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Functional and radiographic outcomes of reverse shoulder arthroplasty with a minimum follow-up of 10 years

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Background: The use of reverse shoulder arthroplasty (RSA) is becoming increasingly prevalent. However, few studies have been published reporting the long-term outcomes of RSA. This study aims to report the clinical, radiographic, and patient-reported outcomes of the Delta Xtend reverse shoulder prosthesis, performed by a single surgeon and with a minimum follow-up of 10 years.

Methods: All RSA procedures performed between 2005 and 2012 were identified. Patients were contacted and invited for a follow-up visit including clinical assessment, radiographs, and patient-reported outcome measures. Patients with a follow-up of less than 10 years were excluded. The revision-free implant survival was calculated at 10 years. Between 2005 and 2012, 119 procedures in 116 patients meeting inclusion criteria were identified. Of these patients, 35 were deceased before reaching the 10-year follow-up and 23 could not be reached. In total, 63 RSAs could be included in 61 patients (response rate: 75%). The median follow-up was 11.7 years (interquartile range [IQR]: 10.5-13.2).

Results: Of the 61 patients, 7 patients underwent a revision after a median of 3 years (IQR: 0.2-9.8) during the total follow-up period. The 10-year implant survival was 94% (95% confidence interval: 84-98). At final follow-up, the median anterior elevation was 135° (IQR: 130°-160°), the median abduction was 120° (IQR: 100°-135°), and the median level reached with internal rotation was L5 (IQR: sacrum-L5). The median Auto-Constant score was 68 (IQR: 53-78), the median Subjective Shoulder Value was 80 (IQR: 70-93), and the median pain score was 0.2/10 (IQR: 0-2). In total, radiographs could be obtained in 25 patients (40%). Scapular notching occurred in 10 patients (40%), which was classified as Sirveaux-Nerot grade IV in 3 patients (12%). Ossification occurred in 10 patients (40%), and stress shielding in 2 patients (8%). Radiolucencies were observed around the humeral component in 24 patients (96%) and around the glenoid component in 13 patients (52%).

Conclusion: The long-term results of RSA with a Delta Xtend prosthesis are favorable, with long-term improvement in range of motion and patient-reported outcome measures, and a satisfactory implant survival rate. Interestingly, the radiographical analysis showed high prevalence of signs associated with loosening, which did not seem to translate to high complication rates or inferior results.

The National Commission on Informatics and Liberty (Commission nationale de l'informatique et des libertés) institutional review board approved this study (IRB no.: 2229193).

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Reverse shoulder arthroplasty (RSA) is used for an increasing range of indications including cuff tear arthropathy, irreparable cuff tears, primary osteoarthritis with an insufficient cuff or bone stock, and complex proximal humerus fractures. In the 2 decades since the introduction of the RSA design by Grammont, technical improvements have led to increasingly favorable outcomes.[4] Current RSA designs result in good range of motion (ROM), patient-reported outcome measures (PROMs), and overall low complications on short-term outcomes.[24]

However, few studies have reported detailed long-term outcomes of RSA. To our knowledge, only three studies have reported outcomes after RSA with a minimum follow-up of 10 years,[2,17,52] and 1 study reported outcomes after 15 years.[26] These studies report favorable functional and patient-reported outcomes, which remain stable at long-term follow-up.[2,17,26,52] Only in 1 out of four studies the Constant score and anterior elevation decreased from mid- to long-term follow-up,[2] in the other three studies the significant functional improvements after RSA did not decrease after 10 years.[17,26,52]

Despite cohorts in the four studies with a minimum follow-up of 10 years ranging from 22 to 93 patients, radiographic analysis was only available in relevant numbers in 1 study; Bacle et al.[2] assessed radiographs of 64 RSAs after 10 years and found scapular notching in 74% of cases. Other studies reporting radiographic outcomes at mid-to long-term follow-up report similar results with scapular notching rates ranging from 68% to 94%,[2,8] and grade III or IV notching in 42% of cases.[20] A previous meta-analysis found that patients with scapular notching had significantly worse clinical outcomes and reduced ROM compared to patients without scapular notching.[34,53] Previous studies have also shown that notching is influenced by glenoid component positioning; inferior overhang reduces rates of notching.[16,38] The preferred placement of the glenoid component may vary between surgeons, resulting in different rates of notching.

