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Analysis of three different reverse shoulder arthroplasty designs for cuff tear arthropathy – the combination of lateralization and distalization provides best mobility

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Abstract

Background The two major reverse shoulder arthroplasty (RSA) designs are the Grammont design and the lateralized design. Even if the lateralized design is biomechanically favored, the classic Grammont prosthesis continues to be used. Functional and subjective patient scores as well as implant survival described in the literature so far are comparable to the lateralized design. A pure comparison of how the RSA design influences outcome in patients has not yet been determined. The aim of this study was a comparison focused on patients with cuff tear arthropathy (CTA).

Methods We analyzed registry data from 696 CTA patients prospectively collected between 2012 and 2020 in two specialized orthopedic centers up to 2 years post-RSA with the same follow-up time points (6,12 24 months). Complete teres minor tears were excluded. Three groups were defined: group 1 (inlay, 155° humeral inclination, 36 + 2 mm eccentric glenosphere (n = 50)), group 2 (inlay, 135° humeral inclination, 36 + 4 mm lateralized glenosphere (n = 141)) and group 3 (onlay, 145° humeral inclination, + 3 mm lateralized base plate, 36 + 2 mm eccentric glenosphere (n = 35)) We compared group differences in clinical outcomes (e.g., active and passive range of motion (ROM), abduction strength, Constant-Murley score (CS)), radiographic evaluations of prosthetic position, scapular anatomy and complications using mixed models adjusted for age and sex.

Results The final analysis included 226 patients. The overall adjusted *p*-value of the CS for all time-points showed no significant difference ($p = 0.466$). Flexion of group 3 (mean, 155° (SD 13)) was higher than flexion of group 1 (mean, 142° (SD 18) and 2 (mean, 132° (SD 18) ($p < 0.001$). Values for abduction of group 3 (mean, 145° (SD 23)) were bigger than those of group 1 (mean, 130° (SD 22)) and group 2 (mean, 118° (SD 25)) ($p < 0.001$). Mean external rotation for group 3 (mean, 41° (SD 23)) and group 2 (mean, 38° (SD 17)) was larger than external rotation of group 1 (mean, 24° (SD 16)) ($p < 0.001$); a greater proportion of group 2 (78%) and 3 (69%) patients reached L3 level on internal rotation compared to group 1 (44%) ($p = 0.003$). Prosthesis position measurements were similar, but group 3 had significantly less scapular notching (14%) versus 24% (group 2) and 50% (group 1) ($p = 0.001$).

Conclusions Outcome scores of different RSA designs for CTA revealed comparable results. However, CTA patients with a lateralized and distalized RSA configuration were associated with achieving better flexion and abduction

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with less scapular notching. A better rotation was associated with either of the lateralized RSA designs in comparison with the classic Grammont prosthesis.

Level of Evidence Therapeutic study, Level III.

Keywords Reverse shoulder arthroplasty, Reverse, Lateralization, Grammont, Design, Shoulder arthroplasty

Introduction

The physiological function of the shoulder joint is dependent on an intact rotator cuff. Cuff tear arthropathy (CTA) is defined by advanced damage of the rotator cuff that leads to successive arthritic degeneration with radiologically classified signs of structural osseous modifications [1]. Besides cranialization of the humerus with reduced acromiohumeral distance, erosion of the humeral head and superior glenoid surface leaves distinct joint alterations with a medialized joint line and poor function [2].

Reverse shoulder arthroplasty (RSA) is a widespread treatment option for irreparable rotator cuff deficiency and associated osteoarthritic joint degeneration. The first RSA concept which became widely used for patients with CTA was presented by Paul Grammont. He used a medialized and distalized design to create a stable fulcrum around which the humerus could rotate and provided enough delta tension to enable very good elevation and abduction movements [3]. With the rising recognition of associated complications of this concept such as inferior scapular notching and unsatisfying outcomes in axial rotation, modified reversed arthroplasty designs were developed [2, 4–7]. Reduction of the humeral neck-shaft angle (NSA) and lateralization of the center of rotation aim to reduce conflict at the scapula neck. A reduced NSA improves impingement-free range of motion (ROM) and axial motion by creating a more anatomical vector and more tension of the remaining anterior and posterior rotator cuff muscles [8–11]. Mark Frankle popularized a bipolar lateralization with a lateralized glenosphere and reduced NSA of 135° (compared to the 155° of the Grammont design) [10].

Generally, it has be to be said that in all RSA designs the center of rotation remains medialized in comparison to a native glenoid joint. The terminus “lateralized” refers to more lateralized compared to the original Grammont (“more medialized”) design.

The advantages of a glenoidal lateralization were kept in further design evolutions [12]. On the humeral side, onlay systems for humeral lateralization were introduced [13]. Furthermore, the NSA shifted towards a way in between the Grammont and Frankle concept aiming to gather the advantages of a distalized and a lateralized concept [14]. Therefore, various humeral designs with an NSA of 145° were introduced [15].

The influence of various lateralized designs on clinical outcome has been widely reviewed and several advantages over medialized RSAs have been outlined such as decreased inferior scapular notching, better stability, and rotational mobility [8, 11, 16–18]. Nonetheless, the more recent reviews were unable to highlight any significant differences in shoulder function and outcome scores [11, 16]. There is a lack of evidence on how different RSA designs (the Grammont design, the Frankle design or a distalized and lateralized design) perform in comparable patient populations; this knowledge would improve the surgeon’s choice of prosthesis design based on specific indications. Our purpose was to compare these three concepts, with regards to clinical and radiographic outcome in a homogeneous cohort of patients with CTA. We hypothesized that by lateralizing and distalizing, better outcome scores and superior ROM as well as reduced notching would be achieved. The analyzed outcomes were ROM, a radiological core set evaluation [16] and outcome scores (CS, SPADI).

Materials and methods

Patient selection

This is a retrospective cohort study on patients with CTA who were treated with one of three different RSA prostheses at one of two specialized orthopedic centers. Since June 2012 all patients receiving a shoulder arthroplasty at one center (KWS) were prospectively documented in a local register. At the second center (BER), all patients were prospectively documented since June 2016. Trained specialized shoulder surgeons performed the operation at both centers. From both databases, patients with CTA were selected for this analysis when they had complete preoperative and 2-year clinical and radiographic examinations and were treated with one of the following implants: 1. Aequalis Reversed II prosthesis with 155° neck-shaft inclination and 36 + 2 mm eccentric glenosphere (Wright Medical Group N.V., Memphis, TN) (Group 1, medialized and distalized concept). 2. Univers Revers II prosthesis with 135° neck-shaft inclination and 36 + 4 mm lateralized glenosphere (Arthrex, Naples, FL) (Group 2, lateralized concept) or 3. Aequalis Ascend Flex prosthesis with 145° neck-shaft inclination, + 3 mm lateralized baseplate and 36 + 2 mm eccentric glenosphere (Wright Medical Group N.V., Memphis, TN) (Group 3, lateralized and distalized concept)). Based on the three prosthesis types, the theoretical global lateralized offset (tGLO) is 15.6 mm, 24.7 mm and 27.5 mm for groups 1, 2 and 3, respectively [12]. In addition, only data from the first operated side per patient were analyzed. Patients diagnosed with a complete teres minor tear were excluded. This analysis used prospectively documented clinical data that was approved by the local ethics committee for research purposes.

Surgical technique and postoperative protocol

All reverse prostheses were implanted according to manufacturer instructions by mainly 4 and in total 7 experienced shoulder surgeons. A deltopectoral approach was used and tenotomy of the subscapularis (SSC) tendon was performed followed by circular capsulotomy. The tendon of the long head of the biceps, if still intact, was tenotomized. The humeral head was resected by all surgeons consistently with 20° retroversion. After preparation of the humeral shaft the glenoid was exposed and remaining cartilage and labrum were removed. The central drill wire was inserted, and the central peg channel was drilled. The baseplate was placed centrally (group 2) or more flush to the inferior border of the glenoid (group 2 and 3) and fixed with two head locking and compression screws each for group 1 and a central bicortical screw followed by four peripheral screws for the group 3. The baseplate of group 2 patients was inserted and fixed with a central and two peripheral screws followed by peripheral overreaming of the circumferential bone; the eccentric glenosphere was positioned and secured with a locking screw connection to the baseplate. In Onlay type prosthesis the humeral cut might have been slightly deeper sometimes, depending on the tension (that is higher in onlay type of designs), but for all patients the initial cut was at the anatomical neck and a recut was done depending on the intraoperative individual surgeon's decision.

