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A kinematical analysis of the shoulder after arthroplasty during a hair combing task

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Abstract

Background. After shoulder arthroplasty, post-operative Range of Motion is usually compromised. It is, however, unclear to what extent limitations in Range of Motion are related to functional outcome in terms of Activities of Daily Living.

Methods. The upper extremity motions of 13 patients (16 shoulders) and a control group ($N = 24$) during four Range of Motion tasks and Activities of Daily Living were measured using a six degree-of-freedom electromagnetic tracking device. Based on the results for the Activities of Daily Living task 'hair combing', the patient groups was divided into a group that could perform this task ('Able', $N = 8$, 10 shoulders) and a group that could not perform the task ('Unable', $N = 6$, six shoulders).

Results. Both patient groups showed considerable limitation in glenohumeral Range of Motion, when compared to controls, but between patient groups only axial rotation Range of Motion was different: the 'Able' group has a larger external rotational Range of Motion, but less internal rotation. During 'combing hair' the Able group appeared to successfully perform the task through a larger clavicular retraction.

Interpretation. The ability to perform, or not perform a task appeared to be related to a compensatory movement implementation by means of clavicular retraction. It is concluded that the functional outcome after arthroplasty is limited due to a lack of glenohumeral Range of Motion but that it is possible to compensate for this restriction.
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1. Introduction

Shoulder arthroplasty is generally recognized as successful in terms of pain relief, with an improved, but still limited Range of Motion (RoM). Patients with rheumatoid arthritis achieve an average post-operative thoracohumeral elevation angle of 100° (Gill et al., 1999; Levy and Copeland, 2001; Torchia et al., 1997), where 160° might be expected for healthy subjects. Function is also still limited: after shoulder arthroplasty 75% is able to perform perineal care, but only 55% are able to comb their hair and to reach shoulder level. How these poor results relate to limitations in glenohumeral motion is not clear. To our knowledge, only few studies have investigated (2D) motion patterns after shoulder arthroplasty (Barrett et al., 1987; Boileau et al., 1992; Friedman, 1995) during arm elevation. These studies found an increase in scapular motion contributing to arm elevation, or a 2:3 relationship for the

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scapula–humeral rhythm, apparently compensating for a loss in glenohumeral elevation, instead of 1:3 relationship as found in healthy subjects (Groot et al., 1998). In a previous study on the movement requirements during selected Activities of Daily Living (Magermans et al., 2005) we concluded that the reasons for the poor results for hair combing were, however, most likely not found in a limitation in elevation, but might be due to the large external glenohumeral rotation observed during this task in healthy controls.

The aim of this study is to determine the relationship between RoM and the ability to perform combing hair after shoulder arthroplasty and to compare these with results from a study on healthy subjects (Magermans et al., 2005). It is hypothesized that despite the reduction in pain, glenohumeral elevation is still limited after implantation of a prosthesis, when compared to a healthy norm population. In addition, we expect that differences between patients that are and are not able to perform a key task such as combing hair will become visible in differences in glenohumeral external rotation as quantified during active Range of Motion measurements.

2. Materials and methods

2.1. Subjects

Thirteen patients ($N = 13$, 16 shoulders) and a healthy control group ($N = 24$) participated in this study. The patient group's mean age was 66.6 ± 16.2 years, versus 36.8 ± 11.8 years for the controls, which was significantly older ($t = 7.7$, $p < 0.00$). Seven shoulders had undergone a Hemi Shoulder Arthroplasty (HSA), nine shoulders a Total Shoulder Arthroplasty (TSA). All subjects gave written informed consent prior to the experiment.

2.2. Measurement device

A six degree-of-freedom electromagnetic tracking device, the Flock of Birds (Ascension Technology Inc., Burlington, Vermont, USA) was used for the recording of kinematic data. We used a set-up with five sensors, which comprised a 60-mm long pointer, and sensors fixated to the sternum, arm, forearm and a scapula locator (Johnson et al., 1993). The sensor on the sternum was attached to the skin with double-sided adhesive tape. Arm and forearm sensors were fitted on a cuff. All three sensors were additionally covered with Fixomull stretch self-adhesive bandage (Beiersdorf AG, Hamburg, Germany). The arm sensor was attached on the dorso-lateral side of the distal humerus. The forearm sensor was attached dorsally on the distal forearm, approximately 5 cm proximal to the ulnar and radial styloid.

