How Much Will High Tension Adversely Affect Rotator Cuff Repair Integrity?

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Purpose: To suggest a cutoff value of tension related to retear of a repaired chronically contracted rotator cuff and to analyze the correlation between predictive factors and integrity of repair in large to massive contracted rotator cuff tears (RCTs). **Methods:** We analyzed arthroscopic rotator cuff repairs for large to massive (>3 cm) contracted RCTs, not amenable to complete repair by standard means with meticulous release, with a minimum of 1 year follow-up. An intraoperative procedure was designed for the estimation of repair tension using a tensiometer. Clinical and radiological findings were compared between the healed group and the retear group, and magnetic resonance imaging was performed ~1 year postoperatively for the evaluation of integrity of the repair site. The receiver operating characteristic curve was used to identify the cutoff value of the independent factors. Factors affecting postoperative retear were examined with multivariate analysis. **Results:** Fifty patients were enrolled in this study and divided into the healed group (31 patients) and the retear group (19 patients) according to the follow-up magnetic resonance imaging findings. Significant results showed that tension (5.13 < 95% confidence interval [CI] < 58.15, $P < .001$) and acromiohumeral interval (AHI) (1.13 < 95% CI < 33.10, $P = .013$) were important factors for the integrity of rotator cuff repair. The cutoff value of tension was 35 N, and an AHI <6.6 mm may also be considered a predictor of retear. An occupation ratio of the tension >35 N was the strongest predictor of retear, with an area under the curve of 0.799, sensitivity of 84.2%, and specificity of 67.7% (accuracy = 76.0%). **Conclusions:** The integrity of a large to massive rotator cuff repair is strongly related to the tension to reach the articular margin of the footprint and AHI. We found that the possibility of retear increases when tension ≥35 N is required. AHI <6.6 mm may also be considered a predictor of retear. **Level of Evidence:** Level III, retrospective cohort design.

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A long-established goal of surgical treatment of rotator cuff tear (RCT) has been to repair the tendon on the footprint with minimal tension.[1-3] Although many surgeons favor complete repair, certain large to massive (>3-cm) RCTs may be fixed and contracted, and this lack of mobility precludes tension-free repair to the bone. Theoretically, strain at the repair site can predispose to mechanical failure of rotator cuff repair.[4,5] Several procedures including margin convergence, interval slide, medialization, and biological augmentations have been introduced to relieve undue tension on the repair site.[6] However, it remains uncertain what the actual tension is that would prevent retear of the cuff tendons. Although some studies have measured rotator cuff tension,[7-9] few studies have analyzed the relationship between the actual tension at the time of surgery and retear of repaired chronically contracted RCTs; thus, there is no standard regarding the value for repair tension.

A previous prospective clinical study by Davidson and Rivenburgh[1] reported that rotator cuff repair with high tension >8 lb (35.59 N) showed poor clinical outcomes. However, evaluation of tendon retear was not performed in their postoperative analysis; thus, they could not suggest whether it was because of muscle function or tendon-to-bone healing. The clinical research of Kim et al.[10] revealed that

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there was a significant inverse correlation between repair tension and healing at the repair site. However, they could not suggest a cutoff value of tension related to retear of contracted RCTs.

In the current study, we analyzed the relationship between the actual tension to mobilize the rotator cuff tendon to the medial margin of the footprint at the time of surgery and retear of the repaired rotator cuff by magnetic resonance imaging (MRI). Therefore, the purposes of this study were to suggest a cutoff value of tension related to retear of the repaired chronically contracted rotator cuff and to analyze the correlation between predictive factors and integrity of repair in large to massive contracted RCT. We hypothesized that tension would be a major factor of rotator cuff integrity and that if more than a certain amount of tension was required to repair a chronically contracted rotator cuff, it would be more likely to cause retear than if lesser tension was applied.

Methods

Inclusion and Exclusion Criteria

From January 2015 to September 2017, RCTs were treated by arthroscopic surgical procedure by 1 surgeon (S-G.P.). Arthroscopic repairs for large to massive contracted RCTs, not amenable to complete repair with meticulous release of fibrous bursal and articular adhesions, with a minimum of 1-year follow-up were analyzed. The following inclusion criteria were applied: 1) large to massive full-thickness (>3-cm) tears verified by preoperative MRI and confirmed using a 5-mm premarked probe at the time of surgery, 2) torn rotator cuff tendons that were not able to reduce to the medial row of the greater tuberosity before meticulous release of both articular and bursal surfaces, 3) rotator cuff tension measured intraoperatively when the released tendons were reduced to the medial border of the original footprint, and 4) availability of functional outcome assessment and MRI at ~1 year after surgery for the evaluation of the healing at the repair site.

