ORIGINAL ARTICLE

CiSE
Clinics in Shoulder and Elbow

Clinics in Shoulder and Elbow Vol. 17, No. 4, December, 2014
http://dx.doi.org/10.5397/cise.2014.17.4.166

Isokinetic Muscle Strength and Muscle Endurance by the Types and Size of Rotator Cuff Tear in Men

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Background: Our study was to determine the effect on shoulder isokinetic muscle strength and muscle endurance in isolated full-thickness supraspinatus tendon tear and combined other rotator cuff tear.
Methods: Total of 81 male patients (mean age 57.8 ± 7.4 years) who were diagnosed as a full-thickness supraspinatus tendon tear were included. They were classified into isolated or combined tear. The isokinetic muscle strength and muscle endurance were measured using the Biodex multi-joint system PRO® (Biodex Medical Systems, Shirley, NY, USA) in following movements: shoulder abduction, adduction, flexion, extension, external rotation, and internal rotation. Then, the difference in muscle function according to the type of tears were assessed. Fifty-seven patients had isolated supraspinatus tendon (mean age 56.9 ± 7.3 years). They were classified into either anteroposterior tear or modified mediolateral tear. The size were measured using T2-weighted magnetic resonance imaging scans in sagittal plane.
Results: Between subjects categorized into the type of tear, we found significant inter-categorical differences in isokinetic muscle strength during abduction, adduction, flexion, extension, and internal rotation, and in muscle endurance during flexion, extension, and internal rotation. Anteroposterior diameter tear, we did not show significant differences in either isokinetic muscle strength or muscle endurance during any movements. However, with modified mediolateral diameter, we found significant differences with isokinetic muscle strength during adduction, and in muscle endurance the external rotation and internal rotation.
Conclusions: We found that a supraspinatus tendon tear associated with more numbers of rotator cuff tears has lower isokinetic muscle strength and muscle endurance than a tear found alone.
(Clin Shoulder Elbow 2014;17(4):166-174)

Key Words: Rotator cuff; Tear; Muscle strength; Isokinetic test

Introduction

Rotator cuff injuries are common causes of chronic shoulder pain in adults.[1,2] A cuff tear-induced biomechanical imbalance of the shoulder can compromise the coordinated and synchronized action of the rotator cuffs. A dysfunctional rotator cuff can be the cause of pain and decreased muscle strength.[3] Rotator cuff injuries are known to show a mismatch between the extent of deterioration of the cuffs and the extent of detectable symptoms.[4] Nevertheless, restoration of muscle strength after repair of rotator cuff tears is one of the key clinical markers of patient recovery.[5-8] Therefore for clinicians the pre- and post-operative assessments of the shoulder muscle strength make up an important part of the treatment and rehabilitative procedure. The peak torque, a parameter for muscle strength, is the maximum energy generated from a single muscle contraction. And a weakened peak torque in torn rotator cuffs is considered as one of the most prominent factors that contribute to the loss of initial torque and overall function of each individual muscle of the rotator cuffs. As well as a reduction in initial torque, the ability of each independent muscle to engage in contraction over a sustained period of time, which is called muscle endurance, is reduced in impaired rotator cuffs. Thus, a weakened muscle strength and reduced muscle endurance may lead to many clinical consequences.

Received July 14, 2014. **Revised** November 1, 2014. **Accepted** November 2, 2014.

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Financial support: None. **Conflict of interests:** None.

pISSN 2383-8337
eISSN 2288-8721

Muscle strength and muscle endurance can be improved by training in terms of both growth and cooperativeness. Individuals who have enhanced muscle strength and endurance of rotator cuffs show less sports-related degeneration of rotator cuff muscles and more protection against damages from accidents than those who do not.[9] We postulated three hypotheses from these findings. First, we hypothesized that isokinetic muscle strength and endurance will become lower as rotator cuff tears are associated with multiples tears. Second, we hypothesized that isokinetic muscle strength and endurance will become lower as the size of the all-thickness tears of the supraspinatus tendon becomes larger. Third, a closer correlation will be seen between muscle strength and endurance with the medio-lateral diameter than the antero-posterior diameter of the tears. In this study, we assessed how isokinetic muscle strength and muscle endurance correlated to the type and size of all-thickness tears of the rotator cuff.