Furthermore, there is an incongruence in the literature regarding the long-term survival rate of RSA; the reported survival rates vary between 82% and 93% after at least 10 years.[2,13,26,44,52] The number at risk at this time point was low in all studies. The survival rate is also highly dependent on implant design and fixation techniques that are used, which are highly variable between studies. With regard to the Delta Xtend prosthesis specifically, a 97% survival rate has been reported after 8 years, but no survival analysis is available after 10 years.[3]

Another point of discussion is the decision to repair the subscapularis tendon, leave it detached, or use a subscapularis-sparing approach. Previous short-to mid-term studies comparing subscapularis tendon repair with leaving the subscapularis tendon detached report conflicting results in terms of ROM and patient-reported outcomes.[22,43,46] To our knowledge, long-term data are lacking; none of the four studies with a minimum follow-up of 10 years mention whether the subscapularis tendon was spared, repaired, or left detached.[2,17,26,52]

To address these gaps and inconsistencies in the literature, this study aims to assess the functional, patient-reported, and radiographic outcomes of RSA using the Delta Xtend prosthesis performed by a single surgeon using a standardized technique (including ensuring an inferior overhang of the glenosphere and systematically not repairing the subscapularis tendon) at a minimum follow-up of 10 years.

Materials and methods

For this case series, RSA procedures using the Delta Xtend prosthesis (DePuy Synthes, Raynham, MA, USA) performed by the senior author between 2005 and 2012 were identified. Patients were contacted and invited for a follow-up visit including clinical assessment, radiographs and PROMs. If patients were unable to visit the hospital, questionnaires were completed by telephone. All patients in which contact was established after 10 years and the presence or absence of a revision could be confirmed were considered eligible, regardless of the completeness of the outcome parameters. Patients with a follow-up of fewer than 10 years were excluded.

Surgical technique

In all cases, the following procedures were performed. The Delta Xtend prosthesis was used, which is based on the original Grammont design.[4] A superolateral approach was used unless preoperative evaluation of imaging indicated that an inferior extension of the incision might become necessary, for example, to remove inferior osteophytes. The subscapularis was tenotomized without reattachment when it was still present. An intramedullary guide at 30° of retroversion and neck-shaft angle (NSA) of 155° was used to determine the level of the humeral cut enabling the humeral component placement, which is different from the anatomical NSA of 135°. Due to the inlay design of the glenoid baseplate, this does not create unwanted distalization of the humerus. The metaglene was positioned at the inferior edge of the glenoid. In general, a size 42 glenosphere was used to achieve

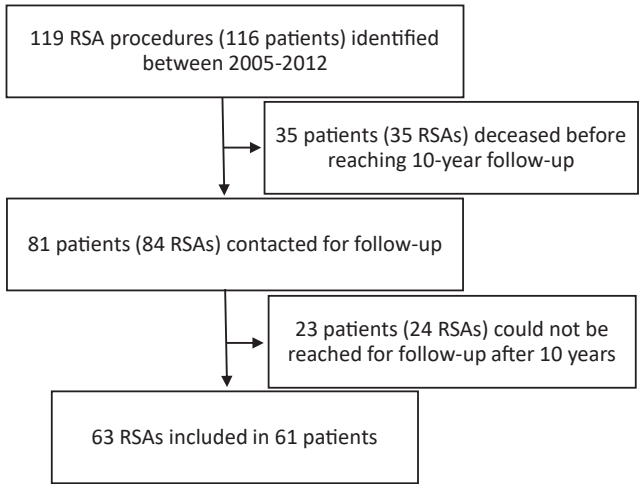

Figure 1 Inclusion flowchart (*RSA*, reverse shoulder arthroplasty).

sufficient inferior overhang, a size 38 glenosphere was used exceptionally in small female patients. A 'high mobility' polyethylene component was used, which decreases the risk of impingement and increases the ROM.

Patient-reported and clinical outcome measures

At the final follow-up, the Auto-Constant score, the Subjective Shoulder Value (SSV), and a visual analog scale (VAS) for pain were completed.[28] A previous study has shown an excellent correlation between the self-reported Auto-Constant and the Constant score assessed by a physician.[14] Furthermore, the ROM was measured during the follow-up visit by at least two physicians; 1 fellowship-trained shoulder surgeon and 1 orthopedic surgeon in fellowship. In case patients were unable to visit the hospital for follow-up, self-reported ROM for anterior elevation, abduction, and external and internal rotation was assessed in a standardized fashion using example videos recorded by the researchers which were sent to the patient to imitate for the patient to properly demonstrate and record their ROM. Two previous studies found that self-assessed ROM was accurate in the majority of cases (>85%).[10,61]

