture conversion plate = conversion from fracture fixation with a plate, AVN = avascular necrosis (osteonecrosis) of the humeral head.

progression over time. The rate of tuberosity resorption was in general low but appeared progressive. The analysis of preoperative glenoid morphology using the modified Walch classification revealed 79 A1 (59%), 19 A2 (14%), 5 B1 (4%), 4 B2 (3%), 2 B3 (2%), 1 C (1%), and 25 D (19%) glenoids. The mean glenoid version was −3° ± 8°.

A total of 38 shoulders that underwent RTSA (38 patients; 28%) had at least 1 complication. Of those, 15 shoulders (15 patients; 11% of the analyzed group) underwent a cumulative number of 25 reintervention procedures. The complications are presented in Table IV.

An analysis using the absolute CS as the dependent variable revealed the following predictive factors for an inferior outcome: younger age (coefficient, 6.39; 95% confidence interval [CI], 0.30 to 12.48; p = 0.040), grade-II notching (coefficient, −10.05; 95% CI, −20.02 to −0.08; p = 0.048), resorption of the tuberosities (coefficient, −12.28; 95% CI, −22.17 to −2.38; p = 0.015), and radiolucent lines of <2 mm around the glenoid (coefficient, −10.88; 95% CI, −19.65 to −2.11; p = 0.015 (see Appendix Supplemental Tables 13 and 14).

Discussion

There is limited evidence on the long-term outcomes of patients following primary RTSA, with few studies offering a comprehensive preoperative and postoperative radiographic evaluation or analysis to identify the predictors of a poor outcome. To our knowledge, the present study represents the largest series of RTSAs to include a minimum follow-up of 10 years. The primary finding was the good-to-excellent outcome scores (i.e., the CS and SSV) that were achieved from the outset and maintained up to the mean follow-up of 10.9 years. Second, the study showed that flexion and external rotation deteriorated over time.

Only 4 other studies[14-17] have reported clinical outcomes following RTSAs at a minimum follow-up of 10 years; these studies are summarized in Table V. All 4 studies included

TABLE III Radiographic Measurements Preoperatively and at Various Follow-up Time Points*

		Postop.					
	Preop.	Immediate (6 Weeks)	1 Year	>4-7 Years	>10 Years	P Value, >10 Years vs. 1 Year†	Postop. ANOVA P Value‡
General							
CSA *(deg)*	35 ± 5	31 ± 7	31 ± 7	31 ± 7	32 ± 8	0.295	0.231
LSA *(deg)*	98 ± 14	41 ± 10	42 ± 10	40 ± 11	40 ± 11	0.499	0.099
DSA *(deg)*	29 ± 12	88 ± 9	87 ± 9	87 ± 10	86 ± 10	0.176	0.377
ACHD *(mm)*	9 ± 9	34 ± 9	36 ± 9	33 ± 9	33 ± 9	0.021	0.035
COR-LA *(mm)*	45 ± 30	42 ± 5	42 ± 6	41 ± 7	41 ± 8	0.179	0.055
LA-GT *(mm)*	17 ± 14	15 ± 7	13 ± 6	13 ± 7	13 ± 8	0.483	0.025
COR-GT *(mm)*	56 ± 38	57 ± 6	55 ± 6	54 ± 6	53 ± 6	0.009	<0.01
Glenoid component height *(mm)*	–	4 ± 2	4 ± 2	4 ± 2	4 ± 3	0.973	0.666
RSA *(deg)*	66 ± 9	79 ± 8	79 ± 9	79 ± 8	80 ± 8	0.429	0.601
Deltoid tuberosity index	1.5 ± 0.2	–	–	–	–	–	–
Follow-up *(mo)*	–	0 ± 0	1 ± 0	5 ± 1	11 ± 2	–	–
Glenoid *(no. of shoulders)*							
Notching§						<0.01	<0.01
None	–	85 (66%)	38 (30%)	28 (22%)	23 (18%)		
Grade I	–	31 (24%)	50 (40%)	46 (36%)	37 (28%)		
Grade II	–	8 (6%)	27 (21%)	25 (19%)	29 (22%)		
Grade III	–	4 (3%)	8 (6%)	24 (19%)	27 (21%)		
Grade IV	–	0 (0%)	3 (2%)	6 (5%)	14 (11%)		
RL <2 mm	–	1 (1%)	5 (4%)	10 (8%)	17 (13%)	<0.01	<0.01
RL ≥2 mm	–	0 (0%)	1 (1%)	3 (2%)	6 (5%)	0.014	0.082
Humerus *(no. of shoulders)*							
RL <2 mm	–	0 (0%)	7 (5%)	9 (7%)	3 (2%)	0.08	0.003
RL ≥2 mm	–	0 (0%)	0 (0%)	1 (1%)	5 (4%)	0.024	0.231
Stress shielding	–	0 (0%)	0 (0%)	1 (1%)	3 (2%)	0.082	0.113
Heterotopic ossification#						<0.01	<0.01
No	–	98 (75%)	59 (46%)	55 (43%)	49 (37%)		
Grade 1a	–	13 (10%)	24 (19%)	23 (18%)	23 (18%)		
Grade 1b	–	19 (15%)	42 (33%)	47 (36%)	56 (43%)		
Grade 1c	–	0 (0%)	0 (0%)	0 (0%)	0 (0%)		
Grade 2	–	0 (0%)	2 (2%)	4 (3%)	3 (2%)		
Grade 3	–	0 (0%)	0 (0%)	0 (0%)	0 (0%)		
Resorption of tuberosities						0.032	0.181
No	–	125 (96%)	119 (94%)	117 (91%)	116 (89%)		
Greater tuberosity only	–	4 (3%)	7 (6%)	8 (6%)	10 (8%)		
Lesser tuberosity only	–	0 (0%)	0 (0%)	1 (1%)	1 (1%)		
Both	–	1 (1%)	1 (1%)	2 (2%)	3 (2%)		
Stress shielding	–	0 (0%)	0 (0%)	1 (0%)	3 (1%)	<0.01	0.025

