The active and passive kinematic difference between primary reverse and total shoulder prostheses

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Background: Reverse shoulder arthroplasty (RSA) and total shoulder arthroplasty (TSA) effectively decrease pain and improve clinical outcome. However, indications and biomechanical properties vary greatly. Our aim was to analyze both active and passive shoulder motion (thoracohumeral [TH], glenohumeral [GH], and scapulothoracic [ST]) and determine the kinematic differences between RSAs and TSAs.
Methods: During 3 range-of-motion (ROM) tasks (forward flexion, abduction, and axial rotation), the motion patterns of 16 RSA patients (19 shoulders), with a mean age of 69 ± 8 years (range, 58-84 years), and 17 TSA patients (20 shoulders), with a mean age of 72 ± 10 years (range, 53-87 years), were measured. The mean length of follow-up was 22 ± 10 months (range, 6-41 months) for RSA patients and 33 ± 18 months (range, 12-87 months) for TSA patients. Kinematic measurements were performed with a 3-dimensional electromagnetic tracking device.
Results: All patients showed better passive than active ROM. This difference was significantly larger for RSA patients than for TSA patients (TH in sagittal plane, 20° vs 8° [$P = .001$]; GH in sagittal plane, 16° vs 7° [$P = .003$]; TH in scapular plane, 15° vs 2° [$P < .001$]; GH in scapular plane, 12° vs 0° [$P < .001$]; and ST in scapular plane, 3° vs −2° [$P = .032$]). This finding also showed that in the scapular plane, TSA patients showed hardly any difference between active and passive ROM. Furthermore, TSA patients had 16° to 17° larger active TH motion, 15° larger active GH motion, and 8° larger active ST motion compared with RSA patients. The GH-ST ratios showed similar figures for both types of prostheses.
Conclusion: TSA patients have larger active TH motion because in the scapular plane, they completely use the possible GH motion provided by the prosthetic design. This larger active ROM in TSA patients only applies for elevation and abduction, not for axial rotation or passive ROMs.

In the majority of patients with advanced shoulder arthritis in whom nonoperative treatment has failed, both reverse shoulder arthroplasty (RSA) and total shoulder arthroplasty (TSA) effectively decrease pain and improve clinical outcome.[6,8,10,11,15,22,25,29,30] However, the indications for these 2 different procedures and the biomechanical properties of the 2 prostheses vary greatly, which likely will influence the kinematics of the shoulder girdle. A recent comparison of RSA and TSA patients indeed showed better postoperative active range of motion (ROM) in TSA patients, but those ROM measurements were performed with a digital goniometer during a video-recorded physical examination, thus only measuring the movement of the arm relative to the thorax (thoracohumeral [TH] motion).[20] Because the total TH motion consists of both glenohumeral (GH) and scapulothoracic (ST) motion, using a measurement tool that can measure both elements will provide more detailed and useful information on shoulder kinematics with these prostheses and give more insight into the differences between RSA and TSA.

Using an electromagnetic system (Flock of Birds [Ascension Technology, Burlington, VT, USA] with Motion-Monitor software [Innovative Sports Training, Chicago, IL, USA]), Bergmann et al[3] found better passive than active ROM in RSA patients, for both TH motion and GH motion. However, their group of patients consisted of primary RSAs, as well as RSAs used for revision surgery, and it is known that in RSAs in revision cases, the GH motion is altered compared with primary cases.[2] Similar differences in ROM, using the same measurement method, were found for anatomic shoulder replacements by Veeger et al,[27] but half of this group consisted of patients with hemiarthroplasties. By measuring both active and passive ROM, it might be possible to find an explanation for the differences between the 2 types of prostheses. However, to our knowledge, a more controlled comparison between RSA and TSA, taking the indication (primary or revision) and active/passive contribution into account, is not yet available.

