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ORIGINAL ARTICLE

The lateralization and distalization shoulder angles are important determinants of clinical outcomes in reverse shoulder arthroplasty

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Background: Reverse shoulder arthroplasty (RSA) designs vary in the lateralization and distalization geometry, which may affect functional outcomes. The purpose was to determine the effect of RSA lateralization and distalization on final functional outcomes by using the "lateralization shoulder angle" (LSA) and the "distalization shoulder angle" (DSA).

Methods: Forty-six consecutive patients who underwent RSA for cuff tear arthropathy were retrospectively evaluated. Functional outcome and radiographs were evaluated at a minimum of 2 years postoperatively and compared between implants with or without glenoid lateralization and with or without humeral-sided lateralization. Anteroposterior shoulder radiographs were used to evaluate the LSA and DSA.

Results: Both angles showed substantial to almost perfect intrarater and inter-rater agreement. Higher LSA values were found in more lateralized RSAs ($P = .027$), and values between 75° and 95° were correlated with better active external rotation (quadratic regression analysis $R^2 = 0.553$, $P < .001$). Postoperative active anterior elevation ($R^2 = 0.2$, $P = .008$), Constant ($r_s = 0.29$, $P = .05$), and Activities of Daily Living Requiring External Rotation scores ($r_s = 0.4$ $P = .007$) had a positive correlation with the LSA. The quadratic regression analysis also showed that a DSA between 40° and 65° resulted in better active anterior elevation ($R^2 = 0.4$, $P < .001$) and abduction ($R^2 = 0.4$, $P < .001$). The negative correlation between the LSA and DSA ($r_s = -0.7$, $P < .001$) revealed that, according to the implant used, the more distally the RSA is placed the less lateralization is achieved.

Conclusions: The LSA and the DSA are reproducible measurements that may be used to estimate "lateralization and distalization" after RSA. These measurements are correlated with postoperative clinical outcomes.

Level of evidence: Level II; Prognosis Study

Keywords: Reverse shoulder arthroplasty; lateralization; distalization; functional outcomes; LSA; DSA

The Institutional Review Board of the Centre Ostéoarticulaire des Cèdres (Grenoble, France) Ethical Committee approved this study (COAC IRB #2016-02).

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The initial Grammont reverse shoulder arthroplasty (RSA) consisted of a glenoid hemisphere with diameter of 36 or 42 mm, without lateral offset, and a humeral cup with an almost horizontal humeral inclination of 155°.[9,10] With this

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design, the center of rotation is medialized, and the humerus is distalized relative to the acromion. This increases deltoid muscle tension and aids in recruiting more fibers of the anterior and posterior deltoid to facilitate active anterior elevation (AAE) and abduction.[5]

This initial RSA design has demonstrated good long-term functional results, with restoration mainly of abduction and forward flexion and 93% overall 10-year survival rates.[1,5,29,30] However, the medialized position of this design has largely failed to improve active external rotation (AER) (7° to 11° reported) and led to scapular notching rates as high as 74% to 88%.[4,20] Furthermore, excessive arm lengthening has led to neurologic injury in some cases.[21,22,24,25]

To overcome these problems and achieve better soft tissue balancing of the deltoid and the remaining rotator cuff muscles, several authors have proposed design modifications that have more lateralization and less distalization of the RSA.[2,4,6,18-20] On the glenoid side, bony increased-offset RSA (BIO-RSA)[4] or "metallic lateralization" via the glenosphere or the baseplate have been used to increase lateralization.[6,19] On the humeral side, a more anatomic humeral inclination of 145° to 135° or onlay humeral trays, or both, have been used to increase lateralization.[2,14,20]

Previous authors have attempted to determine the optimal lateralization and distalization of RSA based on 3-dimensional computer-assisted or cadaveric models. Nevertheless, the effects of these parameters remain unclear in vivo.[11,13,20,32] In the clinical setting, Lädermann et al[24] described an objective evaluation of arm lengthening after RSA by performing bilateral preoperative and postoperative true anteroposterior scaled radiographs of the humerus. Furthermore, some authors have attempted to measure the exact distalization of the humerus and medialization of the center of rotation after RSA by using calibrated preoperative and postoperative simple radiographs.[17,27] However, these techniques are demanding and difficult to apply during daily clinical practice.

Our hypothesis was that the "lateralization shoulder angle" (LSA) and the "distalization shoulder angle" (DSA) are reproducible and correlated to clinical outcome after RSA.

