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Accuracy of reverse shoulder arthroplasty angle according to the size of the baseplate

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Background: Glenoid inclination must be assessed precisely during preoperative planning for reverse shoulder arthroplasty (RSA) to position the glenoid baseplate correctly. We hypothesized that a more dynamic measurement method would better match the diversity of glenoid heights in the population and the variety of commercialized glenoid baseplates. Our purpose was to describe a new method to measure the RSA angle accounting for the baseplate size.
Methods: Computed tomography scans of 50 shoulders that underwent RSA for primary osteoarthritis or cuff tear arthropathy between June 2019 and February 2020 were included (mean age, 76 years). Three variants of the RSA angle were measured: the RSA angle as originally described by Boileau et al, the relative RSA 25 angle (which simulates the implantation of a 25-mm baseplate), and the relative RSA 29 angle (which simulates the implantation of a 29-mm baseplate). Measurements in the 2-dimensional true reformatted scapular plane were made by 3 independent operators.
Results: The mean R-S distance (ie, distance between point R [intersection of supraspinatus fossa line with glenoid surface] and point S [inferior border of glenoid]) was 24.2 $\pm$ 4.0 mm. The mean RSA angle was 20.3° $\pm$ 8.4°, whereas the mean relative RSA 25 angle was 19.3° $\pm$ 7.8° and the mean relative RSA 29 angle was 15.6° $\pm$ 7.6°. The mean difference between the RSA angle and the relative RSA 25 angle was 1.0° $\pm$ 4.1° ($P = .16$). The mean difference between the RSA angle and the relative RSA 29 angle was 4.7° $\pm$ 3.8° ($P < .0001$). In half of the shoulders in our series, the difference between the RSA angle and the RSA 29 angle exceeded 5°.
Conclusion: The RSA angle is a reproducible measure of the inclination of the inferior part of the glenoid that is reliable in most cases for glenoid baseplates of 24-25 mm in height. However, surgeons should be aware that the RSA angle may overestimate the superior orientation of the inferior glenoid for baseplates of different sizes or for small- or large-stature patients. In these cases, the relative RSA angle adapted to the size of the baseplate more accurately evaluates the inclination of the inferior glenoid.
Level of evidence: Anatomy Study; Imaging

Keywords: Reverse shoulder arthroplasty; RSA angle; shoulder morphometry; preoperative planning software; accuracy; baseplate

Superior tilt of the glenoid baseplate is a known risk factor for glenoid loosening, instability, and poor range of motion after reverse shoulder arthroplasty (RSA).[8,10,14,16] In 2008, the Favard classification was introduced to describe how glenoid wear patterns in the coronal plane

Institutional review board approval was not required for this anatomy study.

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can lead to superior tilt of the glenoid.[17] This vertical inclination of the glenoid needs to be precisely assessed and quantified during preoperative planning in order for the surgeon to be able to position the glenoid baseplate with a neutral or even inferior tilt postoperatively.[7,11-14,21] Similarly to what has been described for the management of retroversion in the axial plane, correction of a superior tilt can be achieved by reaming the high inferior side, by grafting the superior part of the glenoid, by using metallic augmentations, or by combining these techniques.[8] Several authors have described methods to measure the inclination of the glenoid surface either in 2 dimensions on plain radiographs[15,19] or on 3-dimensional computed tomography (CT) reconstructions.[1,3] These methods measure the inclination of the entire glenoid; however, it has been demonstrated that the ideal position of a glenoid baseplate is flush with the inferior glenoid rim[20] and the height of most glenoid implants on the market is much smaller than the height of the entire glenoid.[4] Therefore, in most cases, the back surface of the baseplate lies in contact with only the inferior part of the glenoid surface.

For this reason, in 2019, Boileau et al[4] described the RSA angle. This angle is defined as the angle between the inferior portion of the glenoid surface and a perpendicular line to the floor of the supraspinatus fossa. Boileau et al showed that this angle was significantly different from the β angle described by Maurer et al,[19] which measures the inclination of the entire glenoid surface. The RSA angle allows surgeons to better position glenoid implants in the coronal plane, contrary to the β angle, which underestimates the superior inclination of the inferior portion of the glenoid surface, especially in type E1 glenoids. However, the RSA angle appears to be insufficiently precise as it is only correct in cases in which the height of the implant matches the distance between the inferior rim of the glenoid and the intersection point between the glenoid surface and the floor of the supraspinatus fossa. Therefore, we hypothesized that a more dynamic measurement method could be used to match the diversity of existing implants on the market and the diversity of glenoid heights in the population. The objective of this study was to describe and assess a new method to measure the relative RSA angle corresponding to the size of the planned baseplate.

