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The influence of posture and scapulothoracic orientation on the choice of humeral component retrotorsion in reverse total shoulder arthroplasty

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Background: The literature suggests implantation of the humeral component in reverse total shoulder arthroplasty (RTSA) in 0°-40° of retrotorsion without further specification. We hypothesized that optimal humeral component retrotorsion to avoid notching and gain balanced rotational capacity would depend on scapular position and posture.
Methods: We investigated 200 shoulders in 100 patients with available whole-body computed tomography scans and created 3-dimensional models. Implantation of a humeral component in 20° of retrotorsion was simulated, and a correction angle (CA) to yield perfect opposition to the glenosphere was calculated. Patient-specific variables such as age, sex, posture, and scapular orientation parameters were correlated with this CA.
Results: Scapular orientation showed large interindividual differences. A highly significant correlation was seen between the CA and scapular internal rotation ($R = 0.71$, $P < .001$) and protraction ($R = 0.39$, $P < .001$). When the CA was adjusted for glenoid retroversion, the correlation coefficient of scapular internal rotation increased even further ($R = 0.91$, $P < .001$). Scapular internal rotation itself showed a correlation with thoracic kyphosis ($R = 0.27$, $P < .001$), protraction ($R = 0.57$, $P < .001$), tilt ($R = 0.29$, $P < .001$), and scapular translation ($R = -0.23$, $P < .001$).
Conclusion: Scapular orientation and posture should be integrated into the determination process of humeral component retrotorsion in RTSA. In theory, implantation of the humeral component with increased retrotorsion leads to improved neutral opposition of the RTSA components in patients with extensive internal rotation of the scapula. On the basis of varying scapular internal rotation, we propose the distinction of 3 different posture types (A-C) for enhanced appraisal of scapulothoracic orientation.
Level of evidence: Basic Science Study; Computer Modeling

Keywords: Reverse total shoulder arthroplasty; retrotorsion; humeral component; posture; scapular internal rotation; posture types

The ethics committee of Charité–Universitätsmedizin Berlin, Corporate Member of Freie Universität Berlin, Humboldt-Universität zu Berlin, and Berlin Institute of Health, Germany, approved this study (EA4/119/19).

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Although active abduction and elevation can often successfully be improved by means of reverse total shoulder arthroplasty (RTSA), many patients experience limitations in internal and external rotation with subsequent restriction in daily life activities.[4,10,13,19,20,22] In Grammont-style RTSA, the center of rotation is shifted medially and inferiorly and stabilized by the more constrained design compared with the native anatomy. As a result, the biomechanics not only of arm elevation but also of rotation are affected.[4,10] The humeral component rotates in semicircular movements around the glenosphere.[10] Therefore, a neutral opposition of the humeral component to the glenosphere in neutral rotation of the arm is favorable for optimal rotational capacity (Fig. 1). By choosing the angle of humeral component retrotorsion, we directly influence component opposition and therefore impingement-free rotation range of the humeral component.

On the basis of biomechanical studies and surgeons' expert opinion, a retrotorsion angle between 0° and 40° is recommended.[4,9,12,20] However, to date, there are no clear guidelines for selection of humeral component retrotorsion in RTSA. As physiological humeral torsion and scapular orientation are variable among individuals, it is unclear whether a uniform torsion angle should be applied for all patients.[3,6] In an aging population, patients often present with increased thoracic kyphosis, combined with protraction and internal rotation of the scapula. These changes in scapular orientation could consequently alter the opposition of the humeral component to the glenosphere.

We hypothesize that the optimal retrotorsion angle to achieve neutral opposition in RTSA would be highly variable and increase with progressive scapular protraction. Furthermore, we hypothesized that posture and thoracic dimensions would influence scapular orientation and therefore would influence the angle of optimal humeral component retrotorsion.

Materials and methods

We searched our institutional radiology database for patients who had received a positron emission tomography (PET)–computed tomography (CT) backward from May 2019 until we had identified 100 patients who met the following inclusion criteria: (1) age 18 years or older; (2) supine positioning of the patient with arms at the side and elbows resting on the examination table; (3) complete depiction of the trunk from the base of the skull to the proximal femora including both humeri; and (4) sufficient CT quality for 3-dimensional rendering. Patients with visual pathologies of the upper extremities or thorax that potentially could alter humeral torsion, scapular orientation, or scapulothoracic dimensions (eg, fractures, prostheses, or dysplasia) were excluded. For each patient, both shoulders were analyzed as individual cases, which led to a total of 200 shoulders. CT imaging was performed with identical scan parameters in all patients as either low- or full-dose imaging (field of view, 70 cm; tube voltage, 120 kV; automatic tube current modulation with maximum threshold, 100 mA [low dose] or 200 mA [full dose]; and primary slice thickness, 1.25 mm [both low and dose]) using a single scanner (Discovery MI; GE Healthcare, Chalfont St Giles, UK). The resulting study cohort consisted of 74 male and 26 female patients with a mean age of 61.1 years (range, 18-89 years). All patients had undergone PET-CT with fludeoxyglucose (^{18}F) for suspected or proven malignant, infectious, or inflammatory disease.

Measurements

For all measurements except thorax dimensions (which were determined with 2-dimensional CT scans), CT data were rendered into 3-dimensional models using Visage software (version 7.1; Visage Imaging, Berlin, Germany).

Correction angle for perfect opposition

To determine the angle at which the humeral component would be in neutral opposition to the glenosphere with the arm in neutral rotation, we virtually simulated a humeral component implantation on both sides in each patient. First, a perpendicular line to the epicondyle axis (forearm axis line) in the transverse plane was drawn; then, a line (humeral osteotomy line [HOL]) with 20° of retroversion compared with the first line was drawn to simulate a humeral head osteotomy. The forearm axis line was then aligned with the sagittal vertebral axis to simulate neutral arm position. The HOL was adjusted to the same degree. The angle between the adjusted HOL and a tangential line on the glenoid (glenoid version line [GVL]) was calculated to determine the correction angle (CA) for neutral opposition (Fig. 2). In addition, the GVL was adjusted to a glenoid version of 0° to account for possible correction of glenoid version during implantation of the glenosphere (ie, adjusted GVL) and an adjusted correction angle (ACA) was calculated.