Materials and methods

Study design

A retrospective review was performed of consecutive RSAs performed between January 2009 and January 2015 by 1 surgeon (J.B.). Inclusion criteria were a primary RSA for rotator cuff arthropathy and minimum follow-up of 2 years. We included patients with 2 different humeral stems: a straight Grammont style inlay stem with 155° of inclination (Aequalis Reversed; Wright Medical Group Inc., Memphis, TN, USA) and a short curved onlay stem with an inclination of 145° (Ascend Flex; Wright Medical). On the glenoid side, patients with or without a BIO-RSA were included. Accordingly 4 combinations were possible: group I (Grammont style stem and a neutral glenosphere), group II (Ascend Flex stem and a neutral glenosphere), group III (Grammont style stem with glenoid lateralization with a 10-mm BIO-RSA graft and a neutral glenosphere), and group IV (Ascend Flex stem with glenoid lateralization with a 10-mm BIO-RSA graft and a neutral glenosphere). The construct choice was based on surgeon preference and reflected an evolution in technique and implants over time.

Exclusion criteria were revision RSA, RSA for proximal humeral fracture, preoperative teres minor fatty infiltration with concomitant latissimus dorsi transfer, postinfection RSA, primary glenohumeral arthritis, and incomplete follow-up. Finally, we excluded patients with preoperative deltoid impairment that was proven clinically (atrophy, muscle defects), with electromyographic examination signs of denervation or radiologic assessment, or both, confirming grade 3 or 4 fatty infiltration on computed tomography or magnetic resonance imaging.[23,28]

Surgical procedure

All procedures were performed with the patient under general anesthesia in a beach chair position without interscalene block to facilitate a neurologic examination immediately after the operation. In all cases, a deltopectoral approach was performed, a tenotomy of the subscapularis was performed to access the glenohumeral joint, and the axillary nerve was identified.

For BIO-RSAs, a 10-mm-thick cancellous bone graft was initially harvested from the humeral head. The humeral osteotomy inclination was 155° with the Grammont type stem and 132.5° with the short curved Ascend Flex. In the latter, an asymmetric polyethylene insert was used to result in a final inclination of 145°.

The glenoid was prepared in the same manner, with the only difference being the addition or lack of a BIO-RSA technique to provide increased lateral offset.[4,16] A 29-mm glenoid guide was placed flush with the inferior border of the glenoid with 10° of inferior tilt. In all shoulders, a standard (centered) glenosphere was chosen. A 42-mm glenosphere was placed in 6 patients (5 men and 1 woman), and a 36-mm glenosphere was placed in the remaining 40 patients. In the case of a BIO-RSA, the graft thickness was the same 10 mm regardless of glenosphere size.

The humeral component was placed with retroversion preferred between 20 and 30°. All of the Grammont type (Aequalis) stems were cemented, and all of the short curved (Ascend Flex) stems were press-fit. A 9-mm-thick polyethylene insert was used in 4 patients with the Grammont type stem without BIO-RSA, and a 6-mm-thick polyethylene insert was used in all other patients.

In all cases we attempted to repair the subscapularis tendon, even if it was initially torn, by performing a release of it from the capsule, the superior and middle glenohumeral ligaments, and the subcoracoid bursa, reaching the axillary nerve medially. Although tendon quality varied, the subscapularis tendon was repaired in every case with a Masson-Allen suture technique using 3 pairs of 2-mm holes made on the lesser tuberosity.

The rehabilitation protocol was the same for all patients. A simple shoulder sling was used for 4 weeks postoperatively. Pendulum exercises and passive mobilization of the shoulder joint were allowed on the first postoperative day. The patient was generally encouraged to use his or her arm for activities of daily living on the first postoperative day, and hydrotherapy in a swimming pool was initiated 3 weeks postoperatively. All types of activities (eg, sports, weight lifting, heavy house work) were permitted at 6 months.

Clinical evaluation

The following data were collected from a record review: age, sex, body mass index, type of prosthesis (implants details), preoperative range of motion (ROM), muscle fatty infiltration (Goutallier classification[8]), Hamada cuff tear arthropathy stage,[15] and Constant score.

At the final follow-up, ROM and the following outcomes were assessed: Constant score, subjective shoulder value (SSV), Simple Shoulder Test (SST), American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form (ASES), and the ADLER score (score for quantification of activities of daily living [ADL] which require active external rotation [ER])[3]. The visual analog scale (VAS) was also used to assess pain (range, 0-10). An independent examiner (A.B.), blinded to the type of the prosthesis, used a goniometer to perform the final clinical evaluation of all patients.

Radiographic evaluation

True anteroposterior (in neutral rotation) and lateral plain radiographs were obtained at final follow-up. On anteroposterior radiographs, the following 3 bony landmarks that normally remain intact after the operation were used to define the LSA:

1. The superior glenoid tubercle
2. The most lateral border of the acromion
3. The most lateral border of the greater tuberosity

First, a line was drawn to connect the superior glenoid tubercle and the most lateral border of the acromion. Second, a line was drawn to connect the most lateral border of the acromion with the most lateral border of the greater tuberosity. The angle between these 2 lines formed the LSA (Fig. 1).