Materials and methods

Patient population

This study retrospectively evaluated CT scans of 50 shoulders that underwent RSA for primary osteoarthritis or cuff tear arthropathy between June 2019 and February 2020. The patients were randomly selected from a shoulder arthroplasty registry. All patients had previously authorized the use of their anonymous data for clinical research purposes. The average age of the patients was 76 years (standard deviation, 9.5 years; range, 51-91 years). There were 28 women and 22 men with 30 right and 20 left shoulders.

Measurements

As proposed by Boileau et al[3] and similarly to the β angle proposed by Maurer et al,[19] the supraspinatus fossa line was used as the reference line. Three variants of the RSA angle were measured (Fig. 1):

1. RSA angle: As described by Boileau et al, the RSA angle is calculated as the angle between the line from point R to point S and the line from point S to point A, where point S represents the inferior border of the glenoid, point R represents the intersection of the supraspinatus fossa line with the glenoid surface, and point A represents the vertex of the right triangle created by the supraspinatus fossa line and a perpendicular line passing through point S.
2. Relative RSA 25 angle: Measurement of the relative RSA 25 angle simulates the implantation of a 25-mm baseplate and is calculated as the angle between the line from point R25 to point S and the line from point S to point A25, where point S is unchanged (ie, inferior border of the glenoid), point R25 is the point of the glenoid surface 25 mm from point S, and point A25 represents the vertex of the right triangle created by the line parallel to the supraspinatus fossa line passing through point R25 and a perpendicular line passing through point S.
3. Relative RSA 29 angle: Measurement of the relative RSA 29 angle simulates the implantation of a 29-mm baseplate and is calculated as the angle between the line from point R29 to point S and the line from point S to point A, where point S is unchanged (ie, inferior border of the glenoid), point R29 is the point of the glenoid surface 29 mm from point S, and point A29 represents the vertex of the right triangle created by the line parallel to the supraspinatus fossa line passing through point R29 and a perpendicular line passing through point S.

The distance between point R and point S (R-S distance) was also measured, in millimeters. We chose 25- and 29-mm baseplates as they are representative of the sizes of most baseplates available on the market.

CT analysis

All the CT scans included the entire scapula with the patient positioned supine on the CT table. All images were obtained using the following acquisition parameters: slice thickness < 1.0 mm, number of slices > 200, field of view consisting of whole scapula, X-Y resolution < 0.5 mm, matrix size of 512×512, 140 kV, and >300 mA. The axial CT scan images were stored in DICOM (Digital Imaging and Communications in Medicine) format and transferred to a validated medical device software program (Mimics Medical, version 22; Materialise, Leuven, Belgium). After bone segmentation, on the 3-dimensional CT–reconstructed scapula model of each specimen, the 2-dimensional (2D) true reformatted scapular plane was created based on 3 points[16,22]: the