The exclusion criteria were as follows: 1) small or medium tears and partial-thickness tears, 2) isolated subscapularis tears, 3) previous rotator cuff surgery on the affected shoulder, 4) glenohumeral arthritis or inflammatory arthropathy, 5) incomplete follow-up data or lack of follow-up MRI evaluation, 6) incomplete repairs, and 7) partial repairs. The patients were divided into healed and retear groups according to the presence of retear on MRI findings at a minimum of 1 year postoperatively.

Surgical Technique

General anesthesia was administered to all patients without additional nerve block. The operative procedure was all-arthroscopic repair of a full-thickness RCT using the suture-bridge technique in the lateral decubitus position. The operative arm was placed in 30° abduction and 20° forward flexion (Star Sleeve Traction System; Arthrex, Naples, FL). Four routine arthroscopic portals (anterior, posterior, lateral, and anterolateral) were used to perform arthroscopy. Initially, a glenohumeral examination was performed through the posterior portal. When a biceps tendon lesion was found, a biceps procedure, either tenotomy or tenodesis, was performed depending on the tear size, patient age, and daily activity level. If an unstable subscapularis tendon tear was identified, either a simple repair in a single-row fashion or a mattress repair with transtendon technique was performed. All subscapularis tendon tears were completely repaired.

After the completion of intra-articular procedures, the arthroscope was moved to the subacromial space. Acromioplasty was performed using a motorized bur (Vortex Router and Linvatec Turbo Shaver System; Linvatec, Largo, FL) in all patients with subacromial spur. Osteophytes in the inferior surface of the acromioclavicular joint and distal end of clavicle were also removed, if necessary. While viewing from the lateral portal, the mobility of the rotator cuff tendon was assessed using arthroscopic graspers (KingFisher; Arthrex), usually through the anterolateral portal. After the degenerated tendon edges were debrided, tear size and extent of retraction were measured using a calibrated probe. If the torn rotator cuff stump was not able to reach the medial border of the greater tuberosity, articular and bursal pretendinous adhesions, coracohumeral ligaments, and capsular contractures were thoroughly released to mobilize the tendon. Interval slide, biceps augmentation, or margin convergence were not performed in any case. After the contracted structures were adequately released, the mobility of the rotator cuff was reassessed using arthroscopic graspers at the edge of the maximally retracted torn rotator cuff. The grasper was usually passed through the anterolateral portal to pull the tendon following the direction of the final repair construct. When the direction was not parallel, an accessory anterolateral or posterolateral portal was made to pull the tendon. The grasper was then loaded to a tensiometer (Tensioning Device; Arthrex) (Fig 1), and manual traction was applied until the edge of the torn rotator cuff tendon reached the medial border of the footprint (Fig 2). This procedure was performed after 30 s of manual traction, allowing for stress relaxation (Fig 3). Tear pattern, reparability, and amount of tension required to lateralize the tendon edge were noted. Then, rotator cuff repair was performed.

The footprint of the greater tuberosity was prepared to cause bleeding and medialize ~5 mm in all patients using a round burr. Bio-Corkscrew suture anchors (4.5-mm; Arthrex) for the medial row were inserted just

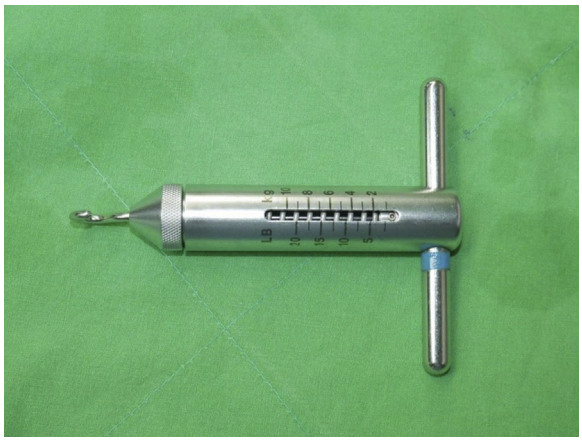

Fig 1. Tensiometer for measuring repair tension of the rotator cuff.

lateral to the remaining margin of the articular surface. The interval between the inserted anchors on the medial row was 1 cm. All suture limbs were passed 2−3 mm lateral to the musculotendinous junction using a retrograde shuttle relay technique with a suture-passing device (Expressew; DePuy Mitek, Raynham, MA). After tying the medial-row sutures, knotless anchors for the lateral row were placed distal to the greater tuberosity with sutures under tension to compress across the footprint. However, if the remnant tendon was extremely short, a partial repair was performed, and such cases were excluded from this study. The number of suture anchors used was based on the size of the tear.

