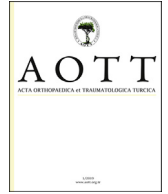


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Isokinetic Evaluation of Shoulder Strength and Endurance after Reverse Shoulder Arthroplasty: A Comparative Study



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ABSTRACT

Objective: The present study aimed to compare the isometric strength and endurance of shoulder abduction and internal and external rotation between operated shoulders and nonoperated, contralateral shoulders of patients who underwent reverse shoulder replacement due to unilateral rotator cuff tear arthropathy.

Patients and methods: With a diagnosis of cuff tear arthropathy, 41 consecutive patients (mean age of 70.8 years; age range, 57 to 84; 36 females, 5 males) who underwent unilateral reverse shoulder arthroplasty were reviewed based on functional and radiological data. In all cases, cuff tear arthropathy was unilateral and contralateral shoulder was asymptomatic, with normal shoulder function. The average length of follow-up was 34 months (range of 12–67).

To assess patients' functional level, the Constant score and the Disabilities of the Arm, Shoulder, and Hand (the Quick-DASH) outcome measure were used preoperatively and at the final examination.

The primary outcomes of the present study were measurement of isokinetic strength and endurance of shoulder abduction and internal and external rotation using an isokinetic evaluator.

Results: Patients exhibited marked improvement in functional level as reflected by a significant increase in the mean Constant score from 38 preoperatively to 65 at the final follow-up ($p = 0.03$). The functional improvement was supported by a decrease in the mean Quick-DASH from 64 preoperatively to 26 at the final follow-up ($p = 0.018$).

In the comparison of the isokinetic strength and endurance of shoulder abduction, no statistical difference was observed between operated shoulders and contralateral shoulders ($p > 0.05$). However; the strength and endurance of internal and external rotation were lower in operated shoulders than in contralateral shoulders ($p < 0.05$). Similarly, there was no statistically significant difference in comparisons of the durability of abduction ($p > 0.05$); however, the durability of internal and external rotation were significantly lower in operated shoulders ($p < 0.05$).

Conclusion: In terms of durability and strength of abduction, similar results with the unaffected shoulder may be accomplished; nonetheless, the surgeon should be aware that durability and strength of rotation would be weak.

Level of evidence: Level III, Therapeutic Study.

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Introduction

Recently, reverse shoulder arthroplasty (RSA) has been increasingly performed, with expanded indications.^{1–3} Nonetheless, cuff tear arthropathy remains the prime indication for this popular technique, and some authors have reported long-term successful outcomes of reverse shoulder arthroplasty performed

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for this indication.⁴ The goal of RSA is to improve the shoulder abduction strength by lengthening the deltoid moment arm with medialization of the center of rotation, thus increasing the shoulder abduction to between 100° and 140°. ^{5,6} Although data regarding functional gains in shoulder abduction following RSA are available in the literature, an important question as to whether patients regain rotational functions was unanswered. ^{7,8}

It is considered that the maximum range of motion (ROM) obtained by RSA is directly proportional to the tensional force generated by the deltoid muscle. Although this phenomenon was investigated by a few biomechanical cadaveric studies based on computer modeling, there is a lack of clinical evidence in the literature regarding this issue. ^{10,11}

Furthermore, endurance can be defined as the ability to withstand stress over prolonged periods of time during daily repetitive movements. Otherwise, strength can be defined as the capacity of a muscle to withstand great force. Therefore, endurance may be a more reasonable measure to evaluate shoulder functions following RSA.

The purpose of this study was to carry out a comparative study on the strength and endurance of shoulder rotators and deltoid muscles between operated and nonoperated, contralateral shoulders of patients who underwent RSA due to cuff tear arthropathy. We hypothesized that although RSA would improve shoulder abduction strength and endurance by lengthening the deltoid moment arm, rotational forces would not be regained due to the dearth of RC muscles.

Patients and methods

With a diagnosis of cuff tear arthropathy, 51 consecutive patients who underwent RSA between 2009 and 2015 were reviewed. According to the inclusion criteria given in Table 1, 9 patients were excluded, and the remaining 41 patients (36 females, 5 males) were enrolled in the study. After institutional review board approval was obtained, medical and radiological records were retrospectively analyzed.

In all patients, who had a mean age of 70.8 years (ranging from 57 to 84), cuff tear arthropathy was unilateral and grade III or higher according to the Hamada classification (reference). Additionally, contralateral shoulders were asymptomatic, with normal shoulder function, according to physical examination. The average length of follow-up was 34 months (range: 12 to 67).

