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Kinematic and clinical evaluation of shoulder function after primary and revision reverse shoulder prostheses

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Hypothesis: Results of the reverse shoulder prosthesis on pain are generally satisfying; however, active range of motion (ROM) is often not optimal, especially after revision. A kinematic and clinical analysis of the reverse prosthesis was performed to provide more precise information on its glenohumeral motion pattern. We hypothesized that the difference in the primary and revision cases is due to differences in the motion in the glenohumeral joint.
Materials and methods: The motion pattern of 31 patients with a reverse prosthesis (35 shoulders, 19 primary and 16 revisions) was measured during 3 active ROM tasks—forward flexion, abduction, and axial rotation. Average age was 71 ± 8 years (range, 58-85 years). Average follow-up was 23 ± 14 months (range, 4-63 months). Kinematic measurements were performed with a 3-dimensional electromagnetic tracking device. Clinical evaluation was performed by obtaining Constant score, Disabilities of Arm, Shoulder and Hand (DASH) score, and the Simple Shoulder Test (SST). Acromial-prosthetic distance was measured on anteroposterior radiographs.
Results: Primary placed prostheses showed significantly better active glenohumeral motion than revisions for forward flexion (71° ± 18° vs 53° ± 26°, $P < .05$), abduction (64° ± 15° vs 46° ± 24°, $P < .05$), and active external rotation (31° ± 25° vs 13° ± 16°, $P < .05$). Constant score improved for the whole group from 24 (range, 5-47) to 50 (range, 8-87; $P < .001$), for the primary group from 28 (range, 13-47) to 60 (range, 8-87; $P < .001$) and for revisions from 20 (range, 5-47) to 38 (range, 11-73; $P < .001$). Acromial-prosthetic distance showed no significant correlation for active glenohumeral motion. Five shoulders with a deficient teres minor muscle showed no significant decrease of external rotation.
Conclusion: Active ROM is better in primary placed prosthesis, and this difference takes place mainly in the glenohumeral joint. In all our patients, Constant scores improved significantly postoperatively. However, we could not find any clinical correlating parameters to explain this difference.

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Level of evidence: Level III, Case Control Study, Treatment Study.

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In the treatment of patients with glenohumeral arthritis and severe rotator cuff deficiency, the reverse prosthesis offers a solution with good short-term and medium-term results in pain reduction. The active range of motion (ROM) is often not optimal and the contribution of this prosthesis to restoration of the arm function is less clear. The maximum postoperative active elevation is diverse, ranging from 88°[1] to 118°[5] and even to 138°.[18]

A possible explanation for the diversity in this elevation outcome could be the inconsistency in measuring the ROM. Although most studies do not include a detailed measurement protocol, most studies measured this ‘‘elevation’’ as the complete thoracohumeral motion. However, this thoracohumeral motion actually consists of 2 separate phases: a glenohumeral and a scapulothoracic motion. Because the prosthesis only replaces the glenohumeral joint, more accurate information on the function of this prosthesis may be provided by describing both parts of the arm motion separately and, in particular, the glenohumeral motion.

In an earlier study, we described[1] that the reverse prosthesis enables a motion pattern with a normal glenohumeral contribution comparable to that of a normal shoulder.[6] That study also showed that when the glenohumeral motion of the reverse prosthesis is limited, this seems to be the result of a lack of muscle force generation rather than a structural limitation caused by the prosthetic design, because we found a significant difference between the active and passive ROM in these patients. Therefore, the question remains whether this lack of force generation is mainly a problem related to a change of muscle properties (lengthening, shortening) or that other clinical parameters are also involved.

When the reverse prosthesis is used in revision surgery, the improvement of function is even less, only to approximately 70° of active elevation,[12] and the complication rate is higher.[21] Again, this improvement in active elevation mostly represents the total thoracohumeral motion. Our hypothesis is that the difference in the primary and revision cases is due to differences in the motion in the glenohumeral joint.