After testing the RSA reduction and stability with trial implants, the definitive implant was inserted and tested again for impingement-free mobility. The SSC was reattached with FiberWire® sutures (Arthrex, Naples, FL) using the Mason-Allen technique.

Patients were required to keep their arm immobilized in a sling for 4 weeks after surgery while following a standardized physical therapy program starting from Day 1. Passive mobilization the first 4 weeks post-surgery followed by active-assisted mobilization. By the sixth postoperative week, patients were allowed to apply progressive active motion. Internal rotation against resistance was avoided for the first 6 weeks.

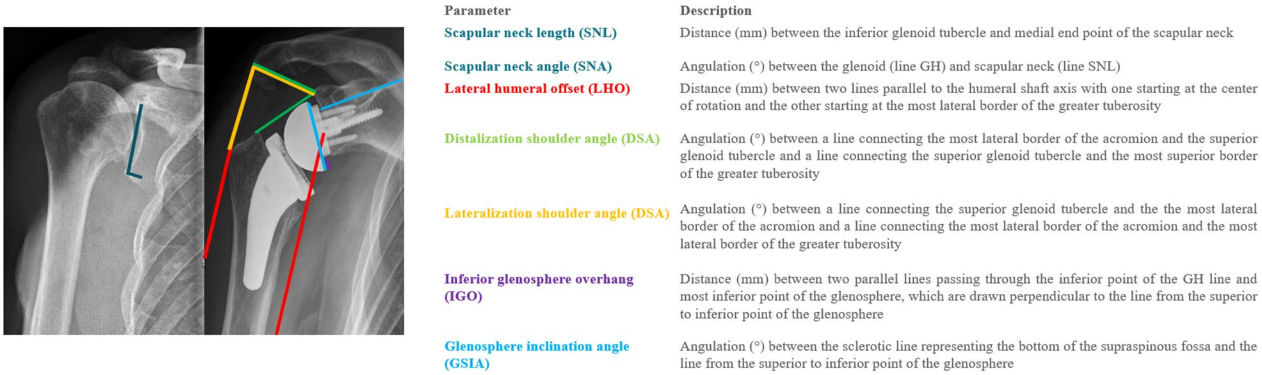
Clinical evaluations

Patients underwent clinical examination preoperatively (baseline) and at 6-, 12- and 24 months after surgery, at 6 months mostly by the surgeons, at 12 and 24 months by independent observers. Clinical parameters of shoulder ROM (included elevation, abduction, internal and external rotation at 90° abduction, external rotation at 0° abduction, capacity of internal rotation (using the Apley scratch test) at 0° abduction and shoulder strength in 90° abduction were assessed. Functional outcome was based on the Constant-Murley score (CS) [19, 20], Subjective Shoulder Value (SSV) [20] and the patient-reported Shoulder Pain and Disability Index (SPADI) [21].

Radiological baseline and 2-year follow-up parameters

Baseline (preoperative) and 2-year postoperative radiographs included standard anteroposterior (Fig. 1) and axial views. From anteroposterior images, a range of parameters were assessed at both time points to provide details on scapular anatomy and prosthetic position (Fig. 2). Scapular anatomy was defined by scapular neck length (SNL) and angle (SNA), where SNL is the

Fig. 1 Prosthetic designs (ap x-rays pre- and 2yrs postoperative): **a** Group 1; NSA:155°, Inlay, GS: 36 + 2 mm ecc, **b** Group 2; NSA:135°, Inlay, GS: 36 + 4 mm lat **c** Group 3; NSA:145°, Onlay, BP: + 3 mm lat, GS: 36 + 2 mm ecc



Parameter	Description
Scapular neck length (SNL)	Distance (mm) between the inferior glenoid tubercle and medial end point of the scapular neck
Scapular neck angle (SNA)	Angulation (°) between the glenoid (line GH) and scapular neck (line SNL)
Lateral humeral offset (LHO)	Distance (mm) between two lines parallel to the humeral shaft axis with one starting at the center of rotation and the other starting at the most lateral border of the greater tuberosity
Distalization shoulder angle (DSA)	Angulation (°) between a line connecting the most lateral border of the acromion and the superior glenoid tubercle and a line connecting the superior glenoid tubercle and the most superior border of the greater tuberosity
Lateralization shoulder angle (DSA)	Angulation (°) between a line connecting the superior glenoid tubercle and the the most lateral border of the acromion and a line connecting the most lateral border of the acromion and the most lateral border of the greater tuberosity
Inferior glenosphere overhang (IGO)	Distance (mm) between two parallel lines passing through the inferior point of the GH line and most inferior point of the glenosphere, which are drawn perpendicular to the line from the superior to inferior point of the glenosphere
Glenosphere inclination angle (GSIA)	Angulation (°) between the sclerotic line representing the bottom of the supraspinous fossa and the line from the superior to inferior point of the glenosphere

Fig. 2 **a** Preoperative anteroposterior radiograph highlighting scapular neck length as indicated by the blue line (long) and neck angle lying between the two blue lines **(∡)**;**b** colored lines featured on the postoperative image indicate various radiological measurements of prosthetic position, i.e., lateral humeral offset (red), distalization shoulder angle (green), inferior glenoid overhang (purple) and glenosphere inclination angle (blue)

distance (mm) between the inferior glenoid tubercle and medial end point of the scapular neck and SNA is the angle (°) between the glenoid and scapular neck length (SNL). Prosthetic position was described by the following parameters of lateral humeral offset (LHO), distalization shoulder angle (DSA), lateralization shoulder angle (LSA), inferior glenosphere overhang (IGO) and glenosphere inclination angle (GSIA): LHO is the distance (mm) between two lines (red) parallel to the humeral shaft axis with one starting at the superior glenoid tubercle and the other starting at the most lateral border of the greater tuberosity; DSA lies between a line (green) connecting the most lateral border of the acromion and the superior glenoid tubercle and a line (green) connecting the superior glenoid tubercle and the most superior border of the greater tuberosity; IGO indicates the distance (mm) between the inferior point of the glenohumeral line and most inferior point of the glenosphere; and GSIA lies between the sclerotic line (blue) representing the bottom of the supraspinatus fossa and the line (blue) from the superior to inferior point of the glenosphere. The degree of baseline glenoid erosion was assessed using the established Favard classification system [2].

Throughout the 2-year postoperative period, various adverse events of inferior scapular notching based on the Sirveaux classification [2], signs of osteolysis around the implant components, ossification, component migration or breakage, and periprosthetic fractures were documented based on an international consensus core set [22].

Data management and statistical analysis

Register data were managed using the REDCap (Research Electronic Data Capture) system [23] and exported for statistical analysis using Intercooled Stata version 17 (StataCorp LP, College Station, TX). Baseline patient demographic, radiological and functional parameters were tabulated separately per group using standard descriptive statistics and compared using standardized differences (where values closest to 0.10 indicate stronger group similarity) [24] and clinical judgment. Comparative analyses at the 2-year postoperative follow-up were conducted using standard linear regression analyses, and we used generalized linear mixed models to account for repeated measurements when outcome data were available at each clinical follow-up examination, as applicable. For all models, we included the demographic parameters of age and sex as well as respective baseline preoperative values. All eligible patients from the two databases were included, so there was no predetermined sample size based on comparative analyses; all analyses were explorative with a significance level set at 0.05.

Results

Between June 2012 and June 2020, there were 67, 172 and 40 RSA in the groups 1, 2 and 3, respectively. At the 2-year postoperative follow-up, 50, 141 and 35 patients respectively, met the inclusion criteria and were selected for this analysis (Fig. 3). Most patients were women and the average age at the time of surgery was 76 years (range 52–93). The three defined groups shared similar baseline characteristics (except for a higher proportion of female patients in group 2, a higher proportion of low-grade Hamada 1 CTA (Table 1)), and preoperative shoulder function (Table 2).

Clinical examination and patient-reported outcomes

Two-years post-RSA, flexion of group 3 (mean, 155° (SD 13)) was higher than flexion of group 1 (mean, 142° (SD18) and group 2 (mean, 132° (SD18) ($p < 0.001$).

