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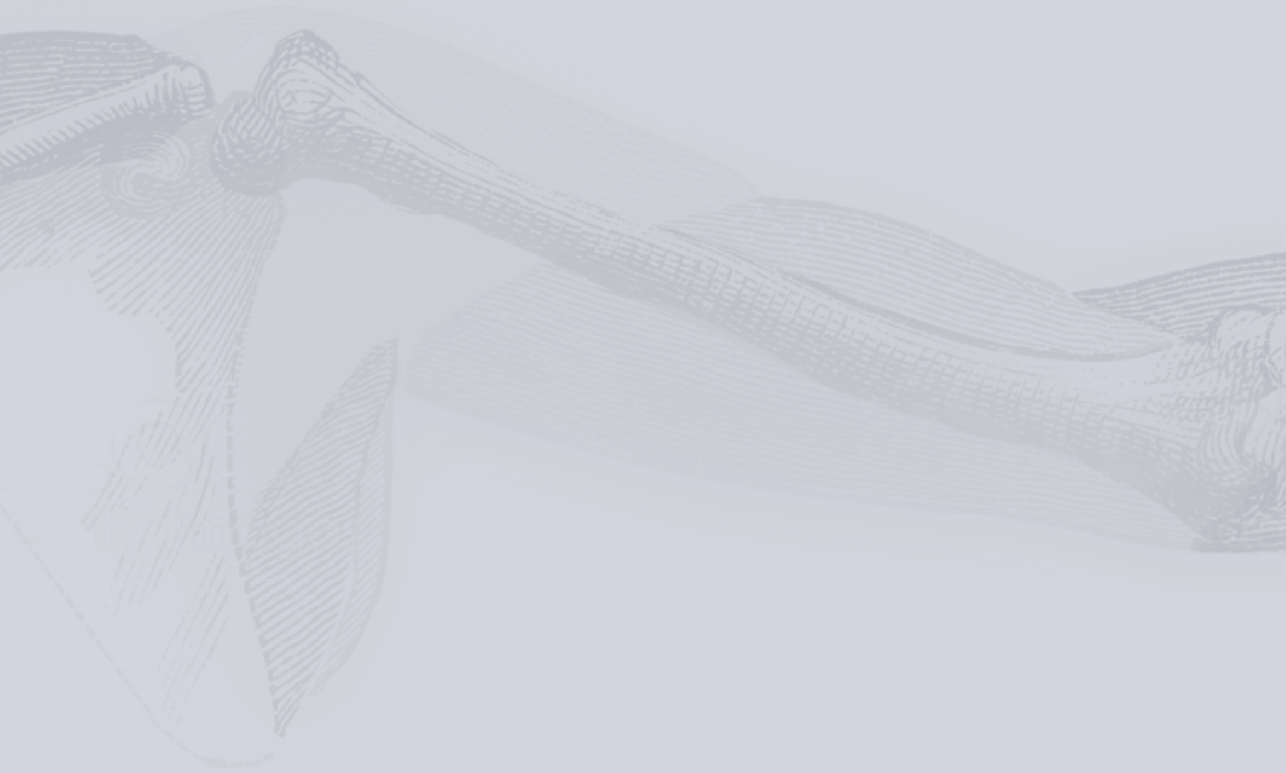

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Three-dimensional shoulder kinematics normalise after rotator cuff repair

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ABSTRACT

Background: Patients with a rotator cuff tear often exhibit scapular dyskinesia with increased scapular lateral rotation and decreased glenohumeral elevation with arm abduction. We hypothesised that in patients with a rotator cuff tear, scapular lateral rotation, and thus glenohumeral elevation, will be restored to normal after rotator cuff repair.

Methods: Shoulder kinematics were quantitatively analysed in 26 patients with an electromagnetic tracking device (Flock of Birds) before and one year after rotator cuff repair in this observational case series. We focused on humeral range of motion and scapular kinematics during abduction. The asymptomatic contralateral shoulder was used as the control. Changes in scapular kinematics were associated with the gain in range of motion. Shoulder kinematics were analysed using a linear mixed model.

Results: Mean arm abduction and forward flexion improved after surgery with 20° (95% confidence interval 2.7° – 36.5°, P = 0.025) and 13° (95% confidence interval 1.2° – 25.5°, P = 0.044), respectively. Kinematical analyses showed decreases in mean scapular internal rotation (i.e. protraction) and lateral rotation (i.e. upward rotation) during abduction with 3° (95% confidence interval 0.0° – 5.2°, P = 0.046) and 4° (95% confidence interval 1.6° – 8.4°, P = 0.042), respectively. Glenohumeral elevation increased with 5° (95% confidence interval 0.6° – 9.7°, P = 0.028) at 80°. Humeral range of motion increased when scapular lateral rotation decreased and posterior tilt increased.