Methods

Subjects of Study

To assess the effect of the type of rotator cuff tears, we first selected patients with all-thickness tears of the supraspinatus tendon of the shoulder, as diagnosed by magnetic resonance imaging (MRI) from September 2012 and February 2014, including only male patients with tears that were classified as single all-thickness tears. Next, we selected patients with all-thickness tears of the supraspinatus tendon that were combined all-thickness tears of either the infraspinatus tendon and/or the subscapularis tendon. We categories all the patients into the type of tears they had but did not categorize the tears into horizontal lengths. In total, 81 patients were enrolled with an average age of 57.8 ± 7.4 years into the tear-type group. To assess the effect of the size of rotator cuff tears, we classified the patients with single all-thickness tears of the supraspinatus tendon into tear-size. In total, 57 patients with an average age of 56.9 ± 7.3 years were included into the tear-size group. In both groups, patients with bilateral tears of the rotator cuffs, previous history of shoulder surgery, partial tears of the rotator cuffs, a diagnosed frozen shoulder, chronic pseudoparalysis, or with neurological condition were excluded from the study subjects (Table 1, 2).

Table 1. Goutellier Classification Stage

	0	1	2	3	4
Supraspinatus	2	24	36	14	5
Infraspinatus	3	54	18	3	3
Subscapularis	5	51	22	0	3

Study Design

1) Methods of measurement

A Biodex multi-joint system PRO® (Biodex Medical Systems, Shirley, NY, USA) was used to measure the concentric isokinetic

Table 2. Demographics, Tear Type, Tear Size and Tear Chronicity

Variable	Value
Age (n=81), yr	
≤50	8
51–60	46
61–70	22
>70	5
Body weight (n=81), kg	
≤50	2
51–60	18
61–70	30
71–80	22
>80	9
Dominant arm (n=81)	
Dominant	59
Non-dominant	22
Tear type (n=81)	
Supraspinatus	57
Supraspinatus+infraspinatus	11
Supraspinatus+subscapularis	9
Supraspinatus+infraspinatus+subscapularis	4
Symptom duration (mo)	12.1 (1–120)
Tear size	
Antero-posterior group (n=57)	
Group 1	12
Group 2	43
Group 3	2
Group 4	0
Modified medio-lateral group (n=57)	
Group 1	22
Group 2	27
Group 3	6
Group 4	2

Values are presented as number or median (range). Antero-posterior group (AP group): AP group 1<1 cm; 1 cm≤AP group 2< 3 cm; 3 cm≤ AP group 3<5 cm; AP group 4≥5 cm. Modified medio-lateral group 1: the torn end of the supraspinatus is within its insertion site of the greater tubercle of humerus, group 2: the torn end of the supraspinatus is located medial to the greater tubercle and lateral to the center of the humeral head, group 3: the torn end of the supraspinatus is medial to the center of the humerus and lateral to the glenoid, and group 4: the torn end of the supraspinatus is found at or medial to the glenoid, which are illustrated in Fig. 2.

muscle strength (60°/s) and muscle endurance (180°/s) of the shoulder at flexion, extension, abduction, adduction, external rotation, and at internal rotation. Although the optimal velocity for measuring the isokinetic strength is unknown, following past examples of use of low angular velocity to measure muscle strength, and high angular velocity to measure muscle endurance, in our study, we used 60°/s and 180°/s angular velocities for the measurement of isokinetic muscle strength and endurance, respectively.[7,10] To prepare patients for optimal condition for measurement, the patients were asked to do 5 minutes of stretching before the examination. The measurement of muscle strength and endurance for the flexion and extension were taken with the arms starting from various positions; elbows at extension or the shoulder girdle at maximum flexion, whilst the patient sat with their antebrachium in neutral position. For abduction and adduction, the measurements were taken with the elbows from extension and the shoulder girdle from maximum adduction. For external and internal rotation, the measurements were taken with the shoulder from 90° of abduction and the elbow from 90° flexion. The elbows were fixed at 90° throughout the assessment. During the measurements, to ensure that patients generated force using only the rotator cuff muscles, the patients' abdominal region and trunk were fastened using a belt. Further, the shoulder axis was matched to the center of the dynamometer by asking the patient to grab the handles comfortably on either side of the seat. In total, an average of the 5 measurements for isokinetic muscle strength and an average of 10 measurements of muscle endurance were taken after a practice run of 3 times. All measurements were taken by an experienced examiner with 11 years of experience. A resting period of 3 minutes between each measurement ensured initialization to normal resting conditions before the next measurement. For all patients, the contra-lateral side was measured first to compare with the affected arm and to give time for patients to get accustom to the dynamometer. Shklar and Dvir[11] have shown that in healthy individuals, irrespective of laterality there is no difference in the isokinetic muscle function between the two sides of the shoulders. Given that the range of motion was normal, there was no pain, and no shoulder abnormalities when assessed by physical examination, the unaffected arm of the affected arm was termed as the contra-lateral side. No radiological tests were performed on the contra-lateral arm.