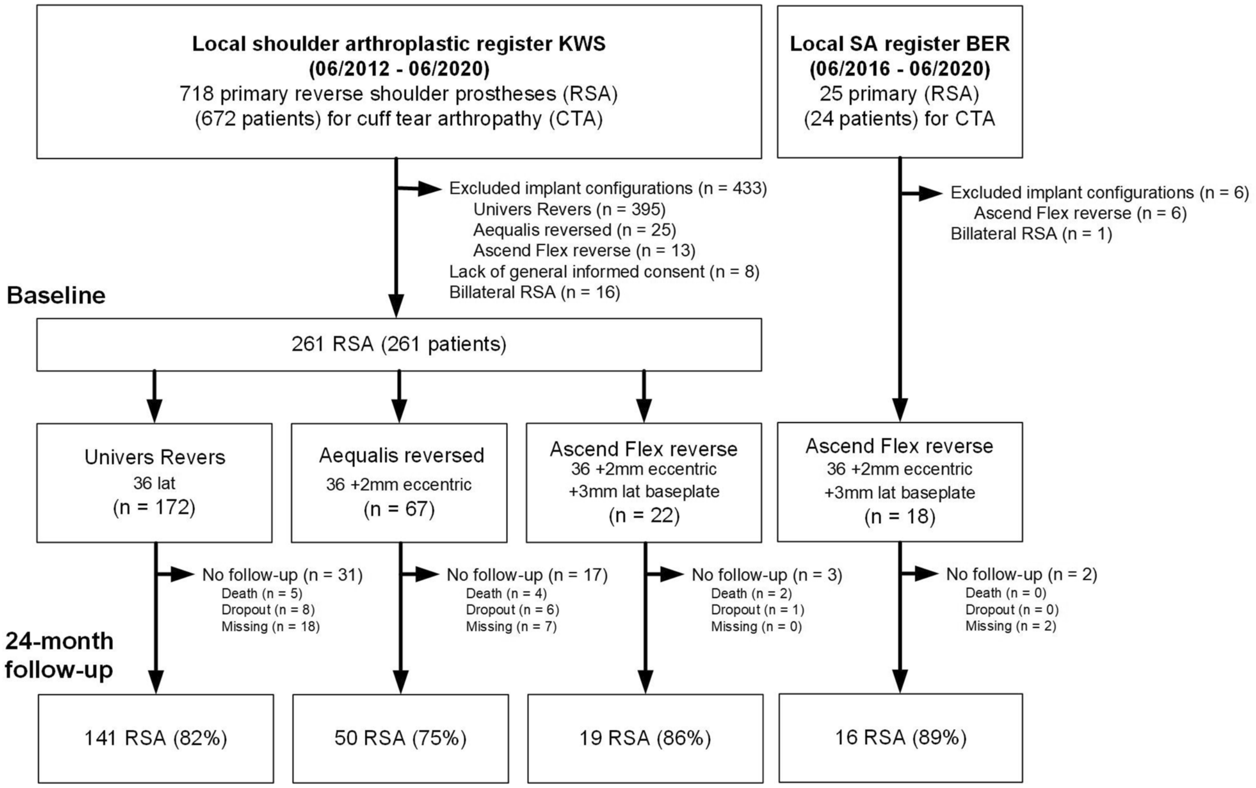


Fig. 3 Flowchart for patient selection

Abduction of group 3 (mean, 145° (SD 23)) was also higher than abduction of group 1(mean, 130° (SD22)) and group 2 (mean, 118° (SD25)) ($p<0.001$). Mean external rotation for group 3 (mean, 41° (SD 23)) and group 2 (mean, 38° (SD17)) was larger than external rotation of group 1 (mean, 24° (SD 16)) ($p<0.001$); a greater proportion of group 2 (78%) and 3 (69%) patients reached L3 level for internal rotation compared to group 1 (44%) ($p=0.003$).

Group 3 patients had significantly better ROM compared to patients in groups 1 and 2 (Table 3): group 3 patients achieved an average anterior flexion of 155°, which was 15° (95% confidence interval [CI] 7° to 23°) and 23° (CI 16° to 30°) better than groups 1 and 2 ($p<0.001$) (Fig. 4). Mean abduction for group 3 was 147°, 19° (CI 8° to 30°) higher compared to group 1 and 28° (CI 17° to 38°) better than group 2 ($p<0.001$) (Fig. 4). The low mean external rotation achieved by group 3 (41°) was 18° (CI 11° to 26°) higher than group 1 and 7° (CI 1° to 14°) higher than group 2 ($p<0.001$) (Fig. 4); this difference was due to a better active external rotation (Fig. 4). Greater proportions of group 2 (78%) and 3 (69%) patients were able to reach the lumbar vertebrae 3 (L3) compared to group 1 (43%) ($p=0.003$) (Fig. 5).

Outcome scores, adjusted for baseline values, showed no significant differences at follow-up (Table 3; e.g. CS: $p=0.466$). At 2 years the baseline- and gender-adjusted Constant score was on average 3 points higher (CI -3 to 9) for group 3 (76 points; range 56–96) in comparison with group 2 (68 points; range 26–85) and 7 points (CI 1 to 13) compared to group 1 (68 points; range 40–85 points), an observation however that showed only a statistical trend but no significance ($p=0.088$) (Fig. 5). Mean outcomes of SSV and SPADI were also not significantly different between groups ($p=0.325$ and $p=0.225$) (Fig. 5).

Radiological outcomes

All groups shared similar baseline measurements of SNL and SNA (Table 3). At the 2-year follow-up, there was a statistically significant difference in GSIA ($p=0.013$), but mean LHO was significantly lower in group 1 (33 mm) and group 2 showed a lower mean IGO (3 mm) ($p<0.001$) (Table 3).

There was significantly less scapular notching (14%) reported for group 3 compared to groups 2 (24%) and 1 (50%) ($p=0.001$). Grade 1 notching was reported in 50% group 1 patients, in 14% group 3 patients and in 20% group 2 patients; Grade 2 notching was only found

Table 1 Baseline patient and shoulder characteristics according to the defined prosthesis groups

	Group 1		**Group 2**		**Group 3**		**StdDiff**
	n(%^{a})	**mean (SD)**	**n(%^{a})**	**mean (SD)**	**n(%^{a})**	**mean (SD)**	**1vs.3/ 1vs.2 / 2vs.3**
Age at surgery		74.4 (7.7)		75.5 (5.7)		75.7 (6.2)	0.189 / 0.165 / 0.033
Sex							0.847 / 0.055 / 0.789
Female	33(66)		136(96)		24(69)		
Male	17(34)		5(4)		11(31)		
Diagnosis							0.563 / 0.117 / 0.148
RC tear without arthrosis	9(18)		27(19)		11(31)		
RC tear with arthrosis	41(82)		114(81)		24(69)		
Radiological examination							0.281 / 0.630 / 0.452
None	3(9)		8(8)				
Magnetic resonance imaging	20(63)		86(83)		23(100)		
Ultrasound	9(28)		9(9)				
RC tear type according to Lädermann[b]							0.205 / 0.396 / 0.446
A	3(10)		17(18)		4(17)		
B	1(3)		3(3)		2(9)		
C	18(60)		50(53)		14(61)		
D	8(27)		23(24)		3(13)		
E			1(1)				
Supraspinatus							0.099 / 0.820 / 1.064
Intact tendon	1(3)						
Partial tear	1(3)		16(17)				
Complete tear	27(93)		80(83)		23(100)		
Infraspinatus							0.108 / 0.306 / 0.311
Intact tendon	7(24)		23(24)		2(8)		
Partial tear	10(34)		32(33)		9(39)		
Complete tear	12(41)		41(43)		12(52)		
Subscapularis							0.211 / 0.432 / 0.379
Intact tendon	9(31)		28(29)		8(34)		
Partial tear	16(55)		54(56)		11(48)		
Complete tear	4(14)		14(15)		4(17)		
Teres minor							0.179 / 0.219 / 0.151
Intact	28(97)		88(92)		19(83)		
Partial tear			6(6)		3(12)		

Table 1 (continued)