Some publications evaluated RSA function: Kwon et al,[13] also using the Flock of Birds, measured elevation, abduction, and movement in the scapular plane between 30° and 120°; they showed that in RSA patients, as compared with healthy subjects, the kinematics of the shoulder were altered with a larger ST contribution, in that way changing the scapulohumeral rhythm (GH-ST ratio). They also found that the ST contribution was even more pronounced when external loads to the arm were added.

Similar results were obtained by de Toledo et al[7] comparing healthy subjects with TSA and RSA patients, with and without external loads, using the same electromagnetic measuring device. However, they only measured the movement of the arm until 90° of anteflexion and abduction, and their RSA group consisted of a large number of revision cases. To be able to analyze a possible difference in the way that RSAs and TSAs alter shoulder kinematics in combination with the ST contribution, a comparison of the GH and ST motion for the total TH motion, between patients with primary RSA and TSA placement, could provide this information but has not yet been performed.

Therefore, the objective of this study was to obtain kinematic data (TH, GH, and ST motion) in both patient groups and test the following hypotheses: (1) There is a difference in active and passive ROM between RSA and TSA patients, and (2) the GH-ST ratio is altered in TSA patients and in RSA patients.

Materials and methods

Participants

To rule out other possible influencing factors, we only included primarily placed prostheses and excluded revision cases. Between May 2000 and September 2007, we treated 45 patients (49 shoulders) with a reverse shoulder prosthesis (Tornier, Edina, MN, USA). Of these patients, 16 (10 women and 6 men) volunteered to participate in this study. The operation was performed on the left side in 6 patients, on the right side in 7, and on both sides in 3 (total of 19 shoulders). In all patients, the indication for the reverse prosthesis was cuff tear arthropathy. The mean time between surgery and measurement was 22 ± 10 months (range, 6-41 months). The mean age of the patients was 69 ± 8 years (range, 58-84 years). For the recruitment of TSA patients, we selected the period from August 2005 to November 2008, during which we treated 99 patients (109 shoulders) with a total shoulder prosthesis (Aequalis; Tornier). From this group, 17 consecutive patients (13 women and 4 men) participated in this study. The operation was performed on the left side in 7 patients, on the right side in 7, and on both sides in 3 (total of 20 shoulders). In all patients the indication for the TSA was primary osteoarthritis. The mean time between surgery and measurement was 33 ± 18 months (range, 12-87 months). The mean age of the patients was 72 ± 10 years (range, 53-87 years). All patients gave their written informed consent before the experiment.

All patients were operated on under general anesthesia with an interscalene plexus block in the beach-chair position. We used a
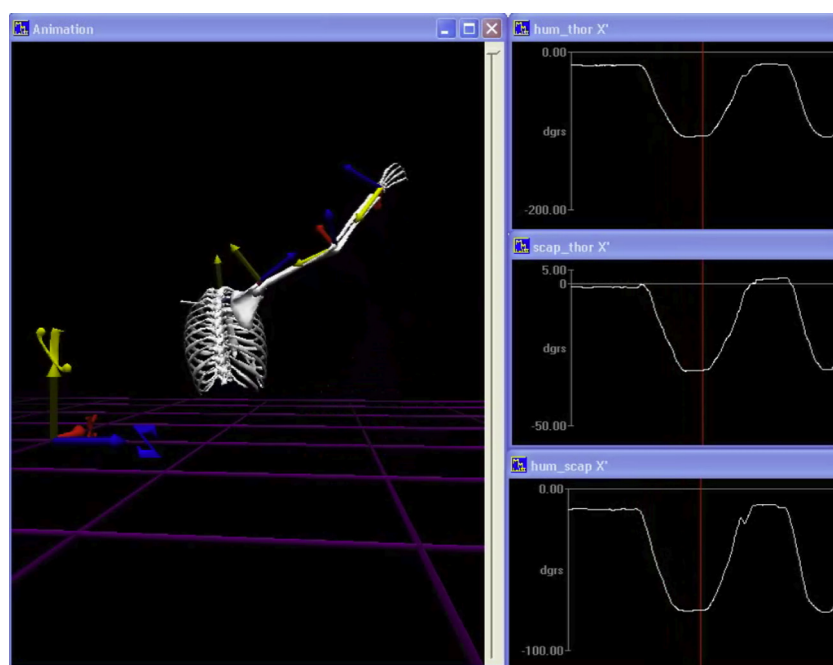
Figure 1 MotionMonitor image of one of the patients, with the real-time visualization of the virtually constructed skeleton with the x-, y-, and z-axes of all the joints, together with the TH, ST, and GH motions in the scapular plane. This image is a still image from a video, where the *red line* in the images on the right is moving from left to right during elevation of the arm, showing the contribution of all 3 elements (TH, ST, and GH) at every moment.

