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Recovery of the shoulder kinematics after reverse shoulder arthroplasty

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ABSTRACT

Background: There is very limited information about the changes in shoulder kinematics in patients with reverse shoulder arthroplasty. The aim of the study was to investigate the changes in the scapulohumeral rhythm and shoulder kinematics over time after the reverse shoulder procedure.
Methods: Nineteen patients with reverse shoulder arthroplasty (age: 65.8 ± 10.3 years) were included to the study. During arm elevation in the sagittal and scapular planes, operated shoulder kinematics (humerothoracic elevation, glenohumeral elevation, scapulohumeral rhythm, and scapular rotations) were assessed using an electromagnetic tracking system at the postoperative 3rd, 6th, and 18th months. Asymptomatic shoulder kinematics were also assessed at the postoperative 18th month. Shoulder function was assessed using The Disabilities of the Arm Shoulder and Hand score at the postoperative 3rd, 6th, and 18th months.
Findings: Maximum humerothoracic elevation increased from 98° to 109° over the postoperative period ($p = 0.01$). The scapulohumeral rhythm was similar on the operated and asymptomatic shoulders at the final follow-up ($p = 0.11$). Both the operated and asymptomatic shoulder demonstrated similar scapular kinematics at the postoperative 18th month ($p > 0.05$). The Disabilities of the Arm Shoulder and Hand score decreased over time in the postoperative period ($p < 0.05$).
Interpretation: Shoulder kinematics may be improved after reverse shoulder arthroplasty in the postoperative period. Focusing on scapular stabilization and deltoid muscle control in the postoperative rehabilitation program may enhance the shoulder kinematics and upper extremity function.

1. Introduction

Reverse shoulder arthroplasty (RSA) has become the preferred treatment option for patients with cuff tear arthropathy (Boileau et al., 2005). It offers promising results in terms of pain, shoulder function, and quality of life (Farshad and Gerber, 2010). Several anatomic and biomechanical changes occur in the shoulder girdle with the reverse design of the prosthesis; improving the efficiency of the deltoid muscle and enabling the deltoid to compensate for the deficient rotator cuff muscles (Boileau et al., 2006; Grammont and Baulot, 1993). Due to good clinical results, surgeons have started using RSA in other shoulder pathologies as well (complex proximal fractures and rheumatoid arthritis) (Bufquin et al., 2007; Kontaxis and Johnson, 2008).

Although RSA improves shoulder function considerably, patients cannot use the full range of motion provided by the reverse prosthesis. Active shoulder elevation after the RSA surgery ranges between 88° and 125°, which is lower than passive shoulder elevation (Alta et al., 2011; Alta et al., 2014; Bergmann et al., 2008; de Toledo et al., 2012; Lee et al., 2016; Lehtimäki et al., 2021). Inefficiency in the rotator cuff (RC) muscles, impingement, decreased muscle strength, and altered biomechanics are the main factors for decreased glenohumeral and shoulder elevations (Kontaxis and Johnson, 2008; Terrier et al., 2013; Walker et al., 2015). Scapular motion is increased in patients with RSA surgery to compensate for the decreased glenohumeral elevation to increase overall active shoulder elevation (Roren et al., 2017). Studies reported increased scapular upward rotation (UR) and decreased scapulohumeral rhythm (SHR) after the RSA procedure (de Toledo et al., 2012; Kontaxis and Johnson, 2008; Lee et al., 2016; Terrier et al., 2013; Walker et al., 2015). However, most of the studies were conducted in the long term (between 23 and 57 months) after the surgery (Alta et al., 2011; de

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Toledo et al., 2012; Roren et al., 2017; Walker et al., 2015). In contrast, the data about the alterations in the scapular motion in the early postoperative period is limited. It is also unclear whether we can improve the shoulder kinematics SHR with the postoperative rehabilitation program.

Previously, only Matsukiet al. (Matsuki et al., 2018) and Merola et al. (Merolla et al., 2019) investigated the changes in the scapular kinematics over a time period after the RSA surgery. However, they assessed the scapular motion at 6 and 12 months postoperatively (in mid-terms) and did not provide any information about the early period. They also did not assess the changes in the SHR. Therefore, this study was performed to investigate the changes in the maximum humerothoracic (HT) elevation, SHR, and three-dimensional scapular kinematics over the postoperative period after the RSA surgery. We hypothesized that maximal HT elevation would increase and scapular compensation would decrease from postoperative 3rd to 18th months. We also hypothesized that both the RSA and asymptomatic shoulders would have similar shoulder kinematics at the final follow-up (18th month).

2. Methods

2.1. Study design

This was a retrospective study that included patients with RSA. Patients who had RSA surgery and received the postoperative rehabilitation program in our clinic at Hacettepe University between May 2016 and June 2022 were screened for eligibility. The study was approved by the ethical committee of Hacettepe University.

2.2. Participants

Twenty-five patients who had RSA surgery and were rehabilitated at our clinic were screened for eligibility. The inclusion criteria were having RSA surgery with a deltopectoral approach, having an asymptomatic contralateral extremity, and having their shoulder kinematics analyzed with the electromagnetic device. If patients had a neurological disorder or received revision surgery, they were excluded from the study. After the assessment, six patients were excluded (one had a gunshot wound on the contralateral shoulder, one had Parkinson's disease, two had cervical disk herniation that had neurologic signs and two patients' shoulder kinematics were not analyzed) from the study, and the data of nineteen patients were included (Table 1). The indications for the RSA surgery were: rotator cuff arthropathy or irreparable massive rotator cuff tear in 15 patients, proximal humerus fracture in 3 patients, and glenohumeral arthropathy due to recurrent shoulder dislocation in one patient.