2) Classification of tears and tear-size

Patients with rotator cuff tears were classified according to the type of, or the combination of, tears they had. Group 1 included those with a single all-thickness tear of the supraspinatus tendon. Group 2 included those with a supraspinatus tendon tear that was combined with an infraspinatus tendon tear. Group 3 included those with a supraspinatus tendon tear that was combined with a subscapularis tendon tear. Lastly, group 4 included those with multiple tears of supraspinatus tendon, infraspinatus tendon, and the subscapularis tendon.

We used a modified approach of DeOrio and Cofield's arthroscopic approach[12] that measures the antero-posterior diameter of tears. However, instead of an arthroscopic approach we used a radiological approach to measure the antero-posterior and the medio-lateral diameters of cuff tears as our parameters for tear size. First, a T2-weighted MRI scan was taken at sagittal plane to measure the maximum antero-posterior diameter of the supraspinatus tendon tear (henceforth called the antero-posterior diameter) (Fig. 1). Next, a T2-weighted MRI scan at the coronal plane was taken to measure the maximum medio-lateral diameter of the supraspinatus tendon tear (henceforth called the medio-lateral diameter). For the medio-lateral diameter classification of the supraspinatus tendon size, an additional classification was made according to how the supraspinatus tears were positioned relative to the glenohumeral joint (henceforth called the modified medio-lateral diameter). First, if the tear resided within the root of the greater tuberosity of the supraspinatus tendon, the patients were grouped into group 1. Second, if the tear was medial but was more lateral than the center of the humeral head then the patients were grouped into group 2. Third, if the tear was more medial than the center of the humeral head and lateral to the glenoid cavity, then they were grouped into group 3. Lastly, if the tear was medial to or further than the glenoid cavity they were grouped into group 4 (Fig. 2).

3) Statistical analysis

Statistical analyses of the effect of the type of cuff tear on muscle strength and endurance were performed using ANOVA. Statistical analyses of the effect of antero-posterior and modified medio-lateral diameters of the supraspinatus tear were also performed using ANOVA. *Post hoc* analyses were performed using a Dunnett T3 multiple comparison test. All statistical tests were run on IBM SPSS Statistics ver. 20.0 (IBM Co., Armonk, NY, USA).

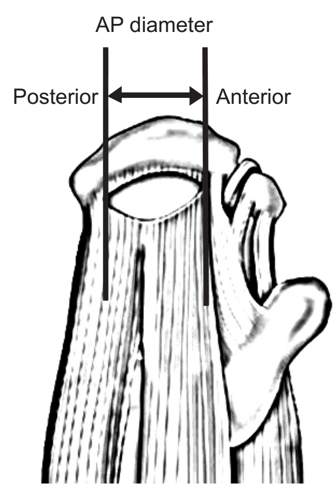

Fig. 1. This figure shows the anterior to posterior diameter of the rotator cuff tear. AP: antero-posterior.