standard deltopectoral approach in all patients. In the RSA patients, all glenoid components had been placed inferior on the glenoid surface with no inferior or superior inclination. In 18 shoulders, a 36-mm glenosphere was implanted, and in 1 shoulder, a 42-mm glenosphere was used. The humeral components had all been placed in 10° to 20° of retroversion; in 17 shoulders, the teres minor muscle was still intact; in all cases, the infraspinatus muscle was completely ruptured; and in almost all cases, the inferior two-thirds part of the subscapularis muscle was still intact and was reattached at the end of the procedure. In the TSA patients, both components of the third-generation modular prosthesis were cemented, with a curved keeled polyethylene glenoid prosthesis.

Postoperative management was the same for all patients, consisting of a sling and passive ROM exercises for 6 weeks, followed by 6 weeks of active-assisted ROM exercises. At 3 months, strengthening exercises were added to the rehabilitation.

Kinematics

To obtain the kinematic data, measurements were performed at the Duyvensz-Nagel Research Laboratory of Reade (Amsterdam, The Netherlands), using the Flock of Birds, which is a 6-*df* electromagnetic tracking device.

This system consists of an extended-range transmitter that creates a 3-dimensional magnetic field. Electromagnetic sensors were attached to the sternum, humerus, forearm, and acromion.[12] The sensor on the sternum was located on the upper part of the sternum, the sensor on the humerus was positioned on the middle part of the arm, the sensor on the forearm was located on the middle part of the forearm, and the sensor on the acromion was placed on the flattest part of the acromion. The sensors on the

sternum and acromion were fixed with double-sided adhesive tape and covered with a Fixomull stretch self-adhesive bandage (Beiersdorf AG, Hamburg, Germany), and the sensors on the arm and forearm were fitted by use of a brace.[16] An additional sensor, which was attached to a pointer, was used to digitize 13 bony landmarks relative to their sensors. The pointer is a non-metal object with a fine point upon which a kinematic sensor can be secured, and it assists in locating segment endpoints and other bony landmarks with greater precision. For tracking of the scapula, we used a scapula locator, which has also been applied in other studies,[2,3,14,27] in combination with the sensor on the acromion. The local vectors from the bony landmarks related to the sensors were calculated and were used to construct anatomic local coordinate systems for the thorax, humerus, scapula, and forearm, using MotionMonitor software (Fig 1). Subsequently, the segments and joint rotations were calculated using the combination of these local anatomic coordinate systems and the sensor motions. For the humerus, the proximal landmark was assumed to be in the GH rotation center estimated by the rotation method.[26] Local anatomic coordinate systems, segments, and joint rotations were all defined in accordance with the International Society of Biomechanics standardization proposal for the upper extremity.[31]

Three ROM tasks were actively and passively performed: (1) elevation in the sagittal plane ("forward flexion"), (2) abduction in the scapular plane ("abduction"),[17] and (3) rotation (internal and external rotation) of the arm with 90° of abduction ("axial rotation"). We instructed the patients to reach a maximal joint angle when performing each active ROM task. When performing forward flexion, the patients were instructed to elevate the arm as high as possible. By using a semicircular board, which the patients could follow as a reference during scapular abduction, the right plane of motion was maintained. This board was fixed in a 30°

angle relative to the frontal plane. The passive ROM tasks were performed by one of the investigators, by moving the arm of the patient for him or her, until considerable resistance was met. Each task was performed 3 times. If all 3 attempts were available for analysis, the second attempt was used for further processing.