2.3. Surgical procedure and postoperative rehabilitation

All the surgical procedures were performed in the beach-chair position. A standard surgical technique through the deltopectoral approach was used. The subscapularis muscle was detached from its insertion to access the shoulder joint. The humeral component of the prosthesis was placed without any inclination. A standard 36-mm glenosphere was used for the glenoid component and fixed with a 10° inclination. Subscapularis and other rotator cuff muscles were repaired if they were repairable.

A shoulder sling with a 45° abduction pillow was used for the first four weeks after the surgery. All patients received a standard rehabilitation program and visited our clinic for the first three months after the surgery. In the postoperative third week, passive flexion and abduction in the scapular plane were initiated. In the postoperative fourth week, active-assistive exercises were allowed and gradually increased to active and resistive exercises. Deltoid re-education exercise proposed by Levy et al. (Levy et al., 2008) was adopted in the early period. Scapular stabilization exercises were initiated with low intensities and progressively increased. Patients were also given a home-exercise program which was to be performed four times a day. Patients returned to daily activities after the postoperative 12th week (Appendix 1).

Table 1
Demographic characteristics of the patients.

	Mean (SD) ($n = 19$)	Min-Max
Age (years)	65.8 (10.3)	38–77
Height (cm)	157.7 (5.9)	144–178
Weight (kg)	68.7 (12.9)	40–95

SD: Standard deviation, Min-Max: Minimum-Maximum.

2.4. Outcome measures

2.4.1. Three-dimensional shoulder kinematics

Kinematic data of the operated shoulder were collected at the postoperative 3rd, 6th' and 18th months and of the asymptomatic shoulderw at the postoperative 18th month. Kinematic measurements were conducted using a three-dimensional electromagnetic tracking system (Motion Monitor® Skeleton Analysis System, Innovative Sports Training Inc., Chicago, ABD) consisting of a transmitter, six sensors (5 wired receivers, 1 digitizer) (1.9 × 3.3 × 3.5 cm), and a motion monitor software program. The system has a sampling rate of 100 Hz and the root-mean-square accuracy of 0.5° for orientation according to the manufacturer. It has shown good reliability in between-day measurements in our previous study (ICC scores of between 0.61 and 0.83) (Yildiz et al., 2020).

Before the analysis, specific bony landmarks on the patients were marked for the digitization process. Subsequently, five sensors were attached to the specific places using double-sided tape and were fixed with rigid tape; one sensor to the T1 spinous process, two sensors to flat surfaces of the acromion bilaterally, and two sensors to the insertion of deltoid muscles bilaterally. Following the sensor placements, patients were asked to stand in a relaxed posture in front of the transmitter while facing the positive x- axis. Via the sixth sensor, the digitization process was conducted and the three-dimensional model of the patients was constructed.

During the testing procedure, patients were instructed to perform bilateral maximum arm elevation and lowering while their thumbs were pointing upwards. A metronome was set at 60 beats per minute and arm elevation and lowering trials were performed in a count of six beats (elevation in three beats and lowering in three). Patients performed three arm elevation and lowering trials on the sagittal and scapular planes. The scapular plane was defined as 40° anterior to the frontal plane (Meskers et al., 1998). Two leader sticks were used to guide the patients during the arm elevation and lowering trials (Fig. 1). The patients were instructed to avoid any compensatory movements during the testing procedure. The average of the three trials was recorded for the analyses. The same two physiotherapists (experienced in the kinematic analyses) conducted all the kinematic measurements.

Scapular and humeral motions were calculated relative to the thorax (humerothoracic and scapulothoracic motion) and scapula (glenohumeral motion). Sensor placements, digitization process, and joint angles were performed according to the recommendation of the International Society of Biomechanics (ISB) (Wu et al., 2005). The 'y-x-z' Euler angle sequence was used to describe the motion of the scapula and humerus (Wu et al., 2005). The rotation center of the glenohumeral joint was estimated by regression analysis (Meskers et al., 1998).

2.4.2. Shoulder function

The Disabilities of the Arm Shoulder and Hand (DASH) score was used for the self-assessment of the shoulder function of the patients at the postoperative 3rd, 6th' and 18th months. DASH is a 30-item questionnaire where each question has 5 possible answers (1: No difficulty, 5: Unable to do it). A higher score indicates increased disability (Düger et al., 2006; Tongprasert et al., 2014).

Fig. 1. Sensor placement and arm elevation in the scapular plane.

2.5. Statistical analysis

During the arm elevation and lowering sequences on the sagittal and scapular planes, shoulder kinematics were captured at the 30°, 60°, 90°, and Maximum HT elevation degree and at 90°, 60°, and 30° of HT lowering angles. The captured shoulder kinematics during the arm elevation trials (the average of three trials) were used for the statistical analyses. In addition, changes in the glenohumeral (GH) and HT elevations and scapular UR were recorded to calculate the SHR.

Since the scapular upward rotation is the main component of the SHR and the most investigated scapular motion, it was used for the power analyses. The power of the study was calculated using the changes in the scapular upward rotation during the arm elevation in the sagittal plane in three different timelines (3rd, 6th, and 18th months). At the end of the study, the data of the 19 patients provided %84 power.

