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Functional Improvements by Controlled Suture Tension in Arthroscopic Rotator Cuff Repair

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Background: Although a certain degree of tension in bridging sutures is required for proper tendon healing following suture-bridge rotator cuff repair, excessive suture tension may be detrimental to tendon healing. This study aimed to investigate the effects of bridging suture tension on clinical outcomes and tendon healing. We hypothesized that fixed, low tension of the bridging sutures would improve the tendon healing rate and clinical outcomes compared with maximum manual tensioning.

Methods: A group of 39 patients with a rotator cuff tear were treated with arthroscopic suture-bridge rotator cuff repair, in which the bridging sutures were uniformly tensioned to 20 N (group A). A separate group of 37 patients was treated with the same suture construct, but the sutures were tensioned by maximum manual pulling (mean tension, 36.1 N; group B). The visual analog scale (VAS) score for pain, active anterior elevation, external and internal rotation, and Constant score were compared between the groups preoperatively and at 1, 3, and 6 months and 1 and 2 years postoperatively. Anatomical healing was evaluated using magnetic resonance imaging (MRI) at 1 year after surgery.

Results: At 6 months postoperatively, all clinical values had improved in both groups. The Constant score ($p < 0.001$), VAS pain score ($p < 0.001$), and anterior elevation ($p = 0.004$) were significantly better in group A than in group B. Two years postoperatively, there was no significant difference between groups A and B in the Constant score ($p = 0.847$), VAS pain score ($p = 0.991$), and anterior elevation ($p = 0.855$). Group A demonstrated a significantly lower retear rate (3 of 39, 7.7%) than group B (9 of 37, 24.3%) ($p = 0.0467$).

Conclusions: Double-row suture-bridge repairs with fixed, low tension led to superior clinical outcomes at 6 months and a superior tendon healing rate at 1 year compared with repairs with higher suture tension. However, the clinical outcomes did not differ significantly at 2 years between the 2 tensioning methods.

Level of Evidence: Therapeutic Level III. See Instructions for Authors for a complete description of levels of evidence.

Rotator cuff (RC) tears impair shoulder function and overall activity levels of affected individuals[1]. The double-row suture-bridge RC repair technique attempts to ensure successful restoration of the tendon insertion by achieving firm initial fixation of the repaired tendon over the footprint[2-4]. The ideal tension of bridging sutures in this technique has long been debated.

Some believe that increased tension of the bridging sutures leads to a larger contact area and higher contact pressure between the repaired tendon and footprint. Consequently, increased repair tension results in an increased ultimate failure load[5-8]. However, others believe that excessive suture tension could damage the RC tissue and thus, RC tears should be repaired using a lesser amount of suture tension[9-13].

The purpose of the present study was to investigate the effect of bridging suture tension on clinical outcomes and tendon healing following double-row suture-bridge RC repair. We hypothesized that fixed, low tension of the bridging sutures would improve the tendon healing rate and clinical outcomes compared with the use of higher suture tension through maximum manual pulling. To this end, we performed a retrospective clinical cohort study comparing 2 groups of patients who underwent RC repair: 1 with a fixed, low tension of the bridging sutures (20 N), and the other with a maximum manual tension (mean, 36.1 N).

Disclosure: No external funding was received for this work. The **Disclosure of Potential Conflicts of Interest** form is provided with the online version of the article (http://links.lww.com/JBJSOA/A737).

Materials and Methods

Study Patients

A total of 256 consecutive patients underwent arthroscopic RC repair at our institute (Fig. 1). Patients who met the following inclusion criteria were retrospectively included: patients with medium- to large-sized (≥1 to <5 cm) tears of the supraspinatus and infraspinatus tendons diagnosed by preoperative magnetic resonance imaging (MRI) and followed for at least 2 years, with repair integrity evaluated by MRI at 1 year.

The exclusion criteria were as follows: RC tear with contracture requiring capsular release at the time of repair (n = 56), traumatic isolated subscapularis tear (n = 7), small-sized tear (<1 cm) (n = 34), irreparable massive tear (n = 18), and refusal to participate (n = 18) (Fig. 1). Flap-shaped tears (n = 8) and L- or reverse L-shaped tears (n = 26) were also excluded because they often require different anchor and suture configurations. In the present study, the same number of anchors (2 medial and 2 lateral anchors) and suture configurations (8 bridging sutures and 2 medial mattress sutures) were used in both study groups. L- or reverse L-shaped tears were defined as follows[9]: the lateral-medial retraction of the tear was larger than the anterior-posterior defect, with L-shaped tears occurring at the anterior-most part of the supraspinatus tendon with no intact anterior edge of the tendon remaining, and reverse L-shaped tears occurring at the posterior-most part of the supraspinatus with no intact posterior edge of the tendon remaining. An irreparable massive tear was defined as follows: the anteroposterior dimension of the tear is ≥5 cm or the Goutallier stage of both the supraspinatus and infraspinatus tendons is at least grade 3[10].