For all ROM tasks, 3 different motions were calculated: (1) the motion of the humerus relative to the thorax (ie, TH motion), (2) the motion of the humerus relative to the scapula (ie, GH motion), and (3) the motion of the scapula relative to the thorax (ie, ST motion). All motions were expressed in joint angles, defined based on the International Society of Biomechanics standardization proposal of the International Shoulder Group.[31] Data from the left shoulders were mirrored to the right before further data analysis took place, to ensure that consistent angle definitions were made. Differences between the TH and GH angles represent the contribution of scapular motion to the movement of the arm. For TH motion, as well as GH motion, the decomposition order was chosen following the globographic convention, which is the plane of elevation, elevation, and axial rotation.[9] External rotation is expressed as negative axial rotation and internal rotation as positive axial rotation. The peak TH elevation values for each shoulder were determined for the elevation tasks, and for the axial rotation tasks, the peak external and internal TH rotation values were measured. As has been shown in earlier research on the reverse prosthesis, there is no significant difference between these axial rotations in the TH rotations and GH rotations, suggesting that the axial rotations mainly take place in the GH joint.[3] We calculated the minimum, maximum, mean, and standard deviation for all shoulders for each of the previously mentioned angles. To assess the contribution of the scapula, we determined the GH-ST ratio by dividing (the change in) the peak of the TH elevation angle by (the change in) the peak of the GH elevation angle.

Statistical analysis

By use of a 2×2 general linear model analysis of variance with repeated measures with mode (active vs passive) as the within-patient factor and group (RSA vs TSA) as the between-patient factor, the differences between active and passive ROM and between RSA and TSA, as well as the interaction effect (mode $\times$ group), were evaluated. Subsequently, a paired-sample t test was performed to determine the difference between active and passive ROM within each group for TH, GH, and ST motion and the GH-ST ratio. To evaluate the differences between RSA and TSA for all the ROM variables and the GH-ST ratios, a 1-way analysis of variance was performed. The significance level was set at .05.

Results

For the patient groups combined, passive ROM was significantly larger than active ROM for the TH and GH motions in both planes and for external rotation (Table I), whereas no significant differences were found between active and passive ROM for ST motion and internal rotation. Only for the ST motion in the sagittal plane was a significant main effect for patient group found, with larger ROM in TSA patients than in RSA patients.

The difference between active and passive ROM was significantly larger for RSA patients than for TSA patients for the TH and GH motions in the sagittal plane (20° vs 8° and 16° vs 7°, respectively) (Table I), for all 3 motions in the scapular plane (TH, 15° vs 2°; GH, 12° vs 0°; and ST, 3° vs −2°), and for internal rotation (5° vs −11°, $P = .043$), as indicated by the significant interaction effects.

When active ROM and passive ROM were compared by type of prosthesis, RSA patients had significantly larger passive than active TH and GH ROM in both planes, as well as larger passive external rotation. TSA patients only showed larger passive than active TH and GH ROM in the sagittal plane and larger passive external rotation and internal rotation; they showed no significant difference in active versus passive TH and GH motion in the scapular plane (Table I).

Evaluating the difference in active ROM between the 2 types of prostheses, we found that TSA patients had 16° more TH motion and 8° more ST motion in the sagittal plane ($P = .01$ and $P = .018$, respectively) than RSA patients. In the scapular plane, the TH motion was 17° larger and the GH motion was 15° larger ($P = .016$ and $P = .01$, respectively). Passive ROM only showed a difference in internal rotation of 18° in favor of the RSA cases ($P = .049$) (Table I). Although the prostheses behaved differently, the GH-ST ratios, in contrast, showed similar patterns for both types without significant differences (Table II).