Conclusions: Scapular kinematics normalise after rotator cuff repair towards a symmetrical scapular motion pattern as observed in the asymptomatic contralateral shoulder. The observed changes in scapular kinematics are associated with an increased overall range of motion and suggest restored function of shoulder muscles.

INTRODUCTION

Rotator cuff (RC) tears have a prevalence ranging from 20% to 50% in the general population and frequently lead to pain, deficits in shoulder function, and deprived quality of life.[26, 34] If conservative treatment (e.g. nonsteroidal anti-inflammatory drugs and physiotherapy) fails, surgical repair of the RC is a widely used therapeutic option. The number of RC repairs has increased over the past decade because the procedure is generally considered to relieve pain and to effectively restore shoulder function.[6, 21, 29]

Healthy shoulder function depends on a perfect balance between arm mobility and glenohumeral stability.[30] In patients with a full-thickness RC tear, the balance is disrupted because the affected RC muscle is incapable of exerting sufficient forces on the humerus. As a result, deltoid muscle activity increases to compensate for lost RC forces; this in turn, will cause additional cranially directed forces on the humerus.[4, 14, 27] These forces pull the humerus in a more cranial position relative to the glenoid, introducing translation within the glenohumeral joint.[3, 7] Clinically, lost RC muscle functionality coincides with pain and reduced elevation of the arm. It has been postulated that lost glenohumeral motion is generally compensated for by an increase in scapular lateral rotation.[13, 15] The latter is clinically observed in patients with an RC tear as asymmetry of scapular motion with increased scapulothoracic lateral rotation of the affected side.[13, 15, 23, 28]

Theoretically, RC repair should increase glenohumeral elevation because of the restored insertion of the tendinous part of the RC muscles with subsequent normalization of forces and glenohumeral moment. Observation of shoulder motion before and after RC repair may partly elucidate the observed functional gain. Shoulder motion can be measured quantitatively with six degrees of freedom by a three-dimensional (3D) electromagnetic system.[1, 9, 10, 12, 16, 19, 31] However, evaluations of preoperative and postoperative 3D shoulder motion in RC repair with an electromagnetic system have not been published so far. The purpose of this study is to assess 3D shoulder motions in patients before and after RC repair. We hypothesise that after an RC repair, arm elevation increases, glenohumeral elevation increases, and scapular lateral rotation decreases. Thus, scapulothoracic kinematics normalise towards the scapular motion of the asymptomatic contralateral shoulder.

MATERIALS AND METHODS

Participants

From March 2010 to April 2011 patients scheduled for RC repair at a secondary referral centre (Medical Centre Haaglanden, the Hague, the Netherlands) were evaluated for eligibility in this observational case series.

Patients with complaints of a repairable degenerative full-thickness supraspinatus RC tear or full-thickness supraspinatus and infraspinatus RC tear were included. The RC tear was confirmed with magnetic resonance arthrography or computed topography arthrography. The exclusion criteria were cervical radiculopathy, glenohumeral instability, history of a fracture in the shoulder region, muscle dystrophy, glenohumeral or symptomatic acromioclavicular osteoarthritis, rheumatoid arthritis, previous surgery on the shoulder, restriction in passive shoulder motion (i.e. frozen shoulder), and insufficient Dutch-language skills. In addition, patients with bilateral shoulder complaints were excluded.

Patients with an RC tear were invited to the Laboratory of Kinematics and Neuromechanics (Leiden University Medical Centre, Leiden, the Netherlands) for three-dimensional (3D) electromagnetic motion analysis, clinical evaluation including the Western Ontario Rotator Cuff (WORC) index, and assessment of shoulder muscle activity.[8] The assessment of muscle activity has been previously reported.[4] One year after surgery, participants were invited to undergo a follow-up visit. Thirty-eight patients with an RC tear were eligible for the assessment of shoulder kinematics. Patients who underwent preoperative and postoperative motion analysis were included in the analysis (n=26). Twelve patients were excluded from analysis because of a technical error (n=3) or missing baseline measurements (n=9). Ultrasound was used to evaluate RC integrity after the conducted RC repair. The medical ethical review board approved this study (07.116, P10.026) and written informed consent was obtained from every participating individual.