The following 3 bony landmarks that also normally remain intact after RSA were used to define the DSA:

1. The superior glenoid tubercle
2. The most lateral border of the acromion
3. The most superior border of the greater tuberosity

A line was drawn to connect the most lateral border of the acromion and the superior glenoid tubercle, and a second line was drawn to connect the superior glenoid tubercle with the most superior border of the greater tuberosity. The angle between these 2 lines formed the DSA (Fig. 2).

Considering that both angles could be influenced by the position of the scapula and the rotation of the humerus, all radiographs were performed in the same department and under fluoroscopic control. This study only included true anteroposterior radiographs with clearly visible superior and inferior borders of the glenoid and superior and lateral borders of the scapula[31] (Figs. 1, 2). To assess the intraobserver and interobserver reproducibility of the proposed LSA and DSA angles, 3 senior shoulder surgeons (A.B., H.L., and J.B.) performed the measurements in blinded radiographs of all included patients and repeated the measurement after an interval of 4 weeks.

Finally, according to a recently published study based on a 3-dimensional computer model, the expected ROM values of RSA with 155° inlay and standard glenosphere (the more medialized and distalized type of prosthesis) were AAE, 106°; abduction, 78°; and AER, 16°.[20] These values were used to perform logistic regression and receiver operating characteristic (ROC) curve analyses to determine possible cutoff values for LSA and DSA and to assess sensitivity and specificity.

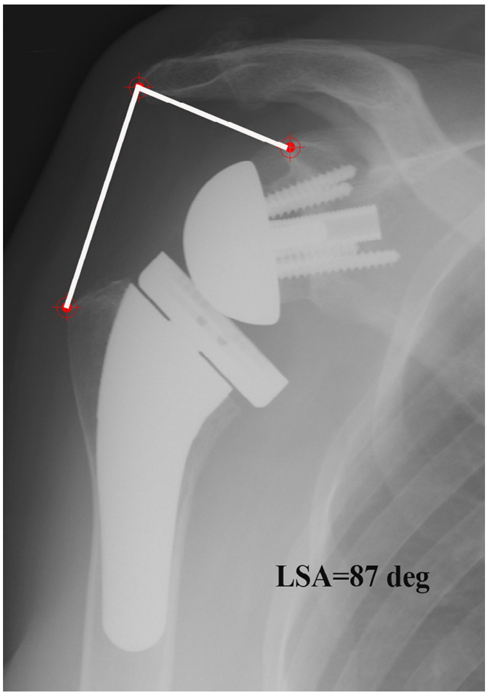

Figure 1 The lateralization shoulder angle (*LSA*) angle is formed by a line connecting the superior glenoid tubercle and the most lateral border of the acromion and a line connecting the most lateral border of the acromion and the most lateral border of the greater tuberosity. In this case with bony increased-offset reverse shoulder arthroplasty and short curved onlay stem (group IV), it is measured at 87°.

Statistical analysis

Continuous data are described by mean, standard deviation, and range. Categoric data are defined by percentage. Baseline characteristics were compared between RSA groups using the Kruskal-Wallis *H* or Mann-Whitney *U* test for non-Gaussian continuous variables, the analysis of variance test for Gaussian continuous variables, and the χ^2 test for categoric variables. In cases that the analysis of variance test revealed significant differences, post-hoc pairwise comparisons using the Bonferroni test were performed. Normality was verified graphically and with the Shapiro-Wilk test.

Intraobserver and interobserver agreements for LSA and DSA were evaluated by the intraclass correlation coefficient (ICC or Kendall coefficient) 2-by-2 with a 95% confidence interval. The power of ICC values is interpreted according to the Landis and Koch classification as no agreement to slight agreement, <0.20; fair agreement, 0.21 to 0.40; moderate agreement, 0.41 to 0.60; substantial agreement, 0.61 to 0.80; and almost perfect agreement, 0.81 to 1.00.

Linear regression analysis was conducted between the final ROM and LSA, DSA, age, body mass index, preoperative infraspinatus fatty infiltration, and preoperative active forward flexion and external rotation. Sequential curvilinear regression analysis was used to investigate the nature of the relationship between final ROM and

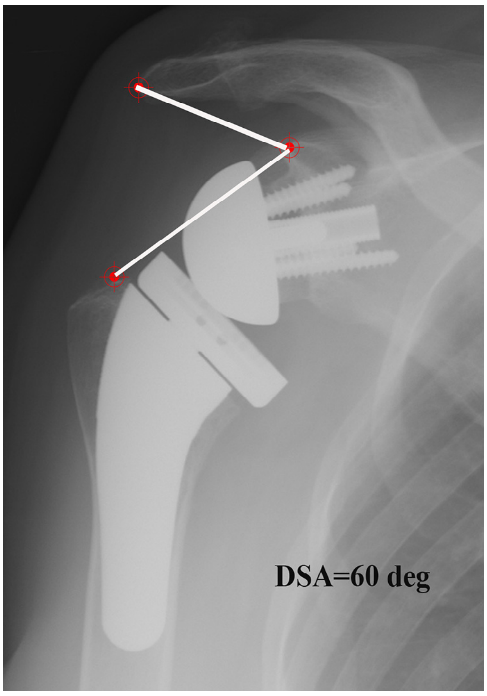

Figure 2 The distalization shoulder angle (*DSA*) angle is formed by a line connecting the most lateral border of the acromion and the superior glenoid tubercle and a line connecting the superior glenoid tubercle and the most superior border of the greater tuberosity. In this case with bony increased-offset reverse shoulder arthroplasty and short curved onlay stem (group IV), it is measured at 60°.

