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The reverse shoulder arthroplasty angle: a new measurement of glenoid inclination for reverse shoulder arthroplasty

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Background: Avoiding superior inclination of the glenoid component in reverse shoulder arthroplasty (RSA) is crucial. We hypothesized that superior inclination was underestimated in RSA. Our purpose was to describe and assess a new measurement of inclination for the inferior portion of the glenoid (where the baseplate rests).

Methods: The study included 47 shoulders with rotator cuff tear arthropathy (mean age, 76 years). The reverse shoulder arthroplasty angle (RSA angle), defined as the angle between the inferior part of the glenoid fossa and the perpendicular to the floor of the supraspinatus, was compared with the global glenoid inclination (β angle or total shoulder arthroplasty [TSA] angle). Measurements were made on plain anteroposterior radiographs and reformatted 2-dimensional (2D) computed tomography (CT) scans by 3 independent observers and compared with 3-dimensional (3D) software (Glenosys) measurements.

Results: The mean RSA angle was 25° ± 8° on plain radiographs, 20° ± 6° on reformatted 2D CT scans, and 21° ± 5° via 3D reconstruction software. The mean TSA angle was on average 10° ± 5° lower than the mean RSA angle ($P < .001$); this difference was observed regardless of the method of measurement (radiographs, 2D CT, or 3D CT) and type of glenoid erosion according to Favard. In Favard type E1 glenoids with central concentric erosion, the difference between the 2 angles was 12° ± 4° ($P < .001$).

Conclusion: The same angle cannot be used to measure glenoid inclination in anatomic and reverse prostheses. The TSA (or β) angle underestimates the superior orientation of the reverse baseplate in RSA. The RSA angle (20° ± 5°) needs to be corrected to achieve neutral inclination of the baseplate (RSA angle = 0°). Surgeons should be aware that E1 glenoids (with central erosion) are at risk for baseplate superior tilt if the RSA angle is not corrected.

The Ethical Committee of the University Institute of Locomotion & Sports (iULS), Pasteur 2 Hospital, Nice, France, approved this study (No. 2017-04).

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Level of evidence: Anatomy Study; Imaging

Keywords: Glenoid inclination; superior tilt; reverse shoulder arthroplasty; β angle; RSA angle; BIO-RSA; augmented baseplate

Implantation of a reverse shoulder arthroplasty (RSA) with superior tilt of the baseplate is associated with an increased rate of complications.[13,16,19,25,29,36] Superior inclination of the baseplate increases the stresses at the implant-bone interface while leading to impingement between the inferior humeral polyethylene insert and scapula pillar,[13] causing medial polyethylene wear, scapular notching, and eventual glenoid implant loosening.[16,19,25,29,36] In addition, superior inclination of the baseplate has been shown to be associated with decreased shoulder range of motion.[23,24] Although there is much debate about the best way to correct this superior glenoid inclination, it is critical to implant the baseplate in at least neutral inclination.[11,12,25] The optimal position of the reverse baseplate is inferior on the glenoid and without superior tilt, in an attempt to optimize impingement-free range of motion while avoiding scapular notching and glenoid loosening.[5,6,13,26,31,32,35]

Glenoid inclination, as described by Hughes et al[20] and Maurer et al,[27] is commonly thought to be the angle between the floor of the supraspinatus fossa and the glenoid fossa line: the β angle. From a surgical standpoint, the β angle is useful when planning the implantation of a total shoulder arthroplasty (TSA), as it represents the global glenoid inclination.[7,20,27] However, although a TSA glenoid component occupies the entire glenoid, most reverse baseplates are implanted on the lower part of the glenoid surface to provide optimal deltoid tension and avoid inferior scapular impingement.[32] Furthermore, although the β angle is appropriate to measure glenoid component inclination in TSA, it is not relevant to the RSA baseplate. In other words, given that each prosthesis (TSA and RSA) has a different position on the glenoid, the assessment of glenoid inclination for each prosthesis should be considered separately (Fig. 1).

Therefore, the purpose of this study was to describe and validate a new method for measuring the inclination relevant to the reverse prosthesis in the inferior half of the glenoid for use in both plain radiography and computed tomography (CT) to avoid superior tilt in RSA. The RSA angle was defined as the angle between a line along the inferior part of the glenoid fossa and a line perpendicular to the floor of the supraspinatus fossa, whereas the TSA angle (or β angle) was defined as the angle between the global glenoid fossa and the perpendicular to the floor of the supraspinatus fossa (Fig. 2). We hypothesized that (1) the RSA angle would reliably and accurately measure the inclination relevant to the reverse prosthesis on plain radiographs and CT scans and (2) preoperative measurement of glenoid inclination over the entire glenoid surface (TSA angle or β angle) would underestimate the potential superior inclination of the RSA baseplate and, therefore, the amount of correction required for implantation in neutral inclination.

Materials and methods

Patient population

The study included 47 shoulders (47 patients) with a diagnosis of rotator cuff tear arthropathy (CTA). Informed consent was obtained from all patients. The exclusion criteria included CT scans that did not contain the entire scapula before surgery and lack of preoperative radiographs. The mean age was 76 years (range, 50-93 years), with 28 male and 19 female patients. The study included 31 right and 16 left shoulders. The Favard classification,[26] as agreed on by 4 shoulder surgeons, included 12 type E0, 12 type E1, 6 type E2, and 17 type E3 glenoids. No patients had type E4 glenoids.

Radiographic parameters

Similarly to the β angle proposed by Maurer et al,[27] the supraspinatus fossa line was used as the reference.[20] The landmark used for the measurements was based on the sclerotic line of the supraspinatus fossa, visible on plain radiographs and CT scans.[27] Positive values of angles represent superior glenoid inclination, whereas negative values represent inferior glenoid inclination.

The TSA angle is relevant to TSA and uses the entire glenoid fossa line,[2] from the superior aspect of the fossa (T) to the inferior aspect of the fossa (S). This measurement is a modification of the β angle[20] designed to obtain a more accurate description of superior inclination. The TSA angle is calculated by the angle between the line from T to S and the line from S to A (Fig. 2, *A*).

The RSA angle was developed to measure the inclination of the inferior portion of the glenoid, which corresponds to the area in which the glenoid component of an RSA is implanted. On a true anteroposterior (AP) radiograph of the shoulder and on a 2-dimensional (2D) CT scan, the line on the supraspinatus fossa and 3 points were drawn: 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 line of the supraspinatus fossa and a perpendicular line passing through point S; line RS (inferior surface of the glenoid) is the hypotenuse of the right triangle (Figs. 2, *B*, 2 *C*).