Surgical procedure

All surgical procedures were performed at the Medical Centre Haaglanden by one of two orthopaedic surgeons (ERAvA, PvdZ) with extensive experience in the field of RC repair, the Hague. Either a mini-open or arthroscopic surgical approach was performed according to the surgeon's personal preference. All patients received general anaesthesia and were placed in a lateral decubitus position. The RC was inspected, and the tear was debrided. A bleeding surface was created at the insertion site on the supraspinatus footprint. The RC was repaired using a double-row suture bridge technique. One or two 5.5-mm Corkscrew anchors (Arthrex, Naples, Florida, USA) were used for the medial row depending on the size of the RC tear. Similarly, one or two 3.5-mm knotless Bio-PushLock anchors (Arthrex, Naples, Florida, USA) were used for the lateral row. Postoperatively the arm was placed in an immobilizing arm sling. Patients followed a standardized rehabilitation protocol under the supervision of a physiotherapist. The physiotherapist supervised active abduction exercises. Abduction was limited to 70° during the first 4 to 6 weeks. No external rotation was allowed during this period. After 6 weeks, more active shoulder movements were permitted and isometric strengthening exercises were started.

Electromagnetic motion analysis

Preoperative and postoperative shoulder motion was captured using the Flock of Birds (FoB) (Ascension Technology Inc., Milton, Vermont, USA), which is a 3D electromagnetic motion analysis system. This electromagnetic system is used to quantify shoulder motion and has been shown to be accurate, valid and reliable.[1, 16-20, 24]

The positions and orientations of eight wired sensors were recorded with six degrees of freedom using an electromagnetic field generated by an extended-range transmitter. The sampling rate of the sensors was about 30Hz. The investigator attached seven sensors in a standardized way to the sitting patient.[1, 17] Adhesive tape was used to attach a thoracic sensor and two scapular sensors. The thoracic sensor was mounted on the manubrium sterni. The scapular sensors were bilaterally adhered to the flat craniolateral surface of the acromion. Straps with hook-and-loop fasteners were used to position two distal humeral sensors on the posterior flat surface of the distal upper arm. Two distal forearm sensors were positioned on the dorsal side of the distal forearm. Twenty-four bony landmarks were palpated as recommended by the International Society of Biomechanics[32]. Subsequently, the bony landmarks were digitized using a sensor with a known stylus vector[16]. The palpated and digitized bony landmarks were used to define a local Cartesian right-handed coordinate system to construct a patient specific 3D bone model relative to the seven sensors.

After providing verbal and visual instructions, the investigator requested that the patient perform the following bilateral arm movements: abduction (i.e. elevation in the coronal plane), forward flexion, backward flexion (i.e. extension) and external axial rotation with at least 40° of humeral elevation and with the elbow flexed 90°. Forward flexion, backward flexion and external rotation were used only for evaluation of range of motion, and not for comparisons of scapulothoracic rhythm.

Data processing

The constructed local coordinate systems consisted of an anteriorly (X_t), superiorly (Y_t) and laterally (Z_t) directed axes. The orientation of each local coordinate system was related to the coordinate system of the thorax. The motions were described by a defined sequence of three rotations.[32] An Euler sequence (y-x-y) was applied to describe humeral motion: 1) plane of elevation, that is rotation around thoracic y-axis; 2) humerus elevation, that is negative rotation around humeral x'-axis; and 3) humerus external rotation, that is negative rotation around the humeral y"-axis. The Cardan sequence (y-x-z) was applied to describe scapular motion: 1) internal rotation (i.e. protraction), that is positive rotation around the thoracic y-axis; 2) lateral rotation (i.e. upward rotation), that is negative rotation around the scapular x'-axis; and 3) posterior tilt, that is positive rotation around the scapular z"-axis. In contrast to Wu et al., we express humeral elevation, external rotation and scapulothoracic lateral rotation in this study as positive rotations.[32] Comparable to scapulothoracic motion, glenohumeral motion was calculated using a Cardan sequence. Glenohumeral elevation was expressed as a positive rotation. Custom-made MATLAB software (2013b release, The MathWorks Inc., Natick, Massachusetts, USA) was applied to process the data.

Maximal humeral elevation (i.e. range of motion) was evaluated for abduction, forward flexion, backward flexion, and external rotation. Scapulothoracic motion was calculated for abduction in the frontal plane. The mean scapular positions were calculated at standardized humeral elevation angles with intervals of 10° up to 110°. As a consequence of skin movement artifacts in overhead arm positions, we did not analyse scapulothoracic and glenohumeral rotations over 110° of humerothoracic elevation[1]. Because movements were not guided, deviations of the (abduction) plane of elevation exceeding 30° were identified and these data were excluded from the analysis.