the LSA and DSA values. If no regression analysis could be established, a correlation analysis was conducted.

Finally, ROC curve analyses were performed to determine possible cutoff values for LSA and DSA.

Statistical significance was set at $P < .05$. Statistical analysis was performed with SPSS 23.0 software (IBM, Armonk, NY, USA).

Results

General

Of 82 RSAs performed during the study period, 59 had complete follow-up and 46 met the inclusion criteria (Fig. 3). The study group consisted of 37 women and 9 men with a mean age of 77 ± 7.5 years (range, 62-90 years) and mean follow-up of 39 ± 18 months (range, 24-84 months). There were 13 patients in group I (Grammont style stem and standard baseplate), 10 patients in group II (Ascend Flex stem and standard baseplate), 11 patients in group III (Grammont style stem with BIO-RSA), and 12 patients in group IV (Ascend Flex stem with BIO-RSA) The 4 groups were comparable preoperatively (Table I).

The functional results of the 4 patient groups are presented in Table II. Statistically significant differences were found for AER ($P = .027$) and LSA ($P < .001$). AER was statistically significantly better in groups II (31° ± 13°) and IV (30° ± 16°) than in group I (14° ± 13°) ($P = .036$ and $P = .038$, respectively). Similarly, LSA values were significantly lower in group I than in group II or IV ($P = .05$ between groups I and II and $P < .001$ between groups I and IV, respectively; Table II).

Finally, the use of a 42-mm glenosphere was the same among the 4 types of prosthesis ($P = .794$) and did not result in different LSA ($P = .81$) or DSA ($P = .56$) values. In addition, although a larger glenosphere resulted in marginally better final ROM and functional outcomes, the differences were not statistically significant (Supplementary Table S1).

LSA and DSA intrarater and inter-rater reliability

The intraobserver agreement for the LSA was substantial to almost perfect (mean, 0.8; range, 0.7-0.86), and the interobserver agreement was also substantial to almost perfect (mean, 0.78; range, 0.73-0.84). Intraobserver agreement for the DSA was always almost perfect (mean, 0.9; range, 0.83-0.93), and the interobserver agreement was substantial to almost perfect (mean, 0.81; range, 0.78-0.85).

Regression analysis results

Final AER of the RSA

A statistically significant positive linear regression ($R^2 = 0.42$, $P < .001$) was found between the final AER and the LSA. A significant negative linear regression was also observed between external rotation and the DSA ($R^2 = 0.22$, $P = .002$; Supplementary Table S2). After evaluating the linear model for the LSA (Fig. 4, *a*), the addition of a quadratic component produced a significant increase in fit ($R^2 = 0.553$, $P < .001$), with the best AER observed with LSA values between 75° and 95°

Final AAE of the RSA

The postoperative AAE showed a positive linear regression with LSA ($R^2 = 0.2$, $P = .008$) and with preoperative AAE ($R^2 = 0.1$, $P = .021$). An inverse linear regression was found between the final AAE and DSA ($R^2 = 0.2$, $P = .004$; Supplementary Table S3). After the linear model for the DSA was evaluated (Fig. 4, *b*), the addition of a quadratic component also produced a significant increase in fit ($R^2 = 0.4$, $P < .001$). DSA values between 40° and 60° predicted better postoperative AAE (Fig. 4, *b*).

Final active shoulder abduction of the RSA

No statistically significant linear regression was found between shoulder abduction and the values of LSA ($R^2 = 0.04$, $P = .28$) or DSA ($R^2 = 0.09$, $P = .45$). However, the sequential curvilinear analysis showed a significant dependence of shoulder abduction on the DSA ($R^2 = 0.4$, $P < .001$; Supplementary Fig. S3). Postoperative abduction was highest with DSA values between 45° and 65° (Supplementary Fig. S3).