All the prosthesis were medialized reverse shoulder prosthesis (DELTA XTEND™ Reverse Shoulder System, DEPUY, USA) by three orthopedic surgeons with expertise in shoulder surgery (MD, ACA, AE). The operation was performed through a standard deltopectoral approach, and the humeral stem was cemented in all cases. Patients had previously received no tendon transfer procedure. Additionally, the postoperative rehabilitation protocol was the same for each patient.

Table 1

Flowchart of the study participants.

Inclusion Criterias
> Having a diagnosis of unilateral cuff tear arthropathy.
> A minimum of 12-months follow-up.
> Undergoing unilateral reverse shoulder arthroplasty.
> Having an asymptomatic shoulder with a normal range of motion.
> Being willing to complete the questionnaires during physician office visits.
Exclusion Criteria
> Patient with revision reverse arthroplasty
> Reverse shoulder arthroplasty for treatment of displaced proximal humerus fractures
> Patients without adequate range of motion for isokinetic test
> Patients with inflammatory diseases

The primary outcome of the present study was to compare the isokinetic strength and endurance for shoulder abduction and internal and external rotation between operated shoulders and non-operated, contralateral shoulders of patients. Therefore, in order to assess strength and endurance of shoulder rotators and deltoid muscles, a CYBEX 350 isokinetic dynamometer (CYBEX HUMAC, version 2009, Stoughton, MA, USA) was used at the final follow-up.

Isokinetic test protocol

Overall isokinetic measurements were performed by the same physiotherapist (T.S.) using a computed dynamometer (CYBEX HUMAC, version 2009, Stoughton, MA, USA). Shoulder abduction strength and endurance were attained from patients in a sitting position on a custom-made dynamometer chair, with the elbow fully extended. Shoulder internal and external rotation strength and endurance were obtained from the patients in a standing position, with elbow flexed at 90°. To measure the muscle strength, the average peak torque (nm) done with four repetitions at a velocity of 60°/sec was determined. To measure the muscular endurance, total work (nm) done with 15 repetitions at a velocity of 180°/sec was determined.

The comparison of active shoulder ROM between operated and contralateral shoulders was an additional, secondary, outcome. The active ROM of abduction and internal and external rotation were measured for each patient by two resident physicians (SB, MD) using a universal standard goniometer preoperatively and at the final follow-up. Both shoulders of the patients were evaluated in the supine position using a standardized order of movement. For shoulder abduction, the shoulder was positioned at 0° flexion and extension, with the elbow fully extended. Stabilizing the thorax, the measurement was done in the externally rotated shoulder. To evaluate shoulder rotation, the shoulder was positioned at 90° of abduction, with a neutral forearm position (Fig. 1A, B). Fixing the elbow at 90°, internal and external rotation were measured (Fig. 2).

Patients' functional status was further evaluated using the Constant score¹⁸ and the Disabilities of the Arm, Shoulder, and Hand outcome measure (the Quick-DASH)¹⁹ preoperatively and at the final examination.

As a radiological outcome of this study, we sought to investigate the correlation between the acromion-greater tuberosity (AGT) distance and the abduction strength. The measurement of the AGT distance was undertaken on preoperative and final control true anteroposterior view radiographs of operated shoulders by two orthopedic resident physicians (SB, MD). The AGT distance was measured as the distance between the inferolateral acromion tip and the most prominent superolateral aspect of the greater tuberosity (Fig. 3A, B).

Postoperative rehabilitation protocol

While all the patients used a sling during the first 6 weeks after surgery, they were allowed forward flexion and abduction starting on the 3rd postoperative day. They were not allowed to do internal and external rotation for 6 weeks in order to protect the subscapularis tendon repair. At 6 weeks postoperatively, all motions of the shoulder were allowed in an active-assistive manner, and the patients were given strengthening exercises at 12 weeks.