Clinical and Radiographic Evaluation

For the clinical evaluation, visual analog scale (VAS), American Shoulder and Elbow Surgeons (ASES), Disabilities of the Arm, Shoulder and Hand (DASH), and Constant−Murley scores were collected in the clinic setting preoperatively and at the latest follow-up in all patients. The mean change from baseline to final follow-up was calculated and used for each variable. Based on the published literature, 1.4 points is the minimal clinically important difference (MCID) for VAS, 11.1 for ASES, 10.83 points for DASH, and 11 points for Constant-Murley.[11-13]

For the radiographic evaluation, the critical shoulder angle (CSA) and acromiohumeral interval (AHI) were measured using a true anteroposterior radiograph. The CSA, the angle between a line connecting the superior and inferior margins of the glenoid and a line drawn from the inferior margin of the glenoid to the lateral border of the acromion, was measured. The AHI was defined as the distance between the tangent to the inferior edge of the dense cortical bone of the acromion and the parallel tangent to the most proximal articular cortex of the humeral head.

All 50 patients underwent preoperative standardized MRI examinations conducted on a 3-T magnetic resonance scanner (Magnetom Tim Trio; Siemens, Erlangen, Germany) preoperatively and a minimum of 1 year after surgery (mean, 13.2 months; range, 12 to 19 months). The MRI scans were reviewed using the Picture Archiving and Communications System (Marosis; Infiniti, Seoul, Korea) in a blinded fashion by 2 independent musculoskeletal radiologists who were not otherwise involved in the study. The tear size was measured in the maximum anterior-to-posterior width on T1-weighted fat-suppression oblique sagittal images. The amount of retraction was measured on a T2-weighted oblique coronal scan from the footprint to the apex of the tear for full-thickness RCTs. Supraspinatus muscle atrophy and the degree of fatty infiltration in the supraspinatus and infraspinatus muscles were measured in most lateral T1-weighted oblique sagittal images where the scapular spine was seen in contact with the scapular body (the "Y-view"). Supraspinatus muscle atrophy was quantified by measuring the occupation ratio between the cross-sectional area of the supraspinatus muscle and fossa. The degree of fatty infiltration in the supraspinatus and infraspinatus muscles was categorized as follows: stage 0, a completely normal muscle without any fatty streak; stage 1, occasional fatty streaks in the muscle; stage 2, obvious fatty infiltration but with still more muscle than fat; stage 3, equal amount of fat and muscle; and stage 4, more fat than muscle.[14]

The tears of the subscapularis were categorized according to Lafosse's classification using arthroscopic findings. We subjectively categorized healthy subscapularis tendon and Lafosse type I lesions as stable status; Lafosse type II and III lesions as partial tear; and Lafosse type IV and V lesions as total tear.[15] Integrity of the repaired rotator cuff was assessed on MRI scans at ~1 year postoperatively. A retorn rotator cuff was

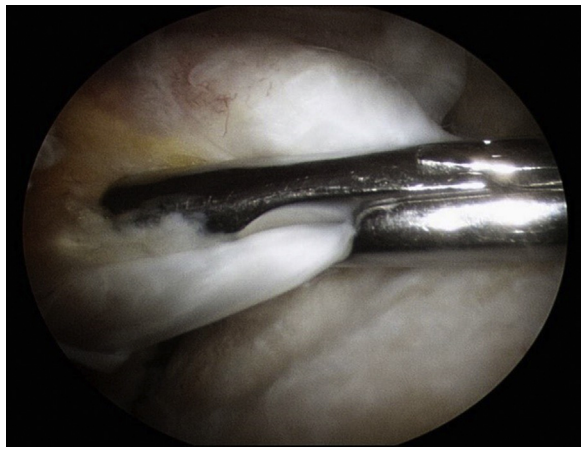

Fig 2. Arthroscopic imaging of a right shoulder with a massive rotator cuff tear through a lateral portal using a 70° arthroscope. The edge of the torn rotator cuff tendon reached the medial border of the footprint using the grasper.