The statistical analysis was performed using SPSS Statistical Software Package 20.00 (SPSS Inc., Chicago, IL, USA). The demographic characteristics of the patients (age, body-mass index, follow-up duration) were presented as mean ± standard deviation (SD). Scapular UR and GH elevation during the arm elevation in the sagittal plane were used to calculate the SHR during the arm elevation trials (de Toledo et al., 2012; Roren et al., 2017). SHR was expressed as the ratio of the GH elevation over the scapular UR (de Toledo et al., 2012; Roren et al., 2017). It was calculated using the changes in the GH elevation and scapular UR between rest to 30°, 30° to 60° and 60° to maximum HT elevation ($SHR = GH^{x}\text{-}GH^{x\text{-}30} / UR^{x}\text{-}UR^{x\text{-}30}$) (Roren et al., 2017). Changes in the SHR, maximum HT elevation, and the DASH score over the postoperative period were analyzed with the Friedman test. When there were significant changes, the Wilcoxon Signed-Rank test was conducted for post-hoc analyses with the Bonferroni correction. The differences in the maximum HT elevation and SHR between the operated and the asymptomatic shoulders at the postoperative 18th month were also analyzed with the Wilcoxon Signed-Rank test.

Changes in the 3-dimensional shoulder kinematics in the post-operative period were analyzed using 3 by 7 repeated measures of ANOVA with the factors of time (3rd, 6th, and 18th months) and HT elevation (seven humerothoracic angles). Differences in the scapular kinematics of the operated and the asymptomatic shoulder at the post-operative 18th month were analyzed with 2 by 7 Mixed-Model ANOVA with the factors of side (operated and asymptomatic) and HT elevation (seven humerothoracic angles). The Greenhouse–Geisser correction was conducted if the sphericity assumption was violated. When there was significant time-by-angle or angle-by-side interactions, pairwise comparisons were conducted. The significance level was set at $p = 0.05$ for all statistical analyses.

Partial eta-squared was used to calculate the effect size (ES) of the repeated measures ANOVA designs. The partial eta-squared (η^2) of ≥0.01, ≥0.06 and ≥ 0.14 were considered small, medium, and large ES respectively.

3. Results

3.1. HT elevation and SHR

Maximum HT elevation was increased from 98.6° ± (11.1°) to 109.3° ± (20.3°) over the postoperative period ($p = 0.01$). Higher HT elevation was observed at the postoperative 18th month compared to the 3rd month ($p = 0.008$). However, it was still lower on the operated shoulder compared to the asymptomatic shoulder at the final follow-up ($p = 0.01$) (Table 2).

Friedman test revealed significant changes in the SHR on the operated side in the post-operative period ($p < 0.05$). There was a lower SHR at the postoperative 3rd month compared to the 6th ($p < 0.05$) and 18th months ($p < 0.05$), while the SHR was similar at the 6th and 18th months ($p > 0.05$). SHR was also similar on the operated and asymptomatic shoulders at the postoperative 18th month ($p > 0.05$) (Table 2).

3.2. Shoulder kinematics

Changes in the scapular internal-external rotation, upward-downward rotation, and anterior-posterior tilt of the operated shoulder over time were summarized in Table 3.

Scapular Internal Rotation: There were no angle-by-time interaction in the sagittal ($F_{(2.5,\ 45.3)} = 0.58$; $p = 0.6$) and scapular planes ($F_{(3.5,\ 63.1)} = 1.3$; $p = 0.28$) (Fig. 2) on the operated shoulder. For side-to-side comparisons, significant angle-by-side interactions were found between operated and asymptomatic shoulders in the sagittal ($F_{(2,\ 36)} = 7.6$; $p = 0.002$) and scapular planes ($F_{(2.3,\ 42.6)} = 812$; $p > 0.001$) at the

Table 2
Scapulohumeral Rhythm, Maximum Humerothoracic Elevation and DASH Score of the patients.

			3-Month	6-Month	18-Month
Scapulohumeral Rythm	Rest-30°	Operated	2.3 (1)	3.3 (1.5) #	3.4 (1.1) #
		Non-Operated			4.3 (1.5)*
	30°-60°	Operated	1.4 (0.6)	2.1 (0.8) #	2.3 (1) #
		Non-Operated			2.5 (0.9)
	60°-Maximum HT	Operated	2 (1.4)	2.3 (1)	2.5 (1.4) #
		Non-Operated			2.9 (1.2)
Max. HT Elevation (°)		Operated	98.6 (11.1)	101.7 (11.3)	109.3 (16.3)
		Non-Operated			115 (11.2)*
DASH Score			48 (13.3)	43.1 (15.1)	35.7 (3.8)

HT: Humerothoracic, (*): Higher SHR on asymptomatic shoulder compared to the symptomatic shoulder, (#): Higher SHR compared to 3rd month.

Table 3
Summarization of the Scapular Kinematics in the Operated Shoulders.