To link the sensors to local anatomical coordinate systems, 16 bony landmarks were digitized relative to their sensors using the pointer. These measurements were performed with the subjects in a standing position with the arms hanging aside the body. From the combination of local coordinate systems constructed from these anatomical landmarks and the sensor motions, both segment and subsequently also joint rotations could be calculated with an inter-subject variability of no more than seven degrees for all three scapula rotations (Meskers et al., 1998). Local coordinate systems, segment and joint rotations were defined following the ISB standardization proposal for the upper extremity (Wu et al., 2005). To correct for underestimation of the axial rotation of the humerus due to sensor-to-skin displacement the axial rotation of the humerus was determined by fitting the orientation of the forearm sensor relative to the arm sensor to a two degree-of-freedom arm model.

2.3. Procedure

Four Range of Motion (RoM) tasks: forward flexion, abduction, internal and external rotation with humeral elevation, and six Activities of Daily Living (ADL) were measured. From these ADL, the activity 'combing hair' was selected for further analysis. Since dynamic tracking of the scapula is very difficult, measurements were performed in a quasi-static mode, implying that after a few practice session, the motion was performed in up to ten steps, during each of which the sensor orientations, including the orientation of the scapula, were recorded.

2.4. RoM

For most RoM tasks the subjects were instructed to reach a maximal joint angle. This means that e.g. for the forward flexion and abduction tasks, the subject was instructed to elevate the arm as high as possible. Internal rotation is defined as positive axial rotation of the humerus and external rotation as negative axial rotation. The axial rotation task and the pronation task started differently from the other tasks. The internal rotation with scapular abduction started with 90° of humeral elevation, the humerus making an angle of 30° with the frontal plane (scapular plane) and in maximum external rotation. The pronation task started with 90° of elbow flexion and the forearm maximally supinated.

2.5. ADL

Subjects were instructed to start in a neutral position with the arms hanging beside the body, but were free to choose their way of performance. Within the control population, the right shoulder was measured. For patients, the operated shoulder was measured. In case a patient had two implants, both shoulders were measured. For calculations all left shoulders were mirrored to the right. All subjects performed the ADL without objects.

2.6. Angle definitions

In this study the motions of clavicle, scapula and of the glenohumeral joint were taken into account. Joint angles were defined based on the International Society of Biomechanics standardization proposal of the International Shoulder Group (Wu et al., 2005). Glenohumeral and thoracohumeral motions are then described according to the globe system (Doorenbosch et al., 2003): "plane of elevation" – "elevation" – "internal/external rotation". For the scapula this implied a rotation order "pro/retraction" – "latero/mediorotation" – "tipping backward/forward". For the clavicle the order was "pro/retraction" – "elevation/depression" – "internal/external rotation".

The forearm angles are rather straightforward: elbow flexion and pronation, where 0° coincides with the anatomical position.

2.7. Data analysis

On the basis of the ADL results, the patient population was divided into two groups: a patient group ($N = 7$) which was able to perform the hair combing task and a patient group ($N = 6$) which was not able to reach the target position. Mean RoM values for the glenohumeral joint were compared between the control group and the two patient groups on the basis of a simple ANOVA. Using a LSD post-hoc test, differences among the three groups (controls, able patients and unable patients) could subsequently be identified.

For the "hair combing" task mean peak values for clavicular, scapular and humeral motions were calculated, as well as the 5–95% percentiles, assuming a normal distribution. Since, however, peak values cannot uniquely describe differences between the Able and Unable group, because the Unable group did, by definition, not finish the task, additional information on the mean motion patterns between groups was obtained using a B-spline fitting method with penalties (Eilers and Marx, 1996). This fitting method can also be used as an exploratory method to find statistical differences in the motion patterns of different groups. The 95% confidence intervals of the mean motion patterns were calculated and when these intervals did not intersect each other, it may be assumed that motion patterns differ significantly during that part of the trajectory.