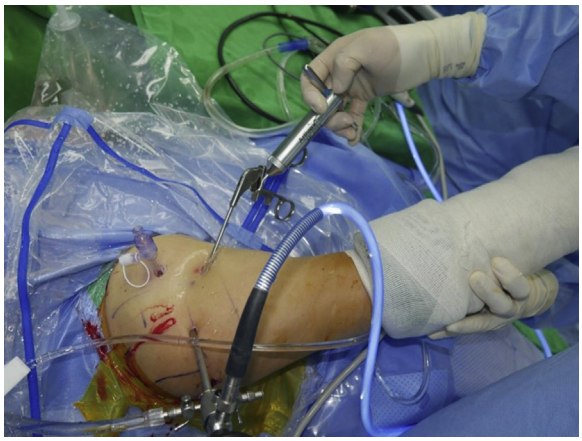

Fig 3. Measurement of repair tension of the rotator cuff. Manual tension was applied to the grasper until the torn rotator cuff tendon reached the medial border of the footprint. Then, the grasper was loaded to the hook of the tensiometer.

defined as a discontinuity of the repaired rotator cuff at the footprint that was found in at least 1 T2-weighted or proton density-weighted image. Retear of the rotator cuff was evaluated using Sugaya's classification.[16] Patients with types IV and V were admitted with postoperative retear.

Postoperative Rehabilitation Protocol

During the postoperative rehabilitation period, we also paid attention to tension that was applied to a repaired tendon. The arms were placed in an abduction brace positioned in 30° abduction for 6 weeks, as Reilly et al.[8] reported that postoperative immobilization with a 30° abduction wedge decreased the repair tension.

Pendulum exercises were started 3 days after relief of acute pain. After 6 weeks of immobilization, gentle, self-assisted, passive range-of-motion exercises, such as supine forward elevation or internal rotation using a towel, were performed. Three months postoperatively, patients began isotonic strengthening exercises and were permitted to do light daily activities. At 6 months, they returned to usual activities and restarted manual work. Contact sports and heavy labor were avoided for 1 year depending on the individual's functional recovery. We applied an identical postoperative rehabilitation protocol to minimize the bias from rehabilitation.

Statistical Analysis

Continuous data are presented as mean and standard deviations. The paired t test and Kruskal–Wallis test were used to compare continuous variables: tear size, degree of retraction, tension required to mobilize the cuff, and VAS, ASES, DASH, and Constant–Murley scores. Chi-square test, Fisher exact test, and linear-by-linear association tests were used to compare proportion differences between 2 groups. The receiver operating characteristic curve was used to identify the cutoff value of the independent factors. Finally, we performed a multivariate logistic regression analysis in a stepwise forward conditional manner to determine the independent variables influencing retears of chronically contracted rotator cuff. Statistical analyses were conducted using IBM SPSS version 23.0 (IBM Co., Armonk, NY). Two-tailed P values $< .05$ were considered significant.

Results

Sixty-one patients with large to massive contracted RCTs, not amenable to complete repair by standard means such as direct tendon-bone repairs with meticulous release of fibrous bursal and articular adhesions, were prospectively enrolled in this study. Four patients were excluded due to incomplete follow-up data, and 7 patients were excluded because the RCTs were partially repaired. Ultimately, a total of 50 patients were enrolled in this study. According to the follow-up MRI findings, these patients were divided into the healed group (31 patients) and the retear group (19 patients). The average follow-up period was 23.5 months. The number of suture anchors varied with the size of the tear. We usually used 3 anchors, and more anchors were used for some massive tears.

Preoperative Factors

Demographic data and preoperative variables of the healed and retear groups are presented in Table 1. The retear rates were similar regardless of age ($P = .352$), sex ($P = .242$), mean follow-up duration ($P = .458$), and dominant arm ($P = .584$). The preoperative internal rotation range was greater in the retear group (75.8° vs 65.2°), and the external rotation range was greater in the healed group (83.7° vs 77.6°); however, these were not significant ($P = .084$ and $P = .092$, respectively). There were no remarkable differences in other preoperative ranges of motion between the 2 groups. Regarding preoperative clinical evaluation, VAS (4.1 ± 2.2 vs 3.3 ± 2.3, $P = .207$), ASES (34.4 ± 16.1 vs 27.6 ± 21.3, $P = .204$), DASH (40.16 ± 17.1 vs 37.1 ± 14.3, $P = .837$), and Constant–Murley (32.9 ± 22.8 vs 26.8 ± 17.8, $P = .327$) scores did not show significant differences between the 2 groups.