Radiographic outcomes

On the most recent radiographic imaging, lateralization, distalization, scapular notching, heterotopic bone formation, radiolucency, stress shielding, and potential other complications were independently measured and graded by two authors in a standardized fashion (Supplement 1). For the angles, the mean of the two measurements was taken as the definitive measurement. For the other assessments, all radiographs were discussed with the senior author and consensus was reached. Lateralization and distalization were measured using the angles described by Boutsiadis et al.[5] Scapular notching was graded according to the Sirveaux-Nerot classification.[54] Based on a previous study reporting all cases of glenoid component loosening occurring in patients with grade IV notching and none in grade I-III, glenoid components with grade IV notching were considered at risk of loosening.[56] Heterotopic bone formation was graded according to a modified Brooker classification.[7,18] Radiolucency occurring between the implanted material and bone interface was assessed and graded according to Schoch et al.[51] Glenoid and humeral components with grade four or five radiolucent lines or the presence of radiolucency in more than three zones around the humeral component as described by Gruen et al.[15,29,39,40,50,55] were considered at risk of loosening. Stress shielding was defined as described by Melis et al.[39] as the presence of medial and lateral cortical bone narrowing associated with osteopenia, condensation lines around the tip of the stem, and a spot weld between the cortical bone and the stem. The presence of other complications, such as fractures, bone cysts, malalignment or material failure, was also assessed.[18] The radiographic classifications are described in detail in supplement 1.

Statistical analysis

Categorical data were represented with numbers and proportions. For numerical data, normality was assessed using histograms and the Shapiro-Wilk test. Normally distributed data were represented by means and standard deviations, and abnormally distributed data by medians and interquartile ranges (IQRs). The revision-free implant survival was calculated at the 10-year follow-up, using a revision for any cause as the event and the time until revision or final follow-up as the survival time. Patients that were deceased before reaching 10-year follow-up or could not be contacted were censored. For the radiological assessment, reliability between the first two authors analyzing the radiographs was assessed using the interclass correlation (ICC) for the angle measurements and Cohen's Kappa (k) for the grades. An ICC of less than 0.50 was considered poor reliability, between 0.5 and 0.75 moderate reliability, between 0.75 and 0.9 good reliability, and greater than 0.9 was considered excellent reliability. A Cohen's Kappa of less than 0.20 was considered a slight agreement, between 0.21 and 0.40 fair, between 0.41 and 0.60 moderate, between 0.61 and 0.80 substantial, and between 0.81 and 1.00 was considered almost perfect agreement. Preoperative PROM scores and ROM were compared with the outcomes at the final follow-up using paired *t*-tests. A *P* value lower than 0.05 was considered statistically significant. Statistical analysis was performed using R version 4.0.5 (R Foundation for Statistical Computing, Vienna, Austria) and R studio (RStudio, Boston, MA, USA). Figure 1.

Study cohort

Between 2005 and 2012, 119 RSA procedures (116 patients) by a single surgeon using the Delta Xtend prosthesis were identified and patients were contacted for follow-up. In total, 61 patients with 63 RSAs could be included (response rate: 75%). The median follow-up was 11.7 years (IQR: 10.5-13.2). The median age at the time of the primary RSA in the cohort was 73 (IQR: 69-76) and the majority of patients were females (n = 44, 69%). Cuff tear arthropathy was the most common indication for RSA (n = 28, 44%; Table I).

Preoperative measurements

Preoperatively, the median Constant score was 25 (IQR: 17-35), the median VAS for pain was 7 (IQR: 3-7) and the ROM was limited in all patients (Table II).

Table I Description of cohort

Female, n (%)	44 (69)	Dominant side operated, n (%)	34 (55)
Age, median (IQR)	73 (69-76)	Approach, n (%)	
Diagnosis, n (%)		Superolateral	58 (92)
Cuff tear arthropathy	28 (44)	Deltopectoral	5 (8)
Revision	2 (3)	Acromioplasty, n (%)	27 (43)
Rheumatoid arthritis	2 (3)	Cemented humerus, n (%)	4 (6)
Acute fracture	1 (2)	Retaining cup, n (%)	4 (6)
Fracture sequelae	2 (3)	Retroversion, median (IQR)	20 (13-30)
Cuff arthropathy	2 (3)	Glenosphere size 42, n (%)	59 (92)
Primary osteoarthritis, other or unknown	26 (42)	Subscapularis detached (without reinsertion) or absent	63 (100)

IQR, Interquartile range.

Table II Preoperative measurements (n = 36)

	Median (IQR)
Constant score	25 (17-35)
VAS pain (0-10)	7 (3-7)
Anterior elevation	70° (45°-79°)
Abduction	68° (45°-75°)
External rotation	10° (0°-20°)
Internal rotation level reached	Sacrum (buttock-L5)

IQR, Interquartile range; *VAS*, visual analog scale.