The primary purpose of this study, therefore, was to compare the kinematics of the arm in total thoracohumeral motion, and subsequently in the glenohumeral and scapulothoracic plane, in patients with a primary placed reverse prosthesis and those with a revision. A second goal was to identify radiologic parameters to explain any of the found differences in motion pattern.

Materials and methods

The research protocol was approved by the Medical Ethics Committee of the Onze Lieve Vrouwe Gasthuis, Amsterdam, The Netherlands (study number WO 05.027). All patients gave written informed consent before the experiment.

Participants

The study recruited 31 patients (18 women, 13 men) with a reverse shoulder prosthesis (Tornier, Edina, MN) inserted through a standard deltopectoral approach between May 2000 and September 2007. Operations were on the left side in 9 patients, on the right side in 18, and on both sides in 4, for a total of 35 shoulders. The indication in 19 patients for the reverse prosthesis was cuff tear arthropathy, and in 16 it was a revision after a failed primary placed hemi or total shoulder prosthesis with a nonfunctional rotator cuff at that time. All the glenoid components had been placed inferior, with no inferior or superior inclination. The sphere diameter was 36 mm in 28 and 42 mm in 7. The humeral components had all been placed in 10° to 20° of retroversion and were cemented. The average time between surgery and measurement was 23 ± 14 months (range, 4-63 months). Patients were a mean age of 71 ± 8 years (range, 58-85 years).

Kinematics

We used an electromagnetic Motion Monitor Biomech tracking device (Innovative Sports Training, Chicago, IL), consisting of a transmitter that created a weak magnetic field and 4 sensors. The sensors were attached to a pointer, the sternum, humerus, and a scapula locator.[9] The sensor on the sternum was fixed using double-sided adhesive tape and covered with a Fixomull stretch self-adhesive bandage (Beiersdorf AG, Hamburg, Germany). The humeral sensor was fitted using a brace.[14] This method and system has been used in studies regarding shoulder kinematics to calculate the three-dimensional (3D) position and orientation of the upper extremity.[13,15,20]

The pointer was used to digitize 13 bony landmarks relative to their sensors; in turn, these sensors were related to local anatomic coordinate systems. 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 chosen in the glenohumeral rotation center estimated by regression analysis using 5 bony landmarks of the scapula. Local anatomic coordinate systems, segment, and joint rotations were all defined following the International Society of Biomechanics standardization proposal for the upper extremity.[22]

We measured 3 actively performed ROM tasks: (1) elevation in the sagittal plane (forward flexion), (2) abduction in the scapular plane (abduction),[16] and (3) internal and external rotation of the