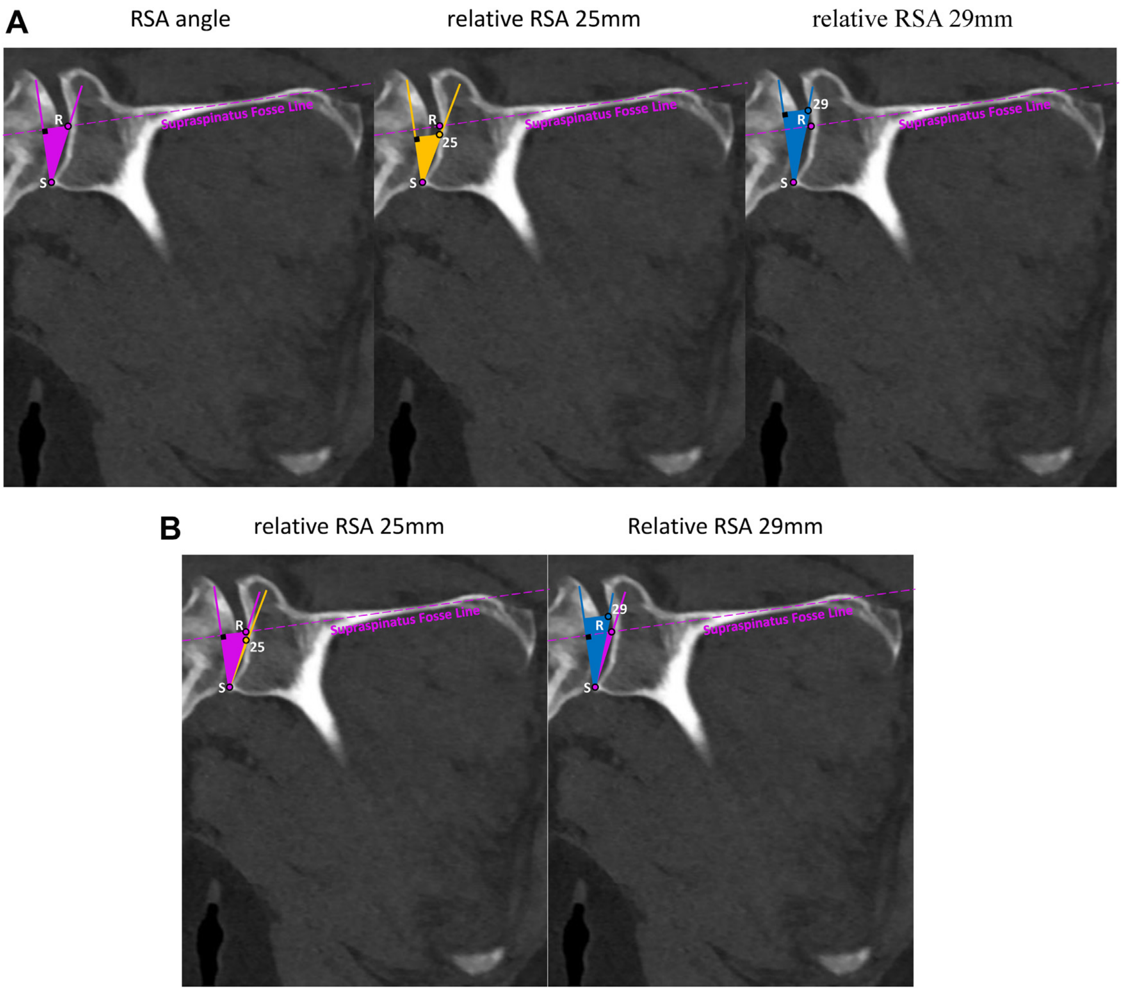

Figure 1 (**A**) Two-dimensional computed tomography scan cut showing various measurements of 3 variants of reverse shoulder arthroplasty *(RSA)* angle: RSA angle, relative RSA 25 angle (simulating implantation of 25-mm baseplate), and relative RSA 29 angle (simulating implantation of 29-mm baseplate). (**B**) Two-dimensional computed tomography scan cut showing differences between RSA and dynamic RSA angles (relative RSA 25 angle and relative RSA 29 angle). Point *S* represents the inferior border of the glenoid, and point *R* represents the intersection of the supraspinatus fossa line with the glenoid surface.

most medial point on the spinal border of the scapula, the inferior angle of the scapular body, and the center of the glenoid fossa. For each patient, the 3 variants of the RSA angle were then measured in the 2D true reformatted scapular plane by 3 independent operators (2 shoulders surgeons and 1 PhD biomechanical engineer, all of whom were familiar with the measurement software) using GeoGebra, version 5 (Linz, Austria) (https://www.geogebra.org/).

Statistical analysis

The reproducibility of measurements among the 3 observers was analyzed by calculating the intraclass correlation coefficient and its 95% confidence interval (CI).[21] For the assessment of intraobserver reliability, each of the observers also performed the measurements twice with a 1-week interval in 10 patients. Descriptive statistics were used for the remainder of the analyses. Comparisons between different measurements were analyzed for significance using the paired Student *t* test or the Wilcoxon test. In addition, a graphic analysis using Bland-Altman plots was performed to compare the method of measurement of the RSA angle. The level of statistical significance was set at $P < .05$. All statistical analysis was performed with MedCalc Statistical Software (version 18.11.6 [2019]; MedCalc Software, Ostend, Belgium; https://www.medcalc.org).