Results

Complications and revisions

In total, 10 complications occurred (16%), of which seven (11%) required a revision after a median of 3 years (IQR: 0.2-9.8). Notably, there were no cases with acromial fractures. The majority of revisions occurred either shortly after the primary surgery or after more than 10 years. The 10-year implant survival was 94% (95% confidence interval: 84-97). One patient underwent a revision for a periprosthetic fracture elsewhere and the exact date of the revision was unknown, this patient was censored in the survival analysis. One case of periprosthetic infection was treated with a two-stage revision (Table III). There were no cases that required a secondary revision. Three complications were treated conservatively: 1 peri-prosthetic fracture, 1 axillary nerve injury leading to deltoid paralysis, and 1 plexus injury. The former healed with conservative treatment (Fig. 2) and the latter resolved completely after two years, the patient with a deltoid paralysis remained symptomatic but opted for conservative treatment.

Patient-reported and clinical outcome measures

PROMs were collected in 48 patients (79%). At the final follow-up, the median Auto-Constant score was 68 (IQR: 53-78), the median SSV was 80 (IQR: 70-93), and the median VAS for pain was 0.2 (IQR: 0-2). Internal rotation did not differ significantly from preoperative measurement to the final follow-up ($P = .144$). All other ROM measurements and patient-reported outcomes showed significant long-term improvement compared to the preoperative measurements ($P < .001$; Table IV).

Radiographic outcomes

In total, radiographs could be obtained in 25 patients (40%). The interobserver reliability between the first two authors was poor for the distalization angle (ICC = 0.36) and moderate for the lateralization angle (ICC = 0.57). The agreement was moderate for ossification (k = 0.52), and slight for scapular notching (k = 0.16), the number of zones around the humeral component with radiolucencies (k = −0.01), the grade of radiolucencies around the humeral component (k = 0.07), the grade of radiolucencies around the glenoid (k = 0.14), and the presence of stress shielding (k = −0.03). All radiographs were discussed with the senior author and the definitive assessment is reported.

Scapular notching occurred in 10 patients (40%), which was classified as grade IV in 3 patients (12%). The glenoid component was considered at risk of loosening (notching grade IV or radiolucency grade IV or V) in 4 patients (16%). Ossification occurred in 10 patients (40%; Fig. 3), and stress shielding in 2 patients (8%). Radiolucencies around the humeral component occurred in 24 patients (96%), 4 humeral components (16%; Fig. 4) were considered at risk of loosening due to the grade or amount of radiolucency (grade IV or V, or radiolucencies occurring in >3 zones).

Table III Revision characteristics

Case	Sex	Age at RSA, yr	Reason for revision	Years to revision	Procedure	Components revised
1	Male	65	Periprosthetic fracture		ORIF	None
2	Male	66	Instability	0.2	Revision	PE
3	Male	69	Instability	0.0	Revision	PE
4	Male	72	Instability	0.3	Revision	Humeral, PE
5	Female	75	Loosening	11.5	Revision	All
6	Female	75	Luxation	11.2	Reduction under anesthesia	None
7	Male	69	Infection	5.7	Two-stage revision	All

ORIF, open reduction and internal fixation; *PE,* polyethylene.

