Original Article
Clinics in Orthopedic Surgery 2022;14:272-280 • https://doi.org/10.4055/cios21133

Importance of Initial Peak Torque of the Supraspinatus Muscle during Shoulder Flexion

Jin Hyuck Lee, PT*, Ji Soon Park, MD†, Woong-Kyo Jeong, MD*,‡

*Department of Sports Medical Center, Korea University Anam Hospital, Seoul, Korea
†Department of Orthopaedic Surgery, Healthpoint Hospital, Abu Dhabi, UAE
‡Department of Orthopaedic Surgery, Korea University College of Medicine, Seoul, Korea

Background: Most previous studies have evaluated flexion strength to assess recovery after arthroscopic rotator cuff (RC) repair. However, limited data are available regarding peak torque at the initial angle (iPT) because most studies have measured flexion strength for peak torque (PT), particularly in small- and medium-sized supraspinatus tears. The purpose of this study was to compare conventional PT and iPT to evaluate supraspinatus muscle strength after arthroscopic RC repair in patients with small- and medium-sized supraspinatus tears.

Methods: Isokinetic muscle performance testing was performed in 42 patients with small tears and in 47 patients with medium-sized tears. PT and iPT were evaluated before and 1 year after surgery and were recorded at an angular velocity of 60°/sec and 180°/sec with an isokinetic test.

Results: PT and iPT were significantly lower in the involved-side shoulders than in the uninvolved-side shoulders (PT: small tear, $p < 0.001$; medium tear, $p < 0.001$; iPT: small tear, $p < 0.001$; medium tear, $p < 0.001$) in both groups, preoperatively. However, postoperatively, in the involved-side shoulders, PTs were not different in both small- and medium-sized tears (all $p > 0.05$), but iPTs were significantly lower in the involved-side shoulders (small tear, $p < 0.001$; medium tear, $p < 0.001$). iPT was significantly lower in the involved side shoulders in the medium-sized tear group than in the small-sized tear group before and after surgery ($p < 0.05$). In the small- and medium-sized tear groups, tear size was significantly correlated with preoperative iPT in the involved-side shoulders (small tear: $r = –0.304$, $p = 0.046$; medium tear: $r = –0.323$, $p = 0.027$). However, pain visual analog scale was significantly correlated with preoperative (small tear: $r = –0.455$, $p = 0.002$; medium tear: $r = –0.286$, $p = 0.044$) and postoperative (small tear: $r = –0.430$, $p = 0.005$; medium tear: $r = –0.354$, $p = 0.021$) iPT in the involved-side shoulders. Furthermore, fatty infiltration grade of the supraspinatus muscle and global fatty degeneration index were not associated with preoperative and postoperative PT and iPT in each group (all $p > 0.05$).

Conclusions: iPT is as important as conventional PT in isokinetic testing to assess supraspinatus muscle strength before and after RC repair.

Keywords: *Shoulder, Rotator cuff, Supraspinatus, Isokinetic test*

Rotator cuff (RC) tears are the most common shoulder disease and they can be the primary cause of shoulder weakness, frequently necessitating RC repair. Escamilla et al.[1] reported that the restoration of muscle strength after RC repair was the most important factor for the stability and function of the glenohumeral (GH) joint. Therefore, several studies[2-4] have investigated the restoration of muscle strength after RC repair, and manual muscle testing (MMT) is often used to assess muscle strength accord-

Received August 6, 2021; Revised January 6, 2022;
Accepted January 6, 2022
Correspondence to: Woong-Kyo Jeong, MD
Department of Sports Medical Center, Korea University Anam Hospital, 73 Goryeodae-ro, Seongbuk-gu, Seoul 02841, Korea
Tel: +82-2-920-5924, Fax: +82-2-920-2471
E-mail: drshoulder@korea.ac.kr
Jin Hyuck Lee and Ji Soon Park contributed equally to this work.

Clinics in Orthopedic Surgery • pISSN 2005-291X eISSN 2005-4408

ingly. However, it is challenging to measure the recovery of muscle strength after RC repair with MMT.[5] Therefore, isokinetic muscle tests have been widely used for muscle performance evaluation,[3,4] and peak torque (PT) is commonly measured to restore muscle strength after RC repair.

Most studies have reported the use of PT measurements after RC repair. PT is defined as the maximal strength or the single highest point in the torque curve during maximal muscle contraction (conventional PT),[6] which is calculated at the midrange during shoulder elevation.[2,7] However, recent studies[8,9] have reported that activation of the supraspinatus muscle may be evaluated at the initial angle (30° of shoulder flexion) during shoulder elevation. Therefore, data on the usefulness of PT at the initial angle (iPT) in evaluating suitable supraspinatus function are scarce. Furthermore, no studies have evaluated or compared PT and iPT after arthroscopic RC repair. Moreover, previous studies[2,10,11] have reported that patients with full-thickness RC tears experience weakness in flexion strength before and after surgery, which may be related to the tear size.[2,10] Tear size is an important determinant of satisfactory treatment outcomes,[2,12] including muscle strength and atrophy. To date, however, the association between tear size and iPT of the involved-side shoulders after arthroscopic RC repair has not been demonstrated in literature.