	Sagittal Plane					Scapular Plane				
HT Elevation	12-week mean (SD)	6-month mean (SD)	18-month mean (SD)	F test	e^2	12-week mean (SD)	6-month mean (SD)	18-month mean (SD)	F test	e^2
Scapular Internal Rotation (+)										
30	35.2 (7.6)	35.2 (7.7)	34.6 (7.4)	0.601	0.032	35.2 (7.6)	33.5 (7.2)	31 (6.4)	0.280	0.068
60	39.2 (8.4)	39.2 (7.5)	38.3 (5.5)			32.8 (8.4)	35.1 (6.6)	33 (8.1)		
90	39.8 (10.3)	38.9 (9.1)	39.4 (6.8)			35.3 (9.6)	36.7 (7.2)	37.7 (9.9)		
Max	36.7 (11.9)	35.2 (7.1)	37 (13.7)			34 (10.3)	34.9 (8)	35.6 (8.8)		
90	38.4 (9.9)	36.6 (9.7)	39.5 (12.6)			34.7 (10)	37.1 (6.9)	37.6 (10.5)		
60	38.6 (7.9)	38.1 (8.8)	40 (10.1)			32.1 (8)	35.4 (7.3)	32.6 (8.5)		
30	35.2 (7.2)	35.1 (7.9)	36 (8.4)			31.5 (7.7)	33.7 (7.2)	30.9 (6.4)		
Scapular Upward Rotation (+)										
30	8 (6)	5.6 (6.7)	4.3 (5.2)*	0.012	0.153	6.6 (5.3)	2.1 (6.3)	1.6 (5.6)	0.098	0.106
60	20.2 (7.9)	16.7 (6.3)	15.7 (5.6)*			21 (6.4)	12 (5.7)	12.7 (6.1)		
90	28.6 (12.7)	24.2 (10.3)	25.2 (7.8)			31.2 (9.1)	21.1 (6.8)	21.8 (9.4)		
Max	35.9 (10.3)	27.2 (10.6)$^{\#}$	29.1 (8.1)*			32.8 (11.1)	25.8 (9.5)	25 (10.3)		
90	28.6 (10.5)	23.2 (9)$^{\#}$	24.4 (7.7)			29 (8.4)	21.5 (8.4)	20.6 (9)		
60	19.1 (7.4)	16.2 (5.5)	16.4 (5.3)			18.2 (6.7)	9.5 (7.6)	12 (6.8)		
30	6.8 (6.1)	4.9 (6.6)	3.7 (6)			4.5 (5.6)	0.1 (6.7)	0.8 (5.3)		
Scapular Posterior Tilt (+)										
30	−12.7 (9.7)	−13.8 (9.9)	−13.4 (7.6)	**0.007**	**0.189**	−15 (10)	−16.6 (8.2)	−13.4 (5.9)	**0.041**	**0.132**
60	−11.9 (10.5)	−12.6 (10.9)	−10.9 (9.8)			−12.6 (11.1)	−16.1 (8.8)	−10.2 (7.2)		
90	−11.9 (12.6)	−11.9 (13.2)	−7.9 (12.6)			−12.8 (14.1)	−15.2 (8.7)$^{+}$	−6.2 10.5)$^{+}$		
Max	−10.9 (16)*	−8.6 (15.3)	−4.9 (11)*			−11.2 (15.1)	−13.7 (10.7)$^{+}$	−5 (11.8)$^{+}$		
90	−12.1 (12.5)	−11.8 (13.2)	−8.1 (13.4)			−11.9 (11.4)	−15.8 (9.1)$^{+}$	−5.7 (11.7)$^{+}$		
60	−14.1 (11.2)	−14.2 (11.4)	−11.6 (10.4)			−12.4 (9.4)	−17.7 (8.9)$^{+}$	−8.8 (8.5)$^{+}$		
30	−14.9 (10.6)	−15 (9.9)	−13.4 (7.8)			−15.5 (7.8)	−18.9 (8.8)$^{+}$	−12.5 (6.1)$^{+}$		

HT: Humerothoracic elevation, Max: Maximum, e^2: Effect size, SD: Standard deviation, *: significant difference between postoperative 18th and 3rd months, $^{\#}$: difference between postoperative 6th and 3th months, $^{+}$ significant difference between postoperative 18th and 6th months.

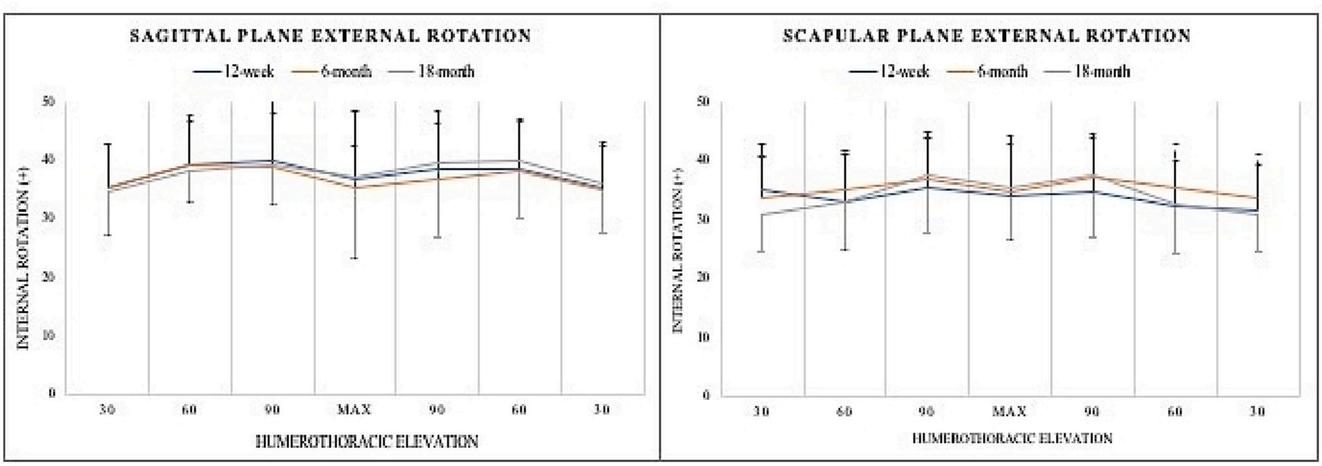

Fig. 2. Scapular internal rotation.