Results

R-S distance and RSA angles

Measurements of the R-S distance and the 3 different RSA angles are presented in Table I. The mean R-S distance was 24.2 ± 4.0 mm. The mean RSA angle was 20.3° ± 8.4°, whereas the mean relative RSA 25 angle was 19.3° ± 7.8° and the mean relative RSA 29 angle was 15.6° ± 7.6°.

The mean difference between the RSA angle and the relative RSA 25 angle, presented in Table II, was not found

Table I Measurements with different methods in shoulders with osteoarthritis or cuff tear arthropathy (N = 50)

	Mean	SD	SE	95% CI	Minimum	Maximum
R-S distance, mm	24.2	4.0	0.57	23.05-25.35	15.0	32.1
RSA, °	20.3	8.4	1.19	17.95-22.72	2.4	42.1
Relative RSA 25 angle, °	19.3	7.8	1.10	17.11-21.55	1.2	43.3
Relative RSA 29 angle, °	15.6	7.6	1.08	13.44-17.78	−1.6	36.7

SD, standard deviation; *SE*, standard error; *CI*, confidence interval; *R-S*, point R (intersection of supraspinatus fossa line with glenoid surface)–point S (inferior border of glenoid); *RSA*, reverse shoulder arthroplasty.
The relative RSA 25 angle simulates the implantation of a 25-mm baseplate, and the relative RSA 29 angle simulates the implantation of a 29-mm baseplate.

Table II Analysis of concordance to RSA with Bland-Altman method

	Mean difference, °	95% CI, °	SD, °	Reliability coefficient (1.96 SD), °
Relative RSA 25 angle	1.0	−0.1 to 2.2	4.1	8.0
Relative RSA 29 angle	4.7	3.7 to 5.8	3.8	7.4

RSA, reverse shoulder arthroplasty; *CI*, confidence interval; *SD*, standard deviation.
The relative RSA 25 angle simulates the implantation of a 25-mm baseplate, and the relative RSA 29 angle simulates the implantation of a 29-mm baseplate.

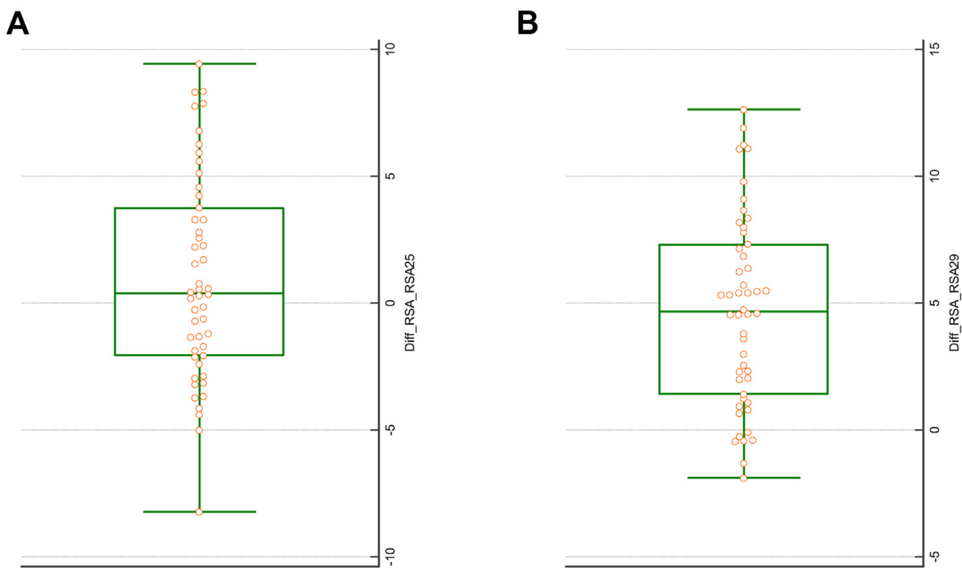

Figure 2 Box plots of differences between reverse shoulder arthroplasty angle and relative reverse shoulder arthroplasty angles for 25-mm-diameter baseplate *(Diff_RSA_RSA25)* (**A**) and 29-mm-diameter baseplate *(Diff_RSA_RSA29)* (**B**).