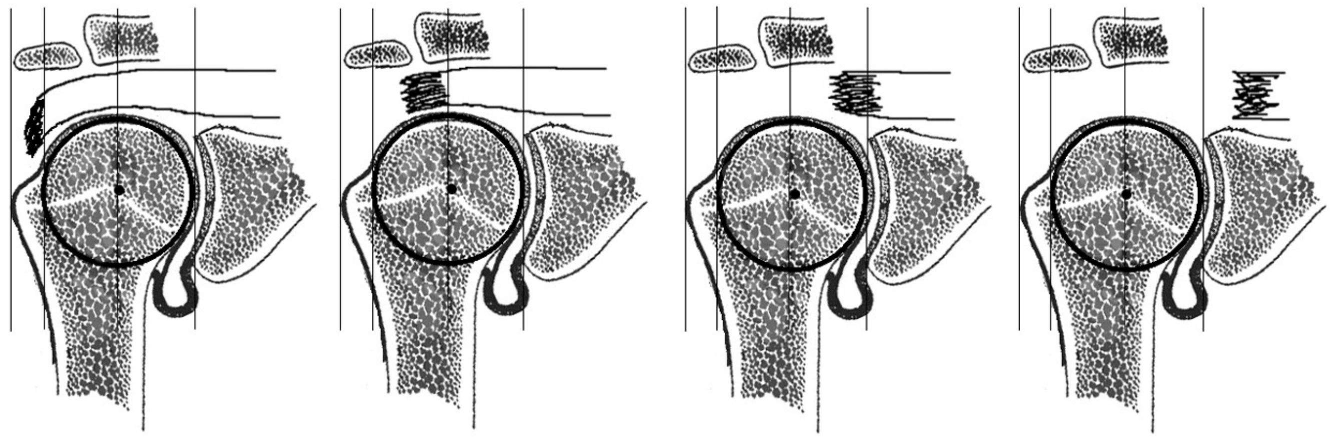

Fig. 2. Modified medio-lateral group. (A) The torn end of the supraspinatus is within its insertion site of the greater tubercle of humerus. (B) The torn end of the supraspinatus is located medial to the greater tubercle and lateral to the center of the humeral head. (C) The torn end of the supraspinatus is medial to the center of the humerus and lateral to the glenoid. (D) The torn end of the supraspinatus is found at or medial to the glenoid.

Results

Effect of the Type of Rotator Cuff Tears on Isokinetic Muscle Strength and Muscle Endurance

Isokinetic muscle strength: The isokinetic strength was the largest in group 1 but the smallest in group 4 during abduction (p=0.038), flexion (p=0.011), extension (p=0.004), and internal rotation (p=0.004). The isokinetic strength largest in group 1 but the smallest in group 2 during adduction (p=0.019). These differences in isokinetic strength between the groups were significant except during external rotation (Table 3).

Muscle endurance: Muscle endurance was the highest in group 1 but the lowest in group 2 during flexion (p=0.015), the highest in group 1 and the lowest in group 4 during extension (p=0.032) and internal rotation (p=0.018). These differences in muscle endurance between the groups were significant. No significant differences were seen in muscle endurance between different tear-types during abduction, adduction, or during external rotation (Table 3).

Effect of the Supraspinatus Tendon Tear-size on Isokinetic Muscle Strength and Muscle Endurance

1) Effect of supraspinatus tendon tears classified according to the antero-posterior diameter

The different tear sizes classified by antero-posterior diameter showed no significant differences in the isokinetic strength and muscle endurance during all movements (Table 4).

2) Effect of supraspinatus tendon tears classified according to the medio-lateral diameter

Isokinetic muscle strength: We found that group 3 showed the largest isokinetic muscle strength during abduction, adduction, flexion, extension and at internal rotation, whereas, group 1 showed smallest value during internal rotation. Group 4 showed the smallest isokinetic strength during all movements. However, between all movements only did we see a significant difference between the values of isokinetic strength during internal rotation between the different groups. We did not see any significant differences between the groups during abduction, flexion, extension, external rotation or during internal rotation (Table 5).

Muscle endurance: We found that group 3 had the highest muscle endurance during abduction, adduction, extension, or at internal rotation, whereas group 1 had the highest during flexion and external rotation. Again, group 4 had the lowest value for muscle endurance during every position. However, a significant difference in the values of muscle endurance between all the groups were seen during external rotation (p=0.008) and internal rotation (p=0.038), but not during abduction, adduction, flexion or extension (Table 5).