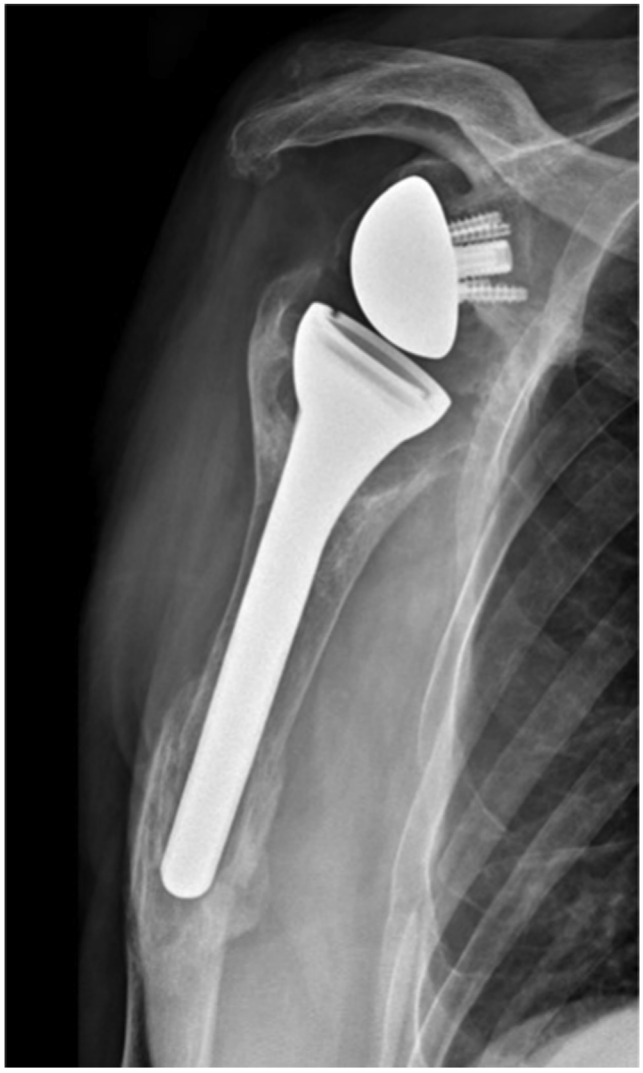

Figure 2 Radiograph of a Delta Xtend prosthesis in situ 13.1 years postoperatively showing a periprosthetic fracture at the distal end of the humeral stem which was treated conservatively and grade III scapular notching.

Radiolucencies around the glenoid component occurred in 13 patients (52%; Table V).

Discussion

This study aimed to report the outcomes of RSA with a minimum follow-up of 10 years, performed by a single surgeon using the Delta Xtend prosthesis and a standardized technique. During the total follow-up period, seven patients (11%) required a revision. The 10-year revision-free survival rate was 94%. Furthermore, the long-term results show satisfactory PROM results and a long-term improvement in ROM. The radiographical analysis showed a high prevalence of signs associated with worse outcomes and complications such as loosening. Scapular notching occurred in 40% of cases, and at least some degree of radiolucencies around the humeral component was found in 96% and around the glenoid component in 52%. However, the radiographical findings did not translate to inferior functional results or high complication rates.

Radiographic outcomes

In the current cohort, the rate of scapular notching was high, but lower in comparison to other long-term reports using similar prosthesis models. Scapular notching occurred in 40% of cases, which was classified as grade III or IV in 16%. Conversely, Bacle et al.[2] found scapular notching in 73% of cases after 10 years, 30% of which were graded III or IV. Previous mid-to long-term studies of RSA report similarly high rates of scapular notching, ranging between 68% and 94%.[2,8] This is markedly higher than our long-term findings (40%). The discrepancy in scapular notching may be explained by the placement of the glenoid component. Previous research has shown that inferior overhang and a large glenosphere size reduce rates of notching.[16,21,38,58] The senior author responsible for all

Table IV Patient-reported outcomes

	At final follow-up (n = 47), median (IQR)	Improvement from pre-operative to final follow-up (n = 26), median (IQR)	*P value
Auto-Constant score	68 (53-78)	42 (32-52)	**<.001**
Subjective Shoulder Value	80 (70-93)		
VAS pain (0-10)	0.2 (0-2)	−7 (−7 to −3)	**<.001**
Anterior elevation	135° (131°-160°)	75° (58°-98°)	**<.001**
Abduction, median (IQR)	120° (100°-135°)	45° (28°-80°)	**<.001**
External rotation, median (IQR)	20° (10°-43°)		
Internal rotation, median level reached (IQR)	L5 (sacrum-L5)	1/5 of total range (−1/5-2/5)	.144

IQR, interquartile range; *VAS,* visual analog scale.
Bold values indicate statistical significance.
* Comparison of the scores preoperatively and at final follow-up using a paired *t*-test.

surgeries in our cohort routinely created an inferior overhang of 5-10 mm by adjusting the glenoid baseplate placement and glenosphere size accordingly, using a size 42 in most cases. This is an important aspect when placing RSA, as a high degree of notching may lead to loosening or breaking out of the component. A previous meta-analysis also found that patients with scapular notching had significantly worse clinical outcomes and reduced ROM compared to patients without scapular notching.[34,53]

Besides component placement and surgical technique, several factors related to the implant design are of influence on the development of scapular notching, such as size, shape, humeral NSA, lateralization, and bearing properties. More recent, short-term studies have highlighted several important aspects of implant design which may reduce the rate of scapular notching.[23] Previous studies have found lower rates of notching in lateralized prosthesis designs.[9,32,35,37] Similarly, bony increased offset RSA decreases the rate of scapular notching.[1] Furthermore, the humeral NSA may be of influence; a systematic review of 38 studies with 2222 shoulders reported a higher rate of scapular nothing with an NSA of 155° compared to a prosthesis with an NSA of 135° and a lateralized glenosphere.[19] Another design option is an inverted bearing RSA (a polyethylene glenosphere and metal humeral component).[11] This implant design leads to a distinct type of scapular notching which appears to be less severe and solely mechanical, differing from notching enhanced by polyethylene-induced osteolysis.[33,36] In a previous study this type of notching caused by the metal component (present in 35% of cases) did not lead to inferior clinical results.[36] However, comparative studies and long-term results of inverted bearing RSA are still lacking. These studies show that several innovations in implant design may decrease the rate of scapular notching, and lead to a lower rate of scapular notching than found in the current cohort. However, long-term results are required to confirm these results. Furthermore, it is difficult to distinguish exactly which aspect of the prosthesis is responsible for the reduction in notching rates as most studies compare two types of prosthesis which differ in multiple aspects of the design.