The purpose of this study was to compare conventional PT and iPT to evaluate muscle strength in functional recovery of the supraspinatus muscle after arthroscopic RC repair in patients with small- and medium-sized supraspinatus tears. We hypothesized that iPT would be different from PT in terms of evaluation of supraspinatus muscle strength after arthroscopic RC repair.

METHODS

Study Design and Patient Classification

This study complied with the Declaration of Helsinki and was approved by the Institutional Review Board of Korea University Anam Hospital (IRB No. 2017AN0175). Informed consents were waived due to retrospective study. The patient in the figure of this article permitted printing of his photography. We retrospectively reviewed all patients who had experienced full-thickness RC tears between 2009 and 2014 and who were treated at our hospital. Full-thickness supraspinatus tears were divided into two groups: small-sized (< 1 cm) and medium-sized (1–2 cm) tear groups.[13-15] The cutoff size for small- and medium-sized supraspinatus tears was 2 cm because the failure rate in patients with tears measuring > 2 cm was similar to that in patients with large-to-massive tears.[14] Tear size was directly measured under arthroscopy by a senior surgeon (WKJ).

In this study, only right-handed dominant RC tear patients were included for a more effective analysis. We excluded patients with tears measuring > 2 cm, large and massive tears, bilateral RC tears, subscapularis tears, involvement of the non-dominant shoulder, and inability to perform the muscle strength test due to limited range of motion and pain. Patients who underwent revision of surgical RC repair, retear, or open repair were also accordingly excluded from the study. Of the 426 patients included, 89 patients without retear (42 with small tears and 47 with medium-sized tears) who underwent arthroscopic RC repair were enrolled in this study. Serial ultrasonography examinations were performed to evaluate repair integrity at 4 weeks, 3 months, 6 months, and 1 year. A senior surgeon (WKJ) from our institution performed all operations and ultrasonography examinations.

Surgical Technique

One senior orthopedic surgeon (WKJ) performed all surgical procedures arthroscopically using four portals: anterior, lateral, posterior, and posterolateral portals. After the procedure in the GH joint, including synovectomy or biceps procedures, the scope was moved to the subacromial space to perform subacromial decompression and RC repair. The anteroposterior size and mediolateral retraction of the RC tear were measured, and RC repair was performed accordingly. The repair technique was decided according to tear size. If the tear was less than 1 cm, single-row repair was performed using the modified Mason Allen technique. If the tear size was between 1 and 2 cm, the transosseous equivalent technique was used using two medial anchors and two lateral anchors.

Evaluation

Isokinetic muscle performance test

Muscle strength and endurance were measured using the isokinetic Biodex multi-joint system 4 (Biodex Medical System, Shirley, NY, USA) before and 1 year after surgery to evaluate flexion strength in the shoulders on the involved and uninvolved sides. Flexion strength and endurance were measured in the upright sitting position between 0° and 160° of flexion in the scapular plane (i.e., 30° of horizontal flexion anteriorly from the coronal plane) with full extension of the elbow joint using an immobilizer to restrict the use of elbow flexors (Fig. 1). The muscle strength test was repeated five times to evaluate

PT and iPT at 60°/sec. In this study, PT was recorded at midrange (83°) during the test with a full range,[2,7] whereas iPT was recorded at 30° of flexion during the test with a full range.[16] Muscle endurance was repeated 15 times to evaluate the total work at 180°/sec. Muscle strength was recorded with correction of body weight (in newton meter kilogram^{-1} × 100) due to differences in the morphological features, such as sex, body weight, and height, of enrolled individuals.[17] Muscle endurance was recorded with the sum of 15 repetitions (J). In this study, to quantify the test-retest reliability for muscle strength, intraclass correlation coefficients (ICCs) were calculated for two trials of flexion strength. ICCs for PT and iPT were 0.87 and 0.81, respectively.

Fig. 1. Isokinetic test position.

Postoperative rehabilitation protocol

All patients with small- and medium-sized supraspinatus tears underwent abduction immobilization for 3–4 weeks. From 3 to 4 weeks postoperatively, passive and active-assisted range of motion exercises such as flexion, abduction, and external rotation were gradually encouraged to a pain-free range. Active elbow exercises with immobilizers were performed immediately after surgery. Isometric and isotonic muscle strengthening exercises were initiated at 8 and 10 weeks postoperatively. Proprioception and neuromuscular retraining were initiated at 6 weeks postoperatively with 30° of flexion in the scapular plane, which was then gradually increased to 90° of flexion. We allowed unrestricted sports activities 6 months after the surgery. All the patients underwent the same rehabilitation protocol.