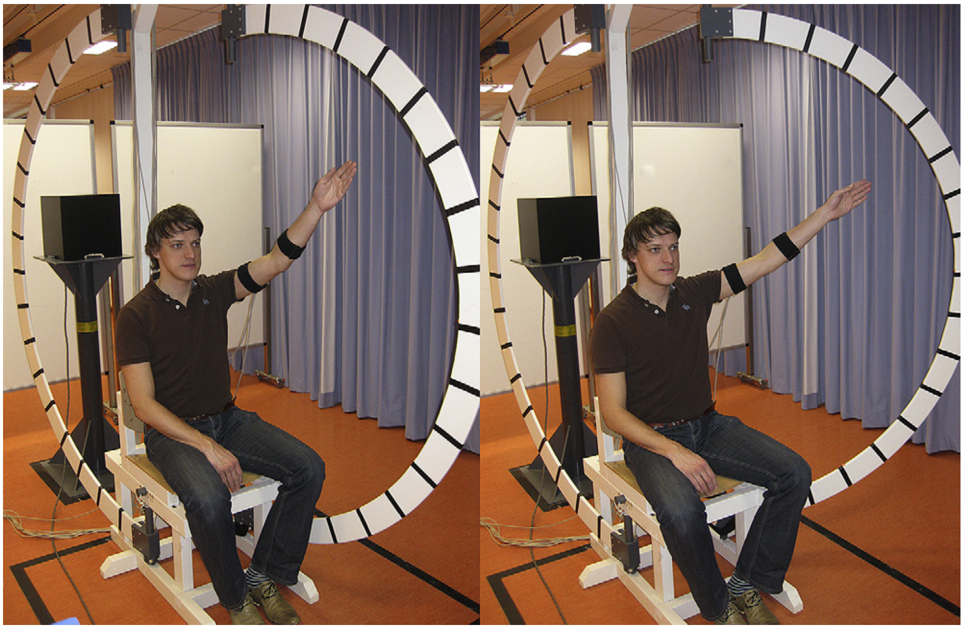

Figure 1 The motion monitor is shown with the transmitter and semicircular board, which can be placed in the sagittal plane and scapular plane, functioning as a reference for the patients to follow during the measurements.

arm with 90° of abduction (axial rotation). Patients were instructed to reach a maximal joint angle in each active ROM task. During the forward flexion, patients were instructed to elevate the arm as high as possible. Scapular abduction was maintained by using a semicircular board that they could follow as a reference. This board was fixed in a 45° angle relative to the frontal plane (Fig. 1).

Measurements were performed in quasi-static mode. No reliable noninvasive approach is available for dynamically tracking the scapula during a maximal humeral elevation, so we used a scapula locator similar to that applied in other studies.[13,20] We asked patients to perform each task 3 times. If all 3 attempts were available for analysis, the second attempt was used for further processing.

For each active ROM task, we calculated the 3 different motions: (1) the motion of the scapula relative to the thorax (ie, scapulothoracic motion), (2) the motion of the humerus relative to the thorax (ie, thoracohumeral motion), and (3) the motion of the humerus to the scapula (ie, glenohumeral motion). All motions were expressed in joint angles defined using the International Society of Biomechanics standardization proposal of the International Shoulder Group.[22] To ensure consistent angle definitions were made, data from the left shoulders were mirrored to the right before further data analysis took place. The difference between the thoracohumeral and glenohumeral angles reflects the contribution of scapular motion to the movement of the arm. For both the thoracohumeral and glenohumeral motions, the decomposition order was chosen following the globographic convention, which is plane of elevation, elevation, and axial rotation.[7] Negative axial rotation is external rotation, and positive axial rotation is internal rotation.

The thoracohumeral and glenohumeral elevation angles and external axial rotation angles were selected for further analysis. For the elevation tasks, we determined the peak thoracohumeral elevation value for each shoulder. For the axial rotation tasks, the peak external and internal thoracohumeral rotation values were determined. As seen in previous research with the reverse prosthesis,[1] there is no significant difference between these axial rotations in the thoracohumeral rotations and glenohumeral rotations, which suggests that the axial rotations take place in the glenohumeral joint. We calculated the minimum, maximum, mean, and standard deviation for all shoulders for each of the previously mentioned angles.

Clinical evaluation

We obtained the preoperative and postoperative (absolute and relative) Constant scores,[3,4] the postoperative Disabilities of Arm, Shoulder and Hand (DASH) score,[10] and the Dutch translation of the Simple Shoulder Test (NSST).[10,19] The absolute Constant score (maximum, 100 points) assesses the overall shoulder function. The relative Constant score is corrected for the age- and sex-related decline in force-generating capacity[23] and expressed as a *percentage* of the respective reference values. The DASH is a 30-item questionnaire that evaluates functional disability in everyday activities, work, and sports, and includes symptoms, physical, social, and psychologic function. A DASH score of 0 indicates good shoulder function, or no disability, and the maximum score of 100 indicates no function at all. The NSST consists of 13 questions with "yes" and "no" answers combining subjective items and items that require patients to complete a physical exercise and evaluates shoulder function in daily activities. The maximum score of 13 indicates good shoulder function.