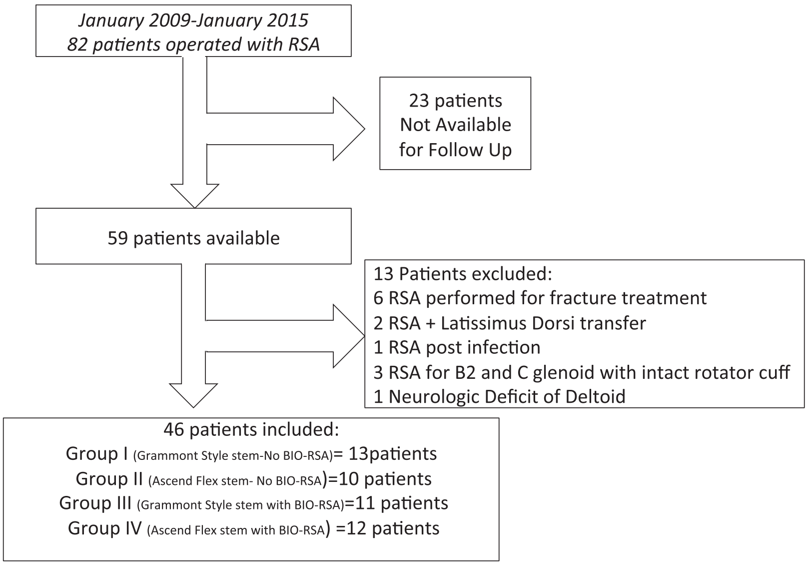

Figure 3 Flowchart of our reverse shoulder arthroplasty (*RSA*) study group.

Table I Preoperative patients characteristics among the 4 patient groups

Variable	Group I	Group II	Group III	Group IV	*P* values
Age, yr	77 ± 2 (62-86)	77 ± 2 (62-89)	76 ± 2 (67-90)	76.5 ± 2.5 (64-90)	.969*
Body mass index, kg/m^2	26 ± 4.7 (19-36)	26 ± 5 (20-39)	29 ± 5 (23-40)	28 ± 5 (18-36)	.2†
Active forward flexion,°	63 ± 21 (10-100)	53 ± 22 (30-90)	74 ± 35 (10-120)	80 ± 35 (0-120)	.416†
Active external rotation (R1)‡,°	14 ± 20 (−30 to 50)	−8 ± 21 (−30 to 20)	5 ± 20 (−30 to 40)	14 ± 20 (−30 to 40)	.09†
Active internal rotation, level	SI (BUT-T12)	BUT (LT-T12)	BUT (LT-SI)	BUT (LT-T12)	.188†
Pre-op absolute Constant score	23 ± 3 (12-45)	21 ± 2.5 (8-30)	19 ± 3.5 (2-33)	26 ± 1 (16-34)	.233*
IS fatty infiltration (Goutallier)	3 (2-4)	3 (2-4)	3 (2-4)	3 (2-4)	.226†
Hamada stage	4 (2-5)	4 (2-5)	4 (1-5)	4 (1-5)	.848†

BUT, buttocks; *T12*, 12th thoracic vertebra; *IS*, infraspinatus; *LT*, lateral thigh; *SI*, sacroiliac joint.
Values are expressed as mean ± standard deviation (range);
Group I: Grammont style stem 155° and standard baseplate; *Group II*: Ascend Flex (Wright Medical Group Inc., Memphis, TN, USA) stem 145° and standard baseplate; *Group III*: Grammont style stem 155° with bony increased-offset reverse shoulder arthroplasty; and *Group IV*: Ascend Flex stem 145° with bony increased-offset reverse shoulder arthroplasty.
* *P* value of analysis of variance test.
† *P* value of Kruskal-Wallis test.
‡ The active external rotation was examined in position 1.

Final active shoulder internal rotation of the RSA

No statistically significant linear regression was found between final shoulder internal rotation and the values of LSA ($R^2 = 0.01$, $P = .49$) or DSA ($R^2 = 0.04$, $P = .19$).

Correlation analysis

Correlation analysis of the LSA with the final functional scores

There were positive correlations between the LSA and the ADLER score ($r_s = 0.4$, $P = .007$), the total Constant score ($r_s = 0.29$, $P = .05$), and the mobility component of the Constant score ($r_s = 0.5$, $P = .003$). However, no significant correlations were found between the LSA and ASES ($r_s = 0.025$, $P = .868$), SST ($r_s = 0.029$, $P = .849$), or SSV scores ($r_s = 0.2$, $P = .18$).

Correlation analysis of the DSA with the final functional scores

Negative correlations were observed between the DSA and the ADLER score ($r_s = -0.3$, $P = .04$) and the mobility component of the Constant score ($r_s = -0.324$, $P = .028$). The correlation with the total Constant score trended toward but did not reach statistical significance ($r_s = -0.28$, $P = .058$). No correlations were observed between the DSA and the ASES ($r_s = -0.097$, $P = .52$), SST ($r_s = -0.081$, $P = .6$), or SSV scores ($r_s = -0.17$, $P = .259$). Finally, a strong negative correlation was found between the LSA and DSA ($r_s = -0.7$, $P < .001$).