A total of 89 patients met the inclusion criteria, and all were treated with a double-row suture-bridge construct using 2 medial and 2 lateral anchors (HEALIX ADVANCE self-punching [HASP] anchor; DePuy Mitek). As the HASP anchors were preloaded with sliding sutures, it was not possible to measure the tension of each suture. To enable measurement of suture tension, HASP anchors were loaded with 3 sutures (number-2 braided DYNACORD [Mitek] in group A, and number-2 braided ORTHOCORD [Mitek] in group B). Therefore, HASP anchors loaded with 3 locked sutures were used as medial anchors, whereas nonloaded anchors were used as lateral anchors.

Of the 89 patients, 45 were enrolled consecutively from February 2021 to February 2022, and their RC tears were repaired using a fixed bridging suture tension of 20 N (group A). A separate group of 44 patients were consecutively enrolled from February 2020 to February 2021 and treated with the same suture-bridge construct; however, the bridging sutures were tensioned using maximum manual pulling (group B). The actual resultant tension achieved by maximum manual pulling ranged from 31 to 39 N (mean and standard deviation, 36.1 ± 1.73 N).

Six patients in group A and 7 in group B were lost to follow-up, leaving 39 and 37 patients in each group, respectively, for complete data analysis.

The institutional review board approved the study design and data collection protocol (R2020-145).

Surgical Procedures

All of the arthroscopic procedures were performed by a single senior surgeon. Two HASP anchors loaded with 3 DYNACORD sutures (group A) or 3 ORTHOCORD sutures (group B) were inserted lateral to the cartilage margin. Three pairs of suture limbs from the anterior medial anchor were passed through the RC tendon (A1, A2, and A3 in Fig. 2-A). Another 3 pairs from the posterior medial anchor were passed through the RC tendon (P1, P2, and P3 in Fig. 2-B).

Suture limbs from A1, A2, P1, and P2 were retrieved laterally to create a suture bridge using an anterior lateral

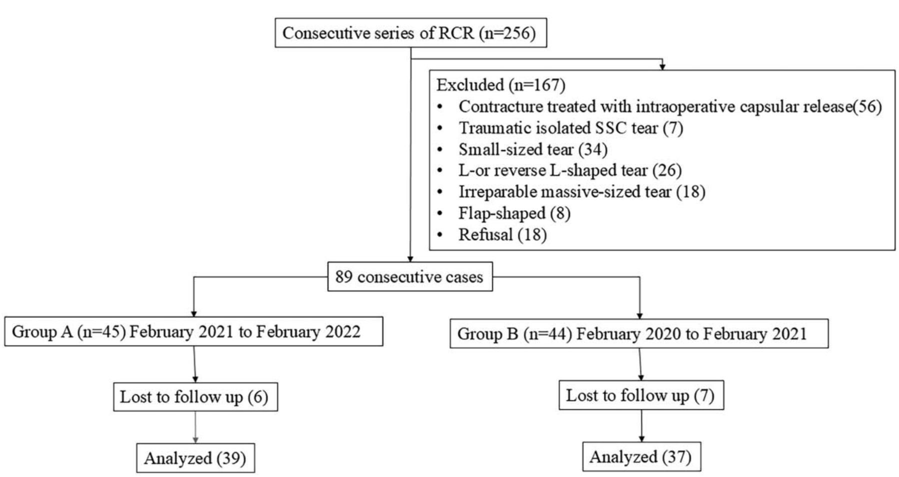

Fig. 1

Flow diagram of the study. Of the 256 consecutive patients who underwent rotator cuff repair (RCR), 167 were excluded, leaving 89 patients. In 45 patients, a 20.0-N tension was consistently applied to each suture (group A). Forty-four patients underwent RCR with a mean manual maximum tension of 36.1 ± 1.73 N (group B). SSC = subscapularis.