Plain radiographs with multiple views were obtained in all the included patients, and the measurements were performed on the true AP image with the beam perpendicular to the

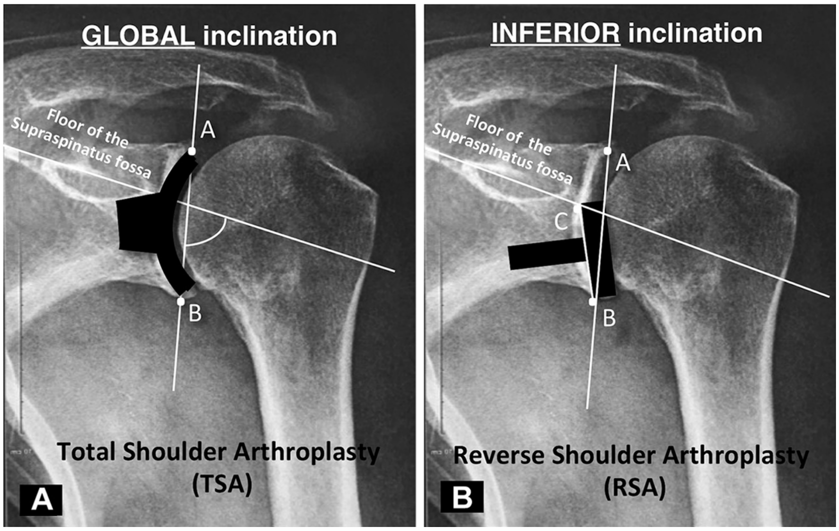

Figure 1 (**A**) Traditional measurement of glenoid inclination (β angle) considers the entire glenoid fossa and is relevant when planning a total shoulder arthroplasty (*TSA*). (**B**) However, because most reverse baseplates are in contact with only the inferior aspect of the glenoid, measurement of the inclination in the inferior half of the glenoid is needed when planning a reverse shoulder arthroplasty (*RSA*).

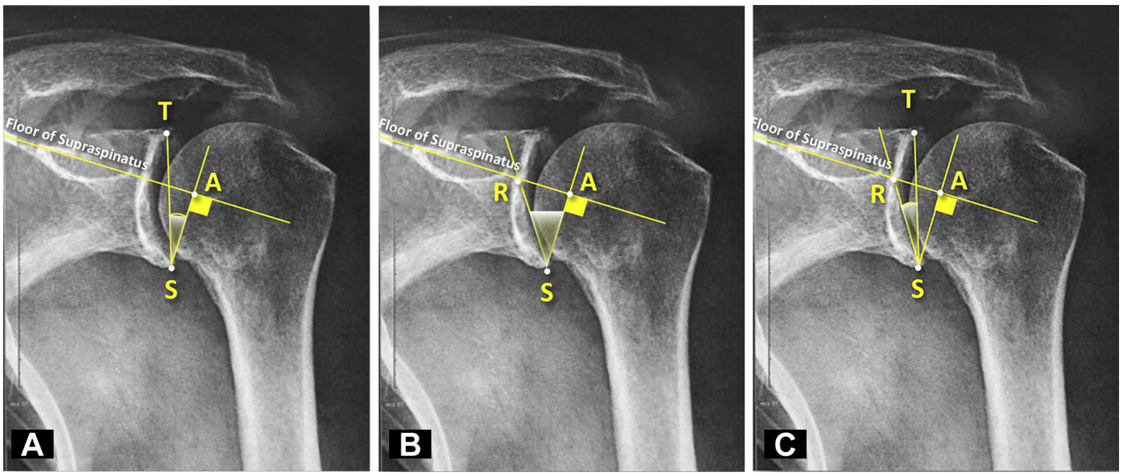

Figure 2 Measurements of total shoulder arthroplasty (TSA) angle (**A**) and reverse shoulder arthroplasty (RSA) angle (**B**) on plain anteroposterior radiographs. The RSA angle was defined as the angle between the inferior part of the glenoid fossa and the perpendicular to the floor of the supraspinatus fossa. The TSA angle is a variation of the β angle. The difference between the TSA and RSA angles is represented by the RST angle (**C**).

glenoid fossa. Two-dimensional CT scans were obtained that included the entire body of the scapula, with coronal views aligned in the plane of the scapula. All native CT scan DICOM (Digital Imaging and Communications in Medicine) series were loaded into 3-dimensional (3D) validated analysis software (Glenosys; Imascap, Plouzané, France). The software provided a fully automatic complete 3D reconstruction of the scapula with automatic measurements of the TSA and RSA angles.[2,17,38]

Radiographic and CT analysis

The measurement of the RSA and TSA angles on the plain radiographs was performed with a specialized goniometry software program (OsiriX, version 5.6, 32-bit format; Pixmeo, Bernex, Switzerland). On the 2D CT scans, the angles were measured using this same software in the multiplanar reconstructions in the plane of the scapula on coronal images. Finally, a 3D CT reconstruction software program (Glenosys) was used to automatically detect the plane of the scapular body; it then uses an algorithm to calculate the glenoid inclination according to set parameters.[2,17,38] To determine this angle, the best-fit sphere model is adjusted to the glenoid surface; then, the angle between the glenoid sphere centerline and the scapular plane is determined and projected onto the scapular body plane.[28] The supraspinatus fossa line, defined in 3D as the best-fit line in the deepest part of this fossa, was used as a reference line.[37]

Three independent observers measured these angles on plain AP radiographs and CT scans. Inter-rater reliability was assessed by performing the measurements within an interval of 4 weeks. The differences between RSA and TSA angles were then calculated for each glenoid type. These measurements were compared with 3D measurements obtained from previously validated software (Glenosys).

Statistical analysis

The reproducibility of the RSA and TSA angles, measured on radiographs and on 2D CT scans, was analyzed by calculating the intraclass correlation coefficient (ICC) and 95% confidence interval (CI) of the mean difference among 3 observers (M.-O.G., G.C., and M.C.). The ICC and 95% CI were calculated between the 2 analyses performed at 2-week intervals by a single observer (M.-O.G.) to assess the intraobserver reliability. Descriptive statistics were used for the remainder of the analyses. Comparisons between different measurements had a normal distribution and therefore were analyzed for significance using the unpaired Student *t* test. The accuracy of the RSA and TSA angles on radiographs and on 2D CT scans was assessed by comparing these measurements with the automatic 3D measurements, which were considered the gold standard. Statistical significance was set at $P < .05$. All statistical analysis was performed with MedCalc Statistical Software (version 12.0; MedCalc Software, Ostend, Belgium).