Statistical Analysis

Based on the findings of a previous study,[4] a difference in shoulder muscle flexion strength of > 15% between the involved- and uninvolved-side shoulders after arthroscopic RC repair in each group was regarded as clinically important. All continuous variables are presented as mean ± standard deviation. The paired *t*-test was used to compare the mean difference of PT, iPT, and total work between the preoperative and postoperative periods in each group. Student *t*-test was used to compare the mean difference of PT, iPT, and total work preoperatively and postoperatively

Table 1. Demographic Data of the Small- and Medium-Sized Supraspinatus Tear Groups

Variable	Small-sized tear group (n = 42)	Medium-sized tear group (n = 47)	*p*-value
Sex (male : female)	18 : 24	17 : 30	0.666
Age (yr)	57.1 ± 9.3	60.4 ± 8.3	0.076
Body mass index (kg/m^2)	24 ± 3	24.6 ± 8.3	0.328
Follow-up (mo)	12.2 ± 0.4	12.1 ± 0.3	0.896
Preoperative P-VAS at activity	6.4 ± 1.7	6.2 ± 1.4	0.398
Postoperative P-VAS at activity	3.1 ± 1.0	2.7 ± 1.0	0.441
Tear size	0.7 ± 0.2	1.7 ± 0.3	< 0.001*
Fatty infiltration grade	0.7 ± 0.7	1.2 ± 0.7	0.004*
GFDI	2.3 ± 2.0	3.6 ± 2.1	0.007*

Values are presented as mean ± standard deviation.
P-VAS: pain visual analog scale, GFDI: global fatty degeneration index.
*Statistically significant.

between the two groups. Correlations between PT and iPT on tear size, pain visual analog scale (P-VAS) scores, fatty infiltration grade of the supraspinatus muscle, and global fatty degeneration index (GFDI) were assessed using Pearson's correlation analysis. Statistical analysis was performed using IBM SPSS ver. 21.0 (IBM Corp., Armonk, NY, USA), with the significance level set at $p = 0.05$.

RESULTS

Demographics

A total of 89 patients with RC tears (42 in the small-sized tear group vs. 47 in the medium-sized tear group) were included in this study, and analysis was performed at a mean of 12 months postoperatively. Patient demographic data are presented in Table 1. There were no significant differences in age, height, weight, duration of follow-up, and P-VAS between the small- and medium-sized tear groups ($p > 0.05$). However, there were significant differences in tear size ($p < 0.001$), fatty infiltration grade of the supraspinatus muscle ($p = 0.004$), and GFDI ($p = 0.007$).

Comparison of Isokinetic Muscle Performance between the Involved and Uninvolved Shoulders in Each Group

Preoperatively, in both groups, PT (small tear: 29.1 ± 15.4 vs. 42.2 ± 16.4, 72.2%, $p < 0.001$) and iPT (medium tear: 10 ± 9.8 vs. 23.5 ± 15.9, 49.6%, $p < 0.001$) were significantly lower in the involved-side shoulders than in the uninvolved-side shoulders (Table 2). However, postoperatively, in the involved-side shoulders of the small- and medium-

Table 2. Comparison of Isokinetic Muscle Performance before and 1 Year after Surgery between Both sides in the Small- and Medium-Sized Supraspinatus Tear Groups

Variable	Preoperative			Postoperative		
	Involved	Uninvolved	*p*-value	Involved	Uninvolved	*p*-value
Small tear (iPT)	14.5 ± 10.4	22.8 ± 11.2	< 0.001*	19 ± 8.3	25 ± 10.3	< 0.001*
Difference (%)[†]	–29.3			–17.6		
MD (95% CI)	8.3 (4.7 to 11.9)			6 (3.6 to 7.5)		
Small tear (PT)	29.1 ± 15.4	42.2 ± 16.4	< 0.001*	43 ± 30.5	42.2 ± 14.4	0.874
Difference (%)[†]	–17.8			5.9		
MD (95% CI)	13.1 (8.6 to 17.6)			–0.8 (–9.8 to 8.3)		
Medium tear (iPT)	10 ± 9.8	23.5 ± 15.9	< 0.001*	15.6 ± 6.1	23.2 ± 11.7	< 0.001*
Difference (%)[†]	–50.4			–26.9		
MD (95% CI)	13.5 (9.5 to 17.6)			7.6 (3.7 to 11.4)		
Medium tear (PT)	23.7 ± 13.9	36 ± 16.9	< 0.001*	32 ± 13	33.3 ± 14	0.300
Difference (%)[†]	–32.2			–3.9		
MD (95% CI)	12.3 (9.0 to 15.6)			1.3 (–1.2 to 3.8)		
Small tear total work	294.2 ± 57.6	368.9 ± 42.4	< 0.001*	351.9 ± 41.0	365.1 ± 49.2	0.220
Difference (%)[†]	–18.7			–3.6		
MD (95% CI)	77.7 (31 to 94)			5.2 (–8.3 to 27.1)		
Medium tear total work	267.1 ± 31.1	334.6 ± 46.1	< 0.001*	341.1 ± 46.4	338.5 ± 40.0	0.613
Difference (%)[†]	–20.2			0.8		
MD (95% CI)	67.5 (19 to 78)			–2.6 (–10.4 to 57)		

Values are presented as mean ± standard deviation unless otherwise indicated. Measurement unit: muscle strength (Nm kg^{-1} × 100) and muscle endurance (J).
iPT: peak torque at the initial angle, MD: mean difference, CI: confidence interval, PT: peak torque.
*Statistically significant. [†]The difference is calculated as a percentage (%) of the involved side value minus the uninvolved side value. Positive percent means that the involved side is greater than the uninvolved side. Negative percent means that the involved side is smaller than the uninvolved side.

sized tear groups, PT was similar (small tear: 43 ± 30.5 vs. 42.2 ± 14.4, 105.9%, $p = 0.874$; medium tear: 32 ± 13 vs. 33.3 ± 14, 96.1%, $p = 0.300$), but iPT was significantly lower than that in the uninvolved-side shoulders (small tear: 19 ± 8.3 vs. 25 ± 10.3, 82.4%, $p < 0.001$; medium tear: 15.6 ± 6.1 vs. 23.2 ± 11.7, 73.1%, $p < 0.001$) (Table 2, Fig. 2).