Ossification occurred in 10 patients (40%) in the current cohort. To our knowledge, there are no studies with a minimum follow-up of 10 years reporting the presence or absence of ossification. Mid-to long-term studies report rates of ossification ranging from 18% to 75%,[12,27,39,42,45,49,59] and are inconclusive with regards to the association between ossification and adverse clinical outcomes.[45,59] Further studies are required to clarify the definition and role of ossification after RSA.

This study demonstrates a relatively high rate of radiolucencies on radiographic assessment 10 years after RSA. Radiolucent lines are a sign of progressive destruction of periprosthetic bone, caused by implant micro-motion, polyethylene wear, and aspects of implant design and positioning,[6,38,41] resulting in an inflammatory cascade and bone resorption.[31] Radiolucent lines have been linked to implant loosening and failure.[41,57] In the current cohort, at least some degree of radiolucencies around the humeral component was found in 96% of patients and 16% of humeral components were considered at risk of loosening due to the grade of radiolucency and the number of zones affected. Radiolucencies were reported around the glenoid component in 52% of patients, 16% were considered at risk of loosening. In contrast to our results, the rate of radiolucency was lower in 1 study with radiographical assessment after 10 years; radiolucent lines around the glenoid component occurred in 5% and radiolucent lines around the humeral component in at least 3 zones (considered at risk of loosening) were seen in 12%.[2] This discrepancy may be explained by the subjectivity in radiographic assessment, as demonstrated by the low agreement between the first two assessors in our study when determining the grades and zones of radiolucency. However, the high grade of radiolucencies combined with a low revision rate in both studies also suggest radiographic findings currently causing the component to be considered at

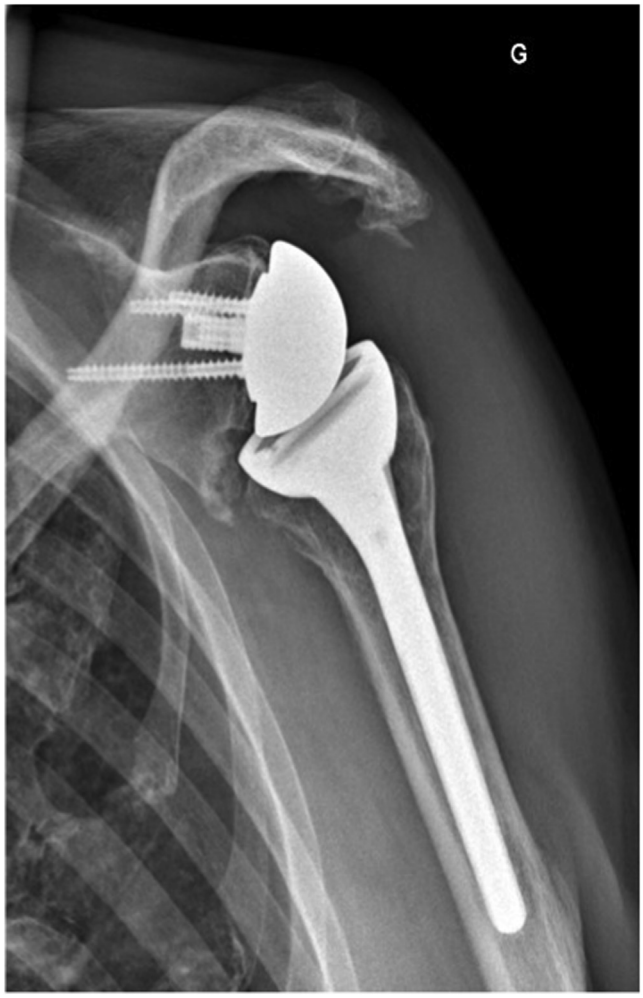

Figure 3 Radiograph of a Delta Xtend prosthesis in situ 10 years postoperatively, showing grade 3 ossification between the humerus and glenoid.