postoperative 18th month. Pairwise comparisons revealed more internally rotated scapula at maximum HT elevation ($p = 0.02$) and 90° lowering angles($p = 0.04$) in the operated shoulder compared to the asymptomatic shoulder on the sagittal plane. For the scapular plane, the scapula was more internally rotated on the operated shoulder compared to the asymptomatic shoulder through the arm elevation and lowering degrees ($p < 0.05$) (Table 3).

Scapular Upward Rotation: In the sagittal plane, a significant angle-by-time interaction was found ($F_{(4.4,\ 80.6)} = 3.24$; $p = 0.01$) on the operated shoulder. Pairwise comparisons indicated decreased UR at 30° (0.04) and 60° ($p = 0.032$) of HT elevations and maximum HT elevation degree ($p = 0.041$) at the 18th month compared to the 3rd month, and at maximum HT elevation ($p < 0.001$) and 90° of HT lowering angle ($p = 0.038$) at the 6th month compared to the 3rd month postoperatively (Fig. 3). In contrast, there was no significant angle-by-time interaction ($F_{(3.3,\ 60.8)} = 2.13$; $p = 0.09$) in the scapular plane (Table 3). For side-to-side comparisons: no angle-by-side interaction was observed between the operated and the asymptomatic shoulders on the sagittal plane ($F_{(1.8,\ 33.7)} = 0.68$; $p = 0.5$), while there was a significant interaction on the scapular plane ($F_{(1.3,\ 24.9)} = 6.57$; $p = 0.01$) at 18th month. Pairwise comparisons showed lower scapular UR at maximum HT angle on the operated shoulder compared to the asymptomatic shoulder ($p = 0.01$) (Tables 3 and 4).

Scapular Posterior Tilt: In the sagittal plane, significant angle-by-time interaction was observed ($F_{(3.4,\ 61.4)} = 4.2$; $p = 0.007$) on the operated shoulder. Pairwise comparisons revealed a more posteriorly tilted scapula at maximum HT elevation at the 18th month compared to the 3rd month postoperatively ($p < 0.05$) (Fig. 4). In the scapular plane,

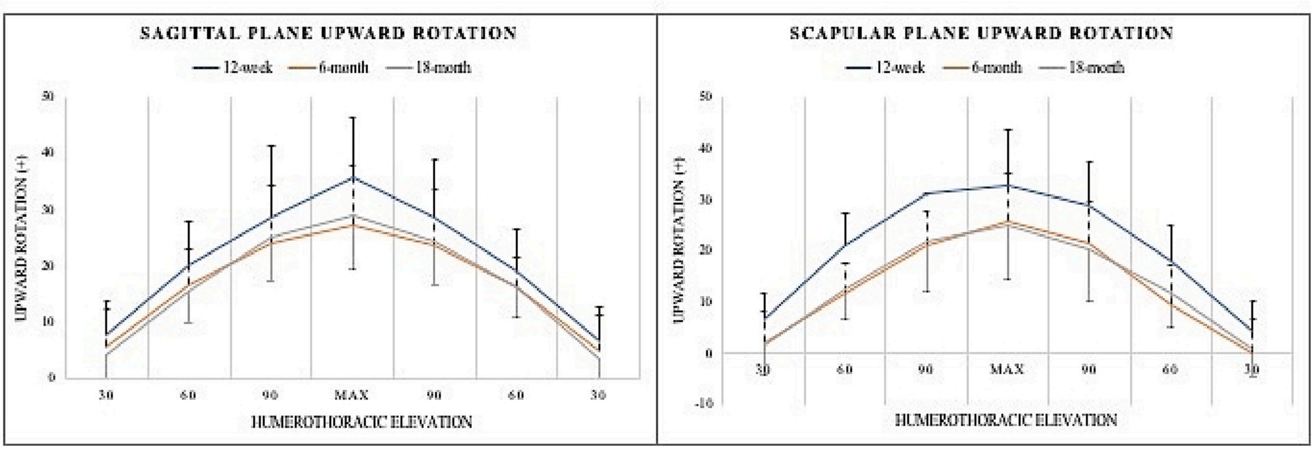

Fig. 3. Scapular upward rotation.

Table 4
Scapular Kinematics in the Asymptomatic Shoulder at 18th Month.