Preoperatively, in both groups, total work (small tear: 294.2 ± 57.6 vs. 368.9 ± 42.4, $p < 0.001$; medium tear: 267.1 ± 31.1 vs. 334.6 ± 46.1, $p < 0.001$) was significantly lower in the involved-side shoulders than in the uninvolved-side shoulders (Table 2, Fig. 2). However, postoperatively, in both groups, total work (small tear: 351.9 ± 41.0 vs. 365.1 ± 49.2, $p = 0.220$; medium tear: 341.1 ± 46.4 vs. 338.5 ± 40.0, $p = 0.613$) was not significantly different between the involved-side shoulders and the uninvolved-side shoulders (Table 2, Fig. 2).

Comparison of Isokinetic Muscle Performance between the Two Groups

On the involved-side shoulders, iPT was significantly higher in the small-sized tear group than in the medium-sized tear group before and after surgery ($p < 0.05$) (Fig. 3A and B). On the involved-side shoulders, PT was not significantly different between the groups before surgery ($p > 0.05$) (Fig. 3A); however, it was significantly higher in the small-sized tear group than in the medium-sized tear group after surgery ($p < 0.05$) (Fig. 3B). On the uninvolved-side shoulders, PT and iPT were not significantly different between the two groups both before and after surgery ($p > 0.05$) (Fig. 3A and B). On the involved-side and uninvolved-side shoulders, total work was not significantly different between the two groups both before and after surgery ($p > 0.05$) (Fig. 3C and D).

Correlation of iPT and PT with Tear Size, P-VAS, Fatty Infiltration, and GFDI in the Involved Shoulders

In the small- and medium-sized tear groups, tear size was significantly correlated with preoperative iPT (small tear: $r = -0.304$, $p = 0.046$; medium tear: $r = -0.323$, $p = 0.027$) (Table 3). P-VAS was significantly negatively correlated with preoperative (small tear: $r = -0.455$, $p = 0.002$; medium tear: $r = -0.286$, $p = 0.044$) and postoperative iPT