Scapular orientation and posture

According to Park et al,[18] we determined the scapular orientation by means of various angles to counteract anatomic bias, such as scapular size and shape. Divergent from their study, we used the 3 following bony landmarks: glenoid (deepest point of the concavity), inferior scapular angle, and medial root of the scapular spine. For accurate measurement, landmarks were set in the respected plane, scouting layer through layer. Protraction was measured as the angle between the sagittal vertebral axis and a line from the glenoid to the center of vertebral body T1 in the transverse plane. Scapular internal rotation was measured as the angle between the perpendicular line to the sagittal vertebral axis through the glenoid and the line from the glenoid to the root of the scapular spine in the transverse plane. Scapular upward rotation was measured as the angle between the longitudinal vertebral axis and the line from the root of the scapular spine to the inferior scapular angle in the frontal plane. Scapular translation was determined as the angle between the longitudinal vertebral axis and the line from the tip of the spinous process of the T1 vertebra to the glenoid in the frontal plane. We measured scapular tilt as the angle between a perpendicular line to the upper baseplate of vertebral body T1 and the line from the

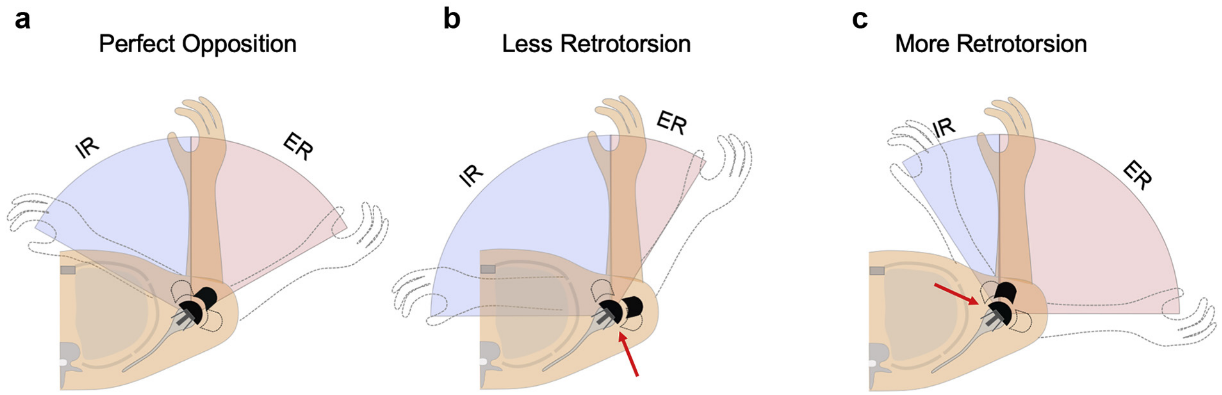

Figure 1 Hemithorax after reverse total shoulder arthroplasty implantation and theoretical range of rotation. (**a**) Placement of humeral component with perfect opposition to glenosphere. (**b**) With less retrotorsion, the component is placed dorsally with respect to the glenosphere, which leads to early impingement (←) during external rotation (*ER*) and a shift toward internal rotation (*IR*). (**c**) With more retrotorsion, rotation is shifted toward ER with early impingement (←) on IR.

medial root of the scapular spine to the inferior scapular angle in the sagittal plane. An index of transverse thorax diameter at the greatest thoracic expansion divided by the anteroposterior diameter was calculated (thoracic index). Humeral torsion was measured as the angle between the epicondyle axis and the line perpendicular to the anatomic neck of the humeral head in the transverse plane.[16] Global thoracic kyphosis was measured as the Cobb angle between the upper baseplate of vertebral body T2 and lower baseplate of T12 in the sagittal plane.[1] Glenoid version was measured as the angle between a line from the medial border of the scapula through the glenoid center and a tangent line to the glenoid surface in the transverse plane (Fig. 3).

Statistical analyses

Statistical analyses including descriptive statistics were performed with IBM SPSS Statistics software (version 24.0; IBM, Armonk, NY, USA). $P < .05$ was considered significant. Two orthopedic residents (P.S. and D.A.) independently conducted the measurements. Intraclass correlation coefficients with 95% confidence interval were calculated and interpreted according to Landis and Koch.[14] An intraclass correlation coefficient of 0.20 or less indicates slight agreement; 0.21 to 0.40, fair agreement; 0.41 to 0.60, moderate agreement; 0.61 to 0.80, substantial agreement; and 0.81 or greater, almost perfect agreement. The means of both raters were calculated. Correlations between parameters were analyzed using the Pearson correlation coefficient. Sex differences were calculated by means of the independent *t* test; differences between both shoulders, invariant analysis of variance; and differences between posture types (A-C), invariant analysis of variance and the post hoc Tukey test.

Results

All measurements showed substantial to almost perfect agreement between the 2 raters (Table I). Measurement results for all parameters are summarized in Table II.

No significant differences were found between both shoulders in each patient for internal rotation, protraction, upward rotation, scapular translation, tilt, CA, and ACA. Humeral torsion and glenoid version showed significant differences between right and left shoulders. Mean humeral torsion measured 32.7° ± 9.8° on the right and 26.3° ± 8.7° on the left ($P < .001$). Glenoid version was −1.3° ± 4.4° and 0° ± 4.4°, respectively ($P = .04$).

Correlations between the CA and scapular internal rotation ($P < .001$), as well as protraction ($P < .001$), were highly significant. Correlations with thoracic kyphosis ($P = .04$), upward rotation ($P = .03$), scapular translation ($P = .04$), and tilt ($P = .02$) were also significant. However, the CA did not correlate with age, humeral torsion, or the thoracic index (Fig. 4). The mean CA was 23.1° ± 5.9° in female patients and 20.7° ± 7.1° in male patients, with a significant difference between sexes ($P = .03$).

The highest correlation coefficient ($R = 0.71$) was seen between the CA and scapular internal rotation. When the CA was adjusted to a glenoid with 0° of version (ACA) by subtracting glenoid anteversion—or adding respective retroversion—an even increased correlation with scapular internal rotation was seen ($R = 0.91$, $P < .001$) (Fig. 5). Scapular internal rotation showed a correlation with thoracic kyphosis ($R = 0.27$, $P < .001$), protraction ($R = 0.57$, $P < .001$), tilt ($R = 0.29$, $P < .001$), and scapular translation ($R = -0.23$, $P < .001$) (Fig. 6).

As scapular internal rotation is a measurable variable, we categorized patients into 1 of 3 groups according to scapular internal rotation. By means of a Gaussian distribution, type B was defined as mean scapular internal rotation ± 1 standard deviation, type A was set at the lower bound (<36.2°), and type C was set at the upper bound (>46.6°) (Fig. 7). Values for all parameters of each type are summarized in Table III.