Preoperative scapulothoracic and glenohumeral rotations during abduction were analysed and compared with postoperative rotations. Kinematics were assessed in the affected shoulder, as well as in the asymptomatic contralateral shoulder, to assess the symmetry of shoulder kinematics. "Normalization" of shoulder motion was defined as changed kinematics towards symmetrical bilateral scapular motion as it is clinically used to identify scapula dyskinesis.[28] The asymptomatic contralateral shoulder was used as reference.

Statistical analysis

The statistical analysis was conducted using IBM SPSS statistics for Windows (version 20.0, IBM Corp, 2011, Armonk, New York, USA). Normally distributed continuous data were expressed as means and 95% confidence intervals (CIs) and categorical data were expressed by numbers with percentages. A paired Student's t-test was used to compare the preoperative versus postoperative WORC scores and maximum humerothoracic range of motion in the operated arm for abduction, forward flexion, backward flexion, and external rotation.

Linear mixed model analysis was used for pair-wise scapulothoracic motion comparisons during arm abduction. The dependent variable was the paired difference between the preoperative and postoperative scapular internal rotation, between the preoperative and postoperative lateral rotation, and between the preoperative and postoperative tilt. The paired difference was calculated by subtracting the postoperative from the preoperative scapular rotations in both the affected and contralateral unaffected shoulders. Abduction intervals were included as a repeated factor per subject. The abduction interval and the appearance of a retear were both included as fixed effects. An autoregressive structure of order one with unequal variances was used to model the covariance at the various time points. An autoregressive structure of order one was used if convergence was not achieved. Even though the preoperative and postoperative data were collected in a similar way, small differences in the plane of elevation or axial rotation may occur when asking the patients to perform an abduction movement twice. Therefore, the humeral plane of elevation and axial rotation were initially included in the model as covariates, but they did not lead to a different conclusion and were excluded from the presented results.

A forced-entry linear regression analysis was performed to evaluate the correlation between range of motion and scapular rotations. For every 10° of humeral elevation, changes in the scapular internal rotation, lateral rotation and posterior tilt were used as independent variables and the change in humeral range of motion during abduction as the dependent variable. A correlation coefficient of < 0.3 was considered as poor, 0.3 to 0.5 as fair; 0.5 to 0.8 as moderate to good and >0.8 as very strong. A two-sided P value of < 0.05 was considered statistically significant.

RESULTS

Clinical characteristics

The twenty-six patients comprised 17 men and 9 women, with a mean age of 60 years (range, 46 – 73 years). Fifteen patients with a supraspinatus tear and eleven patients with a combined tear of the supraspinatus and infraspinatus were included. The median follow-up was 13 months (interquartile range, 1.6 months; range 12 – 17 months). The characteristics of these twenty-six patients are presented in Table 1.

Table 1. Baseline characteristics

	N=26	
Age, yrs	60	(46.4-72.7) †
Female, n (%)	9	(35)
Left side affected, n (%)	15	(58)
Traumatic origin, n (%)	8	(31)
Coronal tear size, mm	23	(19.1-27.2) †
Sagittal tear size, mm	20	(16.4-23.9) †
Posterosuperior tear, n (%)	11	(42)
Fatty infiltration supraspinatus, n (%)		
Stage 0	11	(42)
Stage 1	10	(39)
Stage 2	5	(19)
Arthroscopic repair, n (%)	17	(65)
Biceps tenotomy, n (%)	8	(31)
Retear, n (%)	6	(23)
Constant Score, points	52	(45.3-58.7) †
WORC, %		
Baseline	44	(34.7-53.9) †
Follow-up (1yr)	68	(58.2-78.2) † *

We observed a significant increase in WORC percentage. Preoperative and postoperative WORC score was compared using the paired Student's T-test. Abbreviations: yrs, years; mm, millimetre; WORC, Western Ontario Rotator Cuff Index.

* statistically significant difference from baseline at P < 0.05.

† mean and 95% confidence interval.

The postoperative WORC score improved significantly with 24 percentage points (95%CI 16.3 – 31.5, P < 0.001). One subject did not complete the WORC. Postoperative range of motion significantly increased with 20° for abduction and with 13° for forward flexion (Table 2).

Table 2. Humeral range of motion before and after rotator cuff repair

	Pre-operative Range of motion (N = 26)	Post-operative Range of motion (N = 26)	Mean difference	
	Mean (SD) °	Mean (SD), °	(95% CI), °	P value
Abduction (°)	118 (37.3)	138 (20.0)	20 (2.7 – 36.5)	0.025*
Forward flexion (°)	127 (31.4)	140 (15.6)	13 (1.2 – 25.5)	0.044*
Backward flexion† (°)	53 (12.0)	55 (12.4)	3 (-1.7 – 6.8)	0.223
External rotation (°)	69 (19.9)	75 (17.9)	6 (-1.3 – 13.2)	0.102

After rotator cuff repair, the investigated patients showed more abduction and more forward flexion. Abbreviations: n, number; SD, standard deviation; CI, confidence interval.
* statistically significant difference at P < 0.05.
† i.e. extension.