Results

Glenoid inclination: TSA angle versus RSA angle

Measurements of glenoid inclination for the TSA angle and RSA angle are presented in Table I. By use of the 2D and 3D measurements, the mean RSA angle was 20° ± 5° (Fig. 3). Regardless of whether the measurements were obtained on plain radiographs, on 2D CT scans, or via 3D CT software reconstruction, the RSA angle was approximately 10° more than the TSA angle ($P < .001$). For both the RSA and TSA angles, plain radiographs estimated approximately 5° higher inclinations than CT scans.

Glenoid inclination: Favard classification

The shoulders were grouped according to the Favard classification.[26] The Favard classification describes the most common patterns of glenoid erosion attributed to CTA, with varying degrees of erosion from absent (E0) to central concentric (E1), eccentric superior (E2 and E3), and inferior (E4) erosion. As demonstrated in Tables I and II, TSA angles were on average 10° ± 5° lower than RSA angles ($P < .001$), regardless of the type of glenoid erosion according to the Favard classification. In particular, in Favard type E1 glenoids with central concentric erosion, the difference was 12° ± 4° ($P < .001$). Figure 4 shows 3D measurements of RSA and TSA angles according to glenoid type, whereas Figure 5 demonstrates how a Favard type E1 glenoid (with concentric erosion) is at risk of superior baseplate tilt. The Favard types were similar when

Table I Glenoid inclination measurements for each method (N = 47)

	Radiographs	2D CT	3D CT
TSA angle, °	16 ± 6	11 ± 5	12 ± 6
RSA angle, °	25 ± 8	20 ± 6	20 ± 5
RSA angle − TSA angle, °	9 ± 7	10 ± 3	8 ± 4

2D, 2-dimensional; *3D*, 3-dimensional; *CT*, computed tomography; *TSA*, total shoulder arthroplasty; *RSA*, reverse shoulder arthroplasty.

the differences in the angles were compared between plain radiographs and 2D CT scans.

Reproducibility

The interobserver reliability between the various measurements is presented in Table III. Concordance of measurements made by the different observers showed substantial agreement between the plain radiographs and the 2D CT scans for the measures of TSA and RSA angles. The 3D reconstruction software was fully automated. Concordance of measurements made for the intraobserver reliability showed almost perfect agreement, with ICCs of 0.78 (95% CI, 0.75-0.81) for radiographs and 0.86 (95% CI, 0.84-0.86) for 2D CT scans. We found no significant difference in intraobserver or interobserver reliability according to different Favard glenoid types.

Accuracy

The accuracy (compared with the 3D CT reconstructions) of plain radiographs in measuring TSA and RSA angles was 70% and 67%, respectively, whereas the accuracy of 2D CT scans in measuring TSA and RSA angles was 73% and 82%, respectively. We found no significant difference in accuracy according to different Favard glenoid types.

Discussion

Avoiding superior inclination of the glenoid component in RSA is crucial, given its association with the increased risk of component loosening, scapular notching, and decreased range of motion.[3,26,29,35,40] Whereas traditional measurements of glenoid inclination (β angle or TSA angle) consider the entire glenoid fossa,[7-9,27] most RSA baseplates are in contact with only the inferior aspect of the glenoid. In this study, we describe and address a new measurement of the inferior portion of the glenoid: the RSA angle (Fig. 2). Our study findings confirm our first hypothesis that this angle provides a reliable and reproducible measure of the inclination of the inferior portion of the native glenoid. By use of 2D and 3D reconstruction software (Glenosys), the average RSA angle was measured to

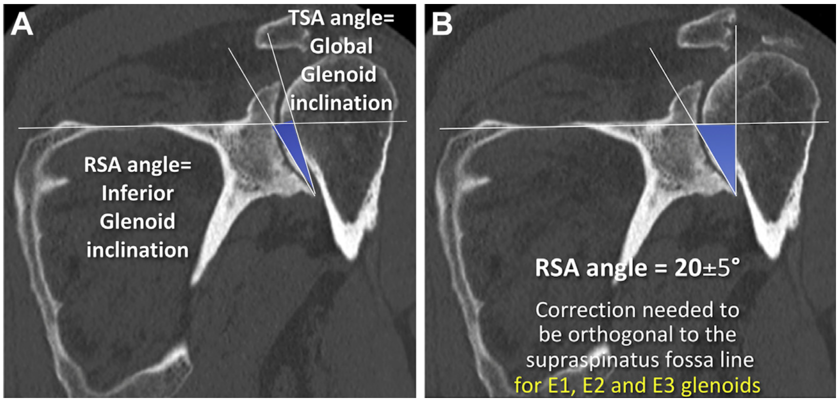

Figure 3 (**A**) Two-dimensional computed tomography scan cut showing the difference (about 10° on average) between the total shoulder arthroplasty (*TSA*) and reverse shoulder arthroplasty (*RSA*) angles. (**B**) The mean RSA angle, measured on 2- and 3-dimensional computed tomography scans, was 21° ± 5°, which represents the angle that needs to be corrected to place the baseplate orthogonal to the supraspinatus fossa line.

Table II Measurements of glenoid TSA and RSA angles by glenoid Favard type: radiographs, CT scans, and 3D CT analysis (N = 47)

Favard type	Radiographs		CT scans		3D CT analysis	
	TSA angle, °	RSA angle, °	TSA angle, °	RSA angle, °	TSA angle, °	RSA angle, °
E0 (n = 12)	11 ± 4 (4 to 18)	20 ± 6 (14 to 28)	8 ± 4 (3 to 15)	16 ± 4 (11 to 25)	8 ± 3 (3 to 14)	16 ± 3 (12 to 20)
E1 (n = 12)	17 ± 4 (11 to 24)	25 ± 11 (−2 to 38)	9 ± 4 (3 to 17)	19 ± 5 (12 to 28)	9 ± 3 (4 to 14)	21 ± 5 (15 to 30)
E2 (n = 6)	23 ± 6 (16 to 33)	27 ± 5 (5 to 20)	19 ± 6 (12 to 29)	28 ± 4 (24 to 36)	22 ± 5 (16 to 27)	26 ± 8 (14 to 39)
E3 (n = 17)	17 ± 6 (11 to 29)	29 ± 7 (21 to 41)	12 ± 5 (4 to 20)	23 ± 4 (12 to 31)	14 ± 3 (9 to 20)	22 ± 4 (14 to 30)

TSA, total shoulder arthroplasty; *RSA*, reverse shoulder arthroplasty; *CT*, computed tomography; *3D*, 3-dimensional.