	Group 1		**Group 2**		**Group 3**		**StdDiff**
	n(%[a])	**mean (SD)**	**n(%[a])**	**mean (SD)**	**n(%[a])**	**mean (SD)**	**1vs.3/ 1vs.2 / 2vs.3**
n.d	1(3)		2(2)		2(8)		
Glenoid wear according to Favard[c]							0.688 / 0.205 / 0.151
E0	21(44)		29(22)		15(42)		
E1	4(8)		29(22)		7(19)		
E2	7(16)		13(10)		1(4)		
E3	4(8)		6(4)		10(30)		
n.d	11(24)		56(42)		2(7)		
RC tear arthropathy according to Hamada[d]							0.544 / 0.861 / 1.054
Grade 1	13(28)		72(54)		7(19)		
Grade 2	9(19)		17(13)		7(19)		
Grade 3	6(13)		7(5)		5(15)		
Grade 4A	4(9)		11(8)		2(6)		
Grade 4B	9(19)		18(14)		5(15)		
Grade 5			4(3)		7(20)		
n.d			4(3)		2 (6)		

SD standard deviation, *StdDiff* standardized difference calculated to three decimal places and equal to the absolute difference between group means divided by the common standard deviation, where values closest to 0.10 or below indicate stronger group similarity. The three values show the standardized difference between groups 155 and 135, groups 155 and 145, and groups 145 and 135, respectively; RC = rotator cuff; n.d. = indeterminable

[a] The percentage refers to the number of patients missing excluded

[b] Lädermann A, Denard PJ, Collin P. Massive rotator cuff tears: definition and treatment. Int. Orthop. 2015;39(12):2404–2414. https://doi.org/10.1007/s00264-015-2796-5: A = supraspinatus and superior subscapularis tears, B = supraspinatus and entire subscapularis tears, C = infraspinatus, supraspinatus and superior subscapularis tears, D = supraspinatus and infraspinatus tears, E = supraspinatus, infraspinatus and teres minor tears

[c] Favard L, Lautmann S, Sirveaux F, Oudet D, Kerjean Y, Huguet D. Hemiarthroplasty versus reverse arthroplasty in the treatment of osteoarthritis with massive rotator cuff tear. In: Walch G, Boileau P, Molé D, editors. 2000 Shoulder Prostheses. Two to ten years follow-up. Sauramps Medical: Paris, France; 2001. p 261–268: E0 = superior humeral head migration without erosion of the glenoid, E1 = concentric erosion of the glenoid, E2 = if erosion was limited to the superior part of the glenoid, E3 = if erosion extended to the inferior part of the glenoid

[d] Hamada K, Fukuda H, Mikasa M, Kobayashi Y. Roentgenographic findings in massive rotator cuff tears. A long-term observation. Clin Orthop Relat Res. 1990 May(254):92–96: 1 = acromiohumeral interval > 6 mm; normal glenohumeral joint, 2 = acromiohumeral interval < 5 mm; normal glenohumeral joint, 3 = acromiohumeral interval < 5 mm, with acetabulization of acromion; normal glenohumeral joint, 4A = glenohumeral osteoarthritis without acetabulization, acromiohumeral interval < 7 mm, 4B = glenohumeral osteoarthritis with acetabulization, acromiohumeral interval < 7 mm, 5 = humeral head subchondral collapse characteristic of cuff tear arthropathy

in 4% of group 2 patients. Overall, we did not report any signs of osteolysis, radiolucency, bone resorption, ossification, implant migration/breakage/loosening for any of the study patients. There were 2 acromial fractures (Levy type 2) in group 2 and one (Levy type 2) in group 1, all of which did not need surgical treatment.

Discussion

Our retrospective study shows that the baseline/gender-adjusted CS difference for all groups comprising all-time points was not significant. A lateralized and distalized design (group 3) achieved superior results for flexion and abduction compared to the Grammont design and the lateralized design in a cohort of 226 patients with CTA. Lateralized implants (either with additional distalization or not) showed better rotational movement compared to the medialized and distalized Grammont design. To precise, the baseline/gender-adjusted CS showed a slight difference of 7 points ($p = 0.03$) between group 3 and group 1 at final 2-years follow-up. The clinical meaning of this fact is questionable as the cut-off number of the MCID (minimal clinically important difference) after RSA treatment for CTA in the literature is 8 points [25].

Pre- and postoperative radiographic measurements showed no relevant design-independent differences between the groups regarding scapular neck anatomy and implant positioning (GSIA was statistically

Table 2 Baseline and postoperative shoulder range of motion (ROM) parameters, strength and functional scores

	Group 1		Group 2		Group 3		Adjusted	Model
	n	mean (SD)	n	mean (SD)	n	mean (SD)	*p*-value	*p*-value*
Active motion parameters								
Flexion (°)								< 0.001
Baseline	50	71 (33)	141	78 (39)	35	69 (36)		
6 months	47	135 (20)	130	125 (25)	14	136 (21)	0.108	
12 months	43	141 (18)	123	130 (23)	22	146 (20)	0.002	
24 months	40	142 (18)	107	132 (18)	33	155 (13)	< 0.001	
Abduction (°)								< 0.001
Baseline	50	65 (25)	141	70 (34)	35	62 (31)		
6 months	47	123 (23)	129	118 (28)	14	120 (31)	0.949	
12 months	43	128 (22)	123	124 (26)	22	138 (25)	0.061	
24 months	40	130 (22)	107	118 (25)	33	147 (23)	< 0.001	
External rotation in 0° abd. (°)								< 0.001
Baseline	48	30 (18)	141	31 (22)	35	22 (23)		
6 months	47	22 (11)	131	33 (14)	14	41 (25)	< 0.001	
12 months	43	23 (11)	123	35 (15)	22	38 (21)	< 0.001	
24 months	40	24 (16)	107	38 (17)	33	41 (23)	< 0.001	
Passive motion parameters								
Flexion passive (°)								
Baseline	50	88 (39)	141	97 (39)	35	94 (45)		< 0.001
6 months	47	142 (19)	130	128 (22)	14	146 (18)	0.001	
12 months	43	149 (18)	123	133 (20)	22	157 (15)	< 0.001	
24 months	40	147 (18)	107	135 (17)	33	163 (11)	< 0.001	
Abduction passive (°)								
Baseline	50	77 (34)	141	85 (38)	35	90 (44)		< 0.001
6 months	47	131 (21)	129	121 (25)	14	130 (32)	0.237	
12 months	43	135 (21)	123	125 (24)	22	151 (20)	< 0.001	
24 months	40	136 (21)	107	121 (24)	33	156 (21)	< 0.001	
External rotation in 0° abd. passive (°)								
Baseline	46	35 (18)	139	38 (23)	35	31 (24)		< 0.001
6 months	47	30 (9)	131	34 (13)	14	50 (22)	< 0.001	
12 months	43	31 (12)	122	36 (14)	22	46 (18)	< 0.001	
24 months	40	35 (14)	107	43 (14)	33	50 (23)	< 0.001	
Passive motion parameters								

Table 2 (continued)

	Group 1		Group 2		Group 3		Adjusted	Model
	n	mean (SD)	n	mean (SD)	n	mean (SD)	*p*-value	*p*-value*
Flexion passive (°)								
Pre-op	77	90 (35)	190	96 (36)	60	89 (40)		< 0.001
6 months	71	140 (20)	176	131 (22)	23	147 (20)	< 0.001	
12 months	67	148 (18)	164	135 (19)	38	156 (22)	< 0.001	
24 months	65	145 (18)	141	137 (17)	57	162 (16)	< 0.001	
Abduction passive (°)								
Pre-op	77	78 (30)	190	83 (34)	60	81 (39)		< 0.001
6 months	71	129 (21)	175	123 (25)	23	134 (30)	0.118	
12 months	67	133 (20)	164	129 (24)	38	151 (27)	< 0.001	
24 months	65	134 (21)	141	125 (24)	57	156 (23)	< 0.001	
External rotation in 0° abd. passive (°)								
Pre-op	70	32 (17)	187	35 (22)	59	26 (22)		< 0.001
6 months	71	30 (11)	176	34 (13)	23	49 (19)	< 0.001	
12 months	67	32 (12)	161	36 (14)	38	42 (18)	< 0.001	
24 months	65	36 (14)	141	43 (14)	57	48 (21)	< 0.001	
Strength, pain level and functional scores								
Strength in abduction (kg)								0.768
Baseline	50	0.4 (0.9)	141	0.4 (1.1)	19	0.3 (1.2)		
6 months	45	4.2 (2.3)	130	3.3 (1.8)	14	3.8 (2.3)	0.669	
12 months	42	4.7 (2.3)	120	3.9 (2.0)	9	4.4 (2.3)	0.950	
24 months	39	5.3 (2.4)	106	3.9 (2.0)	17	4.8 (2.2)	0.627	
Pain NRS (0 = no pain, 10 = maximum pain)								0.008
Baseline	46	6.1 (3.0)	129	6.4 (2.5)	33	6.2 (2.7)		
6 months	49	1.4 (1.7)	129	1.6 (1.9)	15	0.7 (0.9)	0.348	
12 months	44	1.4 (1.7)	129	1.3 (1.9)	27	0.6 (1.2)	0.055	
24 months	47	1.7 (2.1)	128	1.5 (2.1)	34	0.6 (1.2)	0.032	
CS Constant Murley Score (0–100 = best)								0.466
Baseline	42	27 (11)	122	31 (15)	20	30 (14)		
6 months	40	65 (12)	114	62 (13)	11	64 (10)	0.576	
12 months	38	69 (10)	105	67 (13)	21	70 (10)	0.533	
24 months	33	68 (11)	83	68 (10)	31	76 (9)	0.088	
SPADI (0 = worst, 100 = best)								0.252
Baseline	46	33 (22)	128	34 (20)	18	40 (19)		