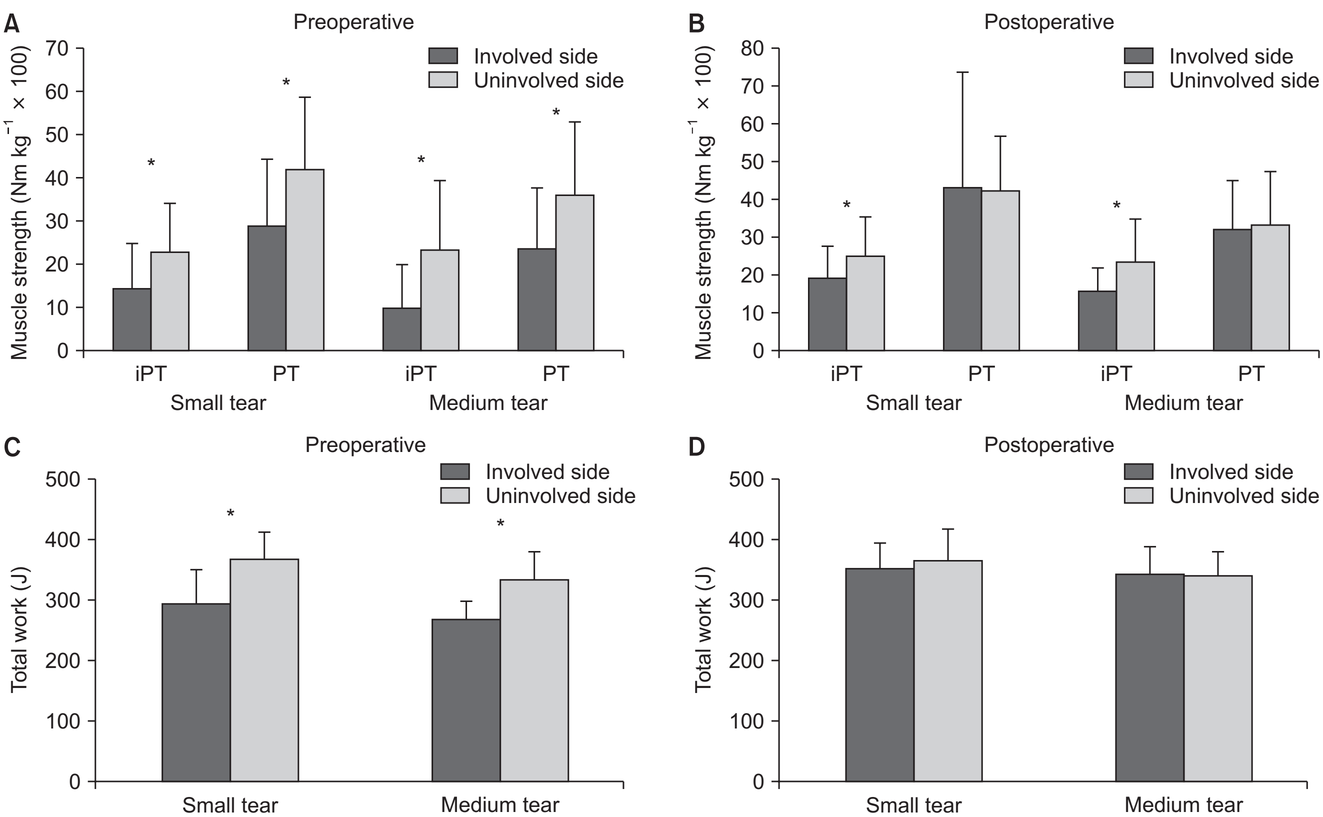

Fig. 2. Isokinetic muscle performance (peak torque at the initial angle [iPT], peak torque [PT], and total work) at preoperative and at postoperative 1 year between the involved and uninvolved side in each group. (A) Muscle strength before surgery. (B) Muscle strength after surgery. (C) Muscle endurance before surgery. (D) Muscle endurance after surgery. Small supraspinatus tear: tear size less than 1 cm. Medium-sized supraspinatus tear: tear size between 1 and 2 cm. *$p < 0.05$.

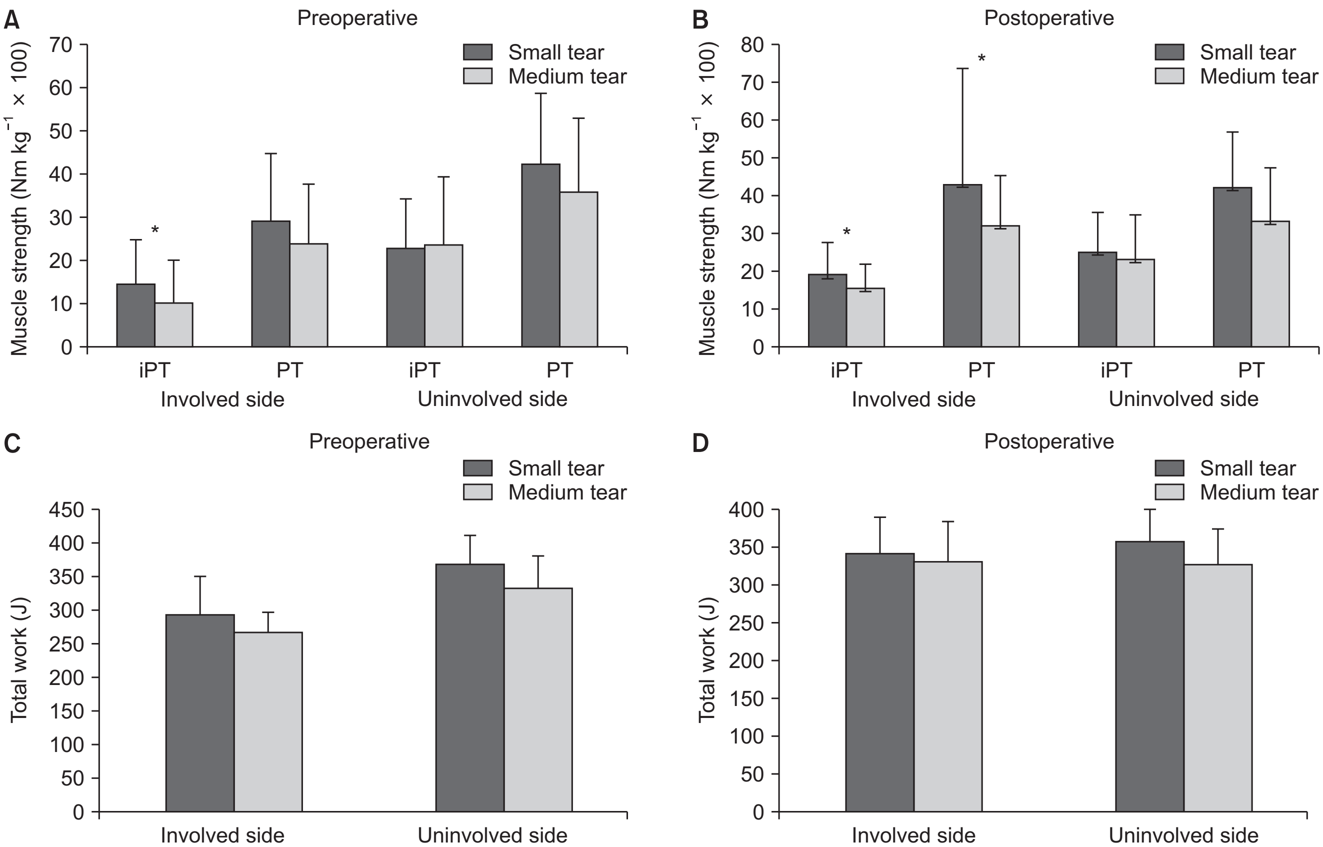

Fig. 3. Isokinetic muscle performance (peak torque at the initial angle [iPT], peak torque [PT], and total work) before and 1 year after surgery between patients with small- and medium-sized supraspinatus tears. (A) Muscle strength before surgery. (B) Muscle strength after surgery. (C) Muscle endurance before surgery. (D) Muscle endurance after surgery. Small supraspinatus tear: tear size less than 1 cm. Medium-sized supraspinatus tear: tear size between 1 and 2 cm. *$p < 0.05$.