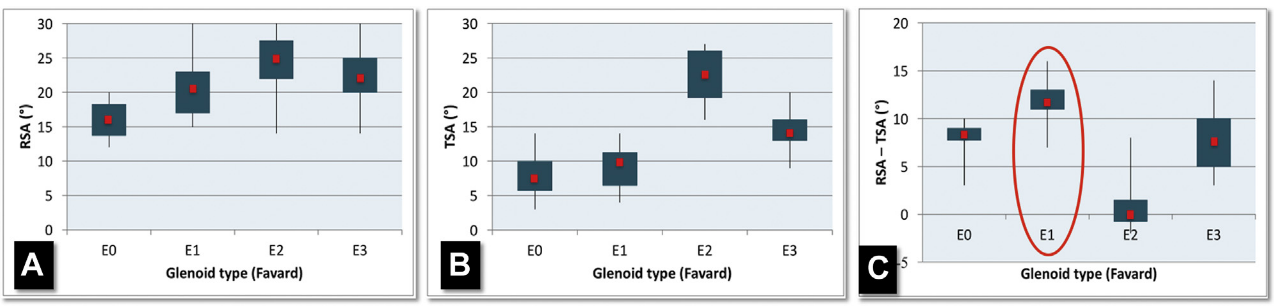

Figure 4 Three-dimensional measurements of RSA angles according to glenoid type (**A**). Three-dimensional measurements of TSA angles according to glenoid type (**B**). Three-dimensional measurements of the difference between RSA and TSA angles according to glenoid type (**C**). Notice the large difference between TSA and RSA angles in E1 glenoids.

be 21° ± 5° in a series of 47 patients with CTA. This implies that when planning preoperatively to perform an RSA procedure in a patient with CTA, between 15° and 25° of superior inclination will need to be corrected to achieve neutral inclination of the baseplate and sphere.

The TSA angle is a modification of the β angle, which provides a measure of the global inclination of the glenoid surface and is useful for planning in TSA. Comparing the RSA and TSA angles, we found that, regardless of the methodology used for measurements (radiographs or 2D or 3D CT scans), the RSA angle consistently measured on average 10° ± 5° more than the TSA angle. In other words, the inclination of the inferior half of the glenoid (where the reverse prosthesis is optimally implanted) in a patient with CTA is on average 10° superior to the inclination of the entire glenoid fossa. These results confirm our second hypothesis: Preoperative measurement of glenoid inclination over the entire glenoid surface (TSA angle or β angle) underestimates the superior orientation of the reverse baseplate and the amount of correction required in RSA.

The Favard classification describes the most common patterns of glenoid erosion attributed to CTA in the coronal or superior-inferior plane,[26] with no erosion (E0) or varying degrees of concentric central (E1), eccentric superior (E2 and E3), and inferior (E4) erosion. We did not find significant differences between different glenoid types

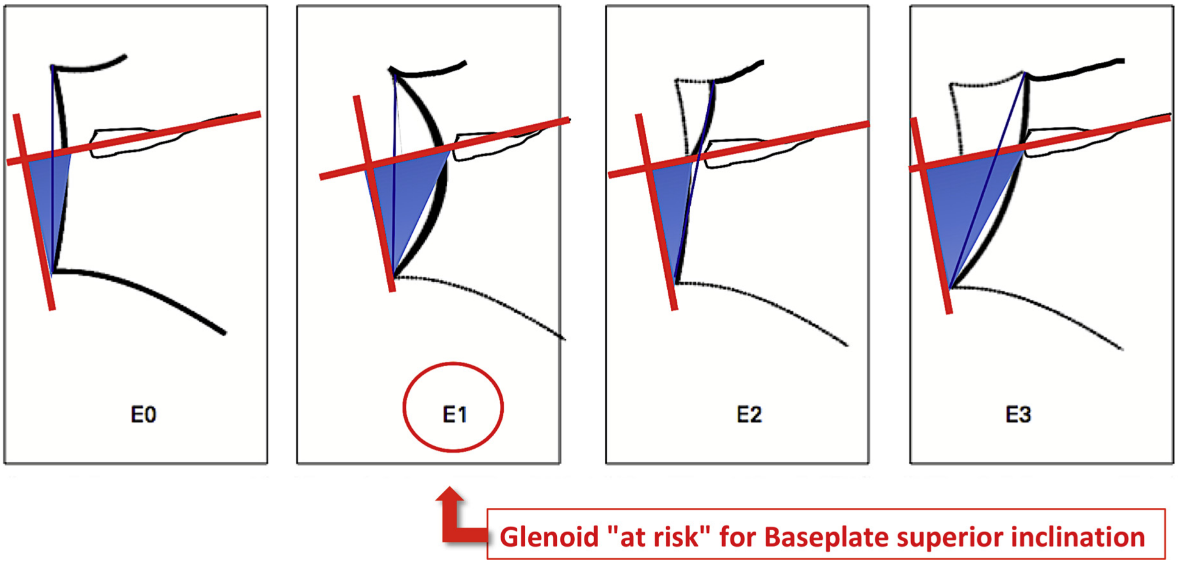

Figure 5 Correction of reverse shoulder arthroplasty angle according to Favard classification. The Favard type E1 glenoid (with concentric erosion) is at risk of superior baseplate tilt and is a trap for the surgeon.