3. Results

3.1. RoM

In general, glenohumeral RoM was reduced for the patient groups in comparison to the healthy population (Fig. 1). Glenohumeral elevation (i.e. both forward flexion and abduction) was approximately 85° for the control group versus 35–55° for the patient groups. Maximal elevation was not different between the Able and Unable group.

There were no significant differences between the healthy controls and Able patient group for internal and external rotation, but external rotation was significantly reduced for the Unable group in comparison to both the controls and the Able group. The Able group showed a peak external rotation of $-67 \pm 18°$ versus $-38 \pm 46°$ for the Unable group. Peak internal rotation was significantly smaller for both patient groups compared to the healthy controls ($-8 \pm 17°$ and $4 \pm 33°$ for the patient groups versus $36 \pm 26°$ for the controls, $F = 12.0$, $p < 0.05$). The negative internal rotation for the Able group implied that this group did on average reach slightly externally rotated values.

3.2. ADL

Combing hair required a thoracohumeral elevation angle of about 100–120° (Fig. 2, x-axes) and was performed with about a peak glenohumeral angle between 73° and 102° (95% confidence interval, Fig. 3) for the healthy group versus 46–67° for the Able group (Fig. 3). The Unable patient group managed to reach 37–62° glenohumeral elevation, but did of course not finish the task. As expected, these peak elevation values were significantly different between groups ($p < 0.000$),

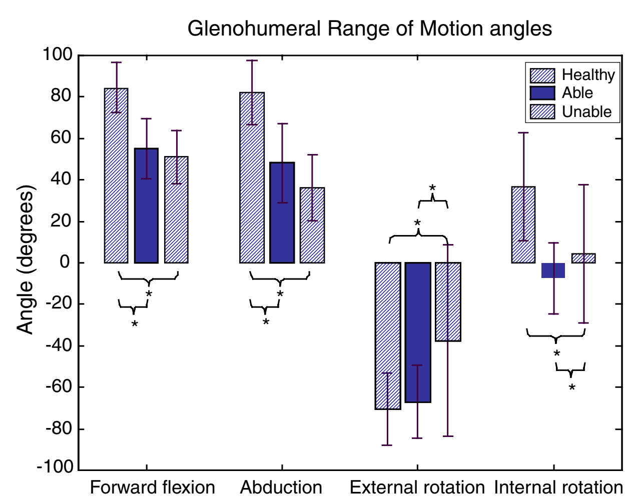

Fig. 1. Glenohumeral RoM for healthy subjects and for both patient groups (Able: able to comb their hair, Unable: not able to comb hair). Asterisks indicate significant differences between groups.