Table 2 shows the mean change in each outcome measure between baseline and final follow-up. In both groups, there were significant improvements in all 4 measures between baseline and final follow-up ($P < .001$). However, when comparing the mean changes in scores between 2 groups, there were no significant improvements. With thresholds for VAS score, 83.8% achieved MCID in the healed group and 73.7% achieved MCID in the retear group; for ASES score, 87.1% achieved MCID in the healed group and 68.4% achieved MCID in the retear group; for DASH score, 93.5% achieved MCID in the healed group and 94.7% achieved MCID in the retear group; for

Constant–Murley score, 80.6% achieved MCID in the healed group and 84.2% achieved MCID in the retear group.

According to the radiographic evaluation, only AHI was significantly greater in the healed group (7.4 ± 2.1 mm) than in the retear group (5.7 ± 2.5 mm) ($P = .013$). There were no significant differences in CSA (35.2 ± 4.6° vs 36.1 ± 4.8°, $P = .173$), mean occupation ratio of the supraspinatus muscle (38.7 ± 9.7 vs 46.6 ± 8.6, $P = .094$), or proximal muscle fat infiltration (grade 0:1:2:3:4, 8:12:9:0:2 vs 6:4:3:4:2, $P = .061$). Moreover, no significant difference was noted in the tear size, extent of retraction, and supraspinatus fatty infiltration ($P = .132$, $P = .168$, and $P = .061$, respectively).

Intraoperative Factors

The number of patients with total subscapularis tendon tear (Lafosse type IV and V) was significantly larger in the retear group than the healed group (stable:partial:total, 6:18:7 vs 4:2:13, $P = .045$). The retear group required more tension (41.6 ± 6.9 N) to mobilize the thoroughly released rotator cuff tendon to reach the articular margin of the footprint than the healed group (31.9 ± 8.3 N), a statistically significant difference ($P \leq .001$) (Table 3).

There was no statistical difference between the 2 groups in terms of biceps tendon lesions requiring tenotomy or tenodesis (54.8% vs 57.9%, $P = .649$). The tear size (41.2 ± 11.0 mm vs 46.5 ± 11.6 mm) and extent of retraction (41.0 ± 9.8 mm vs 46.1 ± 10.3 mm) were greater in the retear group, but not significantly ($P = .113$ and $P = .086$, respectively).

Significant Factors and Cutoff Value of Retear

Based on the MRIs performed ~1 year after surgery, the retear rate was 38% (19 cases). Tension ($P < .001$), AHI ($P = .013$), and subscapularis tear ($P = .045$) were found to be significant factors in the univariate analysis. However, when sex, age, tear size, extent of retraction, supraspinatus atrophy, supraspinatus fatty infiltration, and infraspinatus fatty infiltration were included in the multivariate logistic regression analysis, tension ($P < .001$) and AHI ($P = .013$) were interpreted as important factors for the integrity of rotator cuff repair (Table 4). Receiver operating characteristic analysis was performed to suggest cutoff values of various factors including these 3 statistically significant factors (Table 5). The cutoff value for tension was 35 N, with sensitivity and specificity of 84.2% and 67.7%, respectively (area under the curve [AUC] = 0.799, accuracy = 76.0%). The cutoff value for AHI was 6.6 mm, with sensitivity and specificity of 68.4% and 61.3%, respectively (AUC = 0.690, accuracy = 69.1%).

Discussion

In the current study, repair tension was interpreted as the most important factor for the integrity of rotator cuff repair. Furthermore, the cutoff value for tension was 35 N. This means that a chronic large to massive rotator cuff repair with a tension >35 N had a significantly higher retear rate than that with a tension <35 N. Additionally, AHI <6.6 mm may be considered a predictor of retear of the contracted rotator cuff after repair.