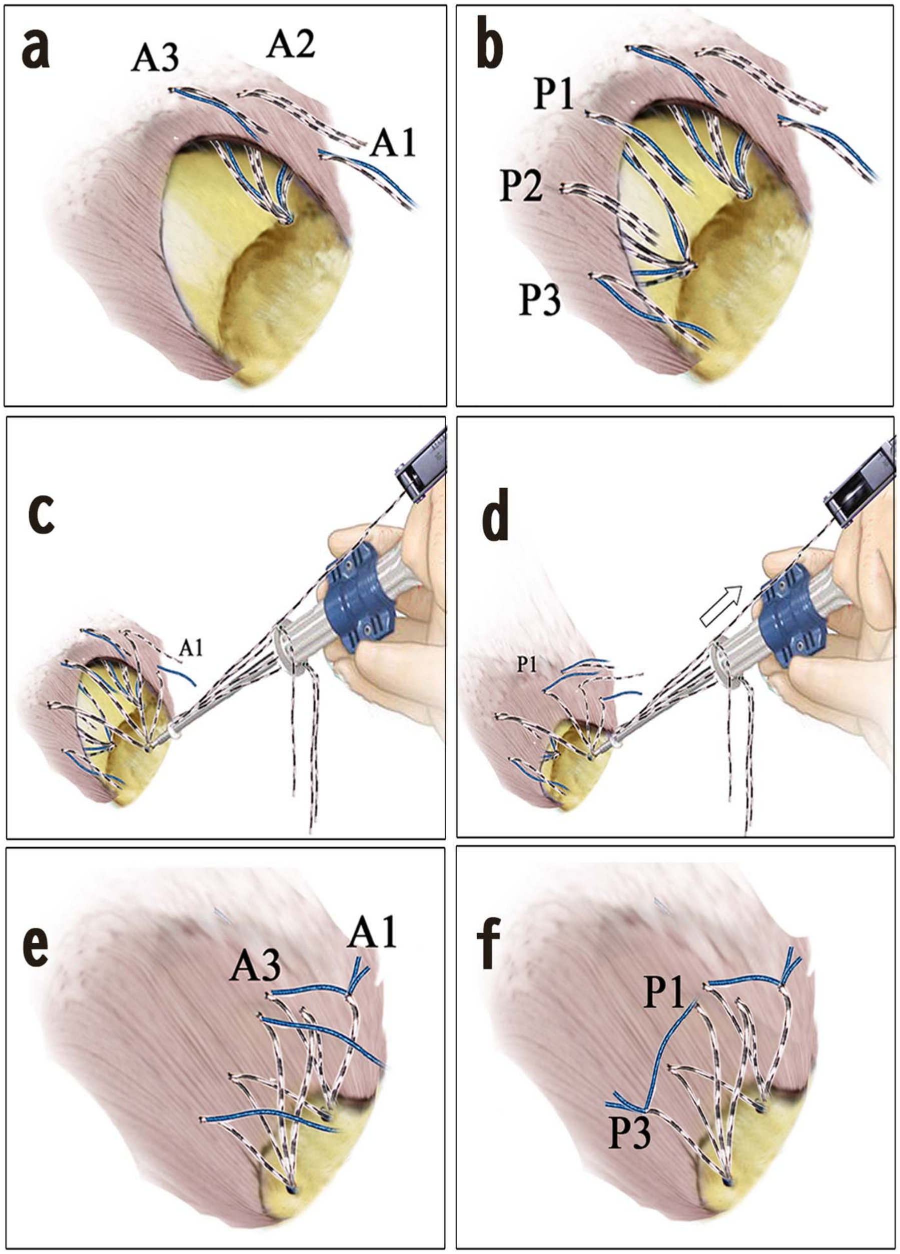

Fig. 2

Figs. 2-A through 2-F The suture-bridge repair technique using a tensiometer with either controlled tension (20 N) or manual maximum suture tension secured with a lateral anchor. **Fig. 2-A** Three pairs of sutures from the anterior medial anchor were passed through the rotator cuff (RC) tendon at points A1 to A3. **Fig. 2-B** Three pairs of sutures from the posterior medial anchor were passed through the RC tendon at points P1 to P3. **Fig. 2-C** Four suture limbs, A1, A2, P1, and P2, were brought laterally using an anterior lateral anchor. **Fig. 2-D** Either 20 N or manual maximum tension (arrow) was applied to each suture. **Fig. 2-E** Medial-row sutures from points A1 and A3 were tied. **Fig. 2-F** Medial-row sutures from points P1 and P3 were tied.

anchor (Figs. 2-C and 2-D). Suture limbs from A2, A3, P2, and P3 were retrieved laterally to create a suture bridge using a posterior lateral anchor. The remaining suture limbs from A1 and A3 were tied over the tendon, as were those from P1 and P3 (Figs. 2-E and 2-F).