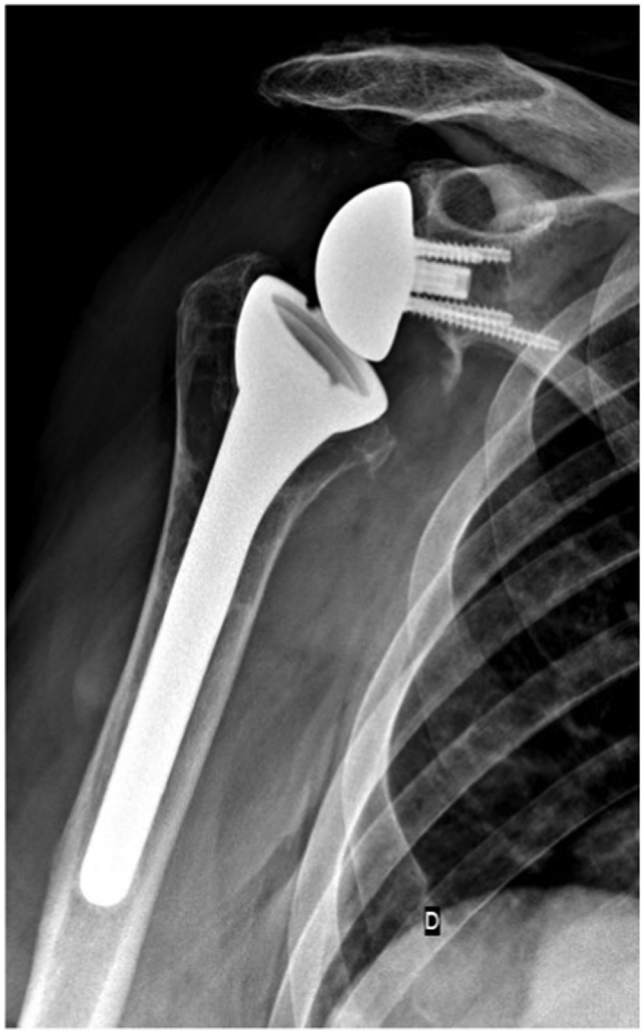

Figure 4 Radiograph of a Delta Xtend prosthesis in situ 13.1 years postoperatively, showing grade 4 radiolucencies and grade 4 scapular notching, potentially caused by an insufficient inferior overhang due to a high position of the metaglene.

risk of loosening may have to be re-evaluated for long-term results. Current methods of assessing and grading radiolucency and risk of loosening seem to be inaccurate and highly dependent on the assessor; further studies are required to develop more objective methods.

Functional outcomes

The outcomes of the current cohort are comparable to previous studies with a minimum follow-up of 10 years after RSA demonstrating significant improvement in functional outcomes and ROM. The median Auto-Constant score was 68, which is comparable to mean scores of 55 and 58 reported in the literature. The median SSV in the current cohort was 80%, similar to 1 previous study which reported a mean SSV of 78% after 15 years.[26] These studies confirm our findings that the improvement in patient-reported functional outcomes after RSA is sustained at a long-term follow-up. Only 1 study reported a significant decrease in anterior elevation and Constant score between the mid- and long-term follow-up periods.[2] In the current study with a median follow-up was 11.7 years, 11% of cases required a revision. The 10-year implant survival rate in this study (94%) is comparable with previous studies reporting the 10-year survival ranging from 82% to 93%.[2,13,26,44,52] The survival rate of 94% is also comparable to a previously published survival rate of the Delta Xtend prosthesis of 97% at 8 years, demonstrating no clear decrease in survival from 8 to 10 years follow-up.[3]

Despite the high degree of positive radiographic findings in the current study, the revision rate remains low, and the functional outcomes are favorable. This discrepancy may be caused by the lack of objective grading methods for radiographic outcomes, which is demonstrated by low interobserver agreement statistics in the current study (ICC$\leq$0.57 and k $\leq$ 0.52). However, all assessments were discussed, and consensus was reached with the senior author. Furthermore,

Table V Radiographic outcomes (n = 25)

Lateralization angle, median (IQR)	78 (76-82)	Humerus: zones with lucencies, median (IQR)	2 (1-2)
Distalisation angle, median (IQR)	51 (45-54)	Humerus: highest grade of lucencies, n (%)	
Notching, n (%)		None	1 (4)
None	15 (60)	Grade I	14 (56)
Grade I	2 (8)	Grade II	3 (12)
Grade II	4 (16)	Grade III	3 (12)
Grade III	1 (4)	Grade IV	1 (4)
Grade IV	3 (12)	Grade V	3 (12)
Glenoid: lucency grade, n (%)		Humerus: at risk of loosening, n (%)	4 (16)
None	12 (48)	Ossification grade, n (%)	
Grade I	9 (36)	None	15 (60)
Grade II	2 (8)	Grade I	6 (24)
Grade III	0 (0)	Grade II	0 (0)
Grade IV	0 (0)	Grade III	4 (16)
Grade V	2 (8)	Stress shielding, n (%)	2 (8)
Glenoid: at risk of loosening, n (%)	4 (16)		