to be significant (1.0° ± 4.1°; 95% CI, −0.1° to 2.2°; $P = .16$, Wilcoxon test). In 10 shoulders (20%), a difference between these 2 angles ≥ 5° was observed, whereas in 22 shoulders (44%), the difference was negative, meaning that the relative RSA 25 angle had a higher value than the RSA angle (Fig. 2, *A*). Among these 22 shoulders, 2 shoulders had differences of −5° and −8.2°. The difference between these 2 angles never exceeded 10°.

Conversely, the mean difference between the RSA angle and the relative RSA 29 angle, also presented in Table II, was found to be significant (4.7° ± 3.8°; 95% CI, 3.7° to 5.8°; $P < .0001$, paired *t* test). The difference was negative

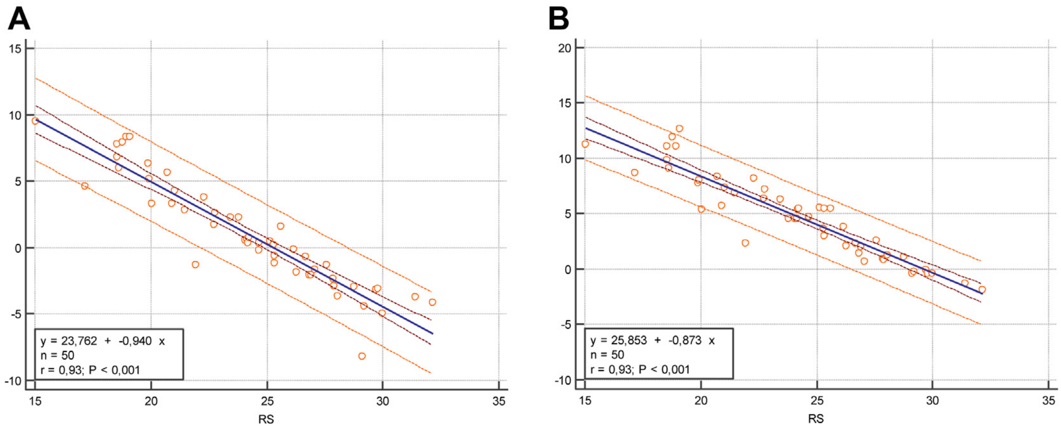

Figure 3 (**A**) Regression between R-S distance *(RS)* (ie, distance from point R [intersection of supraspinatus fossa line with glenoid surface] to point S [inferior border of glenoid]) and difference between reverse shoulder arthroplasty *(RSA)* angle and relative RSA angle for 25-mm-diameter baseplate. (**B**) Regression between R-S distance and difference between RSA angle and relative RSA angle for 29-mm-diameter baseplate.

Table III Interobserver measurements analysis with intraobserver reliability (n = 10) and interobserver reliability (N = 50)

	R-S distance, mm	RSA, °	Relative RSA 25 angle, °	Relative RSA 29 angle, °
Observer 1				
Mean ± SD	24.4 ± 4.2	20.4 ± 8.9	19.5 ± 8.3	15.6 ± 7.8
Range	15.0 to 33.4	2.3 to 43.0	1.2 to 43.9	−0.8 to 37.2
Intraobserver ICC (95% CI)	0.87 (0.48 to 0.97)	0.89 (0.57 to 0.97)	0.96 (0.84 to 0.99)	0.97 (0.87 to 0.99)
Observer 2				
Mean ± SD	24.2 ± 4.2	20.0 ± 8.5	18.8 ± 7.9	15.2 ± 7.8
Range	14.5 to 33.3	2.3 to 44.5	0.7 to 44.5	−2.0 to 37.4
Intraobserver ICC (95% CI)	0.98 (0.94 to 1.00)	0.92 (0.69 to 0.98)	0.97 (0.86 to 0.99)	0.99 (0.95 to 1.00)
Observer 3				
Mean ± SD	24.0 ± 4.1	20.6 ± 8.5	19.7 ± 8.0	16.0 ± 8.2
Range	15.6 to 31.7	2.5 to 41.1	1.6 to 41.5	−2.0 to 36.9
Intraobserver ICC (95% CI)	0.99 (0.95 to 1.00)	0.97 (0.87 to 0.99)	0.98 (0.90 to 0.99)	0.99 (0.95 to 1.00)
Interobserver ICC (95% CI)	0.97 (0.95 to 0.98)	0.97 (0.95 to 0.98)	0.96 (0.94 to 0.98)	0.96 (0.94 to 0.98)