Radiologic evaluation

The distance from the acromion to the top of the prosthesis was measured using digital preoperative Impax 5.1 planning software (AGFA Orthopaedic-Tools, Mortsel, Belgium) on the postoperative radiographs. First, the system was calibrated by a circle matching the sphere of the prosthesis, which was either 36 or 42 mm. Then, the distance was measured from the sclerotic line of the acromion to the top of the humeral component of the prosthesis, parallel to the line of the base plate, because this represents the postoperative subacromial space and could be an indication to what degree the deltoid muscle is tensioned postoperatively and influence the active forward flexion and abduction. The integrity of the teres minor muscle was determined by findings on preoperative magnetic resonance imaging or during the operation.

Statistical analysis

Analysis was done with SPSS 17.0 software (SPSS Inc, Chicago, IL). A formatted quantile-quantile plot showed that all data were normally distributed. The independent *t* test was used to evaluate differences between the primary and revision cases for continuous data (ie, thoracohumeral motion, glenohumeral motion, scapulothoracic motion, Constant scores, DASH, NSST, acromial-prosthetic distance) and a χ^2 test was used for dichotomous data (integrity of the teres minor muscle compared with motion). A paired *t* test was used to analyze the difference between the preoperative and postoperative Constant scores for the whole group and for the primary and the revision cases. Repeated measures analysis of variance was used to determine the progress in Constant scores postoperatively for the primary and the revision cases. A Pearson correlation test was used to correlate the postoperative acromial-prosthetic distance to the glenohumeral motion of the arm. Significance level was set at $P < .05$.

Results

Kinematics

Table I describes the joint angles during the different ROM tasks. Although all movements were normally distributed, wide ranges in active ROM were observed for all 3 movements. Overall, the glenohumeral motion contributed most (66%-72%) to the thoracohumeral motion in the sagittal and scapular planes.

The mean thoracohumeral motion for forward flexion in the sagittal plane was 86° ± 29° for the whole group, with no significant difference between the primary and revision patients (93° ± 21° vs 78° ± 36°, $P = .157$). For the scapular plane, mean thoracohumeral motion for abduction was 84° ± 29° for the whole group. The primary patients tended to reach a higher abduction than the revision patients (93 ± 22° vs 73 ± 34°, $P = .052$).

When the 2 different parts of the elevation of the arm were considered, however, the mean glenohumeral motion differed significantly between the primary and revision patients in both the sagittal (71° ± 18° vs 53° ± 26°, $P = .025$) and scapular planes (64° ± 15° vs 46° ± 24°, $P = .013$). Thus, primary patients had both higher forward flexion and abduction than revision patients. This difference was not seen in the mean scapulothoracic motion. The external rotation showed a maximal rotation of −23° ± 23°, but patients with a primary prosthesis had a significantly higher active external rotation than revision patients (−31° ± 25° vs −13° ± 16°, $P = .015$).

Clinical evaluation

A significant increase in overall shoulder function was shown, as measured with the absolute Constant score (mean improvement, 26 points; $P < .001$) and the relative Constant score (mean improvement, 37%, $P < .001$). Both groups improved, but primary patients (mean improvement 32 points and 47%, $P < .0001$) improved more than revision patients (mean improvement, 18 points and 26%, $P < .001$). This difference was significant, with a mean difference of 13.1 points ($P = .025$) and 20% ($P = .008$).

DASH measurements of functional disability showed that primary patients were significantly less disabled than revision patients (mean difference, 30.2; $P < .001$). The same was found on the NSST (mean difference, 4; $P = .002$; Table II).

Radiologic evaluation

The mean acromial-prosthetic distance was 26 ± 7 mm for the whole group. There was no significant difference between the primary and revision patients (26 ± 7 vs 26 ± 6 mm, $P = .965$). In 30 of the 35 shoulders (85.7%), the teres minor muscle was still intact, and no difference was found between primary and revision patients (89.5% vs 81.2%, $P = 0.489$).

The correlations between the joint angles during the mean acromial-prosthetic distance and the different ROM tasks are presented in Table III. No significant correlation was found between the acromial-prosthetic distance and the sagittal or scapular motion in the whole group or in the 2 subgroups.