IQR, Interquartile range.

previous studies seem to report similar results; high rates of concerning radiographic findings, but positive results.[2,26] Another potential explanation could be the decreasing patient expectations and activity with age. It is possible that older patients put less strain on their shoulder and simultaneously tend to respond more positively on questionnaires due to lower expectations and less demanding daily activities. Unfortunately, due to the low numbers, we were unable to statistically test the association between radiographic findings and outcome variables. Future studies could aim to identify which objective radiographic outcomes influence long-term functional outcomes and complications. In addition, future cohort studies may evaluate influence of patient characteristics such as age on PROM results.

Subscapularis tendon

In the current cohort, the subscapularis tendon was routinely detached and not repaired. A commonly voiced concern for leaving the subscapularis tendon off is a deficient internal rotation and increased instability and dislocation rates. In total, 4 revisions (6%) were performed for these reasons; 3 for instability and 1 for a dislocation. This is comparable to previous studies with a minimum follow-up of 10 years reporting revisions for recurrent instability or dislocation ranging from 4 to 14%.[17,26,52] One study reporting internal rotation after a minimum of 10 years reported a median level of internal rotation reaching the sacrum without mentioning handling of the subscapularis tendon.[2] In the current study, the median level reached in internal rotation was L5, suggesting that not repairing the subscapularis tendon leads to a range of internal rotation which is comparable to the literature. Previous short-term studies report contradicting results on the role of the subscapularis, and there is no conclusive evidence that leaving the subscapularis tendon detached leads to a decrease in functional or objective internal rotation.[22,30,43,46,47] This is supported by a biomechanical analysis demonstrating that the pectoralis major is the main internal rotator after RSA.[48,60] In addition, the limitation in internal rotation after RSA implantation may be related to a conflict between the implants and the bone rather then musculature, for which the most influencing factor is the positioning of the implants.[25] We hypothesize from a biomechanical point of view that the altered mechanics of the shoulder after implantation of a RSA may allow for the deltoid and other muscles to replace the function of the subscapularis muscle, and that the importance of the subscapularis muscle after RSA may be limited. Furthermore, leaving the subscapularis tendon detached may even prevent a potential restriction in external rotation and abduction caused by increased tension on the repaired subscapularis tendon when lateralizing and distalizing the proximal humerus compared to the anatomical situation. A previous study has also shown significantly increased ROM in abduction when not repairing the subscapularis tendon.[22] However, the current study does not include a control group and future long-term comparative studies are required to further investigate the role of the subscapularis muscle.

Limitations

The results of this study must be interpreted in light of its limitations. First, the high degree of missing data and loss to follow-up may introduce a bias in this study. In addition, 35 patients were deceased before reaching the 10-year follow-up, creating a competing risk with revision surgery and potentially introducing a bias favoring healthier patients. However, this is inherent to studies with a long-term follow-up in an elderly population and reflects daily practice. Despite the long follow-up, we were able to achieve a response rate of 75%. However, it is possible that

complications occurred in the 25% of patients that did not respond, which are not taken into account. Furthermore, not all patients were able to visit the hospital for a radiograph. We attempted to minimize bias by obtaining PROMs and ROM in those patients that were unable to visit the hospital. Second, for most radiographic analyses, the agreement between the first two assessors was poor. However, all radiographs were discussed with the senior author and consensus was reached in order to obtain the most objective measurement possible. Nonetheless, the assessment of radiographs and discussion between authors remains subject to bias. Third, only revisions performed at our center could be assessed, it is possible that those patients that were lost to follow-up or deceased underwent a revision elsewhere, resulting in an underestimation of the revision rate. Similarly, this may also apply to the rate of complications, which is also low in the current cohort. This limitation is inherent to a single-center study with a long follow-up. Last, the single-center, single-surgeon, single-technique, and single-prosthesis study design results in a high homogeneity and internal validity of the data. However, this decreases the external applicability of the results.

Conclusion

RSA results in a long-term improvement of functional outcomes and ROM after a minimum of 10 years. The 10-year implant survival rate was 94%. High rates of radiolucency are reported, which do not seem to translate to inferior outcomes or complication rates. The lower rate of scapular notching (40%) in comparison to the literature may be related to the amount of inferior overhang of the glenoid component. Leaving the subscapularis tendon detached did not result in high rates of instability or poor internal rotation relative to the available long-term literature. However, this topic is still debated, and no consensus has yet been reached. Future studies could focus on clarifying the role of the subscapularis muscle and the relationship between radiographic findings and clinical long-term outcomes.

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Supplementary Data

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