Discussion

In support of our first hypothesis, we found that isokinetic strength and muscle endurance was lower when the rotator cuffs were associated with more tears, especially if combined tears were found in the supraspinatus, infraspinatus, or the subscapularis tendons a complete imbalance in force coupling led to a prominent decrease in these strength parameters. We found that the decrease in isokinetic muscle strength varied in terms of the type of rotator cuff tears associated. The isokinetic muscle strength was the largest during all the movements that were tested in patients with only single tears of the supraspinatus tendon, and the lowest, except during adduction, in patients with combined triple tears of the supraspinatus, infraspinatus, and the subscapularis tendons. Similarly, the muscle endurance was the highest during all movements in patients with single tears of the supraspinatus tendon and lowest in patients with a combination

Table 3. Differences according to the Type of Torn Cuffs

	Type group 1 (n=57)	Type group 2 (n=11)	Type group 3 (n=9)	Type group 4 (n=4)	*p*-value
Abd60	26.1 ± 7.5	20.2 ± 8.2	23.8 ± 6.8	18.6 ± 3.1	0.038
T*	a	a, b	a, b	b	
Add60	31.4 ± 16.4	17.1 ± 8.3	28.0 ± 13.0	17.4 ± 10.7	0.019
T	a	B	a, b	a, b	
Flex60	25.6 ± 10.4	16.7 ± 7.7	19.5 ± 7.6	15.5 ± 9.1	0.011
T	a	a, b	a, b	b	
Ext60	46.3 ± 22.5	27.1 ± 18.2	37.0 ± 17.7	15.9 ± 7.9	0.004
T	a	B	a, b	b	
ER60	13.1 ± 5.6	10.0 ± 4.0	12.0 ± 2.8	9.7 ± 5.6	0.189
T	a	B	a, b	a, b	
IR60	24.0 ± 8.7	19.0 ± 7.8	19.0 ± 4.8	10.2 ± 3.5	0.004
T	a	a, b	a, b	b	
Abd180	28.1 ± 7.6	24.0 ± 10.4	27.5 ± 9.2	19.0 ± 5.0	0.099
Add180	39.8 ± 17.9	29.0 ± 19.0	37.3 ± 20.5	24.7 ± 16.9	0.167
T	a	a	a	a	
Flex180	29.6 ± 13.1	18.0 ± 9.6	25.3 ± 11.0	17.1 ± 12.1	0.015
T	a	b	a, b	a, b	
Ext180	40.7 ± 17.3	28.4 ± 18.3	34.0 ± 15.1	20.2 ± 18.6	0.032
T	a	a, b	a, b	b	
ER180	13.0 ± 4.9	12.0 ± 6.0	12.2 ± 3.4	7.9 ± 2.8	0.221
T	a	a	a	a	
IR180	26.2 ± 8.7	20.5 ± 9.3	21.9 ± 6.7	14.8 ± 6.4	0.018
T	a	a, b	a, b	b	

Values are presented as mean ± standard deviation.
Type group 1: supraspinatus, Type group 2: supraspinatus+infraspinatus, Type group 3: supraspinatus+subscapularis, Type group 4: supraspinatus+infraspinatus +subscapularis, Abd: abduction, Add: adduction, Flex: flexion, Ext: extension, ER: external rotation, IR: internal rotation.
*The same letters indicate insignificant difference between groups based on Dunnett T3 multiple comparison test.

of triple tears of the supraspinatus, infraspinatus, and the subscapularis tendons.

Rejecting our second hypothesis, we found that muscle strength and endurance did not decrease with the increase in the size of the single all-thickness tear of the supraspinatus tendon. For patients classified according to antero-posterior diameter, we found that the isokinetic strength was largest in all movements except during flexion in patients with a tear size of an antero-posterior diameter of 1 to 3 cm and smallest in all movements in the 3 to 5 cm group. We found that muscle endurance was highest in all movements except during flexion and external rotation in the 1 to 3 cm group. For patients classified according to the modified medio-lateral diameter, the isokinetic strength was the largest during all movement except during external rotation in group 3, and the smallest during all movements in group 4. We found that the muscle endurance was highest during all movements except during flexion and external rotation in group 3, and the lowest during all movements in group 4.

Lastly, we cautiously conclude, in support of our third hypothesis, that there is a closer correlation between medio-lateral diameter than the antero-posterior diameter with isokinetic strength and muscle endurance in patients with torn supraspinatus tendons. We found that within patients classified by either measures of tear size, those in the classification just below the largest sized tears showed the highest isokinetic strength and muscle endurance for most measurements whereas those of the largest sized tears showed the lowest isokinetic strength and muscle endurance. Although we cannot say that tear size completely reflects tear chronicity and that a supraspinatus tendon tear can become a chronic tear before it becomes a massive tear, it requires further study to reveal whether the results are an artifact of a compensatory growth of muscles other than the