*Except as noted, values are given as the mean± standard deviation for numerical data or as the absolute number, with the percentage in parentheses, for categorical data. In instances of missing values, the category total was utilized to calculate the percentages. ANOVA = analysis of variance, CSA = critical shoulder angle, LSA = lateralization shoulder angle, DSA = distalization shoulder angle, ACHD = acromiohumeral distance, COR-LA = distance from the center of rotation to the lateral acromion, LA-GT = distance from the lateral acromion to the greater tuberosity, COR-GT = distance from the center of rotation to the greater tuberosity, RSA = reverse shoulder angle, RL = radiolucent lines. †The result of a Student t test comparing the values at short-term (1-year) follow-up with those at long-term (>10-year) follow-up. ‡Analysis of the change over the postoperative course. §Based on the classification by Sirveaux et al.[37]. #Based on the classification by Verhofste et al.[43].

TABLE IV All Complications and Reinterventions

Complication	No. of Shoulders (No. of Patients, % of Total Shoulders)	No. of Reinterventions (No. of Patients, % of Total Shoulders)
Total	38 (38, 28%)	25 (15, 11%)
Fracture, acromion	6 (6, 4%)	4 (2, 1%)
Fracture, shaft	2 (2, 1%)	3 (2, 1%)
Infection	4 (4, 3%)	4 (2, 1%)
Instability	2 (2, 1%)	1 (1, 1%)
Loosening, glenoid	11 (11, 8%)	4 (1, 1%)
Loosening, humerus	3 (3, 2%)	2 (2, 1%)
External rotation deficit	1 (1, 1%)	1 (1, 1%)
Nerve damage	4 (4, 3%)	0 (0, 0%)
Pain and/or scarring	5 (5, 4%)	6 (4, 3%)

revision RTSAs, whereas the present study included only primary surgeries in order to reduce the heterogeneity of the cohort. In all 4 studies, the outcome scores were reported to be highly satisfactory in the long term. The results of the present study align with those findings, as the CS scores in the present study are comparable with those reported by Gerber et al.[16] and Bacle et al.[14].

Furthermore, the overall clinical outcome scores, measured as the CS and SSV, did not deteriorate over time in our cohort, which is in accordance with the study results reported by Cuff et al.[15], Gerber et al.[16] and Sheth et al.[17]. Despite maintaining good outcome scores, significant decreases in flexion, from 130° to 117°, and external rotation, from 30° to 25°, were found in the present study and might be explained by a general degeneration of muscle tissue in aging patients[47]. However, given the relatively small decrease in each of these movement ranges in the present study, it is not surprising that the patient-reported scores were not negatively affected. Moreover, a 5° loss of external rotation might not be clinically important, as indicated in the study by Simovitch et al., who reported a minimal clinically important difference of 5° for external rotation, 2° for abduction, and 3° for forward flexion[48]. Interestingly, the analysis of contralateral shoulders without a previous surgery in the present study revealed similar decreases in flexion, from 154° to 135°, and in abduction, from 148° to 139°.

The complication rate in our cohort was 28%, with a reintervention rate of 11%. These data are equivalent to the findings of the existing long-term studies, which demonstrated complication rates between 29%[14] and 64%[17]. We found that the most common complication was glenoid loosening, at 8%, which is in line with the rate reported in the other long-term studies[14,17]. The second most common complication in the present study was acromial fracture, at 4%, which is comparable with the findings of a previously published work from our institution, in which all complications were analyzed regardless of the duration of follow-up[9]. Sheth et al.[17] found an even higher rate of 7% for acromial fractures, which is in accordance with the rates of up to 10% reported in the literature[49]. Although the exact etiology of these fractures is still a matter of debate[50], such fractures undoubtedly cause a substantial deterioration of the clinical outcome[51]. Bacle et al.[14] and Sheth et al.[17] reported instability as the most common complication, with rates of 19% and 27%, respectively. Both studies utilized the original Grammont-style RTSA implants (DePuy Delta III and Tornier Aequalis), whereas the more lateralized design of the Zimmer Biomet Anatomical Shoulder Inverse/Reverse implant was utilized in the present cohort[30]. Interestingly, the second most common complication reported in the literature was infection, with rates of 27% (Gerber et al.[16]), 16% (Sheth et al.[17]), and 13% (Bacle et al.[14]). The infection rate in the present study was only 3% (with 50% of infections being superficial), which is comparably low to just slightly higher than that reported for total hip and knee replacements[52-54].