R-S, point R (intersection of supraspinatus fossa line with glenoid surface)–point S (inferior border of glenoid); *RSA*, reverse shoulder arthroplasty; *SD*, standard deviation; *ICC*, intraclass correlation coefficient; *CI*, confidence interval.
The relative RSA 25 angle simulates the implantation of a 25-mm baseplate, and the relative RSA 29 angle simulates the implantation of a 29-mm baseplate. ICC values < 0.5 are indicative of poor reliability; between 0.5 and 0.75, moderate reliability; between 0.75 and 0.9, good reliability; and > 0.90, excellent reliability.

in only 6 shoulders (12%). A difference ≥ 5° was observed in 24 shoulders (48%), and a difference ≥ 10° was observed in 5 shoulders (Fig. 2, *B*).

In both of the aforementioned assessments, the difference between the RSA angle and the relative RSA angle was a direct regression of the R-S distance ($r = 0.93$, $P < .001$), as illustrated in Figure 3.

Intraobserver and interobserver reliability

The interobserver reliability of the various measurements is presented in Table III and was excellent. The intraobserver reliability of the various measurements for each observer is also presented in Table III. The intraobserver reliability is based on the 95% CI and not the average of the intraclass correlation coefficients. Although the intraobserver reliability was good to excellent for the PhD biomechanical engineer, it was poor to excellent for the shoulder surgeons (one of the limits of the CI was < 0.5).

Concordance of measurements

Analysis of concordance with the Bland-Altman method demonstrated limited reliability, with reliability coefficients of 8° for the relative RSA 25 angle and 7.4° for the relative RSA 29 angle (Table II; Fig. 4).

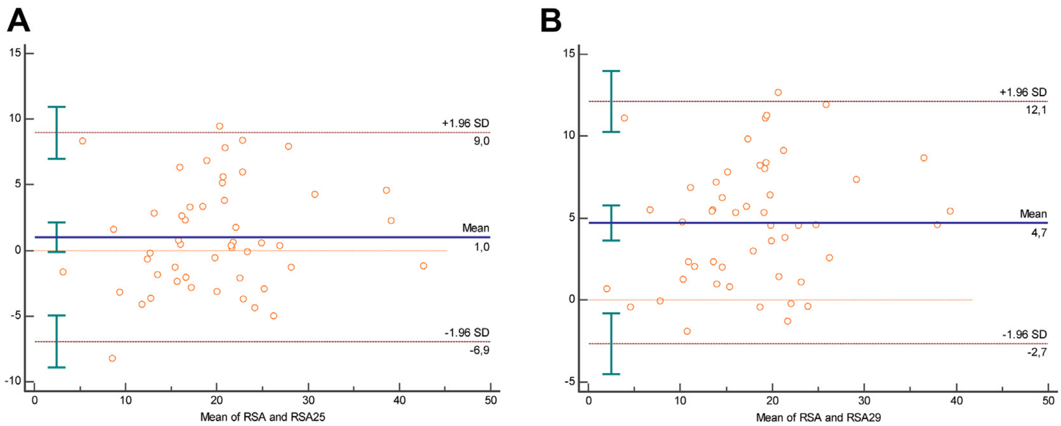

Figure 4 (**A**) Analysis via Bland-Altman method of concordance between reverse shoulder arthroplasty *(RSA)* angle and relative RSA angle for 25-mm-diameter baseplate *(RSA25)*. (**B**) Analysis via Bland-Altman method of concordance between RSA angle and relative RSA angle for 29-mm-diameter baseplate *(RSA29)*. *SD*, standard deviation.