Each pair of the bridging sutures was individually pulled with either fixed, low tension (controlled tension of 20 N) in group A or maximum manual tension (mean, 36.1 ± 1.73 N) in group B using a tensiometer (Figs. 3-A and 3-B). When the tensiometer indicated the desired tension (Fig. 3-C), sutures were wound around the corral (Figs. 3-D and 3-E). This maneuver locked the bridging sutures while maintaining the desired tension (Figs. 3-F, 4-A, 4-B, and 4-C; Video 1). The lateral anchor was advanced into the bone to its first thread, and the sutures were released from the corral. The entire lateral anchor was inserted to its upper end, while maintaining the desired tension. All tears in the enrolled patients were repaired fully back to the footprint.

In both groups, an abduction brace was used to immobilize the shoulder for 5 weeks postoperatively. After the patient was weaned from the brace, active assisted range-of-motion exercises were performed according to a preestablished protocol.

Clinical Assessments

Patients were assessed preoperatively and at 1, 3, and 6 months and 1 and 2 years postoperatively by a research assistant who was blinded to the group assignment.

Active range of motion in anterior elevation and external rotation was measured using a handheld goniometer with the patient in the supine position with the arm at the side. Internal

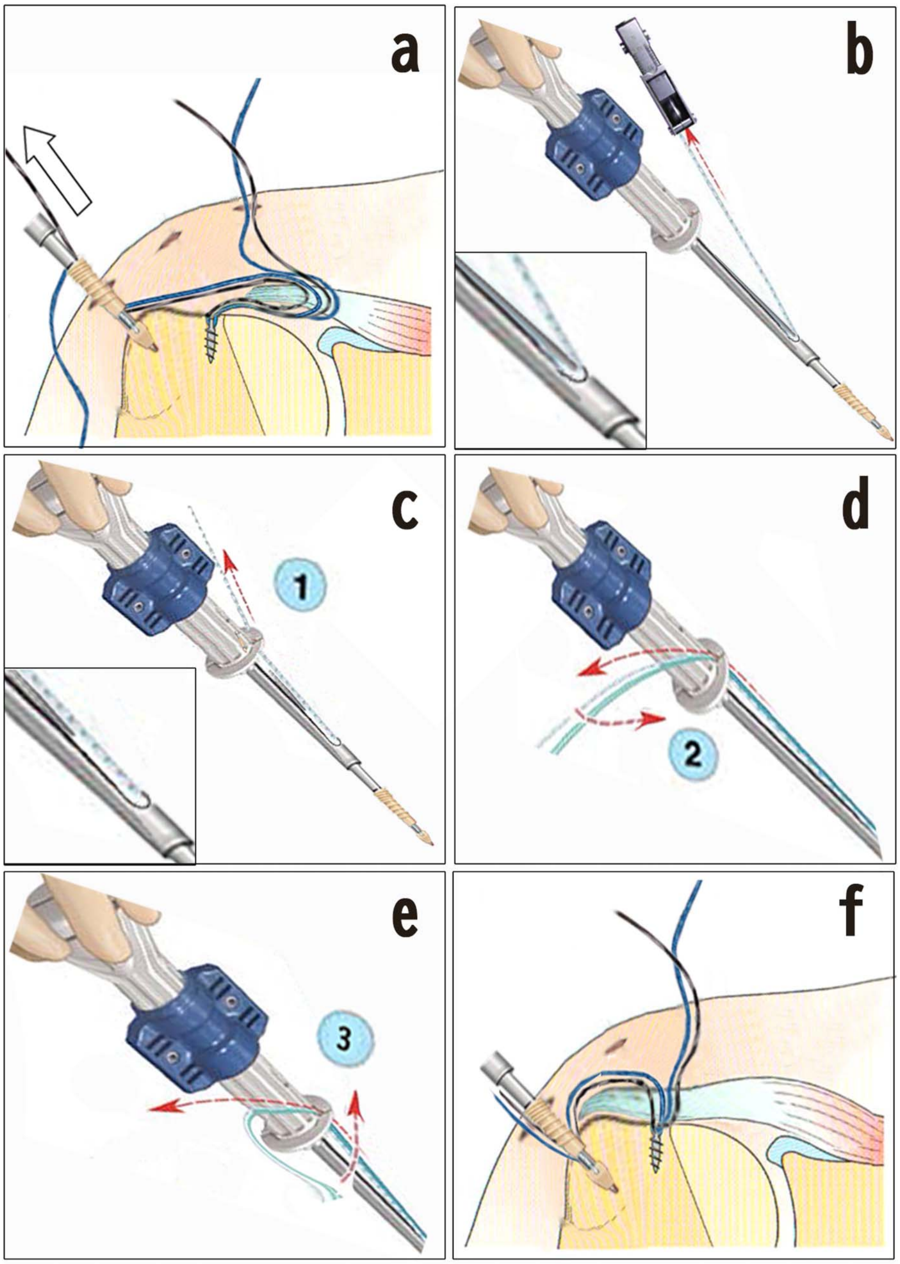

Fig. 3