Table 2 (continued)

	Group 1		**Group 2**		**Group 3**		**Adjusted**	**Model**
	n	**mean (SD)**	**n**	**mean (SD)**	**n**	**mean (SD)**	***p*-value**	***p*-value***
6 months	50	73 (20)	131	78 (18)	15	84 (14)	0.199	
12 months	44	76 (19)	130	82 (18)	14	83 (14)	0.598	
24 months	47	74 (21)	129	80 (20)	17	83 (15)	0.534	
Subjective Shoulder Value (0 = worst, 100 = best)								0.325
Baseline	38	41 (20)	118	39 (20)	34	34 (20)		
6 months	41	74 (18)	112	78 (16)	12	78 (13)	0.856	
12 months	41	75 (18)	117	83 (13)	26	78 (14)	0.110	
24 months	40	77 (18)	114	83 (14)	34	85 (13)	0.323	

SD standard deviation

[*] Mixed model *p*-value for group effect adjusted for age, gender and baseline pre-operative values

Table 3 Comparison of baseline scapula anatomy and 2-year postoperative prosthesis position measurements between defined study groups

	Group 1		**Group 2**		**Group 3**		**StdDiff**
	n	**mean (SD)**	**n**	**mean (SD)**	**n**	**mean (SD)**	**1vs.3 / 1vs.2 / 2vs.3**
Scapular anatomy							
Scapular neck length (mm)	49	14.8 (11.7)	135	13.1 (6.4)	33	13.6 (4.6)	0.02 / 0.03 / 0.01
Scapular neck angle (º)	49	82.4 (13.5)	135	83.2 (11.8)	33	85.1 (12.3)	0.04 / 0.01 / 0.04
							P-value
Prosthesis position							
Lateral humeral offset (mm)	49	33.1 (8.1)	135	40.9 (4.8)	33	44.0 (4.5)	< 0.001
Distalization shoulder angle (º)	49	52.2 (10.8)	135	45.5 (10.5)	33	52.0 (8.2)	< 0.001
Inferior glenosphere overhang (mm)	49	5.9 (12.5)	135	2.8 (2.2)	33	5.8 (1.9)	0.002
Glenosphere inclination angle (º)	49	98.2 (9.0)	135	102.3 (7.9)	33	101.4 (7.6)	0.013
Lateralization Shoulder Angle (°)	49	78.4 (10.4)	135	87.4 (9.6)	33	83.9 (7.4)	< 0.001

SD standard deviation, *StdDiff* standardized difference calculated to two decimal places and equal to the absolute difference between group means divided by the common standard deviation, where values closest to 0.10 or below indicate stronger group similarity. The three values show the standardized difference between groups 155 and 135, groups 155 and 145, and groups 145 and 135, respectively

significant but small angular differences of 4.1° (group 1 vs. 2) and 3.2° (group 1 vs 3) do not have clinical meaning).

In a similar study focused on Hamada Grade 1 to 3 cuff-deficient shoulders better external rotation and a trend towards better internal rotation with less scapular notching for lateralized (135° NSA and 4 mm lateralized glenosphere) over non-lateralized RSAs (155° NSA and 2 mm eccentric glenosphere) was reported [26]. The use of curved stem 145° NSA onlay designs introduced another type of RSA configuration; a computational ROM study for different humeral and glenosphere design concepts showed adequate restoration of glenohumeral ROM only for a lateralized NSA (145°) in combination with eccentric, large or lateralized spheres [14].

The LHO of group 3 (mean, 44.0 mm) was slightly higher than that of group 2 (mean, 40.9 mm). Based on the NSA (10° less distalization) and bigger glenoidal lateralization (additional 1 mm) in group 135°, this difference is arguably due to the onlay and curved stem design of group 145°. This is supported by the findings of Werthel et al. who found that twice the amount of lateralization can be achieved on the humeral side due to changes in design (i.e., onlay or curved stems) [12].

Glenoid lateralization is an accepted approach to decrease scapular notching [27–30] and increases impingement-free motion [31, 32]. In our group 2 the inferior glenosphere overhang was significantly lower than in 3, where an inferiorly eccentric glenodphere was used. This explains a higher value of scapular notching of group 2 in comparison to group 3. However, although eccentricity of the glenosphere was also used in group 1, values of mild scapular notching (grade 1) were significantly higher than in group 2 and 3, where bipolar (glenoidal and humeral) lateralization was performed. Comparing short-term results of a Grammont-style RSA versus the same 145° curved stem used in our study (a subgroup of those additionally treated with a BIO-RSA) showed less scapular notching with humeral lateralization [33].

With the center of rotation shifting more laterally with glenoidal lateralization shearing forces in elevation and abduction increase [34]. Consequently, acromial stress [35, 36] and shearing forces onto the glenoid also increase, which could potentially lead to spine stress fractures [37] or glenoid loosening in the long term [38]. We did observe 2 acromial fractures (Levy Typ 2) in group 2 and no acromial or scapular spine stress fractures in group 3. Overall, there was a low incidence of acromial fractures, with similar values reported in the literature [39] and there was no difference between the groups.

The position of the greater and lesser tuberosity becomes lateralized with a humeral lateralization design, which improves tensioning of the remaining cuff [40] that in turn, improves stability [41] as well as the lever arm [34, 42, 43] and deltoid wrapping [44]. Regarding glenoidal lateralization Collin et al. found that patients with a bony increased-offset RSA (BIO-RSA) achieved better functional results without any difference in ROM compared to those with a non-lateralized Grammont arthroplasty [45]. On the other hand, similar studies with small patient cohorts did not report any significant differences in functional outcomes of ROM, abduction strength, pain, or any other patient-reported scores in short-term follow-up (up to 2 years) [30, 46]. When