Shoulder kinematics during abduction

Kinematics of the unaffected shoulder before and after surgery.

In the asymptomatic contralateral shoulders, no differences were observed in scapular motion before versus after surgery. On the bases of averaged differences over the analysed range of motion (up to 110°) scapulothoracic kinematics in the unaffected shoulder did not significantly change: -1° (95%CI -4.4° – 3.4°, P = 0.787) for scapulothoracic internal rotation, -2° (95%CI -4.5° – 1.1°, P = 0.223) for lateral rotation, and -1° (95%CI -3.6° – 2.2°, P = 0.617) for posterior tilt.

Kinematics of the affected shoulder before and after surgery.

Scapulothoracic rotations changed in the affected shoulder towards the motion patterns as observed in the contralateral asymptomatic shoulder, indicating a more symmetrical movement pattern after RC repair (Figure 1). In the operated shoulders, mean postoperative scapular internal rotation (i.e. protraction) decreased with 3° (95%CI 0.0° – 5.2°, P = 0.046). The preoperative internal rotation was 3° to 4° higher from 20° to 70° of abduction than the postoperative scapular internal rotation (Table 3). Mean postoperative scapular lateral rotation (i.e. upward rotation) in all intervals was reduced with 4° (95%CI 1.6° – 8.4°, P = 0.042). This difference in scapular lateral rotation in the affected shoulder was demonstrated to be ± 5° at 80° – 90° abduction. Scapular posterior tilt in the affected shoulder was, on average 2° (95%CI 0.5° – 5.3°, P = 0.097) higher after surgery, but this difference did not reach significance.

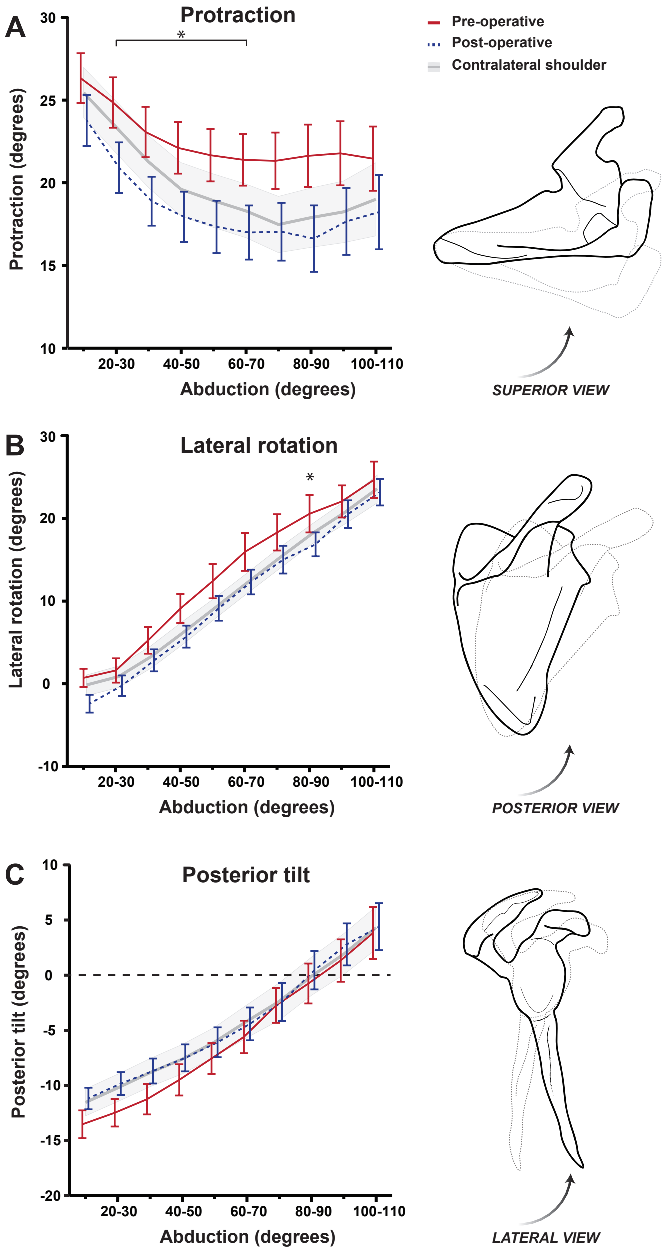

Figure 1. Scapulothoracic movements showing A) protraction, B) lateral rotation, and C) posterior tilt. Data are presented as mean and ± 1 standard error. The data were analysed by pair-wise linear mixed model analysis. Preoperative (solid, red line) scapulothoracic protraction and lateral rotation were significantly higher compared with the postoperative state (dotted, blue line). The postoperative results were comparable to the shoulder movements observed in the symptom-free contralateral shoulder (reference, grey line). This finding indicates a normalization of shoulder kinematics after rotator cuff repair.