Figs. 3-A through 3-F Application of tension secured with the lateral anchor. **Fig. 3-A** A passed suture was pulled through the anchor (arrow). **Fig. 3-B** Applied controlled tension (20 N) or manual maximum tension was measured. The inset shows the angle at which the suture was pulled. **Fig. 3-C** The suture limb was docked in the upper slit of the corral (1). The inset shows that the suture is almost parallel to the shaft. **Fig. 3-D** After removal of the tensiometer, the suture was docked in the lower slit (2). **Fig. 3-E** The suture was docked in the upper slit, thereby locking the suture at the desired tension (3). **Fig. 3-F** The lateral anchor was inserted up to the first thread. After release of the sutures from the corral, the anchor was inserted to its upper end.

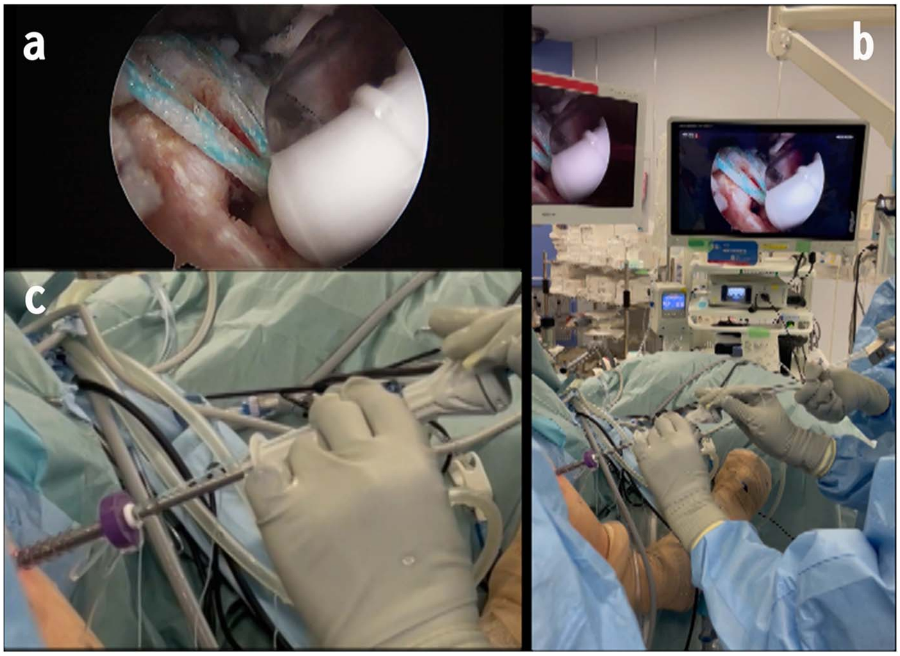

Fig. 4

Figs 4-A, 4-B, and 4-C Intraoperative views of tension application. **Fig. 4-A** Sutures were pulled through the lateral anchor, the tip of which was in the immediate vicinity of the bone hole. **Fig. 4-B** Application of 20 N of tension by an assistant using a tensiometer. **Fig. 4-C** The suture was docked in the upper slit of the corral.

rotation was measured based on the vertebral level that the patient could reach using the thumb. The vertebrae were numbered serially as follows: 1 to 12 for the first to twelfth thoracic vertebrae, 13 to 17 for the first to fifth lumbar vertebrae, and 18 for any level below the sacral region. A visual analog scale (VAS) for pain, which was scored from 0 to 10 (0 = no pain; 10 = worst), was completed by the patients at each follow-up period. The Constant score was also assessed.