	Sagittal Plane			Scapular Plane		
	Internal Rotation (SD)	Upward rotation (SD)	Posterior Tilt (SD)	Internal Rotation (SD)	Upward rotation (SD)	Posterior Tilt (SD)
30	32.6 (11)	2.6 (4.6)	−12.5 (5.8)	23.1 (7.9)	2.2 (3.9)	−11.8 (3.4)
60	36.6 (11.7)	14 (5.3)	11.1 (6.4)	23.4 (8.5)	13 (4.2)	−10 (3.8)
90	34.5 (11.4)	23 (7.4)	−10 (9.3)	23.1 (10.4)	22.6 (5.2)	−9.7 (6.8)
Max	27. 1 (12.4)	30.3 (9.4)	−6.8 (8.4)	22.4 (12.1)	31.9 (5.9)	−9.7 (7.9)
90	32. 1 (9.6)	22.8 (7.4)	−10.7 (8.8)	23.1 (9.2)	22.2 (5.1)	−9.7 (7.1)
60	34 (9.3)	14 (6.4)	−12.7 (6. 1)	23 (7.8)	12.6 (3.5)	−10.4 (4.4)
30	32 (4)	2.7 (5.9)	−13.1 (6.1)	23.4 (7.8)	0.5 (3.9)	−11.6 (3.9)

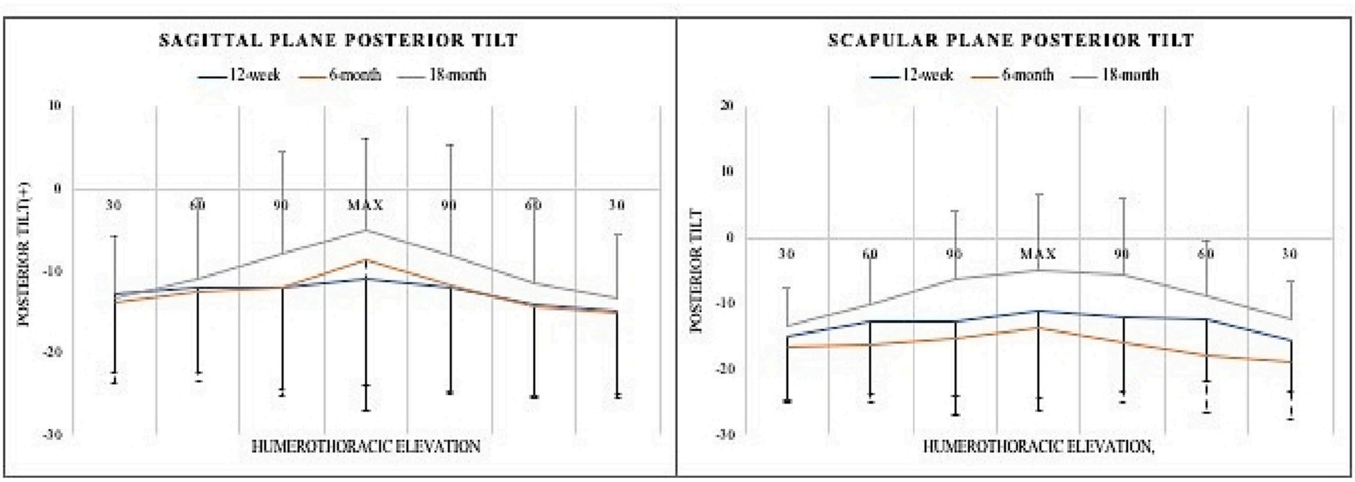

Fig. 4. Scapular posterior tilt.

there was also a significant angle-by-time interaction ($F_{(3.5,\ 63.9)} = 2.74$; $p = 0.04$). Pairwise comparisons showed a more posteriorly tilted scapula at 90° ($p = 0.01$), and maximum HT elevation ($p = 0.02$) during the elevation phase and at 90° ($p = 0.007$), 60° (p = 0.007), and 30° ($p = 0.03$) during the lowering phase at 18th month compared to the 6th month (Table 3). No significant angle-by-side interaction was found between the operated and the asymptomatic shoulders in the sagittal plane ($F_{(2.5,\ 46.3)} = 2.33$; $p = 0.09$). In contrast, there was a statistically significant angle-by-side interaction between the operated and the asymptomatic shoulders in the scapular plane ($F_{(1.5,\ 28.5)} = 8.25$; $p = 0.003$; $\eta^2 = 0.314$). Pairwise comparisons revealed a more posteriorly tilted scapula at the maximum HT angle on the operated shoulder compared to the asymptomatic shoulder ($p = 0.01$).

DASH score significantly decreased over the post-operative period ($p = 0.03$). The analyses revealed decreased DASH score at the post-operative 18th month compared to the 3rd ($p = 0.002$) and 6th months (p = 0.01) (Table 2).

4. Discussion

Previous studies investigated the alterations in the three-dimensional shoulder kinematics after RSA surgery and reported increased scapular motion to compensate for the decreased glenohumeral motion (de Toledo et al., 2012; Kontaxis and Johnson, 2008). However, little is known about the early postoperative period and alterations in the shoulder kinematics over time. In addition, no previous study investigated the changes in the SHR through the postoperative period. Therefore, we aimed to investigate the alterations in the shoulder kinematics in patients with RSA surgery over the postoperative period. The results of the study partly supported our hypothesis that the maximum HT elevation and SHR changed over time after the RSA procedure. However, maximal HT elevation was still lower compared to the asymptomatic shoulder at the postoperative 18th months. Similarly, scapular upward rotation and posterior tilt were also improved (resembled to the asymptomatic shoulder) over the postoperative period. Yet they were still different from the asymptomatic shoulder at the final follow-up too.