(small tear: $r = -0.430$, $p = 0.005$; medium tear: $r = -0.354$, $p = 0.021$), but not with preoperative and postoperative PT ($p > 0.05$) (Table 3). Fatty infiltration grade of the supraspinatus muscle and GFDI were not associated with preoperative and postoperative PT and iPT in each group (all $p > 0.05$).

DISCUSSION

The main finding of the present study is that although PT was not different, iPT was significantly lower on the involved side than on the uninvolved side in the small- and medium-tear groups at 1 year postoperatively. Furthermore, both PT and iPT were significantly lower in the medium-sized tear group than in the small-sized tear group. However, there was a significant difference in muscle endurance between the involved side and the uninvolved side before surgery, but there was no difference at 1 year postoperatively. In addition, tear size and P-VAS were significantly associated with iPT in the involved-side shoulders in both groups. However, fatty infiltration grade of the supraspinatus muscle and GFDI were not associated with preoperative and postoperative PT and iPT in each group.

These findings indicate that iPT may be another useful option for evaluating the functional recovery of the supraspinatus muscle before and after RC repair. Studies evaluating changes in flexion strength at 1 year after surgery in patients with full-thickness supraspinatus tears have reported varying results. Walker et al.[11] showed that PT for flexion of the uninvolved-side shoulders improved by 75% at 1 year postoperatively; however, their study included patients with large to massive tears. Rokito et al.[10] and Kirschenbaum et al.[18] reported that PT for flexion of the uninvolved-side shoulders in patients with small- and medium-sized tears was 97% at 1 year postoperatively. The results of PT in the present study are consistent with these findings. However, the aforementioned studies did not evaluate the iPT. In the present study, patients with small- and medium-sized tears regained 82.4% and 73.1%

Table 3. Correlations of iPT and PT with Tear Size, P-VAS, Fatty Infiltration, and GFDI in the involved side in the Small- and Medium-Sized Supraspinatus Tear Groups

Parameter	Small sized tear group (n = 42)				Medium sized tear group (n = 47)			
	Tear size	P-VAS	Preoperative fatty infiltration grade	GFDI	Tear size	P-VAS	Preoperative fatty infiltration grade	GFDI
Preoperative iPT (involved)								
PCC (*r*)	–0.304	–0.455	–0.106	–0.120	–0.323	–0.286	0.247	–0.018
p-value	0.046*	0.002*	0.504	0.450	0.027*	0.044*	0.094	0.903
Preoperative PT (involved)								
PCC (*r*)	0.027	–0.082	–0.254	–0.096	0.180	–0.217	–0.072	0.005
p-value	0.866	0.571	0.105	0.546	0.226	0.168	0.629	0.974
Postoperative iPT (involved)								
PCC (*r*)	–0.123	–0.430	0.074	0.027	–0.097	–0.354	0.108	0.173
p-value	0.436	0.005*	0.642	0.866	0.518	0.021*	0.470	0.245
Postoperative PT (involved)								
PCC (*r*)	0.231	–0.284	–0.034	–0.015	0.203	–0.190	–0.227	–0.280
p-value	0.141	0.068	0.829	0.923	0.172	0.227	0.124	0.057

iPT: peak torque at the initial angle, PT: peak torque, P-VAS: pain visual analogue scale, GFDI: global fatty degeneration index, PCC: Pearson correlation coefficient.
*Statistically significant.

strength of the involved-side shoulders, respectively, compared to that of the uninvolved-side shoulders at 1 year postoperatively; that is, there was a clinically significant difference even at 1 year postoperatively. Although the reason for this observation is unclear, it may be explained by the function of the supraspinatus muscle at the initial angle of shoulder elevation. Several previous studies[9,19] have reported that the relationship between the supraspinatus and deltoid muscles during shoulder elevation is important for normal shoulder kinematics. In particular, the supraspinatus muscle is more involved during initial shoulder elevation than the deltoid muscle[20,21] because at the initial flexion angle, the deltoid muscle is parallel to the vertical axis of the humerus.[16,22] However, at 90° shoulder elevation, the supraspinatus muscle has a lower flexion activity than the deltoid muscle[20,21] because the supraspinatus muscle contributes more substantially to the stabilization of the humeral head into the glenoid than flexion torque from the higher activation of the deltoid muscle.[23] Chalmers et al.[9] and Alpert et al.[22] reported that while the activity of the supraspinatus muscle is higher at the initial 30° of shoulder elevation, the deltoid muscle is more active at 90° shoulder elevation than at 30° shoulder elevation. Therefore, evaluating the recovery of supraspinatus muscle strength with PT alone after RC repair may be erroneous. Considering the findings of previous studies, iPT may also be useful in evaluating the recovery of supraspinatus muscle strength in patients with limited evaluation due to pain or ROM limitation at high flexion angles such as 90°.