Table III TSA and RSA interobserver analysis from radiographs and CT scan series (N = 47)

	Radiographs		CT scans	
	TSA angle, °	RSA angle, °	TSA angle, °	RSA angle, °
Observer 1				
Mean ± SD	16 ± 6	25 ± 8	11 ± 6	21 ± 6
Range	4 to 33	−2 to 41	3 to 29	11 to 36
Observer 2				
Mean ± SD	13 ± 5	24 ± 7	11 ± 4	23 ± 6
Range	3 to 23	10 to 38	2 to 23	14 to 35
Observer 3				
Mean ± SD	14 ± 5	22 ± 7	11 ± 5	20 ± 7
Range	−3 to 26	2 to 38	0 to 19	1 to 33
ICC (95% CI)	0.59 (0.54 to 0.63)	0.62 (0.58 to 0.65)	0.71 (0.68 to 0.74)	0.75 (0.72 to 0.77)

TSA, total shoulder arthroplasty; *RSA*, reverse shoulder arthroplasty; *CT*, computed tomography; *SD*, standard deviation; *ICC*, intraclass correlation coefficient; *CI*, confidence interval.

regarding the RSA angle's measurement on 3D CT scans (Fig. 4). One important note is that even in the absence of glenoid erosion (E0) or presence of central erosion of the glenoid (E1), correction of the RSA angle is required to be able to implant the baseplate in a neutral position. From a surgical standpoint, surgeons should pay particular attention to a central concentric glenoid erosion (Favard type E1), in which the "RSA angle" measures around 20° to 25° and the risk of baseplate implantation with a superior tilt is underestimated when using the TSA (or β) angle.

Although the optimal method to correct superior inclination of the glenoid in RSA is controversial, it is critical to correct it back to neutral and avoid superior tilt of the baseplate.[11,14,25] The supraspinatus fossa line is a consistent reference line to measure glenoid inclination because the sclerotic line of the supraspinatus fossa line is visible on true AP radiographs and 2D CT scans. Moreover, from a biomechanical point of view, the supraspinatus fossa line indicates the line of action of the rotator cuff muscles.[37] Therefore, the goal of preoperative planning in RSA should be to obtain an RSA angle measurement close to 0° (ie, to implant the baseplate in neutral inclination): In such a configuration, the vectors of the remaining cuff muscles are orthogonal and potentially more efficient.[15,21,22,37]

Many techniques have been described to correct the superior glenoid inclination when performing an RSA.[25,31] One of the more common techniques involves eccentric reaming inferiorly (to obtain the subchondral "smiley face"), with an inferiorly angled guide pin. However, correction of a large amount of superior inclination may require reaming of a large amount of native

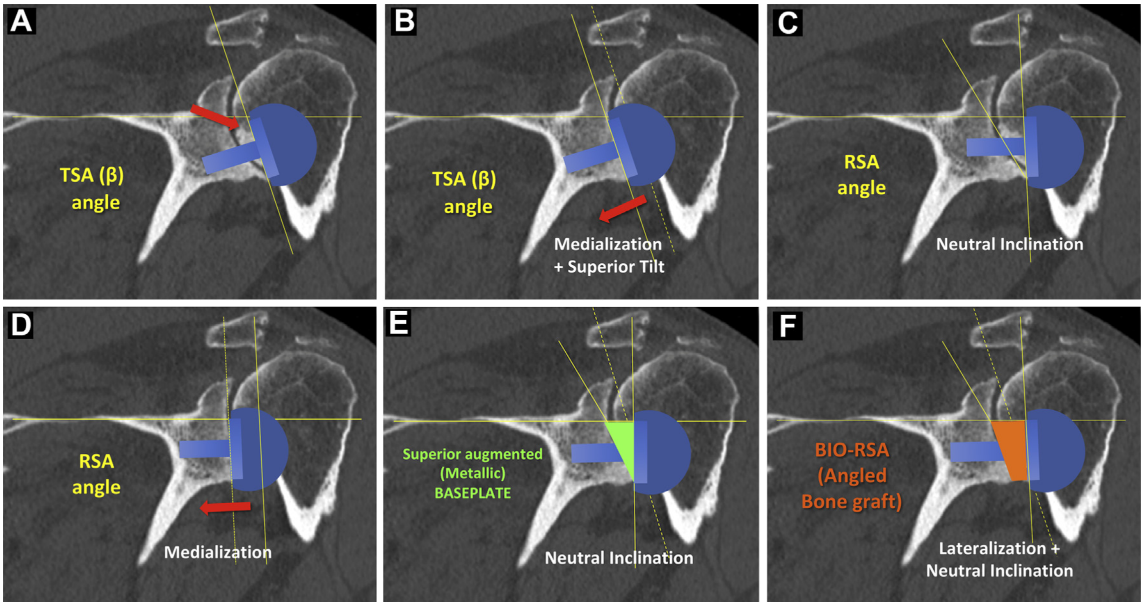

Figure 6 Preoperative 2-dimensional computed tomography templating in a patient with rotator cuff tear arthritis and Favard type E1 glenoid erosion: (**A, B**) Implantation of the baseplate according to the TSA (β) angle leads to superior tilt of the glenosphere. (**C, D**) To ensure neutral tilt of the glenoid component (ie, to correct the *RSA* angle), eccentric inferior reaming of the native glenoid is needed, but this leads to compromise of the bone stock and medialization of the glenosphere. (**E, F**) Compensating for the superior inclination of the inferior portion of the glenoid with metal (superior augmented metal baseplate) or bone graft allows correction of the RSA angle while avoiding medialization of the glenosphere. *TSA*, total shoulder arthroplasty; *BIO-RSA*, bony increased offset-reverse shoulder arthroplasty.

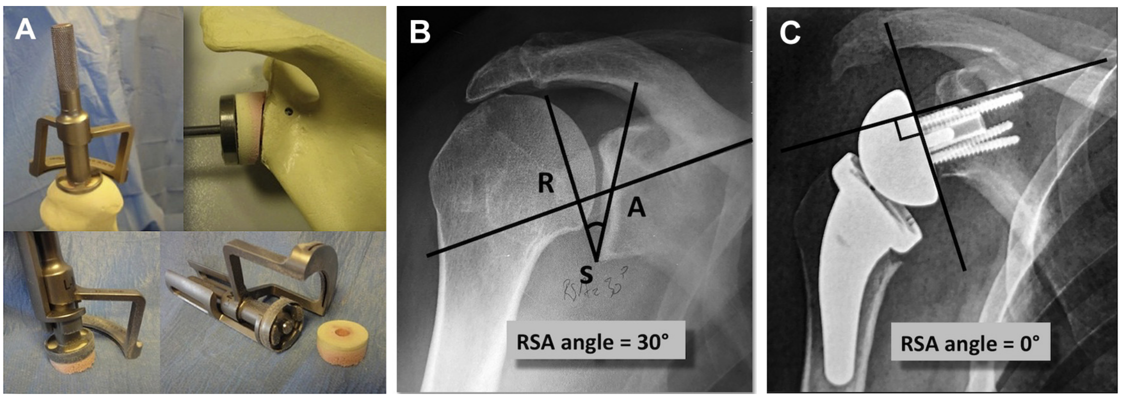

Figure 7 Use of BIO-RSA to lateralize and correct superior glenoid inclination: (**A**) Asymmetrical inferior reaming combined with an inferiorly angled bone graft, harvested from the humerus with an angled cutting guide, is used to achieve neutral inclination of the baseplate and glenosphere (ie, to correct the RSA angle). (**B, C**) Preoperative and postoperative radiographs demonstrate correction of the reverse shoulder arthroplasty (*RSA*) angle with neutral tilt of the baseplate and sphere after angled BIO-RSA.