Restoring active arm elevation is the main goal of the RSA surgery. However, patients mostly cannot actively use the maximum available arm elevation provided by the prosthesis after the surgery (Alta et al., 2014). Progressive deltoid and dynamic scapular control exercises are suggested in the post-operative period to improve the active arm elevation (de Toledo et al., 2012; Uschok et al., 2018). However, previous studies evaluated the shoulder and scapular kinematics only at a certain time point in the long term after the RSA procedure. Therefore they did not demonstrated the efficiency of the exercise treatment. They reported between 88° and 125° of arm elevation in the long term after the RSA surgery (Alta et al., 2011; Bergmann et al., 2008; Cuff et al., 2008; de Toledo et al., 2012; Lee et al., 2016; Roren et al., 2017; Walker et al., 2015). In the current study, our patients achieved 98° of arm elevation at the postoperative third month and increased to 109° at the 18th month. Simovitch et al. (Simovitch et al., 2018) reported that, more than >11° increase in the shoulder flexion and 5° increase in abduction was clinically meaningfull in patients with RSA surgery with a follow-up time of less then 36 months. Given the results, our patients displayed a clinically important increase in the shoulder elevation from early to late postoperative period. Postoperative rehabilitation program addressing the deltoid and scapular control is believed to induce this increase in the active arm elevation.

Although the active arm elevation of our patients was improved after the RSA surgery, it was still decreased compared to the asymptomatic shoulder. The literature also agreed with our study in that there were lower active arm elevation degrees on the operated shoulder compared to the asymptomatic one (Alta et al., 2011; Boileau et al., 2005; Lee et al., 2016; Walker et al., 2015). Alta et al. (Alta et al., 2011) measured the maximum HT elevation after 23 months from the RSA surgery and found an average of 93° maximum HT elevation in the sagittal and scapular planes. They reported that RSA surgery restored active forward elevation approximately 65% of the asymptomatic shoulder. This was mainly caused by the natural design of the reverse prosthesis restricting the GH motion. However, an important difference still existed between the active and passive arm elevation degrees. Therefore, exercise programs addressing deltoid control and scapular stabilization needs to be continued in the long-term after surgery.

No previous study had reported the changes in the SHR over time after the RSA surgery. We found significant alterations in SHR in the postoperative period. In the early period, SHR was lower on the operated shoulder compared to the asymptomatic one indicating higher scapular compensation. After the postoperative 3rd month, the scapular compensation decreased while the maximum HT elevation increased. The increase in the maximum HT elevation in the postoperative 6th and 18th months was mostly due to increased GH motion. At the final follow-up, the SHR ranged between 2.3 and 3.4. It was similar on both shoulders at higher arm elevation degrees while it was decresed on the operated shoulder at the lower arm elevation degrees. Kwon et al. (Kwon et al., 2012) reported between 1.94 and 2.81 and Kim et al. (Kim et al., 2020) reported 2.4 SHR values which were comparable with the present study. In addition, Lee et al. (Lee et al., 2016) presented decreased SHR on the operated shoulder at lower arm elevation degrees while it was similar on both shoulders at higher degrees. However, the overall SHR during the entire arm elevation motion was 1.25 (Lee et al., 2016) which lower compared to our study. Roren et al. (Roren et al., 2017) also found lower SHR values (between 1.1 and 1.9) than the present study. Overall, there is conflicting results regarding the SHR values of the patients with RSA procedure which is probably due to the differences between the populations. However, they all agree that, the SHR was lower on the operated shoulder compared the the asymptomatic one (Kim et al., 2012; Kim et al., 2020; Lee et al., 2016; Roren et al., 2017). In the present study, we also found lower SHR values in the early postoperative period. However, the SHR was similar on both shoulders at the final follow up. We blieve this improvements in the shoulder kinematics were due to our postoperative rehabilitation program focusing on the scapular stabilization and deltoid control. Previous studies also emphasized the importance of the scapular stabilization in the postoperative period (Lee et al., 2016; Walker et al., 2015), yet they did not demonstrated its' effects due to the design of their study. In current study, although we did not be able compare our results with a control group, it is thought that the effects of scapular stabilization and deltoid control were partly demonstrated.

Previous studies reported that the functional adaptations in the scapulothoracic and GH motion might occur within the first six months after the surgery and the adaptations remained almost constant after six months (Matsuki et al., 2018; Merolla et al., 2019). However, no study investigated these adaptations within the first six months. In the present study, we also searched for the possible kinematic changes that occurred in the first six months after the RSA procedure. We observed that shoulder kinematics altered from the early to later periods after the RSA surgery. There was lower maximum HT elevation and the scapula had a major role in this motion during the early periods. This was thought to be due to inadequate deltoid strength where the scapula compensated for this and increased the shoulder elevation. During the later periods, the role of the scapula decreased while the role of the glenohumeral motion increased in the arm elevation. Similar with the previous studies, we also observed that kinematic improvements of the shoulder slowed down after the 6th month. However, it continued to improve after the 6th month though it was not significant. Therefore, exercise treatments needs to be performed in the long term as well.

Scapular UR is the most widely investigated motion of the scapula, since it is one of the main components of the SHR (de Toledo et al., 2012; Kahn et al., 2019; Kontaxis and Johnson, 2008; Lee et al., 2016). Increased scapular UR had been reported on the RSA shoulder compared to the asymptomatic one in the long term after RSA surgery (Kontaxis and Johnson, 2008; Kwon et al., 2012; Lee et al., 2016). In the present study, there was higher scapular UR in the early period while it decreased in the mid and long terms. The decrease in the scapular UR had a large effect size and clinical importance. Together with the increased GH motion, it has important effects on the SHR. At the final follow up, our patients displayed similar scapular UR on the operated and asymptomatic shoulders in contrast to the previous studies. We believed that this could be mainly due to our postoperative rehabilitation program focusing on deltoid muscle control and scapular stabilization.