Many previous studies[12,24,25] have reported an association between the tear size of RC muscles and muscle strength, but most of these studies have been conducted on patients with large to massive tears. However, McCabe et al.[24] and Miller et al.[26] investigated the association between small- and medium-sized supraspinatus tears and flexion strength. The authors found that flexion strength was not associated with small- and medium-sized tears, but it was associated with large to massive tears as the activity of the infraspinatus muscle can increase progressively compared to that of the supraspinatus muscle at

90° shoulder elevation.[12,25] The aforementioned studies measured PT at 90° shoulder elevation. The results related to tear size and PT in the present study are consistent with these findings. However, most of the aforementioned studies did not analyze the association between tear size and iPT. To our knowledge, only one study[24] has investigated the relationship between tear size and muscle strength at an initial shoulder elevation of 10° and reported that small- and medium-sized tears were not associated with the strength at that angle. However, in the present study, small- and medium-sized tears were associated with preoperative iPT. Therefore, our results differ from those of the previous study, which may be due to the difference in the angle of shoulder elevation. In a previous cadaveric study,[27] the initial 20° of shoulder elevation may not have been reliable for the assessment of shoulder muscle activation, especially regarding the supraspinatus muscle.[28] Below the initial 20° of shoulder elevation, the GH joint may be slightly elevated during flexion to prevent inferior translation of the loaded humerus.[27,28] Furthermore, in the present study, iPT was significantly lower in the medium-sized tear group than in the small-sized tear group before and after surgery. In particular, preoperative and postoperative iPT were related to P-VAS measured at activity, but not with fatty infiltration grade and GFDI.

This study has certain limitations. First, this study has a retrospective design; thus, future prospective studies with a larger number of patients with large-to-massive tears and patients with retears are necessary. Second, we did not perform electromyography (EMG) assessments. Generally, muscle activation was measured using EMG, but an EMG device with intramuscular electrodes, which is necessary for the assessment of supraspinatus muscles, may trigger pain and minor discomfort due to needle insertion,[29] which may affect the results of the measurements.[30,31] However, the isokinetic test has also been used to assess the strength and activity of muscles in the upper and lower extremities in many previous studies; this method is noninvasive, unlike needle EMG. Third, we could not evaluate the correlation between postoperative fat infiltration grade and muscle strength because there were 6-month time difference between postoperative magnetic resonance imaging and isokinetic tests. Finally, outcomes in long-term follow-up of more than 1 year should be confirmed, and their correlation with clinical outcome scores need to be investigated in the future.

In conclusion, iPT is as important as conventional PT in isokinetic testing to assess supraspinatus muscle strength during shoulder flexion before and after arthroscopic RC repair. Therefore, clinicians need to identify the muscle strength of small- and medium-sized supraspinatus tears at the initial angle, and therapists must concentrate on exercises for restoration of supraspinatus muscle strength at the initial angle (shoulder flexion 30°) after arthroscopic RC repair.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

ORCID

Jin Hyuck Lee https://orcid.org/0000-0002-7083-4700
Ji Soon Park https://orcid.org/0000-0003-2807-6501
Woong Kyo Jeong https://orcid.org/0000-0001-8602-9290

REFERENCES

1. Escamilla RF, Yamashiro K, Paulos L, Andrews JR. Shoulder muscle activity and function in common shoulder rehabilitation exercises. Sports Med. 2009;39(8):663-85.
2. Shin SJ, Chung J, Lee J, Ko YW. Recovery of muscle strength after intact arthroscopic rotator cuff repair according to preoperative rotator cuff tear size. Am J Sports Med. 2016;44(4):972-80.
3. Rabin SI, Post M. A comparative study of clinical muscle testing and Cybex evaluation after shoulder operations. Clin Orthop Relat Res. 1990;(258):147-56.
4. Bigoni M, Gorla M, Guerrasio S, et al. Shoulder evaluation with isokinetic strength testing after arthroscopic rotator cuff repairs. J Shoulder Elbow Surg. 2009;18(2):178-83.
5. Nagatomi T, Mae T, Nagafuchi T, Yamada SI, Nagai K, Yoneda M. Shoulder manual muscle resistance test cannot fully detect muscle weakness. Knee Surg Sports Traumatol Arthrosc. 2017;25(7):2081-8.
6. Baltzopoulos V, Brodie DA. Isokinetic dynamometry: applications and limitations. Sports Med. 1989;8(2):101-16.
7. Malliou PC, Giannakopoulos K, Beneka AG, Gioftsidou A, Godolias G. Effective ways of restoring muscular imbalances of the rotator cuff muscle group: a comparative study of various training methods. Br J Sports Med. 2004;38(6):766-72.
8. Wickham J, Pizzari T, Stansfeld K, Burnside A, Watson L. Quantifying 'normal' shoulder muscle activity during ab-

duction. J Electromyogr Kinesiol. 2010;20(2):212-22.