All patients (n = 76) underwent MRI for the evaluation of RC healing at 1 year postoperatively. Qualified radiologists with >10 years of experience interpreted the MRI scans and determined the repair integrity. According to the Sugaya classification of MRI findings, type IV or V was regarded as failure of the RC repair[11].

Statistical Analysis

The sample size was determined according to methods described by Tudisco et al.[12], assuming a 50% difference in RC healing rates between the groups as the minimal clinically important difference (MCID) and a 15% standard deviation within the groups ($p < 0.05$). It was determined that 31 patients per group would provide sufficient statistical power (80%) to detect a significant difference in healing rates between the 2 groups.

Patient variables such as age, sex, and tear size were analyzed, and mean values were obtained. Continuous data are presented as the mean and standard deviation, and categorical data are presented as the number of patients. Continuous data were analyzed using the independent t test. Categorical data, including differences in healing rates, were analyzed using the chi-square test. Significance was set at $p < 0.05$.

Results

Preoperative and Intraoperative Assessments

Preoperatively, the mean patient age was 64.5 ± 7.4 years in group A and 63.3 ± 5.1 years in group B (p = 0.395). The patients had a mean follow-up of 27.0 ± 2.1 months in group A and 26.6 ± 2.0 months in group B (p = 0.382) (Table I). There were no significant differences between the 2 groups in fatty infiltration of the RC, the presence of teres minor atrophy, age, sex, hand dominance, or tear size (Table I).

Intraoperatively, the mean anteroposterior size of the tear was 15.5 ± 4.24 mm (range, 10.0 to 41.0 mm) in group A and 16.0 ± 4.90 mm in group B (range, 11.0 to 42.0 mm) (p = 0.77). The mean retraction was 18.4 ± 7.2 mm (range, 10.0 to 41.0 mm) in group A and 19.5 ± 9.2 mm (range, 10.0 to 42.0 mm) in group B (p = 0.565). The mean suture tension with a lateral anchor was 20.0 N in group A and 36.1 ± 1.73 N in group B ($p < 0.001$) (Table I).

In the preoperative clinical assessment, the mean preoperative VAS pain score was 7.46 ± 1.71 points in group A and 7.37 ± 1.64 points in group B (p = 0.825). Preoperatively, there were no significant differences between the 2 groups in the Constant score, anterior elevation, external rotation, or internal rotation (Table I).

Postoperative Assessments

At 6 months postoperatively, all clinical parameters had improved (Table II). Moreover, the Constant score ($p < 0.001$), VAS pain score ($p < 0.001$), and anterior elevation (p = 0.004) were significantly higher in group A than in group B. External rotation (p = 0.648) and internal rotation (p = 0.839) did not differ significantly between the groups.

TABLE I Preoperative Characteristics and Intraoperative Measurements

	Suture Tension Group		
	A	B	
	Controlled Tension (N = 39)	Manual Max. Tension (N = 37)	P Value
Age* *(yr)*	64.5 ± 7.4	63.3 ± 5.1	0.395
Follow-up* *(mo)*	27.0 ± 2.1	26.6 ± 2.0	0.382
Sex *(no.)*			0.651
Male	21	18	
Female	18	19	
Affected side *(no.)*			0.567
Dominant	25	26	
Nondominant	14	11	
Fatty infiltration grade† *(no.)*			
Supraspinatus			0.451
<2	17	13	
≥2	22	24	
Infraspinatus			0.983
<2	33	30	
≥2	6	7	
Subscapularis			0.587
<2	35	36	
≥2	4	1	
Teres minor atrophy *(no.)*			0.573
Yes	2	1	
No	37	36	
Preop. Constant score*	43.1 ± 5.9	41.7 ± 4.53	0.267
Preop. pain VAS*	7.46 ± 1.71	7.37 ± 1.64	0.825
Preop. range of motion*			
Anterior elevation *(deg)*	115.0 ± 10.7	112.0 ± 10.2	0.228
External rotation *(deg)*	43.3 ± 7.35	45.0 ± 7.80	0.340
Internal rotation‡	6.59 ± 2.49	6.42 ± 2.12	0.761
Size of rotator cuff tear§ *(mm)*			
Anteroposterior dimension	15.5 ± 4.24 (10.0-41.0)	16.0 ± 4.9 (11.0-42.0)	0.77
Lateromedial dimension (retraction)	18.4 ± 7.2 (10.0-41.0)	19.5 ± 9.2 (10.0-42.0)	0.565
Tension applied to sutures§ *(N)*	20.0 ± 0.0	36.1 ± 1.73 (33-39)	<0.001

*The values are given as the mean and standard deviation. †Grade according to the system of Goutallier et al[10]. ‡Measurement based on the vertebral level that the patient was able to reach with the thumb, and numbered serially as follows: 1 to 12 for the first to twelfth thoracic vertebrae, 13 to 17 for the first to fifth lumbar vertebrae, and 18 for any level below the sacral region. §The values are given as the mean and standard deviation, with the range in parentheses.