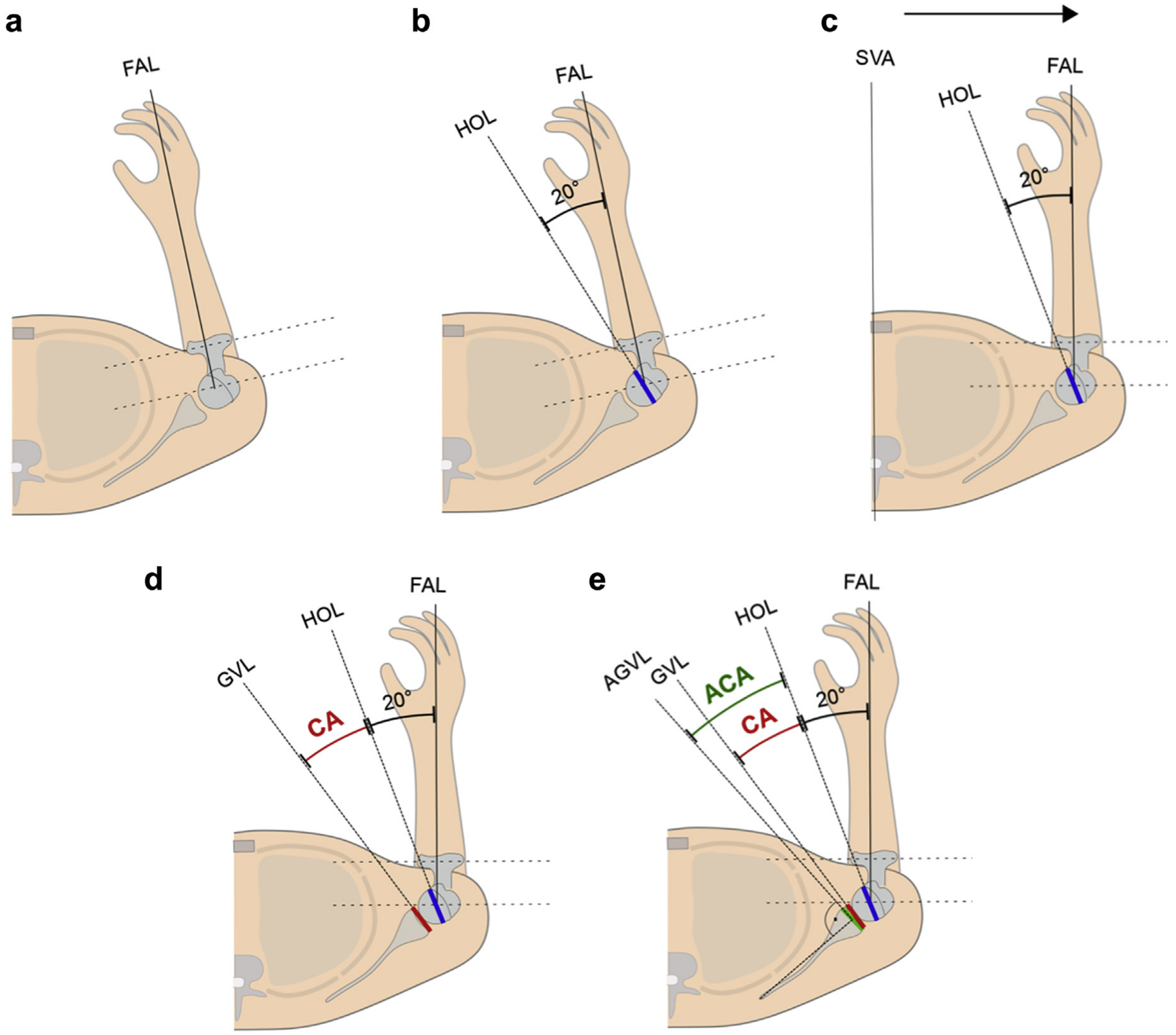

Figure 2 Determination of correction angle (*CA*) and adjusted correction angle (*ACA*). (**a**) A perpendicular line to the epicondyle axis (forearm axis line [*FAL*]) is drawn. (**b**) A line (humeral osteotomy line [*HOL*]) with 20° of retroversion is drawn to simulate a humeral head osteotomy (–). (**c**) The FAL is aligned (→) with the sagittal vertebral axis (*SVA*). (**d**) The CA to yield perfect opposition between the HOL and the glenoid version line (*GVL*) (–) is measured. (**e**) The GVL is adjusted to a glenoid version of 0° (–) (adjusted glenoid version line [*AGVL*]), and the ACA is calculated.

Discussion

The aim of this study was to evaluate the influence of scapular orientation and posture on the choice of humeral component retrotorsion in RTSA. Our data show that scapular orientation—and, in more general terms, posture—directly affects the required retrotorsion to obtain neutral opposition of the humeral component.

Karelse et al[10] described the relationship of prosthetic components in RTSA in the transverse plane. They confirmed the original hypothesis of Grammont and Baulot[8] that an increase in humeral component retrotorsion could favor external rotation. In this study, we used a CA to identify the degree of retrotorsion needed to achieve neutral opposition of the humeral component and the glenosphere with the arm in neutral rotation. The CA showed a strong correlation with scapular internal rotation. When internal rotation of the scapula increases, we observe that the glenoid surface is progressively turned into anteversion regarding the thoracic axes, which consequently increases the CA. A modifiable variable of this correlation is the version of the glenoid. To account for varying glenoid version (eg, type B glenoids), we subtracted the glenoid version measurement and subsequently reached almost perfect correlation of the CA to scapular internal rotation. This result is to be expected, as scapular internal rotation indicates the orientation of the latter implanted glenosphere in the transverse plane if glenoid version is corrected to approximately 0° during surgery. It is interesting to note that scapular internal rotation can easily be measured either on imaging