9. Chalmers PN, Cvetanovich GL, Kupfer N, et al. The champagne toast position isolates the supraspinatus better than the Jobe test: an electromyographic study of shoulder physical examination tests. J Shoulder Elbow Surg. 2016; 25(2):322-9.

10. Rokito AS, Zuckerman JD, Gallagher MA, Cuomo F. Strength after surgical repair of the rotator cuff. J Shoulder Elbow Surg. 1996;5(1):12-7.

11. Walker SW, Couch WH, Boester GA, Sprowl DW. Isokinetic strength of the shoulder after repair of a torn rotator cuff. J Bone Joint Surg Am. 1987;69(7):1041-4.

12. Kim HM, Dahiya N, Teefey SA, Keener JD, Galatz LM, Yamaguchi K. Relationship of tear size and location to fatty degeneration of the rotator cuff. J Bone Joint Surg Am. 2010; 92(4):829-39.

13. Benson RT, McDonnell SM, Knowles HJ, Rees JL, Carr AJ, Hulley PA. Tendinopathy and tears of the rotator cuff are associated with hypoxia and apoptosis. J Bone Joint Surg Br. 2010;92(3):448-53.

14. Park JS, Park HJ, Kim SH, Oh JH. Prognostic Factors affecting rotator cuff healing after arthroscopic repair in small to medium-sized tears. Am J Sports Med. 2015;43(10):2386-92.

15. Post M, Silver R, Singh M. Rotator cuff tear: diagnosis and treatment. Clin Orthop Relat Res. 1983;(173):78-91.

16. Reddy AS, Mohr KJ, Pink MM, Jobe FW. Electromyographic analysis of the deltoid and rotator cuff muscles in persons with subacromial impingement. J Shoulder Elbow Surg. 2000;9(6):519-23.

17. Lee JH, Park JS, Hwang HJ, Jeong WK. Time to peak torque and acceleration time are altered in male patients following traumatic shoulder instability. J Shoulder Elbow Surg. 2018; 27(8):1505-11.

18. Kirschenbaum D, Coyle MP Jr, Leddy JP, Katsaros P, Tan F Jr, Cody RP. Shoulder strength with rotator cuff tears: pre- and postoperative analysis. Clin Orthop Relat Res. 1993; (288):174-8.

19. Wattanaprakornkul D, Halaki M, Boettcher C, Cathers I, Ginn KA. A comprehensive analysis of muscle recruitment patterns during shoulder flexion: an electromyographic study. Clin Anat. 2011;24(5):619-26.

20. Colachis SC Jr, Strohm BR. Effect of suprascauular and axillary nerve blocks on muscle force in upper extremity. Arch Phys Med Rehabil. 1971;52(1):22-9.

21. Illyes A, Kiss RM. Shoulder muscle activity during pushing, pulling, elevation and overhead throw. J Electromyogr Kinesiol. 2005;15(3):282-9.

22. Alpert SW, Pink MM, Jobe FW, McMahon PJ, Mathiyakom W. Electromyographic analysis of deltoid and rotator cuff function under varying loads and speeds. J Shoulder Elbow Surg. 2000;9(1):47-58.

23. Oatis C, Beattie P. Kinesiology: the mechanics and pathomechanics of human movement. Philadelphia: Lippincott Williams & Wilkins; 2004.

24. McCabe RA, Nicholas SJ, Montgomery KD, Finneran JJ, McHugh MP. The effect of rotator cuff tear size on shoulder strength and range of motion. J Orthop Sports Phys Ther. 2005;35(3):130-5.

25. Ruckstuhl H, Krzycki J, Petrou N, et al. Shoulder abduction moment arms in three clinically important positions. J Shoulder Elbow Surg. 2009;18(4):632-8.

26. Miller JE, Higgins LD, Dong Y, et al. Association of strength measurement with rotator cuff tear in patients with shoulder pain: the Rotator Cuff Outcomes Workgroup Study. Am J Phys Med Rehabil. 2016;95(1):47-56.

27. Wuelker N, Plitz W, Roetman B, Wirth CJ. Function of the supraspinatus muscle: abduction of the humerus studied in cadavers. Acta Orthop Scand. 1994;65(4):442-6.

28. Kronberg M, Brostrom LA, Nemeth G. EMG studies of shoulder muscles in subjects with stable or unstable humeroscapular joint. In: Proceedings of the Third Intemational Conference on Surgery of the Shoulder; 1987; Fukuoka, Japan.

29. Armour Smith J, Kulig K. Does insertion of intramuscular electromyographic electrodes alter motor behavior during locomotion? J Electromyogr Kinesiol. 2015;25(3):431-7.

30. Pincus T, Vogel S, Burton AK, Santos R, Field AP. Fear avoidance and prognosis in back pain: a systematic review and synthesis of current evidence. Arthritis Rheum. 2006; 54(12):3999-4010.

31. Mills KR. The basics of electromyography. J Neurol Neurosurg Psychiatry. 2005;76(Suppl 2):ii32-5.