Discussion

Although RSA and TSA effectively decrease pain and improve clinical outcome,[6,8,10,11,15,22,25,29,30] their biomechanical properties vary greatly. To better understand how these 2 types of prostheses affect shoulder kinematics, it seems appropriate to measure not only the total TH motion (the movement of the arm relative to the thorax) but also the two separate parts of the excursion, that is, the GH motion and the ST motion. On top of the separate parts of the motion, measuring both active and passive ROM also could provide an explanation for a possible difference between the 2 types of prostheses. In fact, earlier research showed differences in favor of passive ROM compared with active ROM for RSA[3] and anatomic shoulder prostheses[27] in groups with a variety of types of prostheses and indications. Another point of interest is the larger ST contribution compared with the GH contribution, which Kwon et al[13] recently showed in RSA patients and de Toledo et al[7] showed in TSA and RSA patients. However, de Toledo et al only measured the movement of the arm until 90° of anteflexion and abduction. Therefore, we obtained active and passive kinematic data (TH, GH, and ST motions) in both patient groups and showed the following: (1) There is a difference in active ROM between RSA and TSA patients for the TH motion in both planes, for the GH motion in the scapular plane, and for the ST motion in the

Table I Maximal active and passive joint angles for 19 RSA and 20 TSA shoulders during elevation and rotation tasks

Plane of movement	Shoulder motion	Movement	RSA (°)			TSA (°)			General linear model (P value)		
			Active ROM	Passive ROM	Paired t test for active vs passive (P value)	Active ROM	Passive ROM	Paired t test for active vs passive	Mode	Group	Mode × group
Sagittal	TH	Forward flexion	93 ± 21 (44 to 127)	113 ± 16 (85 to 154)	<.001*	109 ± 18 (59 to 131)†	117 ± 16 (69 to 135)	<.001*	<.001*	.062	.001*
	GH		71 ± 18 (41 to 108)	87 ± 16 (62 to 116)	<.001*	80 ± 17 (34 to 102)	87 ± 17 (42 to 113)	<.001*	<.001*	.388	.003*
	ST		30 ± 11 (1 to 43)	32 ± 10 (3 to 43)	.124	38 ± 11 (23 to 67)†	38 ± 11 (19 to 62)	.848	.139	.03*	.197
Scapular	TH	Abduction	93 ± 22 (41 to 139)	108 ± 21 (62 to 152)	<.001*	110 ± 19 (67 to 141)†	112 ± 17 (71 to 135)	.2	<.001*	.097	<.001*
	GH		64 ± 15 (45 to 95)	76 ± 18 (55 to 111)	<.001*	79 ± 19 (34 to 99)†	79 ± 18 (37 to 106)	.982	<.001*	.118	<.001*
	ST		33 ± 15 (0 to 52)	36 ± 14 (0 to 55)	.096	39 ± 13 (16 to 67)	37 ± 11 (22 to 61)	.18	.769	.399	.032*
Scapular, arm at 90° of abduction	External rotation	Rotation	−31 ± 25 (5 to −93)	−47 ± 32 (34 to −94)	.01*	−42 ± 12 (−23 to −60)	−49 ± 16 (−21 to −80)	.018*	<.001*	.379	.108
	Internal rotation	Rotation	21 ± 24 (−35 to 60)	26 ± 37 (−54 to 90)	.501	19 ± 18 (−11 to 58)	8 ± 17 (−20 to 40)†	.003*	.428	.146	.043*

Data are given as mean ± standard deviation (range). External rotation is negative axial rotation, and internal rotation is positive axial rotation.

* Statistically significant difference.

† Significant difference in ROM between the 2 types of prostheses.

Table II GH-ST ratio for 19 RSA and 20 TSA shoulders for active and passive elevation tasks in both planes

Plane of movement	Movement	GH-ST ratio		One-way analysis of variance for RSA vs TSA (P value)
		RSA	TSA	
Sagittal	Active	1.34 ± 0.3	1.41 ± 0.3	.437
	Passive	1.32 ± 0.2	1.38 ± 0.2	.423
Scapular	Active	1.49 ± 0.3	1.44 ± 0.3	.694
	Passive	1.45 ± 0.3	1.48 ± 0.3	.761

Data are given as mean $\pm$ standard deviation.

sagittal plane in favor of the TSA patients but not for the active axial rotations or any of the passive ROMs, and (2) the GH-ST ratio is altered in TSA patients in a similar way to that in RSA patients.