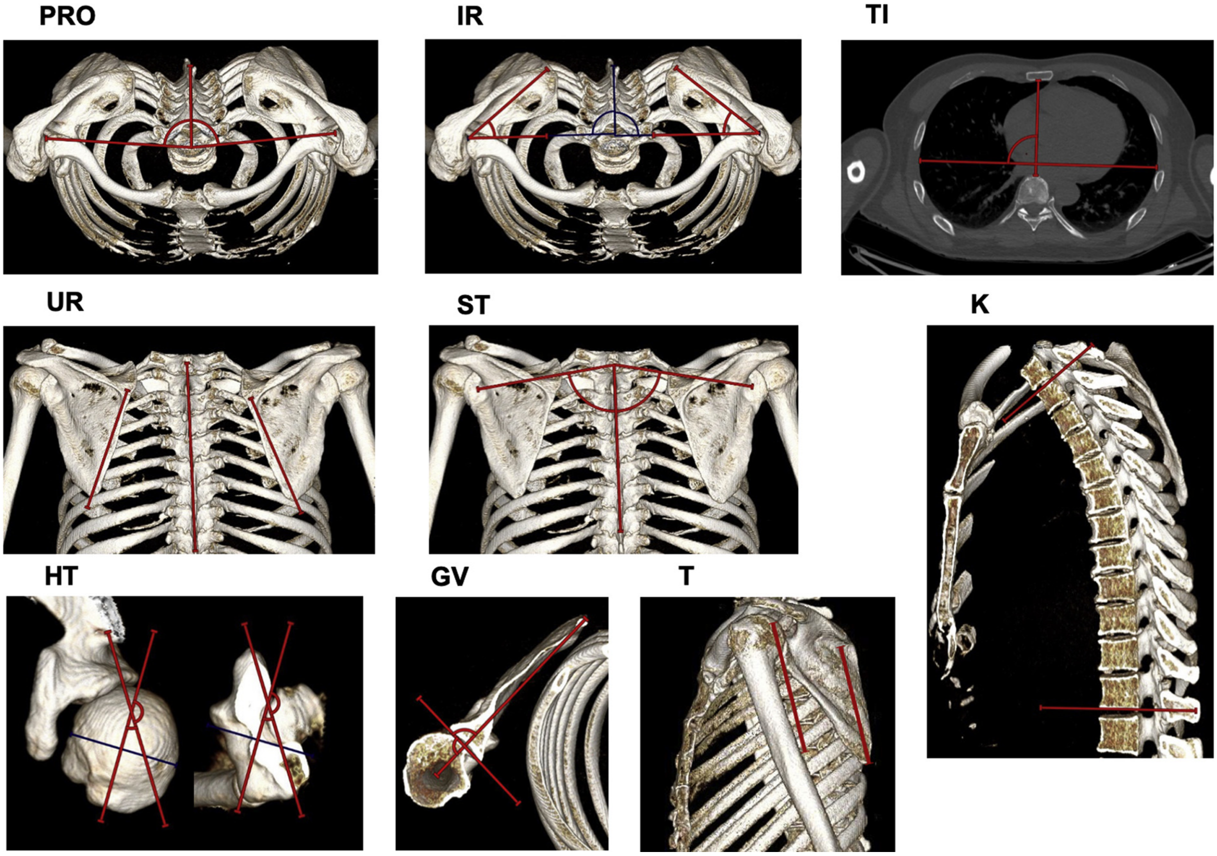

Figure 3 Measurements (–) for scapular protraction (*PRO*), scapular internal rotation (*IR*) (–, sagittal and coronal body axes), thoracic index (*TI*), scapular upward rotation (*UR*), scapular translation (*ST*), global thoracic kyphosis (*K*), humeral torsion (*HT*) (–, anatomical neck), glenoid version (*GV*), and scapular tilt (*T*).

Table I ICCs for all measurement parameters with 95% CIs

	ICC	95% CI		Agreement
		Lower bound	Upper bound	
CA	0.87	0.850	0.911	Almost perfect
PRO	0.85	0.809	0.886	Almost perfect
IR	0.87	0.826	0.897	Almost perfect
UR	0.91	0.877	0.928	Almost perfect
T	0.89	0.854	0.914	Almost perfect
ST	0.76	0.697	0.814	Substantial
TI	0.95	0.930	0.959	Almost perfect
HT	0.78	0.723	0.831	Substantial
K	0.86	0.817	0.891	Almost perfect
GV	0.81	0.755	0.852	Almost perfect

ICC, intraclass correlation coefficient; *CI*, confidence interval; *CA*, correction angle; *PRO*, scapular protraction; *IR*, scapular internal rotation; *UR*, scapular upward rotation; *T*, scapular tilt; *ST*, scapular translation; *TI*, thoracic index; *HT*, humeral torsion; *K*, global thoracic kyphosis; *GV*, glenoid version.

Table II Mean values of all measurement parameters with SDs and ranges ($N = 200$)

	Mean ± SD	Range
PRO, °	88.4 ± 4.7	74.6 to 100.4
IR, °	41.4 ± 5.2	22.7 to 56.6
UR, °	13.3 ± 5.1	0.4 to 25.9
T, °	19.4 ± 8.6	0.7 to 42.1
ST, °	78.8 ± 5.8	65.1 to 98.6
TI	2.2 ± 0.3	1.4 to 3.2
HT, °	29.5 ± 9.8	5.6 to 58.8
K, °	44.2 ± 11.2	18.1 to 83.4
GV, °	−0.7 ± 4.4	−15.0 to 9.9
CA, °	21.3 ± 6.9	−3.0 to 38.5
ACA, °	22.0 ± 5.6	5.5 to 37.2

SD, standard deviation; *PRO*, scapular protraction; *IR*, scapular internal rotation; *UR*, scapular upward rotation; *T*, scapular tilt; *ST*, scapular translation; *TI*, thoracic index; *HT*, humeral torsion; *K*, global thoracic kyphosis; *GV*, glenoid version; *CA*, correction angle; *ACA*, adjusted correction angle.