bone that potentially compromises the bone stock and will medialize the glenoid component. Dilisio et al[11] demonstrated that when correcting glenoid superior inclination, the subchondral smile reaming technique or the use of a 10° cannulated guide pin does not correct glenoid inclination reliably. Excessive medialization of the center of rotation (from excessive inferior glenoid reaming) can lead to prosthetic instability, scapular notching, glenoid loosening, and decreased mobility.[4,5,11] Instead, we suggest the need for component augmentation, including either a superior augmented baseplate[33,39] or an inferiorly inclined bone graft.[4,5,30] In fact, 3 surgical options can be used to correct the superior inclination of the inferior part of the glenoid and obtain neutral inclination of the baseplate (RSA angle, 0°) without medialization of the baseplate: (1) metallic superior augmented baseplate, (2) inferiorly inclined bone graft, or (3) patient-specific baseplate.

In our surgical practice, our preference is to use an angled bone graft harvested from the proximal humerus (BIO-RSA technique) for all cases except when the proximal humerus is not available (humeral head necrosis) or in revision cases in which we use an augmented baseplate or

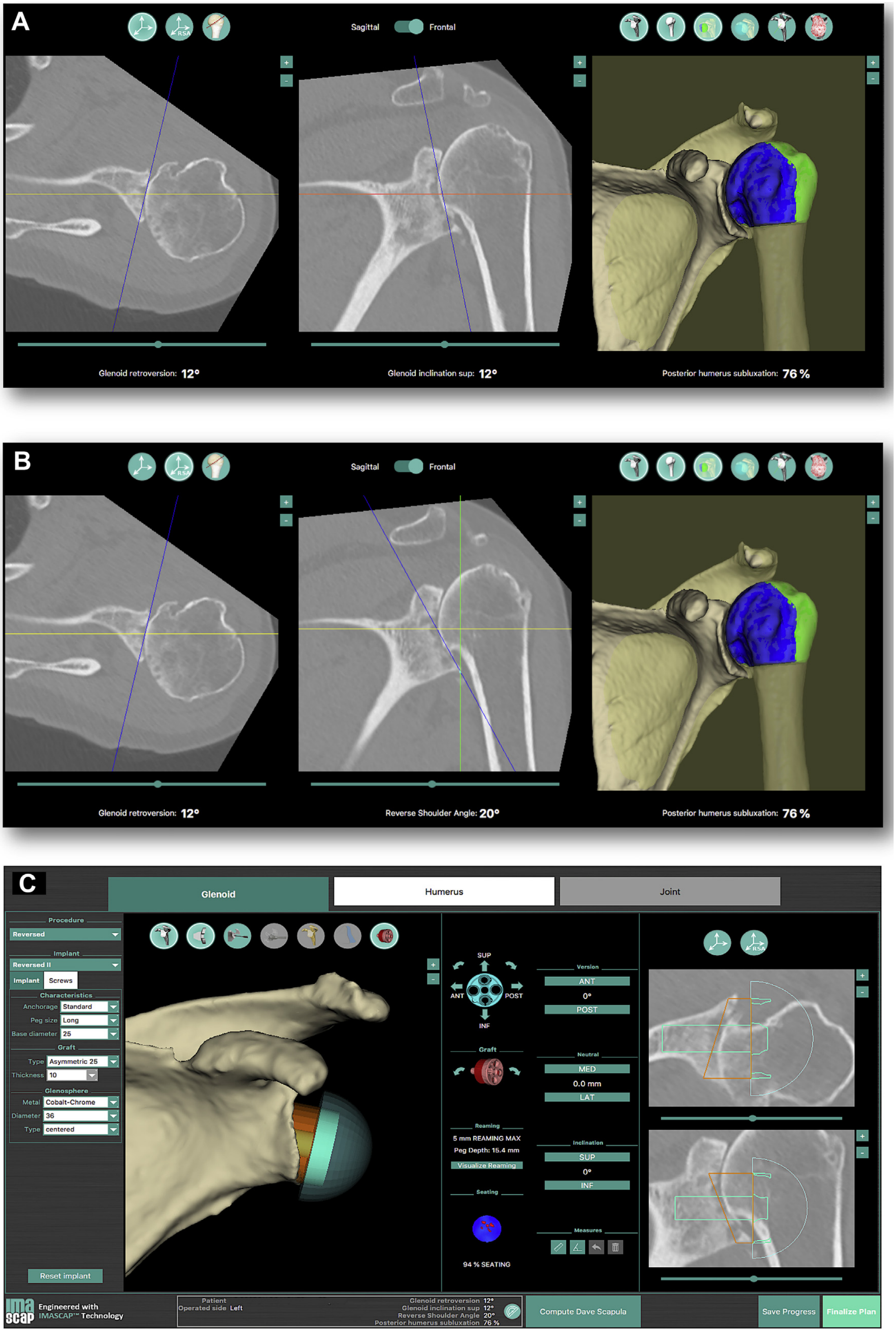

Figure 8 (**A-C**) Screenshots show output provided by 3-dimensional software (Blueprint TM, Wright-Tornier), which provides global glenoid inclination (TSA = 12°) and inferior glenoid inclination (RSA angle = 20°). Use of an angled BIO-RSA allows one to obtain neutral inclination of the baseplate and glenosphere (in adddition to lateralization).

allograft.[1,5,6,18,10] Advantages of the BIO-RSA technique include the flexibility to reconstruct multiplanar deformity (inclination and retroversion) and the low morbidity of the ‘‘in situ’’ bone graft harvesting[4,6,8,34] (Figs. 6 and 7). This technique requires the use of a longer central peg or screw (25-30 mm) to provide full purchase in the glenoid vault and compression of the graft.[4]

Preoperative planning is essential for proper assessment of glenoid erosion and placement of the reverse baseplate tilt. From a surgical standpoint, the RSA angle is useful to ensure a neutral tilt of the glenoid component. By use of 2D or 3D planning, this allows measurement of the thickness and the angle of the bone graft or augmented baseplate needed. One example includes the Blueprint TM (Wright-Tornier) 3D software program, which enables a thorough assessment of glenoid inclination by showing both the global inclination (TSA angle) and the inferior glenoid inclination (RSA angle). This type of preoperative planning software allows the surgeon to anticipate the angulation, dimensions, and shape of the bone graft or metallic augmentation to correct the glenoid inclination and avoid superior tilt of the glenoid component (Fig. 8).