Table II Overall results according to reverse shoulder arthroplasty type

Variable	Group I	Group II	Group III	Group IV	*P* values
Active forward flexion, °	148 ± 7 (100-170)	149 ± 8 (90-175)	158 ± 4 (130-175)	152 ± 8 (80-180)	.749†
Gain, °	*86 ± 36 (20-140)*	*96 ± 33 (40-135)*	*92 ± 37 (50-150)*	*82 ± 40 (0-160)*	*.658**
Active abduction, °	134 ± 8.5 (90-170)	134 ± 9 (80-175)	145 ± 7 (100-170)	129 ± 11 (60-170)	.805†
Active external rotation (R1), °	14 ± 13 (−10 to 35)	31 ± 13 (15-60)	24 ± 12 (0-40)	30 ± 16 (0-50)	**.021***
Gain, °	*0 ± 30 (−30 to 50)*	*32 ± 25 (15-60)*	*19 ± 23(−15 to 60)*	*19 ± 25 (−30 to 40)*	***.009****
Active internal rotation, level	L3 (BUT-T12)	L3 (BUT-T12)	L3 (BUT-T12)	L3 (BUT- T7)	.374‡
Post-op absolute Constant score	62 ± 3 (45-71)	67 ± 4 (41-86)	65 ± 2 (53-77)	62 ± 5 (34-87)	.895†
Gain	*39 ± 11 (13-58)*	*46 ± 12 (23-61)*	*46 ± 8 (37-60)*	*38 ± 21 (4-60)*	.334†
Simple Shoulder Test	7 ± 0.5 (4-11)	7 ± 1 (2-12)	7 ± 0.8 (3-11)	7 ± 1 (1-11)	.992†
ASES score	75 ± 4 (53-98)	79 ± 5 (53-100)	77 ± 4 (57-98)	72 ± 8 (33-100)	.938†
Subjective Shoulder Values	70 ± 4 (50-90)	69 ± 5.5 (40-95)	77 ± 4 (50-90)	74 ± 6 (40-95)	.566†
ADLER	26 ± 1(15-30)	27 ± 1 (22-30)	27 ± 1 (23-30)	27 ± 1 (14-30)	.779†
Lateralization shoulder angle, °	74 ± 1 (67-85)	83 ± 2 (68-95)	80 ± 2 (68-91)	89 ± 3 (65-105)	**<.001***
Distalization shoulder angle, °	55 ± 4 (35-75)	52 ± 3 (40-71)	53 ± 3 (40-66)	49 ± 4 (28-75)	.645*

L3, 3rd lumbar vertebra; *BUT*, buttocks; *T12*, 12th thoracic vertebra; *ASES*, American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form; *ADLER*, Activities of Daily Living Requiring External Rotation.
Values are expressed as mean ± standard deviation (range).
Group I: Grammont style stem 155° and standard baseplate; *Group II*: Ascend Flex (Wright Medical Group Inc., Memphis, TN, USA) stem 145° and standard baseplate; *Group III*: Grammont style stem 155° with bony increased offset-reverse shoulder arthroplasty; and *Group IV*: Ascend Flex stem 145° with bony increased offset-reverse shoulder arthroplasty.
* *P* values by analysis of variance test. Bold values are statistically significant.
† *P* values by Kruskal-Wallis test.
‡ *P* values by χ^2 test.