[*] statistically significant difference at $P < 0.05$.

Table 3. Difference between preoperative and postoperative scapulothoracic rotations

Protraction				
	N	Mean change, °	95% CI	P value
10-20°	25	-3	-5.4 – 0.2	0.063
20-30°	26	-4	-6.8 – -1.3	0.005*
30-40°	25	-4	-6.4 – -1.3	0.004*
40-50°	24	-4	-6.0 – -1.0	0.008*
50-60°	23	-3	-5.7 – -0.8	0.012*
60-70°	22	-3	-5.5 – -0.3	0.028*
70-80°	20	-3	-5.1 – 0.1	0.059
80-90°	17	-3	-5.5 – 0.1	0.055
90-100°	16	-2	-5.2 – 0.8	0.144
100-110°	13	-1	-3.9 – 2.5	0.652
Retear		0	-2.5 – 3.4	0.760
Lateral rotation				
	N	Mean change, °	95% CI	P value
10-20°	25	-3	-5.6 – 0.6	0.110
20-30°	26	-2	-5.1 – 2.2	0.424
30-40°	25	-2	-5.9 – 1.9	0.296
40-50°	24	-3	-7.5 – 1.1	0.141
50-60°	23	-3	-8.0 – 1.4	0.165
60-70°	22	-4	-9.4 – 0.8	0.097
70-80°	20	-4	-8.9 – 0.4	0.069
80-90°	17	-5	-9.3 – -0.3	0.049*
90-100°	16	-3	-7.8 – 1.2	0.142
100-110°	13	-3	-7.6 – 0.9	0.116
Retear		-2	-5.9 – 1.7	0.284
Posterior tilt				
	N	Mean change, °	95% CI	P value
10-20°	25	2	-0.4 – 4.8	0.095
20-30°	26	2	-0.1 – 4.9	0.054
30-40°	25	3	-0.3 – 5.2	0.076
40-50°	24	2	-0.7 – 5.1	0.130
50-60°	23	2	-1.1 – 4.8	0.209
60-70°	22	2	-1.3 – 4.7	0.263
70-80°	20	1	-1.7 – 4.2	0.385
80-90°	17	1	-1.8 – 4.6	0.372
90-100°	16	2	-1.3 – 5.6	0.208
100-110°	13	1	-2.7 – 4.5	0.602
Retear		1	-1.7 – 3.8	0.439

The difference between preoperative and postoperative scapulothoracic protraction and lateral rotation significantly changed over the various humerothoracic abduction intervals. The presented main effects indicate the difference in degrees at the specific abduction intervals. Abbreviations: n, number; 95% CI, 95% confidence interval.

* statistically significant difference at $P < 0.05$.

The reduction of scapulothoracic rotation stratified for humeral elevation indicated an increase in glenohumeral elevation. Indeed, more glenohumeral elevation (5°; 95%CI 0.6° – 9.7°, P = 0.028) was postoperatively shown in the operated shoulder at 80° to 90° of abduction (Figure 2).

In 6 of 26 patients, we observed a retear. Subgroup analysis, however, showed no significant differences in preoperative and postoperative kinematics between patients with a retear versus patients with an intact cuff with respect to internal rotation (0°; 95%CI -2.5° – 3.4°], P = 0.760), lateral rotation (-2°; 95%CI -2.9° – 1.7°, P = 0.284), and tilt (1°; 95%CI -1.7° – 3.8°, P = 0.439).