At 2 years postoperatively, all clinical values had further improved compared with the 6-month assessment (Table II). However, the Constant score (p = 0.847), VAS for pain (p = 0.991), anterior elevation (p = 0.855), external rotation (p = 0.112), and internal rotation (p = 0.758) did not differ significantly between the 2 groups (Table II).

Regarding tendon healing, we assessed tendon integrity using MRI (n = 76) 1 year after surgery. We found that group A had a significantly lower retear rate (3 [7.7%] of 39 patients) compared with group B (9 [24.3%] of 37 patients) (p = 0.0467). Patients with healing failure reported no specific episodes suggestive of rerupture. Patients with an intact repair did not demonstrate significantly superior clinical outcomes, including VAS pain scores and range of motion, compared with patients with a retear, 2 years after surgery (Table III). There were no complications, and no revision surgeries were required in either group during the 2-year follow-up period.

TABLE II Postoperative Findings

	Suture Tension Group		
	A	B	
	Controlled Tension (N = 39)	Manual Max. Tension (N = 37)	P Value
6-mo postop. clinical outcomes*			
Pain VAS *(cm)*	1.95 ± 0.55	2.77 ± 0.49	<0.001
Constant score	62.7 ± 6.84	56.0 ± 5.3	<0.001
Range of motion *(deg)*			
Anterior elevation	147.8 ± 10.6	141.5 ± 7.12	0.004
External rotation	49.9 ± 8.31	48.9 ± 9.69	0.648
Internal rotation†	7.58 ± 2.27	7.45 ± 2.31	0.839
2-yr postop. clinical outcomes*			
Pain VAS	0.63 ± 0.43	0.63 ± 0.45	0.991
Constant score	73.3 ± 4.38	73.0 ± 6.00	0.847
Range of motion			
Anterior elevation *(deg)*	161.4 ± 8.1	161.1 ± 5.04	0.855
External rotation *(deg)*	65.6 ± 10.6	56.9 ± 13.6	0.112
Internal rotation†	8.21 ± 1.36	8.11 ± 1.43	0.758
1-yr postop. MRI findings *(no.)*			0.0467
Retear	3	9	
Healed	36 (healing rate, 92.3%)	28 (healing rate, 75.7%)	

*The values are given as the mean and standard deviation. †Measurement based on the vertebral level that the patient was able to reach with the thumb, and numbered serially as follows: 1 to 12 for the first to twelfth thoracic vertebrae, 13 to 17 for the first to fifth lumbar vertebrae, and 18 for any level below the sacral region.

Discussion

Tendon healing following RC repair has been classically shown to depend on multiple factors, including age[13,14], fatty degeneration[10], tendon quality[14], and tear size[10,15]. Augmented bridging suture tension can increase contact pressure and contact area between the repaired tendon and footprint. Cadaveric and animal experiments have demonstrated enhanced RC healing by increasing bridging suture tension[5-8]. In clinical situations, however, tension overload may lead to a cut-out effect of the hard, braided suture materials in the tendon or a decreased intratendinous blood supply at the tendon repair site[10,16-19]. Because postoperative RC retear could be caused by high tension of the bridging sutures, it is important to identify the optimal degree of bridging suture tension for RC tendon healing.

In the present study, we found that fixed, low tension of the bridging sutures in double-row suture-bridge RC repairs resulted in significantly superior clinical outcomes at 6 months and a significantly lower retear rate at 1 year after surgery. This study also demonstrated that the VAS pain score was significantly higher following RC repair with manual maximum tension (2.77 ± 0.49, group B) compared with controlled suture tension (1.95 ± 0.55, group A) at 6 months postoperatively ($p < 0.001$) (Table II).