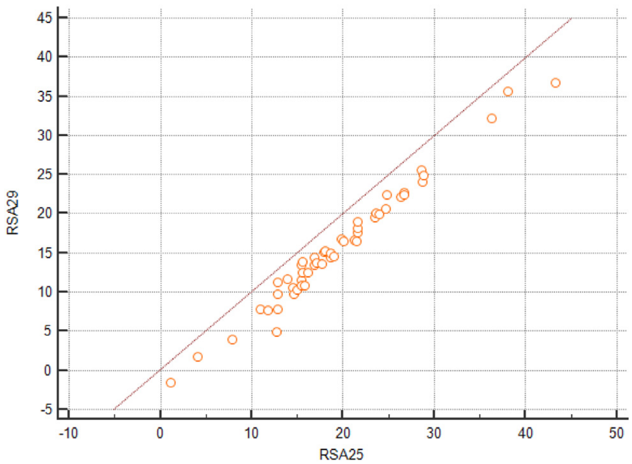

Figure 5 Correlation between relative reverse shoulder arthroplasty angles for 25-mm-diameter baseplate *(RSA25)* and 29-mm-diameter baseplate *(RSA29)*.

Discussion

Superior inclination of the glenoid baseplate was recognized very early as one major avoidable risk factor for scapular notching, glenoid loosening, instability, mechanical impingement, and ultimately, loss of motion.[8,10,14,16,20] Thus, glenoid inclination must be assessed precisely during preoperative planning in order for the surgeon to implant the glenoid baseplate correctly. Six measurement methods have been proposed to assess glenoid inclination preoperatively. These rely on different 2D or 3-dimensional anatomic or radiologic landmarks as reference lines. These include a line joining the most superior point of the glenoid and the most superior point of the scapular blade[18]; a line joining the midpoint of the glenoid and the trigonum scapulae[6]; a line joining the spinoglenoid notch and spine of scapula[15]; a line between the point located at the level of the most lateral and inferior glenoid bone along the inferior glenoid rim and a point located 1 cm medial to the most inferior glenoid point along the inferior glenoid rim or scapular neck[22]; the horizontal line to the floor regardless of any anatomic landmarks[17]; and a line along the floor of the supraspinatus fossa.[19] All these angles measure the vertical orientation of the entire glenoid surface and are important in the setting of anatomic total shoulder arthroplasty in which the glenoid implant back surface is in contact with most of the glenoid surface. However, this is no longer the case in the setting of RSA, where the objective is to implant the glenoid baseplate flush with the inferior rim of the glenoid. Therefore, glenoid baseplates are only in contact with the inferior part of the glenoid surface, which may have a different inclination than the entire surface, especially in case of concentric erosion (type E1 glenoids).[4] For this reason, Boileau et al[4] described a novel method to measure the inclination of the inferior part of the glenoid and called it the RSA angle. This angle has 2 major advantages: First, it only takes into account the portion of the glenoid that will be in contact with the glenoid baseplate. Second, it helps surgeons determine the amount of correction needed to position the baseplate perpendicular to the supraspinatus fossa line, which is the theoretical optimal position for the action of the remaining cuff.[9] In our study, we reproduced the measurement technique described by Boileau et al. Our study confirms its reliability as we found good interobserver and intraobserver reproducibility and a mean value in agreement with their findings (20.3° vs. 20°).[4]

However, the RSA angle seems to be insufficiently accurate because it depends on the position of point R (the point of intersection between the glenoid surface and the floor of the supraspinatus fossa), which varies with