Table 1. Demographics and Preoperative Variables

	Healed Group (n = 31)	Retear Group (n = 19)	95% CI	*P* Value
Age (yr)	64.4 ± 6.5	66.1 ± 6.1	−5.42 to 1.99	.352
Sex (male:female)	15:16	13:6		.242
Follow-up (mo)	22.6 (13 to 34)	23.4 (13 to 36)	−3.52 to 4.47	.458
Dominant arm	28	17		.584
Preoperative ROM (°)				
Flexion	168.8 ± 10.5	163.2 ± 19.1	−40.45 to 30.16	.529
Abduction	172.6 ± 7.4	165.8 ± 27.9	−24.27 to 46.41	.203
Internal rotation	65.2 ± 9.17	75.8 ± 10.6	−16.28 to 9.01	.084
External rotation	83.7 ± 5.9	77.6 ± 9.9	−13.01 to 39.99	.092
Preoperative clinical assessment				
VAS	4.1 ± 2.2	3.3 ± 2.3	−1.11 to 1.15	.207
ASES	34.4 ± 16.1	27.6 ± 21.3	−12.30 to 8.39	.204
DASH	40.16 ± 17.1	37.1 ± 14.3	−10.63 to 9.89	.837
Constant–Murley	32.9 ± 22.8	26.8 ± 17.8	−12.46 to 10.79	.327
Acromio-humeral interval (mm)	7.4 ± 2.1	5.7 ± 2.5	0.37 to 2.98	.013
Critical shoulder angle (°)	35.2 ± 4.6	36.1 ± 4.8	−9.25 to 1.52	.173
Tear size by MRI (mm)	37.6 ± 10.7	42.3 ± 11.5	−11.87 to 1.30	.132
Extent of retraction by MRI (mm)	36.3 ± 8.7	42.1 ± 11.3	−9.25 to 1.52	.168
Supraspinatus atrophy (%)	46.6 ± 8.6	38.7 ± 9.7	−1.46 to 0.15	.094
Supraspinatus fatty infiltration (grade 0:1:2:3:4)	2:6:19:2:2	0:4:13:2:0		.725
Infraspinatus fatty infiltration (grade 0:1:2:3:4)	8:12:9:0:2	6:4:3:4:2		.061

NOTE. Values represent mean ± standard deviation, n, or mean (range).

Abbreviations: ASES, American Shoulder and Elbow Surgeons; CI, confidence interval; DASH, Disabilities of the Arm, Shoulder and Hand; MRI, magnetic resonance imaging; ROM, range of motion; VAS, Visual Analog Scale.

Several factors influence rotator cuff healing after repair.[17] Among them is acceptable reducibility of the torn tendon. Although failure does not mean structural discontinuity, many studies suggest that intact repairs can be associated with significant better clinical outcomes compared with retears.[17-20] One reason for failure of rotator cuff repair in large to massive RCTs could be inadequate tension of the tendon.[1,10] Hersche and Gerber[7] reported that passive tension is increased in chronic torn tendon. In this situation, active tension generation by the supraspinatus would be compromised. Davidson and Rivenburgh[1] studied the effect of rotator cuff repair tension on clinical outcomes. They emphasized that repairs with high tension >8 lb (35.59 N) are not recommended. Furthermore, they showed that lower-tension repairs are associated with increased pain relief.[1] However, a postoperative imaging study about repair site healing was not conducted. Kim et al.[10] analyzed the relationship between the actual intraoperative tension of the torn rotator cuff and healing at the repair site. A braided nonabsorbable suture strand loop was loaded at the hook of the tensiometer. They showed a significant inverse correlation between healing at the repair site and repair tension. This finding suggested that healing at the repair site is less likely with high-tension repairs.[10] However, they could determine neither the relationship between repair tension and retear in repaired chronically contracted large to massive RCTs nor the absolute value of tension that the chronically contracted rotator cuff tendon can endure.

Various studies have dealt with the adverse effect of tendon tension according to anchor type, suture configuration, repair technique, etc.[5,17,21] However, few studies have evaluated the objective value of the actual tension of the contracted rotator cuff tendon. Therefore, the strength of this study is that we present the cutoff value of the tension for the predictive factors. Unlike other studies that used suture strands such as Ethibond, we used arthroscopic graspers for measuring the tension of the rotator cuff after releasing the contracted structures, because a tendon grasper was easy to manipulate for the traction of the tendon. Additionally, the contact area of the tendon was relatively wider and more stable than suture strands. Simultaneously, it could be used to assess the direction of maximum mobility of the tear in an attempt to determine whether relatively tension-free repair to bone could be achieved.