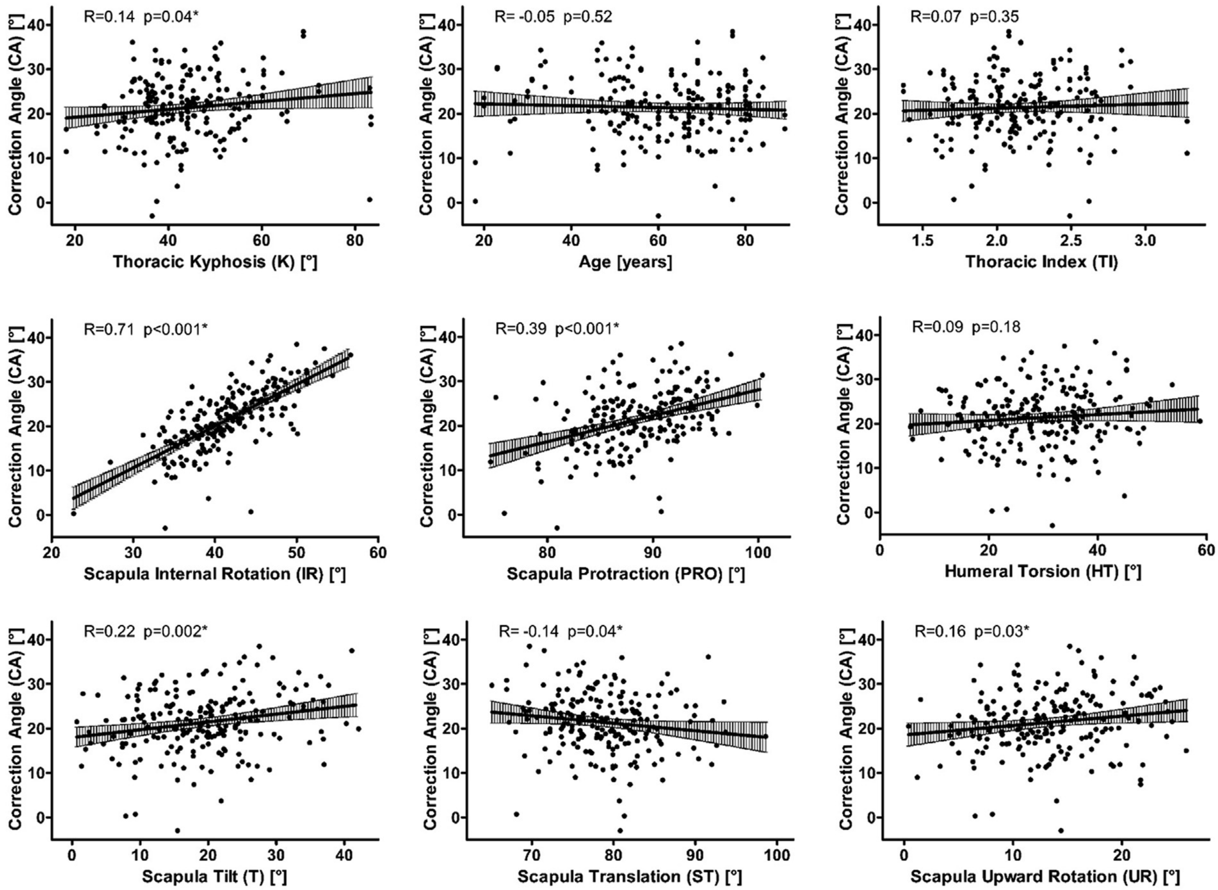

Figure 4 Correlations between correction angle and patient characteristics, posture, and scapular position. Correlation coefficients (*R*) with corresponding *P* values are indicated. A linear correlation line is illustrated, with the 95% confidence interval. *Significant correlations.

studies or even using simple and more dynamic clinical measurements in standing patients in all arm positions.[5,15,17]

We further investigated the influence of patients' demographic characteristics and posture on scapular internal rotation. Our results show that an increase in scapular internal rotation is attributed to posture rather than age. Even though we found no correlation with thoracic dimension, there was a significant positive correlation with kyphosis, scapular protraction, and scapular tilt, as well as a negative correlation with scapular translation. It seems that patients with increased scapular internal rotation present with an anterior shift and tilt of the scapula and with progressive thoracic kyphosis but with lowering of the scapula with respect to the thorax. These findings suggest that an examination of the patient's posture could provide an estimation for the choice of optimal retrotorsion angle for the humeral component in RTSA.

To integrate our model into clinical use, we propose the categorization of 3 different posture types: patients with physiological thoracic posture and retracted shoulders (type A); average patients with moderate hyperkyphosis, scapular protraction, tilt, and internal rotation, as well as moderate scapular drooping (type B); and patients with severe hyperkyphosis, scapular protraction, tilt, and internal rotation, as well as severe scapular drooping (type C) (Fig. 8). We observed significant differences in the CA and ACA between all types, which underlines the importance of

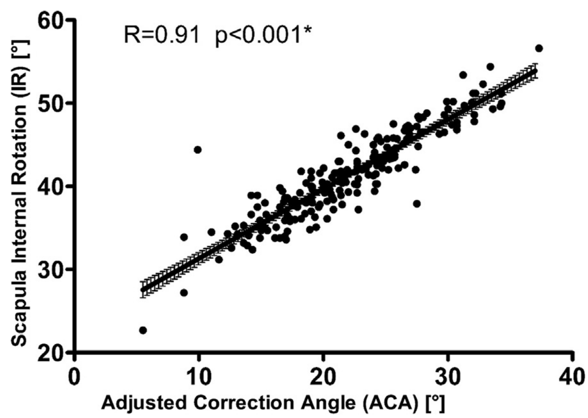

Figure 5 Correlation between scapular internal rotation and adjusted correction angle (*ACA*), with correlation coefficient (*R*) and corresponding *P* value indicated. A linear correlation line is illustrated, with the 95% confidence interval. *Significant correlations.

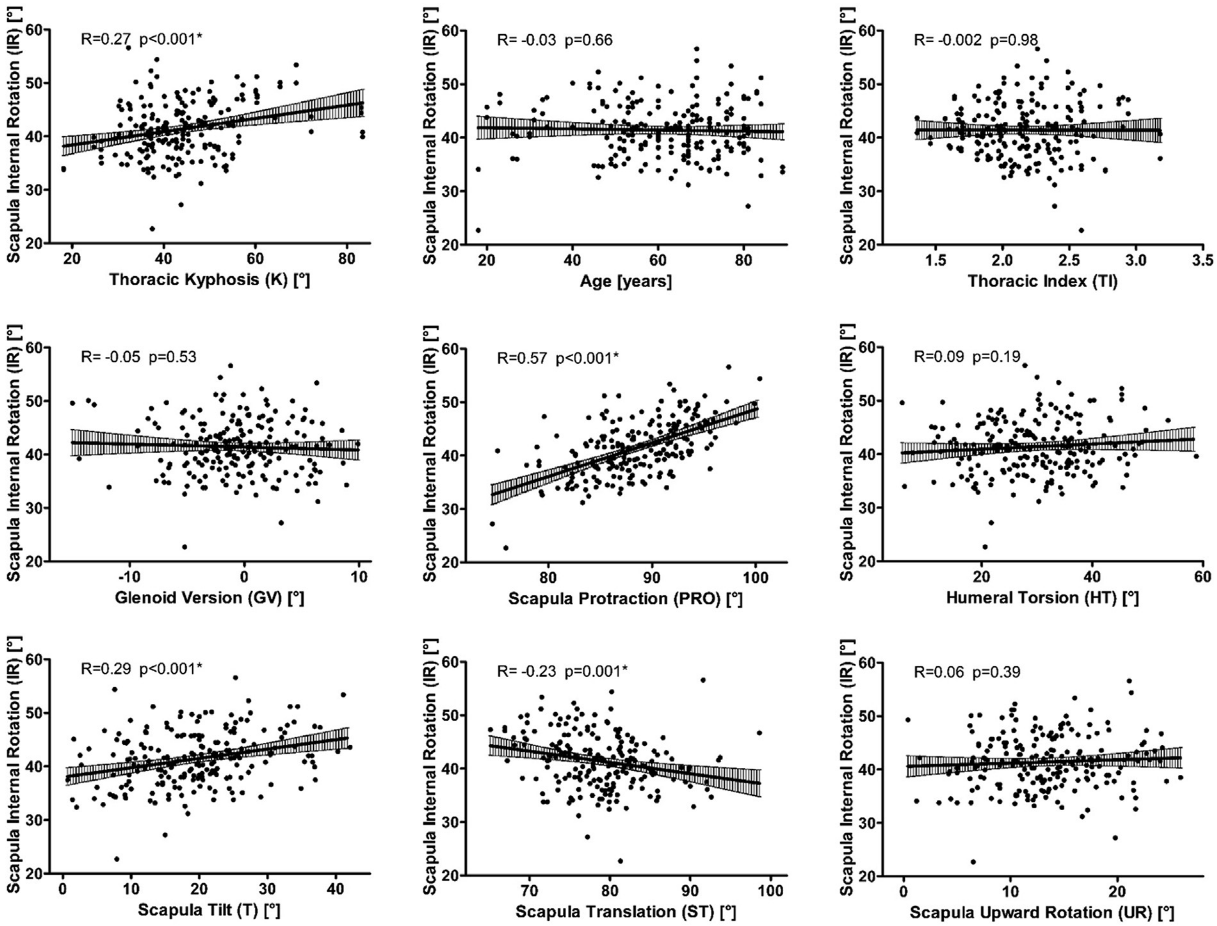

Figure 6 Correlations between scapular internal rotation and patient characteristics, posture, and scapular position. Correlation coefficients (R) with corresponding P values are indicated. A linear correlation line is illustrated, with the 95% confidence interval. *Significant correlations.

considering individualized humeral component retrotorsion angles.