Table IV Size of glenoid implants available on market

Manufacturer	Implant	Shape	Baseplate height, mm	
			Minimum	Maximum
FH Industrie (Quimper, France)	Arrow	Oval	32	41
FH Industrie	Arrow (without tab)	Oval	32	41
FH Industrie	Arrow II	Oval	32	40
FH Industrie	Arrow II (without tab)	Oval	32	40
Exactech (Gainesville, FL, USA)	Equinoxe	Oval	33.8	33.8
Zimmer (Warsaw, IN, USA)	Inverse Reverse	Oval	33.5	33.5
Zimmer	Trabecular	Circular	25	30
Tornier (Edina, MN, USA)	Perform	Circular	25	29
Tornier	Aequalis II	Circular	25	29
DePuy (Raynham, MA, USA)	Delta Xtend	Circular	29	29
DePuy	Delta III	Circular	29	29
Arthrex (Naples, FL, USA)	Univers	Pear	32	38
FX Solutions (Bedminster, NJ, USA)	Humelock Reverse	Circular	24	24
FX Solutions	Easytech	Circular	24	24
Biomet (Warsaw, IN, USA)	Comprehensive	Circular	25	28
Biomet	TESS	Oval	31	39
Lima (San Daniele del Friuli, Italy)	SMR	Oval	28	32
Lima	SMR Axioma	Oval	28	32
DJO (Vista, CA, USA)	Altivate	Circular	28	28
Aston (Saint–Etienne, France)	Duocentric	Oval	36	40
Stryker (Kalamazoo, MI, USA)	ReUnion RSA	Circular	28	28
Medacta (Castel San Pietro, Switzerland)	Shoulder System	Circular	22	27

patient size and anatomy. Therefore, the RSA angle is perfectly correct only in cases in which the R-S distance is equal to the height of the baseplate. In this study, we did not find any significant difference between the RSA angle and the relative RSA 25 angle. This is due to the fact that in our population, the average R-S distance was very close to 25 mm (24.2 mm). This was no longer the case when comparing the RSA angle and the relative RSA 29 angle, which means that using the RSA angle when implanting a 29-mm baseplate overestimates the required correction. Although the mean difference between these 2 angles was found to be minimal (4.7°), this difference exceeded 5° in half of the shoulders and exceeded 10° in 10% of the shoulders. Consequently, in half of the shoulders in our series, the application of the RSA angle for a 29-mm-diameter baseplate would result in an overcorrection of the superior glenoid inclination. In addition to accentuating the inferior tilt, this overcorrection is obtained by excessive inferior glenoid reaming and thus compromises the patient's subchondral bone stock more than necessary. This may also lead to excessive medialization of the glenoid implant, which may in turn lead to prosthetic instability, loss of range of motion, and scapular notching.[2] This study confirms our hypothesis that depending on the size of the glenoid implant, a more dynamic version of the RSA angle appears to be more accurate.

In our study, we only analyzed 2 implant sizes and the effect of increasing the size of the baseplate from 25 mm to 29 mm already led to a significant effect on the RSA angle (Fig. 5). However, the range of sizes of baseplates available on the market (from 22 mm to 41 mm) varies by much more than just 4 mm, as shown in Table IV.

By introducing the RSA angle, Boileau et al[5] made it clear that surgeons should focus on the orientation of the inferior part of the glenoid rather than the entire glenoid when implanting an RSA. Our study shows that the RSA angle is well adapted in most patients when a 25-mm baseplate is used. However, surgeons must be aware that this angle depends on (1) the R-S distance, which can vary greatly in the population, and (2) the size of the glenoid baseplate intended to be used. It is easy to imagine that the greater the R-S distance, the more the entire glenoid surface will be taken into account and the more the RSA angle will approach the total shoulder arthroplasty angle and will decrease with most glenoid shapes. This means that in case of a mismatch between the R-S distance and the size of the glenoid baseplate, the standard RSA angle should not be used but instead should be modified using the superoinferior length of the glenoid baseplate as the new R-S distance.

Our study has several limitations. First, we did not classify the glenoids in our study according to the Favard classification as this did not impact the measurement of the standard RSA angle on the CT scans.[3,15] Second, we chose to include both patients with osteoarthritis and those with cuff tear arthropathy as they were all candidates for RSA. Nevertheless, the results of this study show that the RSA angle is reproducible but should be adapted depending on the size of the patient's glenoid and on the size of the chosen glenoid baseplate.

Conclusion

This study demonstrates that the RSA angle is a reproducible measure of the inclination of the inferior part of the glenoid. This angle is reliable in most cases for glenoid baseplates of 24-25 mm in height. However, for baseplates of different sizes or for small- or large-stature patients who may not have an R-S distance around 25 mm, the RSA angle may overestimate the superior orientation of the inferior part of the glenoid, resulting in an overestimation of the amount of correction needed. In these cases, surgeons should be aware that the relative RSA angle adapted to the size of the baseplate more accurately evaluates the inclination of the inferior part of the glenoid.

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