The present study included a variety of radiographic measurements. Interestingly, the position of the implant remained mainly unchanged over the course of the follow-up period, as demonstrated by the CSA, LSA, DSA, glenoid component height, and RSA. Only 1 of the 3 measurements

TABLE V All Available Studies Reporting RTSA Long-Term Outcomes with a Minimum Follow-up of 10 Years*

Study (Publication Year)	No. of Shoulders (No. of Patients)	Mean Follow-up *(yr)*	Loss to Follow-up	Outcomes†	Complications	Reinterventions
Gerber et al.[16] (2018)	22 (22)	16.1	58%	Absolute CS: 58 ± 19. Relative CS: 73% ± 23%	59%	55%
Cuff et al.[15] (2017)	42 (40)	11	63%	ASES: 74	N/A	9%
Bacle et al.[14] (2017)	87 (84)	12.4	64%	Absolute CS: 55 ± 16. Relative CS: 86% ± 26%	29%	12%
Sheth et al.[17] (2022)	93 (93)	11.4	81%	SANE: 73	64%	51%
Present study	135 (133)	10.9	66%	Absolute CS: 64 ± 16. Relative CS: 79% ± 18%	28%	11%

*RTSA = reverse total shoulder arthroplasty, ASES = American Shoulder and Elbow Surgeons Shoulder Score, CS = Constant-Murley score, SANE = Single Assessment Numeric Evaluation score. †Values are given as the mean, with or without the standard deviation.

related to the center of rotation, the COR-GT, demonstrated a significant change: a decrease of 2 mm. This difference might be the result of a measurement error or the beginning of polyethylene-bearing wear. However, no patient underwent revision surgery for polyethylene wear. Interestingly, the ACHD increased at the 1-year follow-up and then returned to initial postoperative levels at the long-term follow-up. This might reflect either a measurement error associated with the radiographic analysis or the condition of the deltoid muscle over time. Other parameters such as notching, radiolucent lines around the glenoid and the humerus, heterotopic ossification, and resorption of the tuberosities clearly progressed with time. Notching is a well-known phenomenon related to RTSA implant design in general[55] and, in the present study, occurred in 34% of the patients at the short-term follow-up and increased to 82% at the long-term follow-up. Equally high rates were described by Bacle et al.[14] and Gerber et al.[16], who each reported rates of 73%. The long-term radiographic analysis in the present study also revealed progression of heterotopic ossification, from 25% at the early follow-up to 63% at the long-term follow-up. Melis et al.[42] reported a rate of 75% for heterotopic ossification in their analysis. There exist only a few studies on heterotopic ossification following RTSA. Verhofste et al.[43] identified a rate of 30% in their cohort of 132 RTSAs at a mean follow-up of 36 months and found that heterotopic ossification was associated with poorer outcomes. Interestingly, the present study did not demonstrate a negative impact of heterotopic ossification on clinical outcome despite the high rate of heterotopic ossification. In contrast, resorption of the tuberosities was clearly associated with an inferior clinical outcome, which might be explained by the impaired function of the remaining posterior rotator cuff.

The present study aimed to define the predictors of clinical outcome and found that resorption of the tuberosities, grade-II notching, radiolucent lines around the glenoid, and younger age were negative factors. A recently published study on RTSA compared 154 patients who were <60 years old with 1,763 patients who were between 60 and 79 years old and found impaired outcomes in younger patients[56]. This finding might be explained by an expected longer lifespan in patients who are <60 years old or by the higher activity level that younger patients usually have. In addition, multiple studies have highlighted the satisfactory clinical results following RTSA in elderly patients[8,57-59].

The present study had the inherent limitations of a retrospective data analysis. However, prospective follow-up with regular clinical and radiographic analysis was performed for all patients. Utilizing radiographs for follow-up may have resulted in less accuracy than if a CT or other 3-dimensional analysis had been performed, given the potential variance in measurements that is attributed to x-ray projection angles. A major limitation of the present study was the limited follow-up rate of only 34%, leading to a potential selection bias that may have excluded patients with poorer outcomes from the analysis. Additionally, this limitation undermines the generalizability of the results, as a relevant number of patients were not included in the analysis. This issue may have been due to the inherent challenges in conducting long-term studies and compounded by the initial demographic makeup of patients undergoing RTSA, many of whom were elderly individuals who were too frail to attend the 10-year follow-up assessment or who may have died. Notably, this limitation was not unique to our center, as previously published studies have encountered similar challenges in achieving sufficient follow-up rates (Table V)[8].

Conclusions

The initial clinical improvements that were achieved following RTSA were maintained in the long term for most outcome parameters. The predictors of an inferior clinical outcome included younger age, radiolucent lines of <2 mm around the glenoid, grade-II scapular notching, and tuberosity resorption. Surgeons should be mindful of these predictors and provide appropriate counseling for patients.

Appendix

eA Supporting material provided by the authors is posted with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJSOA/A672). ■

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