Our study results suggest that implanting the humeral component at the same torsion angle for all 3 posture types would lead to different degrees of opposition to the glenosphere when holding the arm in neutral rotation. This would result in early impingement on external or internal rotation depending on the type. When we consider the 3 types, we can calculate the theoretical torsion angle of humeral component placement with glenosphere opposition in neutral arm rotation that will match the angle of internal rotation of the scapula when glenoid version is 0° (Fig. 9). We can infer that type C patients would probably benefit most from an increase in the retrotorsion angle of the humeral component.

A biomechanical cadaveric study by Stephenson et al[20] considered a retrotorsion angle between 20° and 40° to be optimal for impingement-free range of motion with an adducted arm. In another biomechanical study, Berhouet et al[2] found that rotational capacity in RTSA is best balanced by matching the angle of native humeral retrotorsion. Both studies, however, evaluated range of motion and impingement with a fixed scapular position, not accounting for anatomic scapular changes regarding the thoracic axes.

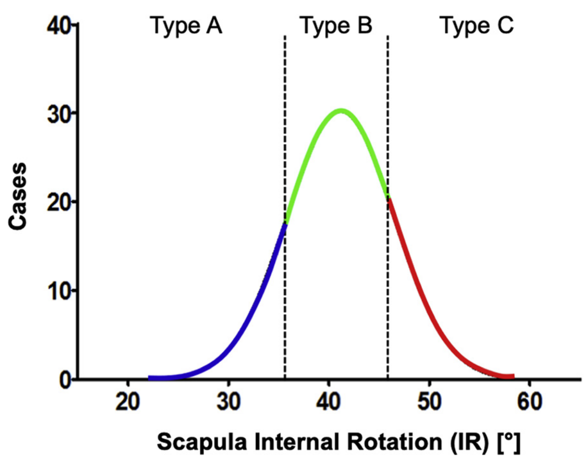

Figure 7 Gaussian distribution of 3 posture types. Standard deviations are illustrated by ----.

Table III Comparison of mean values with standard deviations and ranges of all measurement parameters between 3 different posture types, with corresponding *P* values

	Type A (n = 34)		Type B (n = 132)		Type C (n = 34)		*P* value		
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Type A vs. type B	Type B vs. type C	Type C vs. type A
PRO, °	84.7 ± 4.0	74.6 to 92.0	88.6 ± 4.1	75.1 to 98.1	91.6 ± 4.7	79.6 to 100.4	<.001*	.001*	<.001*
IR, °	33.9 ± 2.6	22.7 to 36.1	41.3 ± 2.8	36.6 to 46.5	49.2 ± 2.3	46.7 to 56.6	<.001*	<.001*	<.001*
UR, °	12.0 ± 5.2	1.2 to 21.7	13.5 ± 5.0	1.5 to 25.9	13.4 ± 5.3	0.4 to 24.1	.32	.99	.53
T, °	14.9 ± 8.2	1.4 to 34.9	19.5 ± 8.2	0.7 to 42.1	23.5 ± 8.8	6.1 to 41.1	.01*	.03*	<.001*
ST, °	79.8 ± 5.3	71.6 to 92.6	79.4 ± 5.4	67.2 to 93.7	75.7 ± 6.7	65.1 to 98.6	.92	.002*	<.001*
TI	2.3 ± 0.3	1.8 to 3.2	2.1 ± 0.3	1.4 to 3.2	2.2 ± 0.3	1.6 to 2.9	.03*	.24	.71
HT, °	26.9 ± 9.7	6.0 to 46.2	29.6 ± 9.9	7.5 to 58.8	31.7 ± 9.5	5.6 to 49.5	.33	.51	.11
K, °	39.9 ± 9.4	18.1 to 55.0	43.8 ± 11.1	24.7 to 83.4	49.5 ± 11.2	30.5 to 68.9	.16	.02*	.001*
GV, °	−0.7 ± 4.9	−11.8 to 8.9	−0.4 ± 4.0	−14.4 to 9.9	−1.7 ± 5.3	−15 to 6.3	.97	.23	.56
CA, °	14.2 ± 5.9	−3.0 to 23.4	21.4 ± 5.4	0.7 to 34.8	28.5 ± 5.4	18.2 to 38.5	<.001*	<.001*	<.001*
ACA, °	14.8 ± 3.2	5.5 to 20.3	21.8 ± 3.5	9.9 to 29.7	30.2 ± 3.1	22.6 to 37.3	<.001*	<.001*	<.001*

SD, standard deviation; *PRO*, scapular protraction; *IR*, scapular internal rotation; *UR*, scapular upward rotation; *T*, scapular tilt; *ST*, scapular translation; *TI*, thoracic index; *HT*, humeral torsion; *K*, global thoracic kyphosis; *GV*, glenoid version; *CA*, correction angle; *ACA*, adjusted correction angle.
* Significant difference.

In theory, the native humeral torsion should closely match scapular internal rotation to achieve neutral opposition of the humeral head and the glenoid in a neutral arm rotation. Even though, similarly to former studies,[6,16] our measurements show highly variable humeral torsion angles among individuals, we did not find a correlation between physiological humeral torsion and the CA. The reason for this unexpected mismatch might be the fact that native humeral torsion is determined during childhood and adolescence[7,21,23] whereas scapular internal rotation increases over time in some elderly patients (types B and C) as thoracic kyphosis increases and the scapula shifts into a more protracted position. Accordingly, the observed mismatch between native humeral torsion and scapular internal rotation was 7° in posture type A, 12° in type B, and 18° in type C (even in the supine position). With respect to musculotendinous balance, this progressive mismatch between native humeral torsion and scapular internal rotation leads to increased internal rotation of the arm in a standing position with the arms resting at the side, as seen clinically in many type C patients.