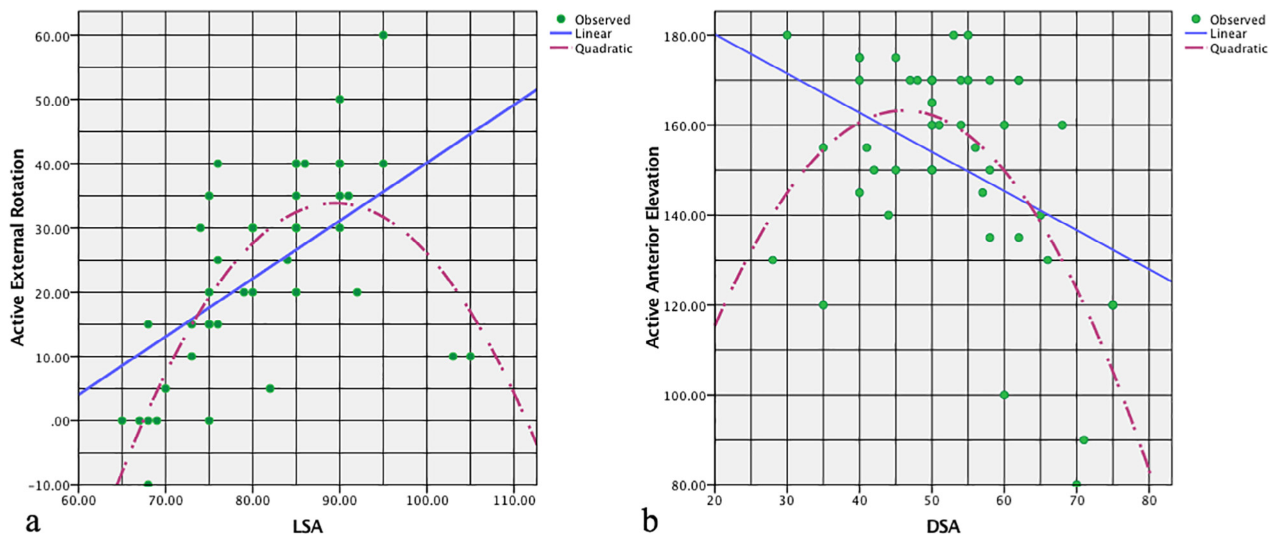

Figure 4 (**a**) Scatterplot shows the linear and curvilinear (quadratic) relationship between the lateralization shoulder angle (*LSA*) and the active external rotation. Better active external rotation could be expected with lateralization shoulder angle values between 75° and 95° ($R^2 = 0.553$, $P < .001$). (**b**) Scatterplot shows the linear and curvilinear (quadratic) relationship between the distalization shoulder angle (*DSA*) and the anterior active elevation. Better anterior active elevation could be expected with distalization shoulder angle values between 40° and 60° ($R^2 = 0.4$, $P < .001$).

Results of ROC curve analyses

Results for predicting AAE >106°

The area under the curve (AUC) for the DSA was excellent at 0.903, and the cutoff value of 65° had a sensitivity of 0.90 and specificity of 0.70 ($P = .02$) for predicting AAE >106° (Supplementary Fig. S1). Four patients had a DSA >70°, all of which had limited postoperative AAE (<110°).

The AUC for the LSA was good at 0.8, and the cutoff value of 70° had a sensitivity of 0.93 and specificity of 0.70, respectively ($P = .05$; Supplementary Fig. S1).

Results for predicting active abduction >78°

Regarding the DSA, the AUC was excellent at 0.955, and the cutoff value of 65° had a sensitivity of 0.95 and specificity of 0.90 for predicting abduction >78° (P = .03). For the LSA, the AUC was fair at 0.72, and the model was not statistically significant (P = .306).

Results for predicting AER >16°

Regarding the DSA, the AUC was good at 0.81, and the cutoff value of 60° showed a sensitivity of 0.94 and specificity of 0.70 for predicting AER >16° (P = .001; Supplementary Fig. S2). For the LSA, the AUC was excellent at 0.9, and the cutoff value of 75° showed a sensitivity of 0.90 and specificity of 0.80 (P < .001; Supplementary Fig. S2).

Discussion

The main finding of our study was that the LSA and DSA were directly correlated with postoperative functional outcomes and final ROM. Regardless of the exact surgical technique used, postoperative AAE and abduction were highest when the DSA was between 40° and 65°. Similarly, postoperative external rotation was highest when the LSA was between 75° and 95°. These findings may have several important clinical ramifications.

The DSA and LSA are based on readily identifiable landmarks. We found the LSA and DSA to be reproducible with substantial to almost perfect intrarater and inter-rater reliability. The LSA and DSA angles do not provide an exact measurement of lateralization and distalization of the humerus after RSA but rather an estimation of them in relation to the glenoid and the acromion. There is also a correlation between the 2 angles. For a given implant configuration, the more medial the arthroplasty is positioned (lower LSA) the greater is the distance between the humerus and the acromion (larger DSA).

We found a positive correlation between the amount of lateralization (expressed by the LSA) and postoperative AER, AAE, Constant score (particularly the mobility component), and the ADLER score. Similarly, recent computer-based models have reported that lateralization of the RSA, whether performed at the humeral side,[20] at the glenoid side[12] or both,[37] leads to increased postoperative AAE and AER. Explanations for this include less bony abutment between the scapular pillar and the polyethylene insert[20] as well as a closer restoration of the anatomic center of rotation, which allows the remaining muscles to function better.[12] Interestingly, we did not observe a loss of abduction due to impingement of the greater tuberosity with the acromion as has been previously suggested.[20,37] This could be explained by the fact that we did not test the effect of implants on final ROM under the idealized and identical conditions of a computer model, which are limited to glenohumeral motion. In the clinical setting, for example, scapulothoracic motion also plays a role and may compensate for bony impingement of the glenohumeral joint, thus possibly explaining our findings.

Several clinical options can be used to increase lateralization. A BIO-RSA resulting in lateralization of the glenoid has been shown to improve postoperative active external rotation.[4,11] Similarly, a mean improvement of 30° of external rotation has been described after metallic lateralization of the center of rotation.[19,35] Our findings confirm that improvement in external rotation can be obtained whether the lateralization was performed at the glenoid (BIO-RSA) or at the humeral side (via an onlay stem; Table II). However, by this study we cannot conclude which type of lateralization and its effect on the center of rotation can lead to better functional outcomes.