This study’s findings should only be considered in light of its limitations. Although measurements using AP radiographs slightly overestimated glenoid inclination, this was likely secondary to incomplete visualization of the supraspinatus fossa line on some of the radiographs that were cut medially. The small number of patients with each specific Favard subtype limits the ability to perform any subgroup analyses within specific types. Furthermore, although rotator cuff arthropathy is the most common pathology of glenoid erosion, another limitation is that our study was limited to these patients. Future investigations into other pathologies associated with superior inclination are warranted to broaden the clinical translation of these findings. Nonetheless, the results of this study indicate that the RSA angle can be reproducibly used to assess baseplate inclination on both preoperative radiographs and reformatted 2D CT scans or with the help of 3D software. Further prospective clinical investigations will be necessary to determine whether correction of the RSA angle translates into improved outcomes, as well as to determine its role in patient-specific guides or components.

Conclusion

This study demonstrates that (1) preoperative measurement of glenoid inclination over the entire glenoid surface (TSA angle or β angle) underestimates the superior orientation of the reverse baseplate and the amount of correction required and (2) the RSA angle provides a reliable measure of the inclination of the inferior portion of the native glenoid, where the glenoid component is optimally implanted. This angle, which on average is $20° \pm 5°$ in CTA, needs to be corrected to obtain neutral inclination of the baseplate (RSA angle $= 0°$). This can be done through inferior glenoid reaming (but at the risk of implant medialization) and/or superior augmentation with bone graft or metal augment. Surgeons should pay particular attention to central concentric glenoid erosion (Favard type E1), as the risk of baseplate implantation with a superior tilt is underestimated with the TSA (or β) angle in these patients.

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Disclaimer

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References

1. 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: 468-73. http://doi.org/10.1016/j.jse.2014.08.015
2. Boileau P, Cheval D, Gauci M-O, Holzer N, Chaoui J, Walch G. Automated three-dimensional measurement of glenoid version and inclination in arthritic shoulders. J Bone Joint Surg Am 2018;100:57-65. http://doi.org/10.2106/JBJS.16.01122
3. Boileau P, Melis B, Duperron D, Moineau G, Rumian AP, Han Y. Revision surgery of reverse shoulder arthroplasty. J Shoulder Elbow Surg 2013;22:1359-70. http://doi.org/10.1016/j.jse.2013.02.004
4. 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: 2558-67. http://doi.org/10.1007/s11999-011-1775-4
5. Boileau P, Morin-Salvo N, Gauci M-O, Seeto BL, Chalmers PN, Holzer N, et al. Angled BIO-RSA (bony-increased offset-reverse shoulder arthroplasty): a solution for the management of glenoid bone loss and erosion. J Shoulder Elbow Surg 2017;26:2133-42. http://doi.org/10.1016/j.jse.2017.05.024
6. Boileau P, O’Shea K, Moineau G, Roussane Y. Bony increased-offset reverse shoulder arthroplasty (BIO-RSA) for cuff tear arthropathy. Oper Tech Orthop 2011;21:69-78. http://doi.org/10.1053/j.oto.2010.11.003
7. Churchill RS, Brems JJ, Kotschi H. Glenoid size, inclination, and version: an anatomic study. J Shoulder Elbow Surg 2001;10:327-32.
8. Daggett M, Werner B, Collin P, Gauci M-O, Chaoui J, Walch G. Correlation between glenoid inclination and critical shoulder angle: a