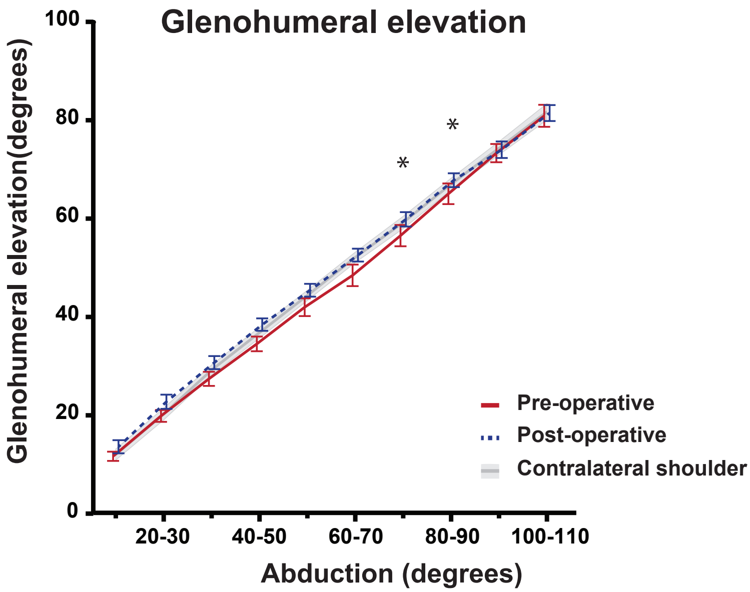

Figure 2. Data are presented as mean and ± one standard error. After rotator cuff repair, the glenohumeral contribution to elevation increased and normalised to the motion observed in the asymptomatic shoulder. This finding is consistent with the changes in scapulothoracic lateral rotation.
* statistically significant difference at P < 0.05.

Scapulothoracic rotations during abduction are correlated with range of motion

There was a moderate to good correlation between change in scapulothoracic motion and the increase in range of motion (i.e. maximal elevation angles) during an abduction movement (Table 4). The humeral range of motion increased by 1° for every 1.6° – 1.9° decrease in scapular lateral rotation at 20° to 60° abduction. The humeral range of motion increased by 1° for every 2.0° – 3.8° increase in posterior tilt.

Table 4. Scapulothoracic movements correlates with maximal range of motion

Humero-thoracic abduction	*R*	*P value*		*B*	*95% CI*	*P value*
10-20°	0.560	0.044*	protraction	-1.2	-3.74 – 1.34	0.337
			lateral rotation	-1.3	-3.79 – 1.25	0.307
			posterior tilt	3.8	1.11 – 6.40	0.008*
20-30°	0.633	0.009*	protraction	-0.8	-3.10 – 1.51	0.482
			lateral rotation	-1.9	-3.74 – -0.02	0.048*
			posterior tilt	3.8	1.30 – 6.28	0.005*
30-40°	0.674	0.005*	protraction	-0.5	-2.97 – 1.98	0.681
			lateral rotation	-1.9	-3.55 – -1.20	0.030*
			posterior tilt	3.4	1.14 – 5.58	0.005*
40-50°	0.702	0.003*	protraction	-0.5	-13.26 – 19.68	0.666
			lateral rotation	-1.9	-3.26 – -0.63	0.009*
			posterior tilt	2.6	0.73 – 4.55	0.006*
50-60°	0.669	0.009*	protraction	-0.1	-9.43 – 19.69	0.893
			lateral rotation	-1.6	-2.66 – -0.44	0.009*
			posterior tilt	2.0	0.17 – 3.92	0.034*
60-70°	0.739	0.002*	protraction	0.0	-1.89 – 1.94	0.978
			lateral rotation	-1.7	-2.65 – -0.85	0.001*
			posterior tilt	1.6	-0.17 – 3.34	0.074

Results of forced entry linear regression analysis with maximal range of motion during abduction as dependent variable and scapular rotations as independent variable. Because the number of scapulothoracic rotation observations decreased, because of elimination of more seriously affected patients, data were analysed until 70° of humerothoracic abduction. Abbreviations: R, correlation coefficient; B, estimate; CI, confidence interval.

* statistically significant difference at $P < 0.05$.

DISCUSSION

This study aimed to assess 3D shoulder motion in patients with an RC tear and to evaluate whether scapulothoracic and glenohumeral elevation normalises after surgical RC repair. Scapulothoracic internal rotation and lateral rotation in patients with an RC tear decreased significantly and normalised after RC repair. An increase in glenohumeral elevation was consistently found. Furthermore, we demonstrated a decrease in lateral rotation and increase in posterior tilt were associated with increased humeral range of motion.

This study demonstrated improved humeral range of motion for abduction and forward flexion after an RC repair, as measured with 3D electromagnetic motion analysis. The observed increase in 3D range of motion is consistent with previous clinical results.[21, 22,

[29] Electromagnetic motion analysis has been applied to study shoulder motion in various other shoulder pathologic conditions, such as frozen shoulder, subacromial pain syndrome, and RC muscle tears.[9, 10, 12, 15, 25, 31] In these pathologies 3D analysis allows separate assessment of glenohumeral and scapulothoracic motion. Although contradictive results exist regarding treatment modalities for shoulder pathology, objective outcome variables such as this accurate 3D shoulder kinematical analysis are rarely used.[11, 31] For that matter, we analysed shoulder motion in RC tear patients before and after surgery and examined scapulothoracic rotations and glenohumeral elevation.