Statistical analyses

All the statistical analysis was performed using the SPSS version 22 statistics software program (IBM Corp, 2011, Armonk, New York). Pre- and postoperative functional results, radiographically evaluation and range of motion were compared using the paired T test. Comparison of results between the opere and non-opere

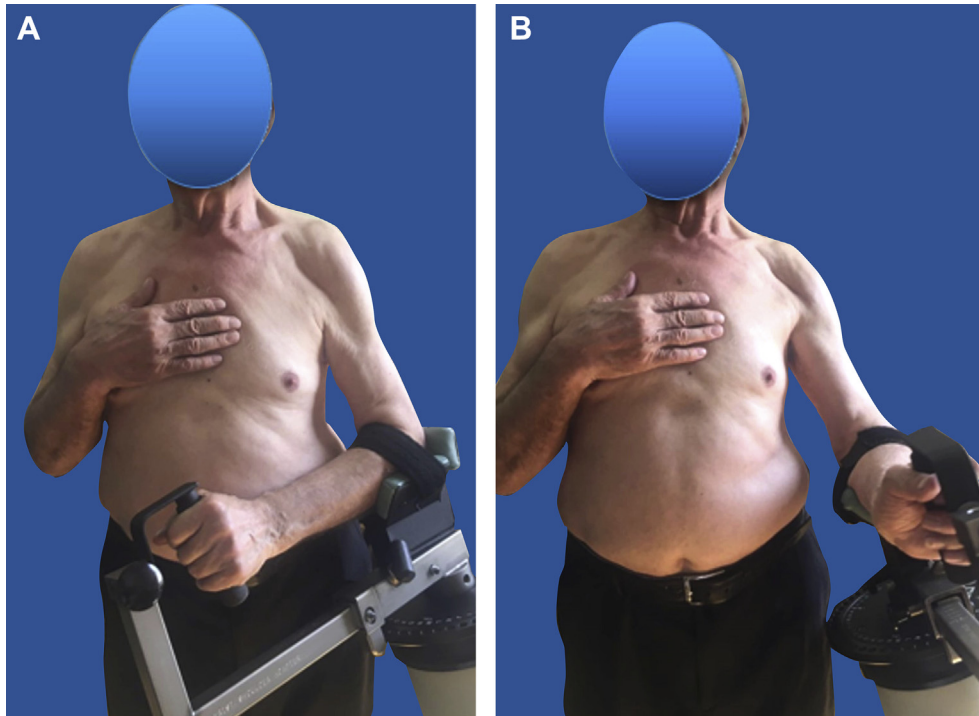


Fig. 1. A–B: Patients performed internal-external rotation cybex who underwent the reverse shoulder prosthesis 2 years ago.

shoulder isokinetic test result were done using Student's t test. A p value less than 0.05 was considered to be statistically significant. Pearson correlation test was used between the abduction strength and acromion-greater tuberosity.

Results

The results of this comparative study are summarized in [Table 2](#) with satisfactory functional conditions, all the patients returned to their daily lives without any limitations. No subluxation or dislocation was observed postoperatively.

Isokinetic strength and endurance

The mean abduction strength was 105 nm (± 21) in the operated shoulders and 115 nm (± 25) in the contralateral shoulders

($p > 0.05$). The mean abduction endurance was found to be 23.8 nm (± 7) in the operated shoulders and 27.6 nm (± 6) in the contralateral shoulders ($p > 0.05$).

Internal rotation strength and endurance were significantly lower in the operated shoulders (mean strength: 100 nm \pm 17; mean endurance: 10 nm \pm 3) than in the contralateral shoulders (mean strength: 248 nm \pm 32; mean endurance: 27 nm \pm 7) ($p = 0.012$ and $p < 0.01$, respectively).

Similarly, lower external rotation strength and endurance were observed in operated shoulders (mean strength: 65 nm \pm 12; mean endurance: 11 nm \pm 1) than in contralateral shoulders (mean strength: 153 nm \pm 22; mean endurance: 27 nm \pm 8) ($p = 0.038$ and $p = 0.026$, respectively).

Active ROM

The mean degree of shoulder abduction increased from 84.5° (range: 30 to 160) to 108.8° (range: 90 to 170) in the operated shoulders ($p < 0.01$). The mean degree of forward flexion was 77.5° (range: 50 to 130) preoperatively and 111.6° (range: 80 to 170) at the final examination in the operated shoulders ($p < 0.01$). However, no significant increase was observed in internal and external rotations of the shoulder between both groups ($p = 0.12$). For external rotation, the operated shoulders showed a mean of 21.3° (range: 0 to 50) ROM preoperatively and 23.8° (range: 0 to 60) at the final examination.