Table 4. Differences between Groups Classified by the Antero-posterior Diameter of the Supraspinatus Tendon Tear

	AP group 1 (n=12)	AP group 2 (n=43)	AP group 3 (n=2)	AP group 4 (n=0)	*p*-value
Abd60	24.9 ± 5.8	26.7 ± 7.9	21.0 ± 9.8		0.478
Add60	29.8 ± 17.0	32.1 ± 16.6	24.6 ± 12.2		0.766
Flex60	29.2 ± 13.1	25.0 ± 9.4	16.3 ± 10.9		0.206
Ext60	41.8 ± 22.4	48.0 ± 22.4	36.5 ± 35.2		0.582
ER60	13.3 ± 5.0	13.3 ± 5.7	9.6 ± 8.6		0.662
IR60	22.9 ± 6.7	24.5 ± 9.0	17.5 ± 12.7		0.488
Abd180	26.7 ± 7.9	28.7 ± 7.6	22.0 ± 3.9		0.373
Add180	34.7 ± 18.3	41.7 ± 17.8	28.9 ± 17.3		0.339
Flex180	34.1 ± 18.2	28.8 ± 11.3	20.8 ± 13.0		0.297
Ext180	36.4 ± 19.7	42.4 ± 16.3	28.1 ± 26.3		0.335
ER180	13.6 ± 3.7	13.0 ± 3.7	10.4 ± 9.8		0.687
IR180	26.0 ± 3.6	26.8 ± 9.4	14.9 ± 8.1		0.165
T*	a	a	a		

Values are presented as mean ± standard deviation. Antero-posterior group (AP group 1)<1 cm, 1 cm≤AP group 2<3 cm, 3 cm≤AP group 3<5 cm, AP group 4≥5 cm.
Abd: abduction, Add: adduction, Flex: flexion, Ext: extension, ER: external rotation, IR: internal rotation.
*The same letters indicate insignificant difference between groups based on Dunnett T3 multiple comparison test.

Table 5. Differences between Groups Classified by the Modified Mediolateral Diameter of the Supraspinatus Tendon Tear

	MML group 1 (n=22)	MML group 2 (n=27)	MML group 3 (n=6)	MML group 4 (n=2)	*p*-value
Abd60	27.1 ± 6.8	24.7 ± 7.3	30.4 ± 9.7	21.0 ± 9.8	0.242
Add60	36.2 ± 16.3	25.1 ± 13.9	44.4 ± 17.7	24.6 ± 12.2	0.014
T*	a, b	a	b	a, b	
Flex60	28.4 ± 11.6	23.3 ± 7.3	28.6 ± 15.4	16.3 ± 10.9	0.170
Ext60	50.0 ± 21.6	42.6 ± 19.1	52.6 ± 36.8	36.5 ± 35.2	0.546
ER60	15.3 ± 5.5	11.5 ± 4.5	14.1 ± 7.7	9.6 ± 8.6	0.087
IR60	25.6 ± 8.7	22.4 ± 7.4	26.8 ± 12.2	17.5 ± 12.7	0.329
Abd180	29.0 ± 7.7	26.5 ± 6.0	33.8 ± 11.7	22.0 ± 3.9	0.101
Add180	41.6 ± 16.5	35.8 ± 16.9	54.4 ± 22.5	28.9 ± 17.3	0.095
Flex180	32.4 ± 15.3	27.5 ± 8.1	32.1 ± 21.5	20.8 ± 13.0	0.419
Ext180	43.9 ± 18.4	37.5 ± 13.4	47.0 ± 25.0	28.1 ± 26.3	0.319
ER180	15.4 ± 4.0	11.0 ± 3.7	14.1 ± 7.3	10.4 ± 9.8	0.008
T	a	b	a, b	a, b	
IR180	28.5 ± 7.2	24.1 ± 7.2	30.7 ± 14.7	14.9 ± 8.1	0.038
T	a, b	a, b	a	b	

Values are presented as mean ± standard deviation. Modified medio-lateral (MML group): modified mediolateral group 1: the torn end of the supraspinatus is within its insertion site of the greater tubercle of humerus, group 2: the torn end of the supraspinatus is located medial to the greater tubercle and lateral to the center of the humeral head, group 3: the torn end of the supraspinatus is medial to the center of the humerus and lateral to the glenoid, and group 4: the torn end of the supraspinatus is found at or medial to the glenoid, which are illustrated in Fig. 2.
Abd: abduction, Add: adduction, Flex: flexion, Ext: extension, ER: external rotation, IR: internal rotation.
*The same letters indicate insignificant difference between groups based on Dunnett T3 multiple comparison test.

supraspinatus tendon, such as rotator cuff and the subscapularis muscles, that compensates for the loss in muscle strength in rotator cuffs with small-sized tears but not by massive tears.