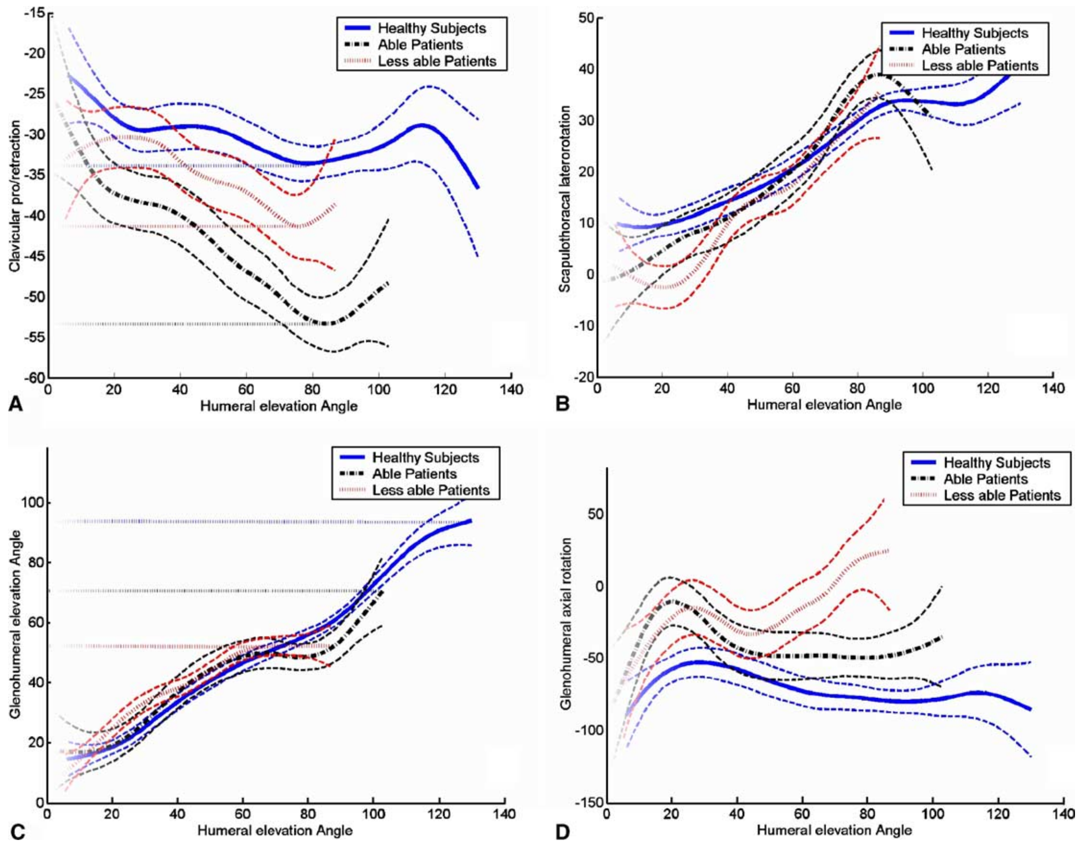

Fig. 2. Mean motion patterns with 95% confidence intervals for clavicular protraction (A), scapular laterorotation (B), glenohumeral elevation (C) and glenohumeral axial rotation (D), for healthy subjects and subjects who were able to perform the comb hair task (Able patients) and those who were not (Unable patients).

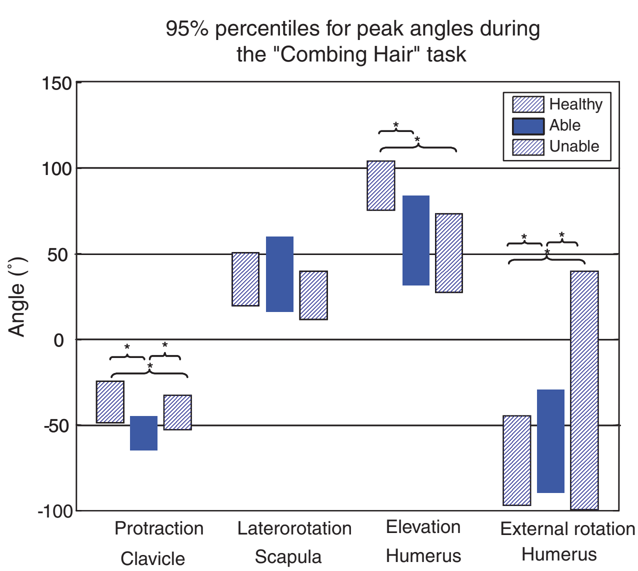

Fig. 3. Fifth to 95th intervals for the peak angles reached during the task ''combing hair''. The healthy control group ($N = 24$) and Able patient group ($N = 10$) were able to perform the task, the Unable group could not.

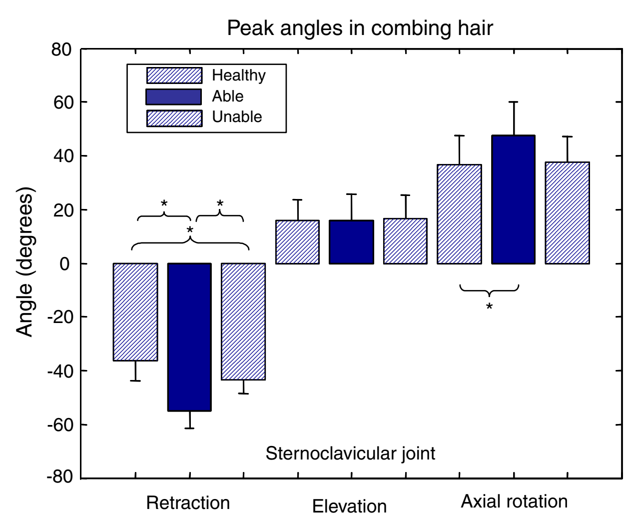

Fig. 4. Results for peak angles in the sternoclavicular joint. Asterisks indicate significant differences between groups.

but trajectories did, however, not differ significantly between groups (Fig. 2C). Peak glenohumeral external rotation during hair combing differed significantly between the three groups (Fig. 3). This was also visible in the glenohumeral axial rotation trajectories (Fig. 2D). The Unable group showed on average less external rotation ($-29 \pm 43°$) than the Able group ($-59 \pm 17°$), or the healthy controls ($-70 \pm 19°$).