We found no significant difference for the active maximal external rotation between shoulders with an intact teres minor muscle and shoulders with a defect in the teres minor muscle (−24° ± 23° vs −16° ± 19°, $P = .473$).

Discussion

In the treatment of patients with glenohumeral arthritis and severe rotator cuff deficiency, the reverse prosthesis offers a solution with good short-term and medium-term results in pain reduction.[8] The active ROM is often compromised. However, especially when the reverse prosthesis is used in revision cases.[12,21] In our study, thoracohumeral motion improved for the whole group to a mean active forward flexion of 86°. This is smaller than the mean improvements of 118°[5] or 138°[18] that were reported in other studies. Even when we just looked at the primary placed prostheses in our series, we only found a mean improvement to 93°.

Table I Maximal active joint angles in degrees for 35 shoulders during the elevation and rotation tasks

Plane of movement	Active motion	Movement	All shoulders	Primary	Revision	P
			Mean ± SD (range)	Mean ± SD (range)	Mean ± SD (range)	Primary vs revision
Sagittal	Thoracohumeral	Forward flexion	86 ± 29 (0 to 127)	93 ± 21 (44 to 127)	78 ± 36 (0 to 120)	.157
	Glenohumeral		62 ± 24 (0 to 108)	71 ± 18 (41 to 108)	53 ± 26 (0 to 88)	.025
	Scapulothoracic		28 ± 13 (1 to 50)	30 ± 11 (1 to 43)	27 ± 15 (0 to 50)	.550
Scapular	Thoracohumeral	Abduction	84 ± 29 (0 to 139)	93 ± 22 (41 to 139)	73 ± 34 (0 to 119)	.052
	Glenohumeral		56 ± 21 (0 to 95)	64 ± 15 (45 to 95)	46 ± 24 (0 to 85)	.013
	Scapulothoracic		32 ± 15 (8 to 52)	33 ± 15 (8 to 52)	30 ± 15 (0 to 51)	.483
Scapular arm in 90° abduction	External rotation*	Rotation	−23 ± 23 (5 to −93)	−31 ± 25 (5 to −93)	−13 ± 16 (3 to −45)	.015

* External rotation is negative axial rotation.

Table II Outcomes of clinical assessments

Scores	All shoulders	Primary	Revision	P
	Mean ± SD (range)	Mean ± SD (range)	Mean ± SD (range)	Primary vs revision
Constant				
Pre-op	24 ± 11 (5-47)	28 ± 9 (13-47)	20 ± 12 (5-47)	.026
Post-op	50 ± 22 (8-87)*	60 ± 21 (8-87)*	38 ± 18 (11-73)*	.002
Relative Constant				
Pre-op	33% ± 17% (7-71)	38% ± 14% (19-68)	27% ± 18% (7-71)	.047
Post-op	70% ± 31% (9-124)*	85% ± 31% (9-124)*	53% ± 22% (14-92)*	.001
DASH post-op	43.9 ± 25.9 (1.7-84.2)	30.1 ± 24.3 (1.7-77.5)	60.3 ± 17.1 (31.2-84.2)	<.001
NSST post-op	7 ± 4 (0-13)	8 ± 4 (0-13)	4 ± 3 (1-10)	.002

DASH, Disability of Arm, Shoulder and Hand; *NSST,* Netherlands Simple Shoulder Test.
* Significant difference compared with preoperative results.

Table III Pearson's correlation between active range of motion postoperatively and the acromial-prosthetic distance measured on anteroposterior radiographs

Plane of movement	Active motion	Movement	All shoulders	P	Primary	P	Revision	P
Sagittal	Thoracohumeral	Forward flexion	0.086	.622	−0.206	.397	0.361	.169
	Glenohumeral		0.066	.707	−0.172	.482	0.322	.223
Scapular	Thoracohumeral	Abduction	0.103	.556	−0.149	.542	0.382	.145
	Glenohumeral		0.073	.679	−0.214	.379	0.37	.158

Taking a closer look at how these studies had obtained their data, we notice that Cuff et al[5] used video to calculate the thoracohumeral motion. This was done on only 1 side of the patient, which is sensitive for lumbar spine movement during the elevation of the arm, without detecting this extra movement. So, these data are prone to overestimations. Sirveaux et al[18] did not specify how they measured active motion, but they already discussed that the 138° active forward flexion they found was rather high compared with other series.