Kinematical analyses showed additional scapular lateral rotation during abduction in patients with an RC tear. This lateral rotation normalised after RC repair towards the scapular motion of the contralateral asymptomatic shoulder. In accordance to others, scapular lateral rotation has been reported to be increased in patients with an RC tear.[15, 25] Mell et al. reported increased scapulothoracic lateral rotation, and consequently, less glenohumeral motion in patients with an RC tear compared with controls with an intact RC.[15] In contrast, Paletta et al. did not observe a significant difference in scapulothoracic motion using plain radiographs, with planar radiographs potentially being less sensitive for kinematic changes.[2, 23] In comparison with patients with an RC tear, Paletta et al. reported more glenohumeral motion in healthy volunteers contributing to overall arm elevation, although this difference was not statistically significant.[23] on the basis of these findings, more glenohumeral elevation and less scapulothoracic rotation were expected after cuff repair. The observed increase in glenohumeral elevation after RC repair in our study is in agreement with the aforementioned studies and suggests that kinematics can be restored after RC repair.

The reasons for the observed scapulothoracic and glenohumeral kinematics in RC tears are not yet completely understood. Mell et al. suggested that more scapular lateral rotation facilitates an improved moment arm for deltoid tensioning.[15] The deltoid may compensate for lost RC function enabling the patient to maintain a functional range of motion.[4, 15] Likewise, a compensatory increase in lateral rotation has been postulated because the supraspinatus does not have a scapulothoracic moment arm to control movement of the scapula.[13] A comparable increase in lateral rotation was found in healthy volunteers after a suprascapular nerve block.[13] Furthermore, pain, changes in shoulder kinematics with age, compression of inflamed subacromial tissues, and instability at the glenoid, resulting in an unfavourable fulcrum for glenohumeral rotations, will have an impact on scapular motion. To study the effect of subacromial pain, scapular motion has been studied before and after the application of subacromial analgetics.[5, 25] Although we found normalization of 3D shoulder kinematics to the contralateral asymptomatic shoulder after RC repair, our results have to be interpreted with caution because contradictive results have been reported on the effect of subacromial anaesthetic infiltration on scapular lateral rotation.[5, 25] Less scapular lateral rotation after infiltration may suggest an effect of pain on lateral rotation.[25] Therefore, our findings do not prove that reinsertion of the RC causes more glenohumeral elevation.

However, our findings stress the importance of evaluating kinematics with validated 3D techniques.

This study has some limitations. Skin-bone displacements limit the possibility of an accurate measurement of scapular movements during overhand activities. This limits the scapulothoracic analysis of a complete abduction movement. The pair-wise analysis in this study is essential for the longitudinal analysis of scapular motion. Preoperatively some patients were unable to elevate the arm to full range of motion. Therefore, we had fewer observations at higher abduction intervals, with selected observations at higher abduction intervals. Although this had little impact on our conclusion that scapular rotations normalise after RC repair, we cannot determine in which abduction interval the 'normalization' after RC repair occurs. Although the contralateral shoulders were asymptomatic, these shoulders might have been affected by asymptomatic RC pathology.[33] Comparative research may outline whether the presented observations are the results of RC repair or regression to the mean. Comparisons between two unconstrained movements might differ in the plane of elevation or axial rotation. Nevertheless, we considered voluntary unguided movements essential for this analysis because standardization of movements would result in uncharacteristic, forced arm movement with a subsequent effect on kinematics. We included the slight variance within the plane of elevation and axial humeral rotation as a covariate in our model to correct for potential small differences. In addition, measurement error as a result of test-retest variability might influence results, even though the inter-session reliability (i.e. reproducibility) of the electromagnetic tracking device proved to be excellent.[24] Therefore, the estimated measurement error, based on reported reliability, was smaller than the observed differences.

In future studies, evaluations of shoulder pathology and therapeutic interventions for the shoulder should be performed with quantitative 3D kinematic analysis next to clinical and validated patient-reported outcome measures, thus having objective evaluation tools for analysis of the contradictive results of treatment modalities for the shoulder.

CONCLUSION

After RC repair, scapular motion during an abduction movement normalised towards a more symmetrical scapular motion pattern. In addition, more glenohumeral elevation was observed after RC repair. The observed changes in scapulothoracic motion were associated with an increase in range of motion. The normalization of shoulder kinematics suggests restored function of shoulder muscles with a subsequent effect on scapulothoracic and glenohumeral motion and increased overall arm elevation after RC repair.

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