Functional outcome measures

Patients exhibited marked improvement in their functional status following RSA as reflected by a significant increase in the mean Constant score from 38 (± 14) preoperatively to 65 (± 11) at the final follow-up ($p = 0.03$). This functional improvement was supported by a decrease in the mean Quick-DASH from 64 (± 11) preoperatively to 26 (± 8) at the final follow-up ($p = 0.018$) ([Table 3](#)).



Fig. 2. Patients performed abduction cybex who underwent the reverse shoulder prosthesis 2 years ago.

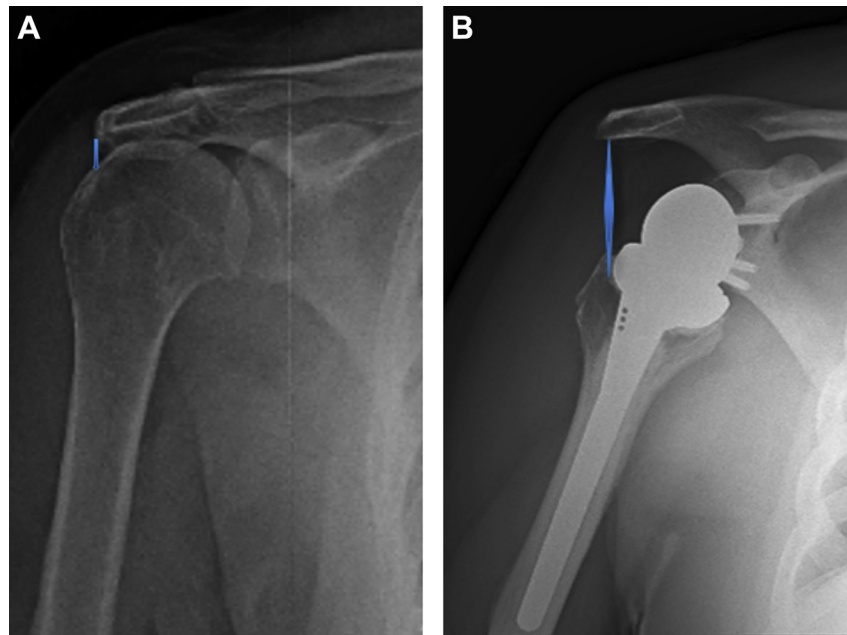


Fig. 3. A–B: Compared measurement of the acromion-greater tuberosity (AGT) distance both preoperatively and postoperatively.

Table 2

Comparison of the groups strength and endurance cybex scores.

	Strength			Endurance		
	Reverse Prosthesis Group	Unaffected Shoulder Group	P value	Reverse Prosthesis Group	Unaffected Shoulder Group	P value
Abduction (nm)	23.8	27.6	>0.05	105	115	>0.05
External Rotation (nm)	11	17	0.026	65	153	0.038
Internal Rotation (nm)	10	17	0.012	100	248	<0.01

Radiographical evaluation

The average AGT distance significantly raised from 6.2 mm (range: 0 to 8.3) preoperatively to 30.4 mm (range: 18, 7 to 40, 8) at the final radiographical examination ($p < 0.01$). A highly positive correlation was observed between the AGT distance and the abduction strength ($r = 0.680$).

Discussion

As in previous studies,^{3,12,13} results of this study confirmed that RSA provides a considerable improvement in functional outcomes, especially abduction of the shoulder, for most patients with cuff tear arthropathy. There is already a focus of interest regarding functional gains in the shoulder abduction following RSA. Nonetheless, it remains unclear whether there is a regaining of rotational functions of the shoulder joint.^{7,8} Therefore, unlike most studies on the topic, we more specifically focused on the rotational functions of the shoulder, and in our study, we defined comparative results of internal and external rotations between operated shoulders and nonoperated, contralateral shoulders of the patients as our secondary outcome. Moreover, according to our literature review, except for few biomechanical cadaveric studies based on computer modeling,^{10,11} no such study had yet been conducted to date to clinically investigate the isokinetic strength and muscular endurance of rotators and deltoid muscles in patients with cuff tear arthropathy following RSA. Accordingly, comparative results of isokinetic strength and muscular endurance following RSA was chosen as the primary outcome of the present study.