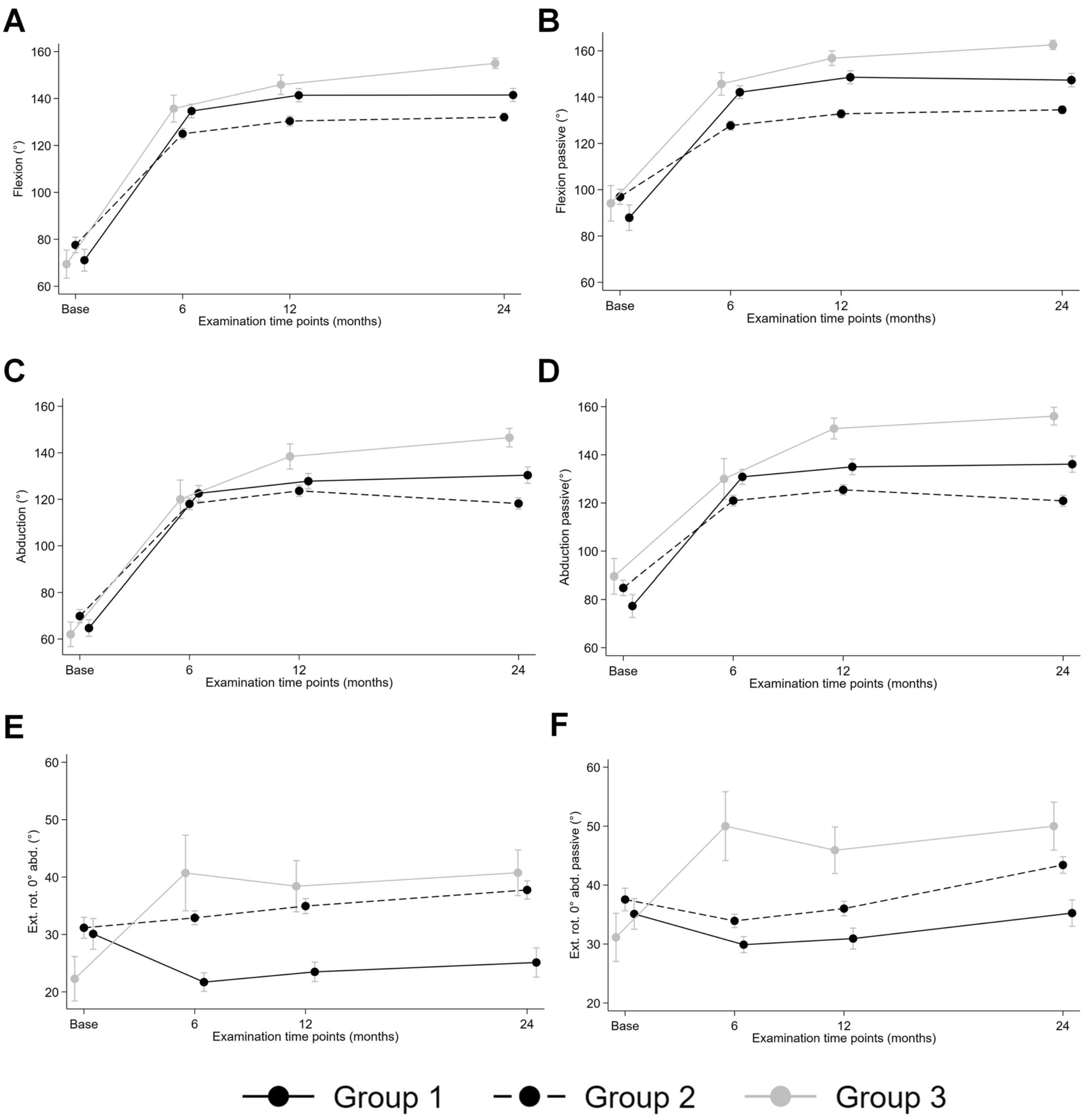


Fig. 4 Graphics of active and passive ROM at various time points

humeral lateralization was introduced, higher functional outcome with glenoid lateralization and a BIO-RSA (CS: 70–71 points) [40, 47] or metallic baseplate offset (CS: 79 points) [48] was achieved.

The same 135° design as that used in our study showed better external rotation and greater abduction strength compared to a 155° design with a tGLO of 18.5 mm at the 1-year follow-up examination [49].

A comparative investigation of two matched cohorts with 135° NSA stems and an inlay (tGLO 23.5 mm) versus lateralized onlay (tGLO 29.3 mm) revealed no differences in scapular notching or acromial fractures, but better external rotation and forward flexion for the onlay design after 2 years [50]. Moreover, a 145° onlay design displayed better external rotation over a 155° inlay implant [51].

A short-term retrospective comparison of the extreme lateralizing Arrow prosthesis (tGLO 34.5 mm) versus the

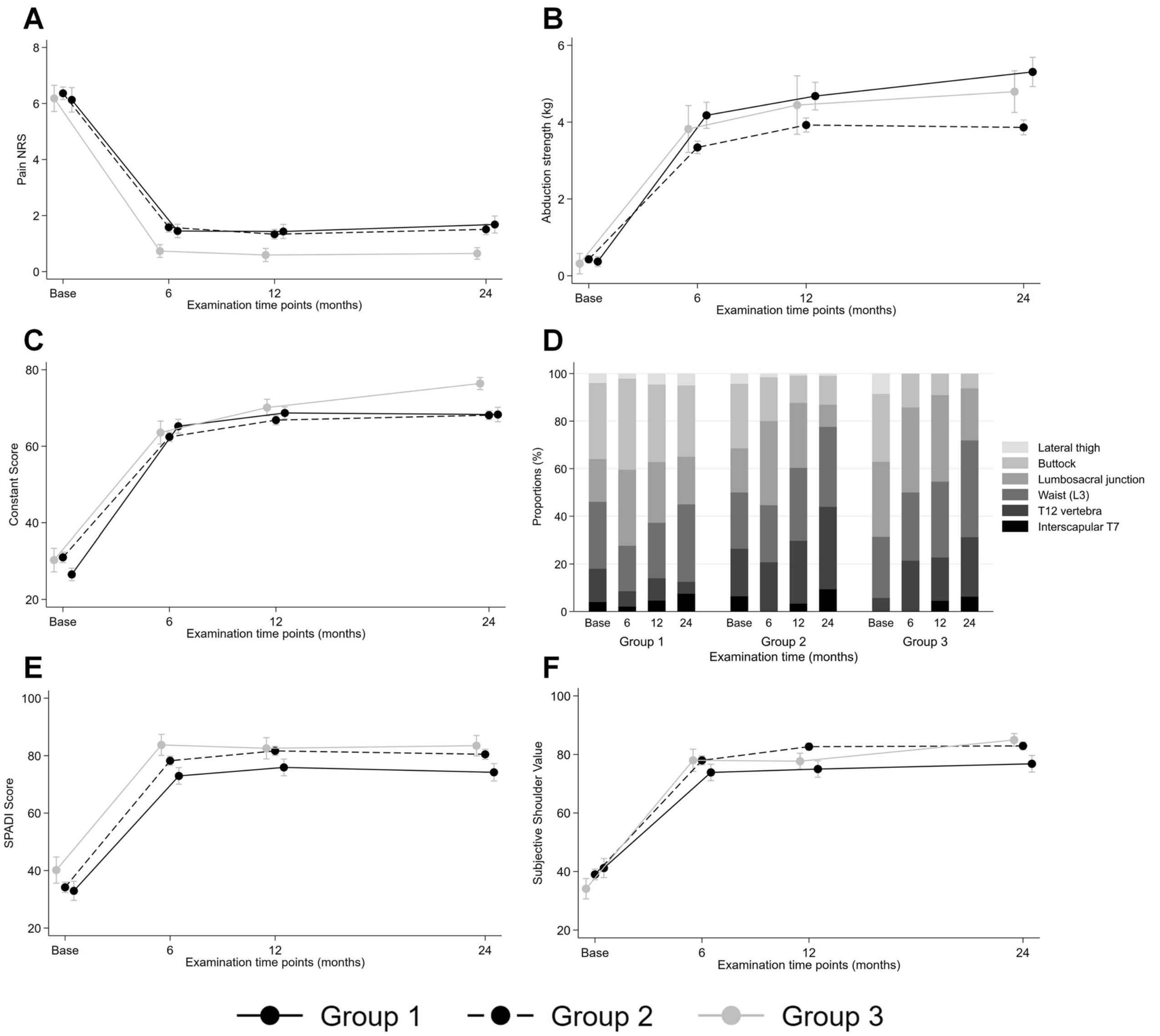


Fig. 5 Graphics of Outcome scores (CS, SPADI) pain, internal rotation (Apley Scratch test) and abduction strength at various time points

Grammont-style Delta III (tGLO 13.1 mm) showed less scapular notching and a trend towards better external rotation for the lateralized implant, yet without an overall superior clinical outcome [52].

These studies support our findings that the sum of bipolar lateralization (more rotational movement (humeral lateralization [49]) and less notching (glenoidal lateralization) [30, 52]) and distalization (more flexion [50]) with inferior glenosphere overhang (less notching [53]) provides best ROM despite no clinically significant difference in outcome scores could be found [30, 46, 52, 54].

All patients in our study had intact teres minor and there was equal distribution of complete infraspinatus ruptures between the groups. Considering the comparable percentage of subscapularis tears, the medialized design of group 1 limits internal rotation, whereas group 2 representing the most “anatomical” design showed similar results for internal rotation as group 3. In this context it is important to mention that all passive movement parameter assessed (flexion, abduction, external rotation) showed significantly higher values for group 3. A part of presumably better muscle tension, a higher passive impingement-free range of motion is likely to cause a better active movement too.