To avoid the harmful effect of tension on the torn rotator cuff tendon and repair site, various surgical techniques have been introduced. The interval slide by Bigliani et al.[22] could reduce tendon tension; however, it does not allow for sufficient mobilization, typically provides an additional 1 to 2 cm of excursion, and can cause devascularization of the supraspinatus.[10] Margin convergence, suggested by Burkhart et al.,[23] is a

Table 2. Patient-Reported Outcomes: Response to Treatment

	Healed Group (n = 31)				Retear Group (n = 19)				Intergroup comparison
	Baseline	1 year	Change	*P* Value	Baseline	1 year	Change	*P* value	*P* Value
VAS	5.8 (5.1 to 6.5)	1.7 (1.2 to 2.2)	4.1 (3.3 to 4.9)	<.001	5.8 (4.9 to 6.7)	2.5 (1.9 to 3.2)	3.3 (2.1 to 4.4)	<.001	.976
ASES	49.7 (42.3 to 57.9)	84.2 (80.2 to 88.2)	34.5 (27.6 to 41.3)	<.001	51.7 (43.5 to 59.8)	79.3 (74.2 to 84.4)	27.6 (16.7 to 38.5)	<.001	.943
DASH	51.6 (42.3 to 57.9)	11.4 (8.0 to 14.8)	40.2 (33.0 to 47.3)	<.001	52.0 (43.9 to 60.0)	14.9 (10.5 to 19.2)	37.1 (27.7 to 46.6)	<.001	.706
Constant−Murley	48.9 (41.7 to 56.1)	81.7 (79.6 to 83.9)	32.8 (24.8 to 41.0)	<.001	49.7 (40.6 to 58.9)	76.5 (73.8 to 79.3)	26.8 (18.5 to 35.1)	<.001	.886

NOTE. Values are presented as mean (95% confidence interval).
Abbreviations: ASES, American Shoulder and Elbow Surgeons; DASH, Disabilities of the Arm, Shoulder and Hand; VAS, Visual Analog Scale.

Table 3. Intraoperative Factors

	Healed Group (n = 31)	Retear Group (n = 19)	95% Confidence Interval	*P* Value
Subscapularis tear (stable:partial:total)	6:18:7	4:2:13		.045
Biceps tenotomy/tenodesis	17 (54.8)	11 (57.9)	−2.04 to 5.21	.649
Tear size (mm)	41.2 ± 11.0	46.5 ± 11.6	−1.46 to 0.15	.113
Extent of retraction (mm)	41.0 ± 9.8	46.1 ± 10.3	−0.78 to 0.82	.086
Tension (N)	31.9 ± 8.3 (range 20 to 50)	41.6 ± 6.9 (range 30 to 50)	−14.22 to −5.06	<.001

NOTE. Values in data cells represent n (%) or mean ± standard deviation unless noted otherwise.
CI, confidence interval.

method that reduces strain and increases fixation strength. It can decrease pain by reducing mechanoreceptor stimulation and facilitate biological healing. However, in chronic poorly degenerated rotator cuff tendon, there may be limitations. Chronically contracted rotator cuff tendons have low compliance and poor tissue quality, making tension-free repair difficult. Medialization can be considered in situations in which the rotator cuff cannot be adequately mobilized and anatomic bone-to-tendon repair would be difficult because of excessive tension.[24] In addition to the above techniques, biceps augmentation and partial repair can be options in repairing chronically retracted large to massive RCTs.[6]

As of yet, there are no clear rationales for comparing the indications and clinical results of these attempts to reduce tension. The current study suggests tension to reach the medial row of the footprint as a basis for comparing the techniques. We excluded partial repair in this study because it is a low-morbidity salvage option as nonanatomic repair. The integrity of partially repaired rotator cuff tendon on MRI cannot be compared with that of our anatomically repaired one. Furthermore, there are no proper standards to measure the tension, because the rotator cuff tendon is not pulled to the medial row of the footprint during the measurement of initial tension before meticulous release. We excluded this because there were no meaningful correlations between initial tension and retear. For a similar reason, margin convergence was not performed in this study. This technique is not anatomic repair but a kind of salvage procedure, so the results from margin convergence could not be compared with ours.

This study found AHI to be a predictor of the retear of contracted rotator cuff and suggested a cutoff value. Normally, AHI is ~7 to 14 mm, and large to massive RCTs can reduce this interval. AHI in the healed group is the only preoperative factor that was significantly greater than that in the retear group in our study, and the cutoff value of AHI was 6.6 mm. A recent systematic review reported that the risk factors for retear after rotator cuff repair included AHI. Kim et al.[25] reported that AHI was a significant prognostic factor, and they suggested a cutoff value of 7.1 mm. Shin et al.[26] studied predictive factors of retear in patients with repaired RCTs. In their study, independent prognostic factors of retear were degree of tendon retraction and AHI.