One of the main principles of the RSA is to lower the humerus relative to the acromion to improve deltoid muscle tension and thus AAE.[5] A computer-based model with different extreme humeral offset configurations demonstrated a strong positive linear regression between acromiohumeral distance and AAE and abduction.[20] However, the desired ideal amount of lengthening is unclear. Jobin et al[17] suggested that postoperative acromiohumeral distance should exceed 38 mm and that overall arm lengthening (compared with the preoperative x-ray images) should exceed 23 mm. The authors reported that this had a 90% positive predictive value of obtaining at least 135° of AAE.[17]

Schwartz et al,[33] however, did not find any correlation between lengthening and ROM. They estimated arm lengthening by calculating the difference in distance between the acromion and the greater tuberosity and between the acromion and the deltoid tuberosity on preoperative and postoperative radiographs. Despite an increase in the distance between the acromion and the greater tuberosity of 18.9 mm (–21.8 to 49.2 mm) and the distance between the acromion and the deltoid tuberosity of 20.6 mm (–31.7 to 77 mm), there was no effect on ROM. Rather, they reported that intraoperative forward flexion, followed by sex and preoperative ROM, were the most important predictors of postoperative ROM.[33]

Bilateral scaled radiographs have also been used to estimate arm lengthening. Lädermann et al[24] used scaled bilateral radiographs and reported a mean of 23 mm of arm lengthening after RSA with a traditional Grammont stem. They did not, however, perform any correlation with the postoperative ROM and functional results.[24] They also did not find any lengthening threshold beyond which nerve damage becomes a risk.[22]

More recently, Werner et al[36] performed bilateral scaled radiographs of the entire humerus after RSA and reported better AAE with arm lengthening between 1 and 2.5 cm. Furthermore, they found that arm lengthening >2.5 cm was related to a decrease in AAE and that brachial plexus palsy developed with values >5 cm.[36]

However, bilateral scaled radiographs are not always practical to obtain and increase radiation. Our goal was therefore to provide an estimation of the distalization of the humerus in relation to the acromion by using an angle, which avoids the need for scaled radiographs and is independent of patient size. This angle was not only reproducible but also appeared to correlate with clinical outcome. On one hand, the curvilinear regression analysis showed that the best postoperative AAE and abduction were obtained when the DSA was between 40° and 65°. On the other hand, all patients with a DSA >70° in our study had limited postoperative AAE (<110°). We believe this increased DSA represented overstretching of the deltoid and surrounding muscles and nerves, leading to poor outcomes. However, we do not know how the DSA and LSA relate to arm lengthening and to alterations of AGT distance.

The main strength of our study is that it introduces a new technique for estimating lateralization and distalization of the final RSA construct, which is easily obtained in clinical practice. The use of an angle as a radiologic index has been proven to be a simple and reproducible tool for other shoulder pathologies also.[31] Despite the different implant combinations, other variables, such as patient demographics, the surgeon, the surgical approach, the subjective assessment of soft tissue tension, the rehabilitation program, and the radiologic evaluation, were controlled for in this study.

Our study has several limitations, however. The study was retrospective, with a relatively small population. We do not know whether LSA and DSA are both sensitive to tilting of the scapula or to rotation of the humerus and at what degree. We did not find any significant correlation of the LSA and DSA with postoperative internal rotation, which could be explained by the differences in subscapularis tendon quality or postoperative subscapularis healing, or both.[7] None of our patients had excessive glenoid deformity (type E3) that could affect the findings, particularly for the LSA.[26,34]

The cohort was not randomized, but rather represented an evolution of technique and implants over time. This study design led to differences in the follow-up period between the 4 groups, which is also why we did not attempt to correlate scapular notching with the angles.

Because we attempted to estimate the final position of the RSA with 2 new radiologic angles, a power analysis based on previous data was not possible. Further larger cohort studies with the same follow-up and several time points are necessary to validate our idea by establishing groups of patients based on our proposed DSA and LSA angle ranges. In addition, computer-based or prospective clinical studies with different implant designs and preoperative calculation of the LSA and DSA using 3-dimensional planning software could verify the clinical importance of this project.

Finally, future studies using additional x-ray images with varying degrees of shoulder abduction could be performed to correlate LSA and DSA with known measurement methods of arm lengthening or lateralization after RSA.

Conclusions

Lateralization and distalization of the final RSA construct can be indirectly measured with 2 different angles: the LSA and the DSA. The optimization of the postoperative ROM and the outcome scores after RSA are correlated with specific ranges of LSA and DSA. The quadratic component of our linear model showed that an LSA between 75° and 95° is correlated with an increased active external rotation and that a DSA between 40° and 65° is correlated with increased active forward elevation.

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Supplementary data

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