The working groups of Streit and Lädermann reported better flexion for a design with greater distalization [14, 55]. We too found best values of flexion in group 3 with a significantly higher DSA compared to our other study groups. The combination of humeral lateralization and distalization of group 3 resulted in favorable abduction, whereas group 2 showed worst abduction values. This might be due to cases of subacromial impingement. Moreover, lateralization increases the force required for abduction due to delta wrapping around the lateralized implant. Additionally, less delta muscle is recruited for abduction in a mainly glenoid-side lateralized implant as the one used in group 2.

Every surgeon had his preferred implant design and there was no choice of implant based on patient's characteristics, pathology or anatomy. Therefor the choice of implant was preset and there was no selection bias a far as the surgeon's choice of implant is concerned.

The strengths of this study are the homogeneous distribution of the three patient cohorts each with the same implant configuration and diagnosis as well as the strict monitoring and continuous follow-up examination protocol. Moreover, a small number of experienced shoulder surgeons performed the RSAs in specialized shoulder arthroplasty centers. Nonetheless, we need to highlight limitations including the retrospective bicentric, observational study design and short follow-up. The heterogeneity of glenoid configurations and deformities as well as scapular setting and motion must also be considered. We didn't adjust for patient comorbidities. Radiological measurements were all performed by one experienced investigator and thus, we cannot provide any estimations of inter-rater reliability. Finally, clinical evaluation of range of motion at follow-up postoperatively was assessed by different observers and differences on the clinical judgement of range of motion between observers cannot be excluded.

Conclusion

There was no difference in outcome scores between a medialized and distalized, a lateralized and a lateralized and distalized RSA. The lateralized and distalized RSA implant was associated with better flexion and abduction. Furthermore, glenoid lateralization combined with an NSA lower than that of the original Grammont design was associated with a reduction of scapular notching. There was an association of further reduction of scapular notching with glenosphere eccentricity because of higher inferior glenosphere overhang. A better rotation was associated with both lateralized implant designs. The outlined design advantages should be favored over the Grammont design.

Supplementary Information

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Supplementary Material 1.

Supplementary Material 2.

Supplementary Material 3.

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Authors' contributions

FF—writing original draft, conceptualization, data acquisition, methodology. PM—reviewing original draft, methodology. LA—analysis, statistics, writing original draft, reviewing original draft. TS—analysis, data curation. YA—data acquisition, methodology. RT—writing original draft. J-PI—writing original draft. MS—supervision, conceptualization, reviewing original draft, methodology.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The study was performed in accordance with the standards of the Ethics Committee of Zurich (Kantonale Ethikkommission [KEK], Stampfenbachstrasse 121, CH-8090 Zurich, Switzerland; KEK-ZH-Nr. 2014–0483), Institutional Board Committee at Charité Universitaetsmedizin Berlin (Ethikausschuss am Campus Virchow-Klinikum, Charitéplatz 1, DE-10117 Berlin, Germany; Antragsnr. EA2/173/18) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

All patients provided written informed consent prior to patient enrolment / data collection and use of their data for research purposes.

Consent for publication

Not applicable.

Competing interests

Florian Freislederer is a paid consultant of Stryker Inc.
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References

1. Hamada K, Fukuda H, Mikasa M, Kobayashi Y. Roentgenographic findings in massive rotator cuff tears. A long-term observation. Clin Orthop Relat Res. 1990 (254):92–6. Epub 1990/05/01.
2. 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(3):388–95. Epub 2004/05/06.
3. Baulot E, Sirveaux F, Boileau P. Grammont's idea: The story of Paul Grammont's functional surgery concept and the development of the reverse principle. Clin Orthop Relat Res. 2011;469(9):2425–31. Epub 2011/01/07.
4. Jobin CM, Brown GD, Bahu MJ, Gardner TR, Bigliani LU, Levine WN, et al. Reverse total shoulder arthroplasty for cuff tear arthropathy: the clinical effect of deltoid lengthening and center of rotation medialization. J Shoulder Elbow Surg. 2012;21(10):1269–77. Epub 2011/11/08.
5. Mollon B, Mahure SA, Roche CP, Zuckerman JD. Impact of scapular notching on clinical outcomes after reverse total shoulder arthroplasty: an analysis of 476 shoulders. J Shoulder Elbow Surg. 2017;26(7):1253–61. Epub 2017/01/24.
6. Werner CM, Steinmann PA, Gilbart M, Gerber C. Treatment of painful pseudoparesis due to irreparable rotator cuff dysfunction with the Delta III reverse-ball-and-socket total shoulder prosthesis. J Bone Joint Surg Am. 2005;87(7):1476–86. Epub 2005/07/05.
7. 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(1):146–57. Epub 2010/12/08.
8. Berton A, Gulotta LV, Longo UG, De Salvatore S, Piergentili I, Bandini B, et al. Medialized versus lateralized center of rotation in reverse total shoulder arthroplasty: a systematic review and meta-analysis. J Clin Med. 2021;10(24):5868.
9. Cuff D, Pupello D, Virani N, Levy J, Frankle M. Reverse shoulder arthroplasty for the treatment of rotator cuff deficiency. J Bone Joint Surg Am. 2008;90(6):1244–51. Epub 2008/06/04.
10. Frankle M, Siegal S, Pupello D, Saleem A, Mighell M, Vasey M. The Reverse Shoulder Prosthesis for glenohumeral arthritis associated with severe rotator cuff deficiency. A minimum two-year follow-up study of sixty patients. J Bone Joint Surg Am. 2005;87(8):1697–705. Epub 2005/08/09.
11. Helmkamp JK, Bullock GS, Amilo NR, Guerrero EM, Ledbetter LS, Sell TC, et al. The clinical and radiographic impact of center of rotation lateralization in reverse shoulder arthroplasty: a systematic review. J Shoulder Elbow Surg. 2018;27(11):2099–107.
12. Werthel JD, Walch G, Vegehan E, Deransart P, Sanchez-Sotelo J, Valenti P. Lateralization in reverse shoulder arthroplasty: a descriptive analysis of different implants in current practice. Int Orthop. 2019;43(10):2349–60. Epub 2019/06/30.
13. Larose G, Fisher ND, Gambhir N, Alben MG, Zuckerman JD, Virk MS, et al. Inlay versus onlay humeral design for reverse shoulder arthroplasty: a systematic review and meta-analysis. J Shoulder Elbow Surg. 2022;31(11):2410–20. Epub 2022/06/08.
14. Lädermann A, Collin P, Denard PJ. Range of motion after reverse shoulder arthroplasty: which combinations of humeral stem and glenosphere work best? Obere Extremität. 2020;15(3):172–8.
15. Werthel JDWG, Vegehan E, Deransart P, Sanchez-Sotelo J, Valenti P. Lateralization in reverse shoulder arthroplasty: a descriptive analysis of different implants in current practice. Int Orthop. 2019;43:2349–60.
16. Cho SH, Lee HJ, Aldhafian OR, Kim YS. Comparison of lateralized versus medialized reverse total shoulder arthroplasty: a systematic review and meta-analysis. Orthop J Sports Med. 2022;10(1):23259671211063920. Epub 2022/01/11.
17. Gruber MD, Kirloskar KM, Werner BC, Lädermann A, Denard PJ. Factors associated with internal rotation after reverse shoulder arthroplasty: a Narrative review. JSES Rev Rep Techniq. 2022;2(2):117–24.
18. Samitier G, Alentorn-Geli E, Torrens C, Wright TW. Reverse shoulder arthroplasty. Part 1: Systematic review of clinical and functional outcomes. Int J Shoulder Surg. 2015;9(1):24–31. Epub 2015/02/25.
19. Constant CR. Age related recovery of shoulder function after injury. Thesis, University College. 1986
20. Gilbart MK, Gerber C. Comparison of the subjective shoulder value and the Constant score. J Shoulder Elbow Surg. 2007;16(6):717–21.
21. Breckenridge JD, McAuley JH. Shoulder Pain and Disability Index (SPADI). J Physiother. 2011;57(3):197. Epub 2011/08/17.
22. Durchholz H, Salomonsson B, Moroder P, Lambert S, Page R, Audige L, et al. Core set of radiographic parameters for shoulder arthroplasty monitoring: criteria defined by an International Delphi consensus process. JB JS Open Access. 2019;4(4):e0025. Epub 2020/02/12.
23. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. J Biomed Inform. 2009;42(2):377–81.
24. Austin PC. Balance diagnostics for comparing the distribution of baseline covariates between treatment groups in propensity-score matched samples. Stat Med. 2009;28(25):3083–107.
25. Torrens C, Guirro P, Santana F. The minimal clinically important difference for function and strength in patients undergoing reverse shoulder arthroplasty. J Shoulder Elbow Surg. 2016;25(2):262–8. Epub 2015/10/01.
26. Freislederer F, Toft F, Audigé L, Marzel A, Endell D, Scheibel M. Lateralized vs. classic Grammont-style reverse shoulder arthroplasty for cuff deficiency Hamada stage 1–3: does the design make a difference? J Shoulder Elbow Surg. 2022;31(2):341–51. Epub 2021/08/28.
27. Boileau P, Moineau G, Roussanne Y, O'Shea K. Bony increased-offset reversed shoulder arthroplasty: minimizing scapular impingement while maximizing glenoid fixation. Clin Orthop Relat Res. 2011;469(9):2558–67. Epub 2011/02/03.
28. Katz D, Valenti P, Kany J, Elkholti K, Werthel J-D. Does lateralisation of the centre of rotation in reverse shoulder arthroplasty avoid scapular notching? Clinical and radiological review of one hundred and forty cases with forty five months of follow-up. Int Orthopaed. 2016;40(1):99–108.
29. Valenti P, Sauzieres P, Katz D, Kalouche I, Kilinc AS. Do less medialized reverse shoulder prostheses increase motion and reduce notching? Clin Orthop Relat Res. 2011;469(9):2550–7. Epub 2011/03/16.
30. Athwal GS, MacDermid JC, Reddy KM, Marsh JP, Faber KJ, Drosdowech D. Does bony increased-offset reverse shoulder arthroplasty decrease scapular notching? J Shoulder Elbow Surg. 2015;24(3):468–73. Epub 2014/12/03.
31. Gutiérrez S, Levy JC, Lee WEI, Keller TS, Maitland ME. Center of rotation affects abduction range of motion of reverse shoulder arthroplasty. Clin Orthopaed Related Res®. 2007;458:78–82.
32. Lädermann A, Denard PJ, Boileau P, Farron A, Deransart P, Walch G. What is the best glenoid configuration in onlay reverse shoulder arthroplasty? Int Orthopaed. 2018;42(6):1339–46.
33. Merolla G, Walch G, Ascione F, Paladini P, Fabbri E, Padolino A, et al. Grammont humeral design versus onlay curved-stem reverse shoulder arthroplasty: comparison of clinical and radiographic outcomes with minimum 2-year follow-up. J Shoulder Elbow Surg. 2018;27(4):701–10. Epub 2018/01/02.
34. Giles JW, Langohr DGG, Johnson JA, Athwal GS. Implant design variations in reverse total shoulder arthroplasty influence the required deltoid force and resultant joint load. Clin Orthopaed Rel Res®. 2015;473(11):3615–26.
35. Wong MT, Langohr GDG, Athwal GS, Johnson JA. Implant positioning in reverse shoulder arthroplasty has an impact on acromial stresses. J Shoulder Elbow Surg. 2016;25(11):1889–95. Epub 2016/07/05.
36. Hess F, Zettl R, Smolen D, Knoth C. Anatomical reconstruction to treat acromion fractures following reverse shoulder arthroplasty. Int Orthopaed. 2018;42(4):875–81.
37. Haidamous G, Lädermann A, Frankle MA, Gorman RA 2nd, Denard PJ. The risk of postoperative scapular spine fracture following reverse shoulder arthroplasty is increased with an onlay humeral stem. J Shoulder Elbow Surg. 2020;29(12):2556–63. Epub 2020/07/28.
38. Harman M, Frankle M, Vasey M, Banks S. Initial glenoid component fixation in "reverse" total shoulder arthroplasty: a biomechanical evaluation. J Shoulder Elbow Surg. 2005;14(1, Supplement):S162–7.
39. Patterson DC, Chi D, Parsons BO, Cagle PJ Jr. Acromial spine fracture after reverse total shoulder arthroplasty: a systematic review. J Shoulder Elbow Surg. 2019;28(4):792–801. Epub 2018/12/01.
40. Franceschetti E, Ranieri R, Giovanetti de Sanctis E, Palumbo A, Franceschi F. Clinical results of bony increased-offset reverse shoulder arthroplasty (BIO-RSA) associated with an onlay 145 degrees curved stem in patients with cuff tear arthropathy: a comparative study. J Shoulder Elbow Surg. 2020;29(1):58–67. Epub 2019/08/12.