The isotonic, isometric, and isokinetic strength of the shoulder can be used to manually assess shoulder muscle strength. As these measurements can be taken quickly and easily, these manual tests are often used to pre- and post-operatively assess the shoulder muscle strength in rotator cuff tear patients.[12] Although as manual tests they are open to influence of subjective examination, especially for the isometric strength tests, meaning that reliability decreases,[12,13] the isokinetic strength test has shown to be effective to measure relatively objectively despite the subnormal force in muscle contraction in injured arms. For isokinetic strength testing, it is however important that the patient is still able to generate the set angular velocity and length-tension function of the muscle is unimpaired. The isokinetic muscle strength has an added advantage of overcoming the problem of spasticity[7] and that it objectively measures dynamic rotator strengths using functional muscle movements.[13] However, isokinetic strength tests are not always useful in measuring the shoulder muscle strength in rotator cuff conditions. For example, if patients cannot attain the set angular velocity then the isokinetic strength measured becomes 0% of the contra-lateral side. Also, if patients are in too much pain, cannot maintain the required position whilst testing, is limited in their range of motion they will not be able to generate the required angular velocity. In this study, 3 patients were excluded midway as they could not maintain the required position for testing, and thus did not reach the required angular velocity.

Previous studies have shown that a loss in strength transfer in torn rotator cuffs leads to decrease in isokinetic muscle strength of the affected arm by around 37% to 70% of the contra-lateral unaffected arm.[7,14,15] In case of small-sized tears, the force is partially transmitted through the center of the tear,[16] but as the tear size increases not only does the supraspinatus tendon lose muscle strength, the infraspinatus tendon and the subscapularis tendon are affected too.[17-19] The muscles involved in shoulder flexion are the anterior deltoid muscle, clavicular pectoralis major muscle, biceps brachii and the coracobrachial muscle. The muscles involved in shoulder extension are posterior deltoid muscle, teres major, clavicular pectoralis major muscle, latissimus dorsi muscle and the biceps brachii long head. The muscles involved in abduction are central deltoid muscle, supraspinatus muscle and the biceps brachii long head. The muscles involved in adduction are pectoralis major muscle, latissimus dorsi muscle, teres major, triceps brachii long head and the coracobrachial muscle. The muscles for external rotation are posterior deltoid muscle, infraspinatus muscle and teres minor. Lastly, the muscles for internal rotation are pectoralis major muscle, teres major, latissimus dorsi muscle, anterior deltoid muscle, and the subscapularis muscle.[11,20-22] The external rotators and internal rotators are directly influenced by the actions of rotator cuffs. However, in our study, we found that the isokinetic strength during external rotation was the lowest in only two groups classified by the type of rotator cuff tears. We believe that this is because the actual shoulder motion is brought about the cooperation of rotator cuffs along with several other muscles, and we did not assess functional strength ratio, which has recently been highlighted as an important indicator of muscle strength. Further, although this was not considered in our study, the chronicity of tears is expected to have a large influence on muscle strength and endurance. Although most people believe that contraction of the muscle is concentric, eccentric muscle contraction, which balance high levels of force without much input of energy, is considered as a far more useful type of contraction than concentric contraction in sports training and in the rehabilitation setting.[23] Recently, the conventional strength ratio, which is the ratio of the external rotator to internal rotator strength in concentric action, and the functional strength ratio, which is the ratio of eccentric external rotator strength to concentric internal rotator strength, over the simple peak torques have been highlighted as useful indicators of strength. The functional strength ratio is especially useful in that it takes into consideration the various antagonistic muscles of eccentric contraction involved in the dynamic stability of the glenohumeral joints.[24]

The authors compared the difference in muscle strength and muscle endurance between sex, age, and weight. When we compared the data according to the type of rotator cuff tears, males showed a significant difference in terms of the muscle strength during abduction, adduction, flexion, extension, and internal rotation, and in terms of the muscle endurance during flexion, extension, and the internal rotation. However, females did not show any significance difference in muscle strength and endurance during all movement, thus they were not included in this study. In female patients who showed some extent of significant difference between movements in terms of the kinetic muscle strength and endurance, may have been influenced by shoulder girdle muscles rather than the rotator cuff tendons themselves. We found that the isokinetic strength and endurance of both the affected and the contra-lateral arms increased with age, but this trend was more prominent for males than for females. The isokinetic muscle strength and the muscle endurance did not show a significant relationship with weight of either the affected or the contra-lateral arm in both males and females.