Therefore, trying to place our findings more in perspective, it seems wise to compare our data only with arm movements measured in a similar setup. Magermans et al,[13] who used the same electromagnetic tracking device to analyze individuals with healthy shoulders, showed that the mean maximal active forward flexion was 131° in the sagittal plane and 132° in the scapular plane. Comparing these data with our study, the reverse prosthesis restores an active forward flexion of approximately 65% of that of a normal shoulder.

Nevertheless, the results of our study could still be influenced by the way we measured the motion of the arm. We measured in a quasistatic mode, because the scapula needed to be palpated after every change of the arm. Nonetheless, these differences between the active and quasistatic movements have been shown to be negligible in healthy individuals.[6] Although our participants were patients and we therefore cannot exclude that they have more variation between quasistatic and dynamic measurement, we still believe that the electromagnetic, biomechanical method provides valuable insight in the movement of the arm in patients with a reverse prosthesis due to the capacity to record scapulothoracic motion.

Despite the lower improvements in active forward flexion compared with the literature, all patients improved in postoperative arm function, as shown by the significantly improved Constant scores. The overall improvement was 26 points, which is reasonable compared with other studies showing improvement up to 42 points.[18] Progress was most substantial in patients with a primary placed prosthesis. This was also supported by the better outcome shown by the postoperative DASH score and NSST scores in the patients with a primary placed prosthesis. Those findings confirm that the reverse prosthesis used in revision cases shows improvement[21] in clinical outcome, but not to the extent found in primary cases.

The way in which this prosthesis contributes to restoring the function of the arm is not yet completely understood. Especially the contribution of the glenohumeral motion is not well documented. Although the difference in movement between the primary placed prosthesis and revision cases was nearly statistically significant for the thoracohumeral motion in the scapular plane, the largest difference took place in the glenohumeral joint in both planes as well as in the external axial rotation. Possible explanations for this difference in motion between primary placed prostheses and revision cases could be adhesions around the glenohumeral joint from previous procedures. We did not observe any axillary nerve palsies, but the remaining quality of the deltoid muscle may be inferior after previous operations, or the strength and function of the remaining rotator cuff muscles might be better in primary cases.

To quantify this difference, we measured the distance from the acromion to the prosthesis. The lowering of the humerus affects the function of the arm,[2] and measurement of the height of the subacromial space seems to be an objective way to evaluate the postoperative tension of the deltoid muscle.[11] We did not find a difference in acromial-prosthetic distance between the primary and revision cases, nor any correlation between this distance and the active motion of the arm. Although the postoperative radiographs were taken using a standard protocol and the measurement system was calibrated before the measurements took place, possible differences of the x-ray beams could not be ruled out. Therefore, preoperative and postoperative arm length measurements are probably a more reliable method, but this was only recently introduced as a standard measurement in our clinic.

The literature has demonstrated that the reverse shoulder prosthesis restores overhead elevation but fails to restore active external rotation.[17] The teres minor-tendon unit contributes to active external rotation, and its deficiency may impair the clinical outcome.[17] We could not confirm that the presence of the teres minor muscle implies better active external rotation because significant differences between our 2 groups could not be discerned. However, 30 patients with an intact teres minor muscle and only 5 with a defect makes comparison difficult.

Conclusion

The active ROM of the arm with a reverse prosthesis is better in the primary placed prosthesis, and this difference takes place mainly in the glenohumeral joint. In all our patients, the Constant scores improved significantly postoperatively, with the largest improvement in primary placed prosthesis compared with revision cases. However, we could not find any clinical correlating parameters to explain this difference.

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