Even if matching the humeral component retrotorsion to scapular internal rotation seems biomechanically feasible, the resulting retrotorsion angle in some type C patients with high scapular internal rotation over 50° would, however, be arguably high. The question arises whether the retrotorsion in patients with posture type C should be set to obtain neutral opposition of the components in neutral rotation of the arm (however, this is not a physiological rotation for these patients) or in the "resting position rotation" present before surgery (however, this might be a pathologic internal rotation caused by hyperkyphosis, scapular protraction, and the inability of the humeral torsion to compensate at an older age). Furthermore, we need to account for a shift from required balanced rotation toward more required internal rotation in elderly patients as rotation generally diminishes and basic activities such as perineal hygiene become a challenge.[11]

Nonetheless, on the basis of the findings of this study and on geometrical considerations, we can calculate the humeral component retrotorsion required to achieve neutral opposition of the components in a desired resting rotation of the arm: Humeral component retrotorsion angle = Scapular internal rotation – Resting position rotation. This new insight allows for a more patient-specific choice of optimal humeral component retrotorsion and potentially can even be included in future arthroplasty planning systems, which currently do not account for scapulothoracic orientation or posture. However, more extensive studies need to be conducted for clinical evaluation of these principles.

This study has some limitations. First, our theoretical model only accounts for opposition of the prosthetic components. The study did not consider soft-tissue structures, which might or might not contribute to rotational capacity (eg, torn rotator cuff); prosthetic variations such as glenosphere size or eccentricity; humeral component inclination; or patient-specific factors such as obesity and stiffness. Nonetheless, in terms of component opposition, the proposed principles seem valid. Second, the scapular orientation angles measured in this study were obtained with the patients in the supine position, which shifts the scapula toward retraction and attenuates kyphosis. Therefore, average kyphosis, as well as protraction and scapular internal rotation, measured in this study is likely lower than what would be expected in standing patients. However, the main

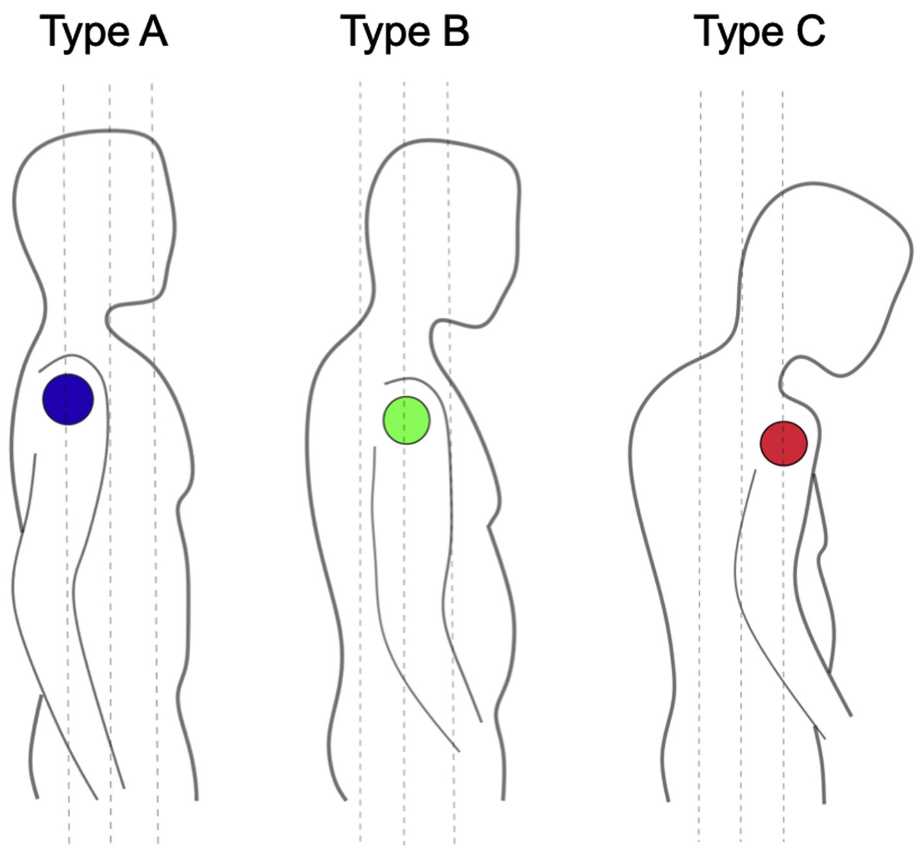

Figure 8 Three different native or acquired posture types (A-C), with progressive scapular protraction, tilt, and internal rotation, as well as drooping. The center of rotation of the shoulder joint is indicated by the ●, ●, and ●.

findings of this study in terms of the relations among scapular internal rotation, humeral component retrotorsion, component opposition, and arm rotation are not affected by this methodologic limitation as the general principle can be transferred to the standing position and even different degrees of arm elevation. Finally, patients

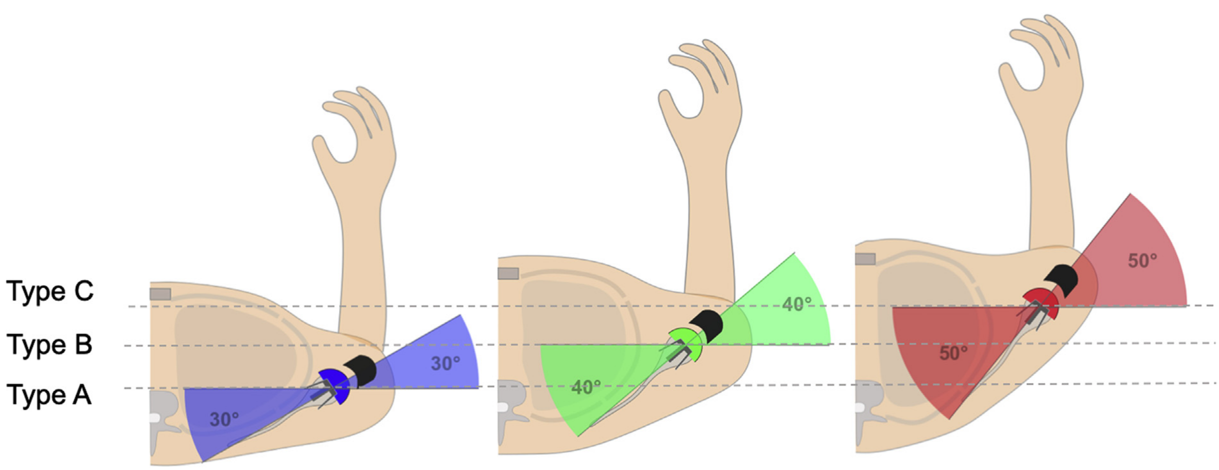

Figure 9 Schema of reverse total shoulder arthroplasty implantation in 3 different posture types (A-C). If the arm is kept in neutral rotation, the humeral component retrotorsion (*black rectangle with concave and convex sides*) needs to match the scapular internal rotation to reach perfect opposition to the glenosphere (type A, *blue*; type B, *green*; and type C, *red*). The displayed angle for each type reflects its mean measurement in the study cohort.

observed in this study were retrospectively analyzed. PET-CT scans were applied for different clinical indications, which could lead to selection bias.