41. Langohr GD, Giles JW, Athwal GS, Johnson JA. The effect of glenosphere diameter in reverse shoulder arthroplasty on muscle force, joint load, and range of motion. J Shoulder Elbow Surg. 2015;24(6):972–9. Epub 2014/12/31.
42. Henninger HB, Barg A, Anderson AE, Bachus KN, Burks RT, Tashjian RZ. Effect of lateral offset center of rotation in reverse total shoulder arthroplasty: a biomechanical study. J Shoulder Elbow Surg. 2012;21(9):1128–35. Epub 2011/11/01.
43. Costantini O, Choi DS, Kontaxis A, Gulotta LV. The effects of progressive lateralization of the joint center of rotation of reverse total shoulder implants. J Shoulder Elbow Surg. 2015;24(7):1120–8. Epub 2015/01/21.
44. Routman HD, Flurin PH, Wright TW, Zuckerman JD, Hamilton MA, Roche CP. Reverse shoulder arthroplasty prosthesis design classification system. Bull Hosp Jt Dis. 2013;2015(73 Suppl 1):S5-14. Epub 2015/12/04.
45. Collin P, Liu X, Denard PJ, Gain S, Nowak A, Ladermann A. Standard versus bony increased-offset reverse shoulder arthroplasty: a retrospective comparative cohort study. J Shoulder Elbow Surg. 2018;27(1):59–64. Epub 2017/10/04.
46. Greiner S, Schmidt C, Herrmann S, Pauly S, Perka C. Clinical performance of lateralized versus non-lateralized reverse shoulder arthroplasty: a prospective randomized study. J Shoulder Elbow Surg. 2015;24(9):1397–404. Epub 2015/07/15.
47. Raiss P, Neumann R. Bipolar lateralization in reverse shoulder arthroplasty for avoidance of scapular notching. Obere Extremität. 2020;15(3):207–12.
48. Imiolczyk JP, Audige L, Harzbecker V, Moroder P, Scheibel M. Metallic humeral and glenoid lateralized implants in reverse shoulder arthroplasty for cuff tear arthropathy and primary osteoarthritis. JSES Int. 2022;6(2):221–8. Epub 2022/03/08.
49. Engel NM, Holschen M, Schorn D, Witt KA, Steinbeck J. Results after primary reverse shoulder arthroplasty with and without subscapularis repair: a prospective-randomized trial. Arch Orthop Trauma Surg. 2023;143(1):255–64. Epub 2021/07/09.
50. Polisetty TS, Baessler AM, Levy JC, Badman BL. Onlay versus inlay reverse total shoulder arthroplasty: a retrospective comparison of radiographic and clinical outcomes. Sem Arthroplasty: JSES. 2021;31(2):202–8.
51. Lee HJ, Yoon CY, Kim YS. Comparison of clinical performance of inlay versus onlay humerus implants in reverse total shoulder arthroplasty. Clin Orthop Surg. 2023;15(1):135–44. Epub 2023/02/14.
52. Kalouche ISN, Wahegaonker A, Sauzieres P, Katz D, Valenti P. Reverse shuolder arthroplasty: does reduced medialisation improve radiological and clinical results? Acta Orthop Belg. 2009;75(2):158–66.
53. de Wilde LF, Poncet D, Middernacht B, Ekelund A. Prosthetic overhang is the most effective way to prevent scapular conflict in a reverse total shoulder prosthesis. Acta Orthop. 2010;81(6):719–26. Epub 2010/11/30.
54. Freislederer F, Toft F, Audige L, Marzel A, Endell D, Scheibel M. Lateralized vs. classic Grammont-style reverse shoulder arthroplasty for cuff deficiency Hamada stage 1–3: does the design make a difference? J Shoulder Elbow Surg. 2022;31(2):341–51. Epub 2021/08/28.
55. Streit JJSY, Gobezie R. Medialized versus lateralized Center of rotation in reverse shoulder arthroplasty. Orthopedics. 2015;38:e1090–103.

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