In this study, we could not observe differences in the degree of tendon retraction between the 2 groups. This may be because of the relatively similar values among the study participants as well as the relatively small number of patients enrolled in this study. Despite the controversy as to the effect of AHI, several studies have similar results to our study; however, few studies have presented a cutoff value. The cutoff may help surgeons predict the results of rotator cuff repair in large to massive RCTs. Studies on these points are still in progress at our hospital.

Table 4. Results of Multiple Logistic Regression Analysis of Retear as a Function of Significant Factors Using a Stepwise Forward Conditional Method

Factor	Odds Ratio	95% Confidence Interval	*P* Value
Tension	13.585	5.13 to 58.15	<.001
Acromiohumeral distance	6.104	1.13 to 33.10	.013
Infraspinatus fatty infiltration	8.919	1.07 to 74.61	.063
Extent of retraction, intraoperative	3.011	0.58 to 15.63	.083
Occupation ratio of supraspinatus muscle	4.858	0.72 to 32.41	.088
Tear size, intraoperative	2.572	0.43 to 15.35	.109

Table 5. Cutoff Value and AUC of the Receiver Operating Characteristic Analysis

Factor	Cutoff Value	AUC
Tension (N)	35	.799
Acromiohumeral distance (mm)	6.6	.690
Occupation ratio of supraspinatus muscle (%)	42	.641
Tear size, intraoperative (mm)	39.3	.638
Extent of retraction, intraoperative (mm)	39.3	.607
Tear size, MRI (mm)	36.5	.578
Infraspinatus fatty infiltration (grade)	1.5	.559
Extent of retraction, MRI (mm)	35.9	.535

Abbreviations: AUC, area under the curve; MRI, magnetic resonance imaging.

A number of studies reported that the risk factors for postoperative retear in large to massive RCTs after repair included age, tear size, and fatty infiltration.[17] In the current study, there were no significant differences in clinical outcomes or in several intraoperative factors. We believe that the follow-up period was not sufficiently long to fully evaluate several factors. Also, a relatively small patient pool could have masked the results. Therefore, a large-scale study is needed.

There were significant differences between the retear group and the healed group in the subscapularis tendon tear. Even isolated subscapularis repairs can cause significant morbidity. Repair can facilitate posterosuperior rotator cuff repair and decrease tension on adjacent supraspinatus repairs. If a subscapularis tendon tear is left unrepaired, it can cause additional strains and stresses that predispose toward failure of the rotator cuff repair. Although we repaired all of the subscapularis tendon, involvement of this tendon may affect the results.

In our study, repairs underwent dual-row fixation with medial knots, yet the tears were mobilized only to the articular margin at the time of tension assessment. In doing so, the potentially adverse effect of increased tension generated by pulling the tendon laterally may have been underestimated. Nevertheless, we continuously checked the overall rotator cuff tendon through the arthroscope, and tears were not pulled or displaced further by the placement of both medial and lateral anchors.

Limitations

This study has several limitations. First, it has a retrospective cohort, short-term follow-up, and relatively small sample size, especially in the retear group. Second, tension might have changed depending on the anesthesia method. In this study, general anesthesia was administered to all patients without an additional nerve block such as interscalene block; this may have affected the results. Third, we selected a similar rehabilitation protocol of abduction pillow for all patients regardless of the tear size. Although numerous rehabilitation protocols have been proposed, the immobilization period after surgery remains controversial.[27] Moreover, we cannot ensure patients' compliance to the postoperative rehabilitation protocol. Finally, if a mechanical digitized tensiometer was used, it might have yielded more accurate data. We tried to measure accurate tension, but it would be different from the actual tension because of unequal traction direction according to the individual patient's patterns of RCT. Additionally, the tensiometer used in this study has not been validated. We could not test the reliability because of limited operation time to repeat the measurement. However, if a surgeon is skilled in managing the tensiometer, it could be a valuable intraoperative decision-making device for chronically contracted large to massive RCTs.

Conclusions

The integrity of a large to massive rotator cuff repair is strongly related to the tension to reach the articular margin of the footprint and AHI. We found that the possibility of retear increases when a tension $\geq$35 N is required. AHI <6.6 mm may also be considered a predictor of retear.

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