We note some limitations to our study. First, we had a wide range of follow-up times between the operation date and shoulder kinematic measurements, especially for the RSA patients. In the ideal situation, our measurements should have been performed with the same time interval postoperatively for every patient, with a minimum follow-up of 1 or 2 years. However, for logistical reasons, it was not possible to include patients with the same follow-up period because this would have required an inclusion period of several years. We therefore decided to include all patients available from our 2 treated pools (RSA and TSA). The second limitation is the lack of proper control data from an age-matched control group without cuff pathology or GH arthritis. However, the prevalence rates of asymptomatic cuff tears of 31% in individuals aged between 70 and 79 years and 51% in individuals aged older than 80 years,[23] together with an increased risk of GH osteoarthritis with age, with odds ratios of 2.20 in individuals aged between 70 and 74 years and 3.42 in individuals aged older than 75 years,[18] make this hard to obtain. Another possibility would be to compare the outcomes with the contralateral side in the same patient. However, cuff pathology in the contralateral shoulder is not uncommon. The mean age of patients with a bilateral cuff tear in the study by Yamaguchi et al[32] was 67.8 years, and logistic regression analysis indicated a 50% likelihood of a bilateral tear after the age of 66 years. In patients who had a full-thickness symptomatic tear, the prevalence rate of a full-thickness tear on the contralateral side was 35.5%. In our patient population, 19% of patients already had an RSA on both sides. A similar argument applies for GH arthritis. Oh et al[18] found bilateral shoulder osteoarthritis in 47.7% of patients with primary shoulder osteoarthritis. In our patient population, 17% of patients already had a TSA on both sides. Third, the displacement of the center of rotation in the vertical plane (distalization), which—together with the change in the position in the horizontal plane (medialization)—is the consequence of RSA, will probably also influence the change in GH-ST ratio. Unfortunately, in our RSA patients, we do not have preoperative and

postoperative arm-length measurement data, and we are therefore not able to make any comments on the distalization of the center of rotation and its possible relation to the GH motion in these patients.

Similar to Puskas et al,[20] we showed that TSA patients have significantly better postoperative active ROM than RSA patients (Table I). It could be possible to find an explanation for this difference by also measuring passive ROM. Bergmann et al[3] reported a significant difference between passive ROM and active ROM for RSA patients and postulated that this difference could not have been caused by the prosthetic design because passive ROM was larger. A similar statement can now be made for TSA patients because, besides internal rotation, no other part of the motion between the 2 types of prostheses showed a significant difference for the passive ROM tasks (Table I). If we look at the differences in passive and active ROM within the types of prostheses, the fact that the RSA patients showed differences between passive and active ROM in both planes (sagittal and scapular) and the TSA patients showed this difference only in the sagittal plane suggests that both prostheses do not mimic the normal shoulder motion. However, the absence of a difference between active and passive motion in the scapular plane in the TSA patients suggests that the TSAs act more anatomically in the so-called zero position[21] and can better actively fully use the possible GH motion of the prosthesis in this plane, as compared with the RSA patients (Table I). Thus, the next question is as follows: Why can the TSA patients better actively use the GH motion than the RSA patients?