For the experimental approach to assess the isokinetic muscle strength and muscle endurance in terms of the size of the rotator cuff tears, we modified DeOrio and Cofield's method of classifying rotator cuffs by their antero-posterior diameter using arthroscopy by taking the measurements from MRI scans instead. As well as classifying the patients into different types of tears by their antero-posterior diameter, we also classified patients in terms of the position of the tears relative to the humeral head and glenoid cavity (we called this the modified medio-lateral diameter) and assessed these factors. There were several reasons behind the modification. First, DeOrio and Cofield's classification could only be made at the time of surgical intervention-our attempt was to make a preoperative decision on the classification through MRI. Second, a clinician tends to be more familiarized with the medio-lateral diameter of rotator cuff tears than the preoperative antero-posterior diameter, thus we determined to see whether there was a difference between the two diameters. Third, we predicted that the anatomical size of the humeral head of an Asian background would be smaller than of a Caucasian background, and we reasoned that the same classification system may not be appropriate for Korean patients. So, if DeOrio and Cofield's classification is followed, a preoperative MRI assessment that rules out a massive tear of the rotator cuffs may sometimes actually be difficult to repair surgically. Using our modified approach to classify tear-size, we did not find a significant correlation between the antero-posterior diameter, which were subcategorized into tear size of 1 cm, 3 cm, and 5 cm, and our parameters of strength to support our second hypothesis. However, we found a significant correlation between the antero-posterior diameter that was subcategorized into their position relative to the humeral head and glenoid cavity and muscle strength. We suggest from these results that at least for the assessment of muscle strength of shoulders of Korean males a new classification of rotator cuff tear sizes may be needed.

There are several limitations to our study. First, we did not factor out individual pain levels at the time of isokinetic muscle strength measurement. An individual with pain would have underachieved in the preoperative rotator cuff muscle strength test, thus potentially giving an underestimated value. As the pain resolved postoperatively, a greater improvement may be seen in the muscle strength than if the pain had been relieved momentarily at the preoperative assessment.[15] However, giving patients subacromial localized injection of anesthesia could unwittingly enhance muscle strength in individuals with rotator cuff tears.[25] Nevertheless, we cannot rule out that not having controlled the pain before a preoperative rotator cuff muscle strength test may have influenced our results. Second, patients with asymptomatic rotator cuff tears could be present in the contra-lateral side. Although we questioned patients of the absence or presence of pain, their previous medical history of the contra-lateral shoulder, and we excluded all individuals who were found to have a bilateral tear through MRI or ultrasound in our study, since prospective studies using MRI or ultrasounds show that all-thickness tears are in 28% of individuals over 60s, 65% in over 70s,[26] a high prevalence of asymptomatic tears makes it likely our subject of studies may have included bilateral patients. Later studies where objectively assessed controls are included and a proper diagnosis of the contra-lateral side to eliminate any possibility of bilateral tears should be performed.

Conclusion

We found that rotator cuff tears that are combined with additional tears are more likely to show lower muscle strength and endurance. However, in case of tears of the supraspinatus tendon, we found that how large the size of the single all-thickness tears of the supraspinatus tendon did not influence the isokinetic strength nor the endurance of the muscles, *i.e.* a large tear of the supraspinatus tendon was not associated with a lower isokinetic strength or muscle endurance any more than a small tear. Furthermore, we found that our modified medio-lateral diameter was more correlated with isokinetic strength and muscle endurance than the antero-posterior diameter. Currently, no studies exist to objectively inform clinicians as to changes the in muscle strength and endurance according to the type and size of rotator cuff tears. Our study gives methods to measure parameters of muscle strength and endurance so that they may be used as objective markers to assess the extent of preoperative condition and postoperative recovery of muscle function.

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