A finite element study was undertaken by Liou et al.¹⁴ to compare the muscle forces and joint reaction forces of three different RSA designs. The authors discovered decreases in deltoid and rotator cuff muscle forces for all RSA designs by simulating a normal shoulder kinematic.¹⁴ However, their study suffered from an important limitation, which is that, due to the computer-assisted design, it did not reflect the effect of healing and tissue relaxation over time. Variations in tissue tensioning with increasing age could affect their results.¹⁴ In contrast to Liou et al.,¹⁴ when compared with contralateral shoulders, the current study found a significant increase in deltoid muscle strength following RSA. Otherwise, internal and external rotation strength were limited, as in Liou et al.'s study.

Reported clinical studies regarding the outcomes of RSA demonstrated unfavorable results in terms of internal and external rotation ROM,^{5,7,15} but knowledge of the reason for this issue is limited in the literature. This study provided additional evidence that the lack of rotator cuff muscle strength might play a role in limitations in shoulder internal and external rotation ROM.¹⁷ It was

Table 3

Comparison pre-postoperative range of motion and functional scores.

	Post-operative Comparison				
	Preoperative		Postoperative		P Value
	Mean	Min-Max	Mean	Min-Max	
Abduction	84.5	30–170	108.8	90–170	<0.01
Forward Flexion	77.5	50–130	111.6	80–170	<0.01
Constant Score	38	27–81	65	53–84	0.03
Q-DASH Score	64	52–79	26	9–53	0.018
Acromiohumeral Distance	6.2	0–8	30.4	18–40	<0.01

suggested that latissimus dorsi tendon transfer can eliminate the deficiency in external rotation and that subscapularis tendon repair and lateralized reverse shoulder prosthesis can improve internal rotation strength.¹⁶

From a radiological point of view, the increase in the AGT distance measured on the postoperative radiographs can provide an estimation of deltoid muscle elongation after RSA.¹⁰ In a retrospective study, which set out to correlate functional results of RSA with deltoid muscle elongation, Jobin et al. suggested that an AGT distance of greater than 38 mm was associated with obtaining 135° of active forward flexion following RSA, with a positive predictive value of 90%.⁹ From different clinical and radiological points of view, the current study investigated the correlation between the AGT distance and deltoid muscle strength and found a highly positive correlation between the two variables. To put it another way, the observed correlation might be interpreted as reflecting that a mean elongation of 30 mm in deltoid muscle according to the mean AGT distance following RSA could generate strength in the contralateral shoulders of the patients.

It is also worth noting that in addition to muscle strength, muscular endurance should also be taken into account for evaluation of functional results of RSA because daily activities most frequently include repeatable patterns of movements rather than motions that require maximum muscle strength. Therefore, we defined muscular endurance as one of the primary outcomes of the study and, as a result, brought new knowledge of shoulder muscle endurance following RSA to the literature. Evidence from this study showed that although RSA can confer favorable results in terms of abduction endurance, it failed to improve rotator muscle endurance. Therefore, it can be interpreted that the results from this study support the hypothesis that although RSA would improve shoulder abduction strength and endurance by lengthening the deltoid moment arm, rotational forces would not be regained due to the dearth of RC muscles.

The argument can be made that the present study has some importance with respect to outcomes of RSA, since our study offered new clinical perspectives with different functional and radiological parameters for RSA, therefore making several contributions to the current literature. First, this study is the first study in the literature to determine strength and endurance of deltoid and rotator cuff muscles in addition to internal and external rotation ROM following RSA, thus assessing treatment efficacy on functional outcome. Second, the relationship between AGT distance and deltoid muscle strength was analyzed for the first time by this study. Consequently, this research extends orthopedic surgeons' knowledge of the functional outcomes of RSA in cuff tear arthropathy.

Finally, several limitations need to be considered in the present study. The first limitation is the retrospective nature of the study. Second, the control group included the nonoperated, contralateral shoulders of the patients treated by RSA. It is well-known that patients with cuff tear arthropathy have a high risk for rotator cuff tear in their asymptomatic shoulders. Third, no preoperative strength measurement was undertaken for the patients. Nonetheless, considerable shoulder pain due to cuff tear arthropathy could cause negative false results in isokinetic measurements of strength and endurance.

Conclusion

The present study confirmed previous findings that RSA confers a considerable improvement in functional outcomes, especially abduction of the shoulder, for most patients with cuff tear arthropathy. What's more, with RSA, favorable functional results in terms of strength, endurance, and ROM can be expected for

shoulder abduction in patients with cuff tear arthropathy. However, deficiencies in strength, endurance, and ROM of internal and external rotation can be observed. Additionally, the amount of increase in AGT distance could be a predictor of postoperative abduction strength.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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