Scapular laterorotation (Fig. 2B) was not different between groups. A large difference was, however, found in protraction/retraction of the clavicle (Figs. 2A and 3). Able patients appeared to retract the clavicle about 15° further than the Unable group. This can also be seen in the peak retraction values reached during the motion: Clavicular retraction was $-55 \pm 6°$ for the Able group versus $-43 \pm 5°$ for the group that was unable to perform the task (Fig. 4).

4. Discussion

When compared with results for our control group, glenohumeral RoM was lower for both patient groups. In contrast to our expectation, there was no significant difference in glenohumeral elevation between both patient groups. Peak glenohumeral external differed, however, significantly between both patient groups. Patients that were able to perform the combing hair task appeared to have more external rotation than the unable group (Fig. 1). This might be one of the explanations for the difference in task performance for the "combing hair" task. It is likely that these patients could keep their arm sufficiently externally rotated to perform the combing task, especially since their peak external rotation angle was significantly smaller that for the healthy group. This difference suggests that either external rotation reached by the able patient group is the minimally necessary rotation, or that the 'Able" subjects show other compensatory motions.

A possible alternative explanation for the observed difference in external rotation during hair combing might have been the effect of the interdependency of Euler decompositions. In this case, a more sagittal (closer to 90°) plane of elevation for the humerus would require less external rotation of the humerus. This effect is found for the total population, as indicated by a correlation of -0.42 ($p < 0.05$) between peak plane of elevation and peak external rotation. However, the peak plane of elevation did not differ between both patient groups ($47 \pm 14°$ for the Able group, versus $51 \pm 18°$ for the Unable group). Also, trajectories did not differ. It is therefore not likely that this alternative explanation is valid.

Difference between both patient groups became particularly visible in the sternoclavicular joint. The successful patient group showed significantly more clavicular retraction than the patient group that was unable to comb their hair. This compensatory motion appears to be necessary to allow for additional thoracohumeral external rotation and therefore compensate for the lower than normal external rotation RoM and glenohumeral elevation RoM.

A possible explanation for the observed limitation in glenohumeral RoM might be that rotator cuff muscles are atrophied to such an extent that glenohumeral motion is not possible. Passive RoM measurements would have been useful to obtain insight into the maximal achievable glenohumeral motion. If passive RoM had been higher than active RoM this would mean that more glenohumeral motion is in principle possible. Also, lack of rotator cuff force might have resulted in reduced stability of the joint. Stabilizing the glenohumeral joint with insufficient rotator cuff force will probably cause co-contraction of alternative muscles, which would subsequently limit glenohumeral motion.

Another possible explanation for why glenohumeral RoM might be limited is that due to the implantation of the prosthesis the glenohumeral rotation centre with respect to the humeral shaft was changed. According to de Leest et al. (1996) the retroversion angle is an important aspect in the positioning of the rotation centre. A change in orientation of the humeral head prosthesis would cause a change in the moment arms of muscles that cross the glenohumeral joint.

Glenohumeral external rotation is important for activities of daily living that require high glenohumeral elevation angles. After shoulder arthroplasty the amount of glenohumeral motion was found to be restricted, but it appeared to be possible to compensate for this limitation, in this case by means of clavicular retraction. It must be taken into account that compensating strategies could of course cause secondary problems in other joints, which will ultimately affect total motion. Therefore, improving glenohumeral RoM should of course remain the most important aspect in shoulder arthroplasty. To assist the clinician in diagnosis and evaluation, it is advisable to measure glenohumeral RoM instead of thoracohumeral RoM, since this will give more insight into joint status and possible functional outcome. Future research should indicate why glenohumeral RoM is limited and how it can be improved. Important aspects that need attention will be the effect of muscle status and the version angle of the prosthesis implant on functional outcome.

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