Limited studies have investigated changes in the scapular internal-external and anterior-posterior tilt after the RSA surgery (Kim et al., 2020;Lee et al., 2016 ; Roren et al., 2017). Roren et al. and Lee et al. (Lee et al., 2016; Roren et al., 2017) reported similar scapular internal rotation on both operated and asymptomatic shoulders during arm elevation. In contrast, Kim et al. (Kim et al., 2020) reported increased scapular internal rotation on the RSA shoulder. Our results agreed with Kim et al. (Kim et al., 2020) as our patients had higher scapular internal rotation on the operated shoulder compared to the asymptomatic one. The increase in deltoid tension after the RSA surgery is thought to be the main reason for the increased scapular internal rotation (Henninger et al., 2012). The rotation center of the glenohumeral joint is replaced inferiorly and medially with the RSA procedure. These changes increase deltoid muscle tension and enable it to stabilize the joint (Grammont and Baulot, 1993; Kontaxis and Johnson, 2009). However, the increased tension in the deltoid muscle is thought to increase the internal rotation moment on the scapula (Kim et al., 2020). Although the scapular stabilization exercise helps to correct the scapular posture, the deltoid exercise could also increase the internal rotator moment on the scapula. Therefore, the increased scapular internal rotation could be considered as a standard adapdation in the RSA shoulders.

In the current study, the scapular posterior tilt of the patients increased over the postoperative period and had similar values with the asymptomatic shoulder at the final follow-up. The lower trapezius muscle is mainly responsible for the scapular posterior tilt (Paine and Voight, 2013). Increased scapular posterior tilt from the 3rd month to the 18th month is thought to be due to increased lower trapezius activity via the scapular stabilization exercise. In contrast, Merolla et al. (Merolla et al., 2019) reported no changes in the scapular kinematics between the postoperative 6th and 12th months. The difference in the time of the collection of the kinematic data could be the main reason for the different results. There were an average of 15 months between the first and the last measurements in our study while there were only 6 months in theirs. In parallel with our results, Roren et al. (Roren et al., 2017) and Lee et al. (Lee et al., 2016) reported similar scapular posterior tilt degrees after 35 and 24 months from the surgery. However, we do not know whether their patients' kinematics improved over time since they only collected the kinematics data at given timelines. Given the current data, it can be concluded that scapular movement patterns may be altered/improved in the long-term after the RSA surgery though the evidence is not very strong.

The DASH score evaluates the person's ability to perform daily activities. It has a close relationship with the active shoulder range (Harrington et al., 2013). In the current study, the maximum HT elevation of the patients was higher at the post-operative 18th month compared to 3rd and 6th months. Therefore, it was not surprising that patients had higher DASH scores after 18 months postoperatively compared to the 3rd and 6th months. As the patients' active shoulder elevation increased, their ability to perform daily activities also improved in the mid-term after the RSA surgery.

5. Limitations

The main limitation of our study was that we compared the shoulder kinematics between the RSA and the contralateral asymptomatic shoulders. However, although the contralateral shoulder of the patients was asymptomatic, degenerative changes could occur on the contralateral shoulder with aging as well. Second, we evaluated the three-dimensional scapular kinematics at the postoperative period as we did not had a chance to assessed the patients preoperatively. Therefore, we could not compare the postoperative shoulder kinematics with the preoperative data. Lastly, since this was a retrospective study, we compared our results with the literature rather than with a control group. Althoug, discussing the results with the literature provide valuable insights, future studies are needed to provide more clear effects scapular stabilizatıın and deltoid exercise with randomized controlled design.

6. Conclusion

The present study demonstrated that shoulder kinematics improves from early to late postoperative period after the RSA procedure. The scapular compensation was decreased while the active arm elevation was increased. The SHR in the opareted shoulder was similar with the asymptomatic shoulder at the end of the study. The scapular stabilization and progressive deltoid exercise could play in these changes. Therefore, rehabilitasyon programs needs focus on the progressive deltoid control and scapular stabilization after RSA surgery.

Declaration of Competing Interest

None.

Appendix A. Postoperative rehabilitation program

0–4 weeks

- Shoulder sling
- Passive shoulder flexion and abduction in the scapular plane (at 3rd week)
- Active-assistive wand exercise (at 4th week)
- Cold therapy
- Manuel therapy program aiming shoulder and scapular mobilizations

4–8 weeks

- Shoulder ROM exercise with pilates ball
- Deltoid re-education exercise were initiated
- Progressed to active shoulder elevation
- Scapular retraction exercises
- Scapular hug exercise
- Shoulder internal-eksternal rotation exercise with resistive band
- Manuel therapy program aiming shoulder and scapular mobilizations (soft tissue mobilization)

8–12 weeks

- Continue Shoulder ROM exercise
- Continue to the scapular retraction exercises with increased resistance
- Scapular stabilization in closed-kinetic chain (wall push-up)
- Bilateral shoulder external rotation with scapular retraction with resistive band
- Continue shoulder internal-eksternal rotation exercise with resistive band
- Deltoid strengthening exercise

12 weeks - ...

- Continue scapular stabilization exercise
- Continue shoulder internal-eksternal rotation exercise
- Continue deltoid exercise

(*continued on next page*)

(*continued*)

• Continue bilateral shoulder external rotation • Exercise were performed 3–4 days in a week in this period • Exercise are performed with increasing loads

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