The ideal TSA prosthesis mimics the normal anatomy of the humerus as much as possible while leaving the center of rotation at its normal anatomic position. In the RSA, the center of rotation is displaced more medially. To prevent impingement occurring during ROM, new developments in different RSA designs have led to lateralization of the center of rotation, closer to its normal anatomic position. This lateralization can be obtained by returning to the previous design of the Grammont prosthesis and creating two-thirds of a sphere,[5] thus increasing the offset of the prosthesis, termed "metallic" lateralization.[11] Another method is to create a long-necked scapula, still leaving the center of rotation within the bone, called

bony increased-offset RSA.[4] A recent computer model study from Virani et al[28] showed that a larger offset of the center of rotation of the glenosphere will lead to an increase in motion in all planes and not only of the axial rotations. Kwon et al[13] performed a kinematic analysis, using the same measurement technique that we used, in patients with an RSA with a more "metallic" lateralized center of rotation. Unfortunately, they only reported their GH and ST motions as part of the scapulohumeral rhythm, expressed in figures and not in exact ROM angles. Therefore, we could only make an estimation of their results to be able to compare them. Kwon et al showed an active GH motion of 65° to 70°, which is similar to ours (Table I). Thus, a more lateralized center of rotation, in the direction of its normal position, could possibly improve the active ROM of an RSA, as described in the computer model study[28] and possibly suggested by the comparison between the study of Kwon et al and our study. However, future research, obtaining GH kinematic data and comparing standard RSA patients with RSA patients with a more lateralized center of rotation, either bony or metallic, should be performed, to be able to conclude whether the lateralized center of rotation really enables those patients to better use the complete GH motion.

Another explanation for the inability of RSA patients to maximally use the possible GH motion of the prosthesis for abduction could be a lack of force-generating capacity, already suggested in earlier research.[3] Puskas et al[20] showed a significantly higher postoperative isometric force-generating capacity in TSA patients compared with RSA patients. A recently submitted study from our group, evaluating the isokinetic force-generating capacity, also found significantly higher joint torques for TSA patients for abduction/adduction and external/internal rotation (unpublished data, T.D.W. Alta, October 2013). The most important reason for this difference is probably the presence of a functional rotator cuff. With the supraspinatus muscle being a synergist of the deltoid muscle during abduction,[1] this will increase the abduction torque and force-generating capacity, as compared with RSA patients. In 2008, Terrier et al[24] showed, in a shoulder model, that during the entire range of abduction, the joint force amplitude was reduced by 50% in RSAs without any rotator cuff muscles and by 30% when only the supraspinatus was deficient, as compared with TSAs. They also found that the maximal contact force in the GH joint was 42% of the body weight when all rotator cuff muscles were missing, 62% when only the supraspinatus muscle was missing, and 86% for the TSAs. Furthermore, the direction of this force in combination with the corresponding contact force on the humeral surface was very different in both types of prostheses. For the TSAs, the contact area on the glenoid remained centered, and on the humeral side, it moved from inferior to superior, using the complete sphere of the humeral component. For the RSAs, however, the contact area on the humeral component remained approximately in the same location, at the inferior

portion of the cup, and only used half of the inferior part of the glenosphere on the glenoid side.

As reported earlier by Kwon et al[13] and de Toledo et al,[7] we found that the contribution of the scapula to the entire motion was larger for both types of prostheses, when compared with controls, but did not differ between the two types (Table II). We expected the scapular contribution to motion in the RSA patients to be larger because the RSA is a semiconstrained prosthesis. The RSA patients can therefore fully use the scapula for elevation and abduction and do not need to use the scapula to also stabilize the humeral head during motion, as is the case in a normal shoulder or in a TSA patient. We therefore expected to find a more altered GH-ST ratio in RSA patients, as compared with TSA patients and healthy individuals (reported in the literature),[19] but for both tasks (active and passive) and both planes (sagittal and scapular), this was not the case. Therefore, we can conclude that TSAs do not mimic normal anatomy.

Conclusion

Primary TSA patients have more active ROM for TH motion than primary RSA patients because, in the scapular plane, they completely use the possible GH motion provided by the prosthetic design. This larger active ROM in TSA patients only applies for elevation and abduction, not for axial rotation or any of the passive ROMs.

For both types of prostheses, we found that the scapular contribution to the complete motion was the same, but it was larger compared with data from healthy subjects reported in the literature. Although we thought that the TSA mimicked normal anatomy, we have to conclude that the RSA and TSA do not fully replicate normal active shoulder motion.

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Disclaimer

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