The imbalanced suture tension across the repair site with maximum manual tensioning may be much larger than expected. Surgeons often experience loosening of the first bridging suture during suture tensioning at the time of the second lateral-row anchor fixation. The tension of the initial bridging suture may drop to zero in a completely loosened suture. Therefore, there can be an enormous tension imbalance ranging from the completely

TABLE III 2-Year Postoperative Clinical Outcomes According to Tendon Healing

	Healed (N = 64)*	Retear (N = 12)*	P Value
VAS for pain	0.65 ± 0.46	0.63 ± 0.26	0.957
Constant score	73.3 ± 5.62	72.6 ± 2.67	0.532
Anterior elevation *(deg)*	161.3 ± 7.34	161.4 ± 2.75	0.926
External rotation *(deg)*	58.9 ± 13.1	60.8 ± 7.78	0.499
Internal rotation†	8.17 ± 1.38	8.15 ± 1.40	0.971

*The values are given as the mean and standard deviation. †Measurement based on the vertebral level that the patient was able to reach with the thumb, and numbered serially as follows: 1 to 12 for the first to twelfth thoracic vertebrae, 13 to 17 for the first to fifth lumbar vertebrae, and 18 for any level below the sacral region.

loosened suture (0.0 N) to the maximum suture tension of 39.0 N. This enormous tension imbalance may cause certain parts of the repair tissue to become susceptible to shear stress, which may hinder proper healing and/or cause discomfort or pain.

Areas with high tension or shear stress are at a higher risk for rerupture, thus negating the effectiveness of RC repair with the recommended maximum tension. Controlled suture tensioning resulted in a higher healing rate (92.3%, group A) than manual maximum tensioning (75.7%, group B; $p = 0.0467$) (Table II).

Although many studies have reported that functional improvement and pain relief were significantly better among patients with an anatomically healed RC repair at midterm follow-up compared with those with an unhealed repair[20-23], the 2-year postoperative clinical outcomes did not differ between the anatomically healed and unhealed repairs in the current study (Table III). Numerous studies, including that by Galatz et al.[24], demonstrated that an anatomically unhealed repair did not necessarily result in final functional impairment at or reoperation by the latest follow-up[3,25,26]. This is one of the unsolved questions concerning RC repair, and the relationship between anatomically unhealed repair and clinical failure after RC repair is still being debated[3,25-27].

The strength of the present study is that the same number of anchors (2 medial and 2 lateral anchors) and the same suture configuration (8 bridging sutures and 2 medial sutures) were used in both study groups. RC tears requiring either a smaller number of anchors (i.e., tear size of <1 cm), massive tears (i.e., size of ≥5 cm), or different suture configurations (i.e., for L-, reverse L-, or flap tears) were excluded.

The Constant score difference at 6 months postoperatively was 6.7, which is smaller than the known MCID of 10.4 for the Constant score in patients with RC repair[28]. Similarly, the difference in VAS pain score between the groups was 0.82, which is less than the known MCID of 2.4 for the VAS for pain in patients with RC repair[29]. Therefore, one should keep in mind that the improved clinical outcomes at 6 months did not reach clinically meaningful differences.

It is well known that suture tension does not remain static but changes from the time-zero value during repair and is likely influenced by tissue quality, cuff thickness, bone density, patient activities, and other factors[30]. To attenuate the influence of these factors, we used DYNACORD sutures for the controlled suture tension group. DYNACORD is a self-contractile suture that approximates the tensile force at 20 N. Manufacturer studies[31] found that, in a static biomechanical model in which the initial tensile force was set to 20 N, the average subsequent tensile force was 19.4 ± 1.73 N with DYNACORD and 8.3 ± 0.7 N with a non-self-contractile suture after a 2-week period ($p < 0.005$). In a cyclic model in which 50-N spike loads were added to the 20-N initial tensile force once per day over 1.5 weeks, the average subsequent tensile force was 19.3 N ± 0.5 N for DYNACORD and 5.5 N ± 1.8 N for the non-self-contractile suture ($p < 0.005$). When the initial tensile force is increased to 30 N, the average subsequent tensile force decreases to approximately 25 N, demonstrating that DYNACORD does not add excessive tensile force[31].

The limitation of this study was that the study groups were not randomized but rather sequential. However, it is unlikely that this resulted in assessment bias, as the research assistant and radiologist were blinded to the groups to which the patients belonged.

In summary, the suture-bridge technique of RC repair with fixed, low tension of the bridging sutures could lead to a superior tendon healing rate at 1 year compared with repairs with higher suture tension. However, clinical outcomes in the current study did not differ significantly at 2 years between the 2 tensioning methods. ■

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