radiographic and computed tomography study. J Shoulder Elbow Surg 2015;24:1948-53. http://doi.org/10.1016/j.jse.2015.07.013
9. Daggett M, Werner B, Gauci MO, Chaoui J, Walch G. Comparison of glenoid inclination angle using different clinical imaging modalities. J Shoulder Elbow Surg 2016;25:180-5. http://doi.org/10.1016/j.jse.2015.07.001
10. 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;81:719-26. http://doi.org/10.3109/17453674.2010.538354
11. Dilisio MF, Warner JJP, Walch G. Accuracy of the subchondral smile and surface referencing techniques in reverse shoulder arthroplasty. Orthopedics 2016;39:e615-20. http://doi.org/10.3928/01477447-20160610-04
12. Edwards TB, Trappey GJ, Riley C, O'Connor DP, Elkousy HA, Gartsman GM. Inferior tilt of the glenoid component does not decrease scapular notching in reverse shoulder arthroplasty: results of a prospective randomized study. J Shoulder Elbow Surg 2012;21:641-6. http://doi.org/10.1016/j.jse.2011.08.057
13. Falaise V, Levigne C, Favard L, SOFEC. Scapular notching in reverse shoulder arthroplasties: the influence of glenometaphyseal angle. Orthop Traumatol Surg Res 2011;97(Suppl):S131-7. http://doi.org/10.1016/j.otsr.2011.06.007
14. Favard L, Berhouet J, Walch G, Chaoui J, Lévigne C. Superior glenoid inclination and glenoid bone loss: definition, assessment, biomechanical consequences, and surgical options. Orthopade 2017;46:1015-21. http://doi.org/10.1007/s00132-017-3496-1
15. Flieg NG, Gatti CJ, Doro LC, Langenderfer JE, Carpenter JE, Hughes RE. A stochastic analysis of glenoid inclination angle and superior migration of the humeral head. Clin Biomech (Bristol, Avon) 2008;23:554-61. http://doi.org/10.1016/j.clinbiomech.2008.01.001
16. Frankle MA, Teramoto A, Luo Z-P, Levy JC, Pupello D. Glenoid morphology in reverse shoulder arthroplasty: classification and surgical implications. J Shoulder Elbow Surg 2009;18:874-85. http://doi.org/10.1016/j.jse.2009.02.013
17. Gauci MO, Boileau P, Baba M, Chaoui J, Walch G. Patient-specific glenoid guides provide accuracy and reproducibility in total shoulder arthroplasty. Bone Joint J 2016;98-B:1080-5. http://doi.org/10.1302/0301-620X.98B8.37257
18. Greiner S, Schmidt C, König C, Perka C, Herrmann S. Lateralized reverse shoulder arthroplasty maintains rotational function of the remaining rotator cuff. Clin Orthop Relat Res 2013;471:940-6. http://doi.org/10.1007/s11999-012-2692-x
19. Gutiérrez S, Walker M, Willis M, Pupello DR, Frankle MA. Effects of tilt and glenosphere eccentricity on baseplate/bone interface forces in a computational model, validated by a mechanical model, of reverse shoulder arthroplasty. J Shoulder Elbow Surg 2011;20:732-9. http://doi.org/10.1016/j.jse.2010.10.035
20. Hughes RE, Bryant CR, Hall JM, Wening J, Huston LJ, Kuhn JE, et al. Glenoid inclination is associated with full-thickness rotator cuff tears. Clin Orthop Relat Res 2003;407:86-91.
21. Kandemir U, Allaire RB, Jolly JT, Debski RE, McMahon PJ. The relationship between the orientation of the glenoid and tears of the rotator cuff. J Bone Joint Surg Br 2006;88:1105-9. http://doi.org/10.1302/0301-620X.88B8.17732
22. Konrad GG, Markmiller M, Jolly JT, Ruter AE, Sudkamp NP, McMahon PJ, et al. Decreasing glenoid inclination improves function in shoulders with simulated massive rotator cuff tears. Clin Biomech (Bristol, Avon) 2006;21:942-9. http://doi.org/10.1016/j.clinbiomech.2006.04.013
23. Lädermann A, Denard PJ, Boileau P, Farron A, Deransart P, Walch G. What is the best glenoid configuration in onlay reverse shoulder arthroplasty? Int Orthop 2018;42:1339-46. http://doi.org/10.1007/s00264-018-3850-x
24. Lädermann A, Gueorguiev B, Charbonnier C, Stimec BV, Fasel JHD, Zderic I, et al. Scapular notching on kinematic simulated range of motion after reverse shoulder arthroplasty is not the result of impingement in adduction. Medicine (Baltimore) 2015;94:e1615. http://doi.org/10.1097/MD.0000000000001615
25. Laver L, Garrigues GE. Avoiding superior tilt in reverse shoulder arthroplasty: a review of the literature and technical recommendations. J Shoulder Elbow Surg 2014;23:1582-90. http://doi.org/10.1016/j.jse.2014.06.029
26. Lévigne C, Boileau P, Favard L, Garaud P, Molé D, Sirveaux F, et al. Scapular notching in reverse shoulder arthroplasty. J Shoulder Elbow Surg 2008;17:925-35. http://doi.org/10.1016/j.jse.2008.02.010
27. Maurer A, Fucentese SF, Pfirrmann CWA, Wirth SH, Djahangiri A, Jost B, et al. Assessment of glenoid inclination on routine clinical radiographs and computed tomography examinations of the shoulder. J Shoulder Elbow Surg 2012;21:1096-103. http://doi.org/10.1016/j.jse.2011.07.010
28. Moineau G, Levigne C, Boileau P, Young A, Walch G. Three-dimensional measurement method of arthritic glenoid cavity morphology: feasibility and reproducibility. Orthop Traumatol Surg Res 2012;98(6 Suppl):S139-45. http://doi.org/10.1016/j.otsr.2012.06.007
29. Molé D, Wein F, Dézaly C, Valenti P, Sirveaux F. Surgical technique: the anterosuperior approach for reverse shoulder arthroplasty. Clin Orthop Relat Res 2011;469:2461-8. http://doi.org/10.1007/s11999-011-1861-7
30. Neyton L, Boileau P, Nové-Josserand L, Edwards TB, Walch G. Glenoid bone grafting with a reverse design prosthesis. J Shoulder Elbow Surg 2007;16(3 Suppl):S71-8. http://doi.org/10.1016/j.jse.2006.02.002
31. Nicholson GP, Strauss EJ, Sherman SL. Scapular notching: recognition and strategies to minimize clinical impact. Clin Orthop Relat Res 2011;469:2521-30. http://doi.org/10.1007/s11999-010-1720-y
32. Nyffeler RW, Werner CML, Gerber C. Biomechanical relevance of glenoid component positioning in the reverse Delta III total shoulder prosthesis. J Shoulder Elbow Surg 2005;14:524-8. http://doi.org/10.1016/j.jse.2004.09.010
33. Roche CP, Stroud NJ, Martin BL, Steiler CA, Flurin P-H, Wright TW, et al. Achieving fixation in glenoids with superior wear using reverse shoulder arthroplasty. J Shoulder Elbow Surg 2013;22:1695-701. http://doi.org/10.1016/j.jse.2013.03.008
34. Seidl AJ, Williams GR, Boileau P. Challenges in reverse shoulder arthroplasty: addressing glenoid bone loss. Orthopedics 2016;39:14-23. http://doi.org/10.3928/01477447-20160111-01
35. Simovitch RW, Zumstein MA, Lohri E, Helmy N, Gerber C. Predictors of scapular notching in patients managed with the Delta III reverse total shoulder replacement. J Bone Joint Surg Am 2007;89:588-600. http://doi.org/10.2106/JBJS.F.00226
36. Sirveaux F, Favard L, Oudet D, Huquet D, Walch G, Molé 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;86:388-95.
37. Van Haver A, Heylen S, Vuylsteke K, Declercq G, Verborgt O. Reliability analysis of glenoid component inclination measurements on postoperative radiographs and computed tomography-based 3D models in total and reversed shoulder arthroplasty patients. J Shoulder Elbow Surg 2016;25:632-40. http://doi.org/10.1016/j.jse.2015.09.003
38. Walch G, Vezeridis PS, Boileau P, Deransart P, Chaoui J. Three-dimensional planning and use of patient-specific guides improve glenoid component position: an in vitro study. J Shoulder Elbow Surg 2015;24:302-9. http://doi.org/10.1016/j.jse.2014.05.029
39. Wright TW, Roche CP, Wright L, Flurin P-H, Crosby LA, Zuckerman JD. Reverse shoulder arthroplasty augments for glenoid wear. comparison of posterior augments to superior augments. Bull Hosp Jt Dis (2013) 2015;73 Suppl 1:S124-8.
40. 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;20:146-57. http://doi.org/10.1016/j.jse.2010.08.001