Conclusion

Scapular orientation and posture should be integrated into the determination process of humeral component retrotorsion in RTSA to provide neutral opposition of the humeral component to the glenosphere in resting arm rotation. In theory, implantation of the humeral component with increased retrotorsion leads to improved neutral opposition of the RTSA components in patients with extensive internal rotation of the scapula. On the basis of varying scapular internal rotation, we propose the distinction of 3 different posture types (A-C) for enhanced appraisal of scapulothoracic orientation: patients with physiological thoracic posture and retracted shoulders (type A); average patients with moderate hyperkyphosis, scapular protraction, tilt, drooping, and internal rotation (type B); and patients with severe hyperkyphosis, scapular protraction, tilt, drooping, and internal rotation (type C).

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References

1. Ailon T, Shaffrey CI, Lenke LG, Harrop JS, Smith JS. Progressive spinal kyphosis in the aging population. Neurosurgery 2015;77(Suppl 4):S164-72. https://doi.org/10.1227/NEU.0000000000000944
2. Berhouet J, Garaud P, Favard L. Influence of glenoid component design and humeral component retroversion on internal and external rotation in reverse shoulder arthroplasty: a cadaver study. Orthop Traumatol Surg Res 2013;99:887-94. https://doi.org/10.1016/j.otsr.2013.08.008
3. Boileau P, Walch G. The three-dimensional geometry of the proximal humerus. Implications for surgical technique and prosthetic design. J Bone Joint Surg Br 1997;79:857-65.
4. Boileau P, Watkinson DJ, Hatzidakis AM, Balg F. Grammont reverse prosthesis: design, rationale, and biomechanics. J Shoulder Elbow Surg 2005;14(1 Suppl S):147S-61S. https://doi.org/10.1016/j.jse.2004.10.006
5. De Wilde LF, Berghs BM, VandeVyver F, Schepens A, Verdonk RC. Glenohumeral relationship in the transverse plane of the body. J Shoulder Elbow Surg 2003;12:260-7. https://doi.org/10.1016/s1058-2746(02)86884-7
6. Edelson G. Variations in the retroversion of the humeral head. J Shoulder Elbow Surg 1999;8:142-5.
7. Goldberg RW, Williamson DF, Hoyen HA, Liu RW. Humeral version and neck-shaft angle correlated with demographic parameters in a study of 1104 cadaveric humeri. J Shoulder Elbow Surg 2020 [Epub ahead of print]. https://doi.org/10.1016/j.jse.2019.10.009
8. Grammont PM, Baulot E. Delta shoulder prosthesis for rotator cuff rupture. Orthopedics 1993;16:65-8.
9. Gulotta LV, Choi D, Marinello P, Knutson Z, Lipman J, Wright T, et al. Humeral component retroversion in reverse total shoulder arthroplasty: a biomechanical study. J Shoulder Elbow Surg 2012;21:1121-7. https://doi.org/10.1016/j.jse.2011.07.027
10. Karelse AT, Bhatia DN, De Wilde LF. Prosthetic component relationship of the reverse Delta III total shoulder prosthesis in the transverse plane of the body. J Shoulder Elbow Surg 2008;17:602-7. https://doi.org/10.1016/j.jse.2008.02.005
11. Kim MS, Jeong HY, Kim JD, Ro KH, Rhee SM, Rhee YG. Difficulty in performing activities of daily living associated with internal rotation after reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2020; 29:86-94. https://doi.org/10.1016/j.jse.2019.05.031
12. Kontaxis A, Chen X, Berhouet J, Choi D, Wright T, Dines DM, et al. Humeral version in reverse shoulder arthroplasty affects impingement in activities of daily living. J Shoulder Elbow Surg 2017;26:1073-82. https://doi.org/10.1016/j.jse.2016.11.052
13. Ladermann A, Gueorguiev B, Charbonnier C, Stimec BV, Fasel JH, 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. https://doi.org/10.1097/MD.0000000000001615I
14. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977;33:159-74.
15. Ludewig PM, Phadke V, Braman JP, Hassett DR, Cieminski CJ, LaPrade RF. Motion of the shoulder complex during multiplanar humeral elevation. J Bone Joint Surg Am 2009;91:378-89. https://doi.org/10.2106/JBJS.G.01483
16. Matsumura N, Ogawa K, Kobayashi S, Oki S, Watanabe A, Ikegami H, et al. Morphologic features of humeral head and glenoid version in the normal glenohumeral joint. J Shoulder Elbow Surg 2014;23:1724-30. https://doi.org/10.1016/j.jse.2014.02.020
17. McClure PW, Michener LA, Sennett BJ, Karduna AR. Direct 3-dimensional measurement of scapular kinematics during dynamic movements in vivo. J Shoulder Elbow Surg 2001;10:269-77.
18. Park JY, Hwang JT, Oh KS, Kim SJ, Kim NR, Cha MJ. Revisit to scapular dyskinesis: three-dimensional wing computed tomography in prone position. J Shoulder Elbow Surg 2014;23:821-8. https://doi.org/10.1016/j.jse.2013.08.016
19. Sirveaux F, Favard L, Oudet D, Huquet D, Walch G, Mole D. Grammont inverted total shoulder arthroplasty in the treatment of glenohumeral osteoarthritis with massive rupture of the cuff. Results of a multicentre study of 80 shoulders. J Bone Joint Surg Br 2004;86: 388-95. https://doi.org/10.1302/0301-620x.86b3.14024
20. Stephenson DR, Oh JH, McGarry MH, Rick Hatch GF III, Lee TQ. Effect of humeral component version on impingement in reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2011;20:652-8. https://doi.org/10.1016/j.jse.2010.08.020
21. Takenaga T, Goto H, Tsuchiya A, Yoshida M, Fukuyoshi M, Nakagawa H, et al. Relationship between bilateral humeral retroversion angle and starting baseball age in skeletally mature baseball players-existence of watershed age. J Shoulder Elbow Surg 2019;28: 847-53. https://doi.org/10.1016/j.jse.2018.10.017
22. Werner CM, Steinmann PA, Gilbart M, Gerber C. Treatment of painful pseudoparesis due to irreparable rotator cuff dysfunction with the Delta III reverse-ball-and-socket total shoulder prosthesis. J Bone Joint Surg Am 2005;87:1476-86. https://doi.org/10.2106/JBJS.D.02342
23. Yamamoto N, Itoi E, Minagawa H, Urayama M, Saito H, Seki N, et al. Why is the humeral retroversion of throwing athletes greater in dominant shoulders than in nondominant shoulders? J Shoulder Elbow Surg 2006;15:571-5. https://doi.org/10.1016/j.jse.2005.06.009