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Am J Sports Med published online December 24, 2014
DOI: 10.1177/0363546514562175

The online version of this article can be found at:
http://ajs.sagepub.com/content/early/2014/12/24/0363546514562175

Published by:
SAGE
http://www.sagepublications.com

On behalf of:
American Orthopaedic Society for Sports Medicine
AOSSM

AJSM PreView, published on December 24, 2014 as doi:10.1177/0363546514562175

Modified Suture-Bridge Technique to Prevent a Marginal Dog-Ear Deformity Improves Structural Integrity After Rotator Cuff Repair

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Background: The arthroscopic suture-bridge technique has proved to provide biomechanically firm fixation of the torn rotator cuff to the tuberosity by increasing the footprint contact area and pressure. However, a marginal dog-ear deformity is encountered not infrequently when this technique is used, impeding full restoration of the torn cuff.

Purpose: To evaluate the structural and functional outcomes of the use of a modified suture-bridge technique to prevent a marginal dog-ear deformity compared with a conventional suture-bridge method in rotator cuff repair.

Study Design: Cohort study; Level of evidence 2.

Methods: A consecutive series of 71 patients aged 50 to 65 years who underwent arthroscopic rotator cuff repair for full-thickness medium-sized to massive tears was evaluated. Patients were divided into 2 groups according to repair technique: a conventional suture-bridge technique (34 patients; group A) versus a modified suture-bridge technique to prevent a marginal dog-ear deformity (37 patients; group B). Radiographic evaluations included postoperative cuff integrity using MRI. Functional evaluations included pre- and postoperative range of motion (ROM), pain visual analog scale (VAS), the University of California, Los Angeles (UCLA) shoulder rating scale, the Constant score, and the American Shoulder and Elbow Surgeons (ASES) score. All patients were followed up clinically at a minimum of 1 year.

Result: When the 2 surgical techniques were compared, postoperative structural integrity by Sugaya classification showed the distribution of types I:II:III:IV:V to be 4:20:2:4:4 in group A and 20:12:4:0:1 in group B. More subjects in group B had a favorable Sugaya type compared with group A ($P < .001$). The postoperative healed:retear rate was 26:8 in group A and 36:1 in group B, with a significantly lower retear rate in group B ($P = .011$). However, there were no significant differences in ROM and all functional outcome scores between the 2 groups postoperatively. When surgical techniques were compared across healed (n = 62) and retear (n = 9) groups, significantly fewer modified suture-bridge technique repairs were found in the retear group ($P = .03$). There were significant differences between healed and retear groups in functional outcome scores, with worse results in the retear group.

Conclusion: A modified suture-bridge technique to prevent a marginal dog-ear deformity provided better structural outcomes than a conventional suture-bridge technique for medium-sized to massive rotator cuff tears. This technique may ultimately provide better functional outcomes by decreasing the retear rate.

Keywords: rotator cuff; suture bridge; modified suture bridge; cuff healing; retear

Rotator cuff tear is a common shoulder lesion that causes pain and disability. Although arthroscopic rotator cuff repair has been proven to provide successful structural and clinical outcomes,[12,13] poor healing of the repair and retear of the repaired tendons are not infrequent, especially in large to massive rotator cuff tears. Such results are reported to be associated with poorer functional outcomes.[15,17-19] Several factors are reported to be responsible for retear, such as patient age, preoperative tear size, extent of retraction, degree of fatty infiltration of the cuff muscles, postoperative rehabilitation, method of surgical fixation, and strength of the initial fixation of the rotator

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The authors declared that they have no conflicts of interest in the authorship and publication of this contribution.

The American Journal of Sports Medicine, Vol. XX, No. X
DOI: 10.1177/0363546514562175

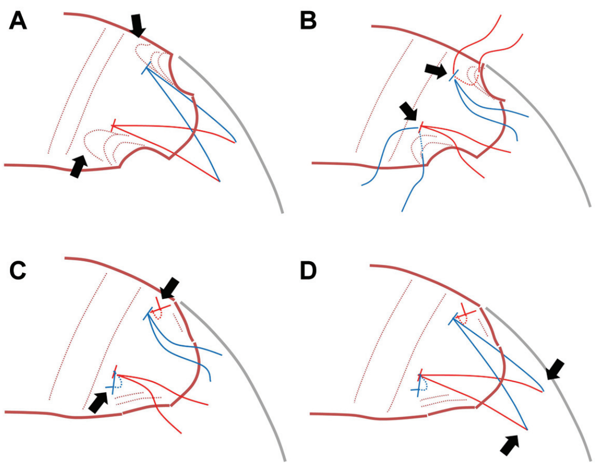

Figure 1. Schematic images of the 2 repair techniques. (A) Marginal dog-ear deformities (arrows) were seen after repair of the torn cuff with a conventional suture-bridge technique. In a modified suture-bridge technique, (B) the medial row was repaired (arrows) with sliding knots first, and (C) anterior and posterior marginal dog-ear deformities were repaired (arrows) with the other suture strand at each suture anchor; then (D) suture limbs from each of 2 medial anchors were bridged over the tendon and fixed laterally (arrows). A solid line indicates that the suture strand is above the cuff, whereas a dotted line indicates that the suture strand is underneath the cuff.

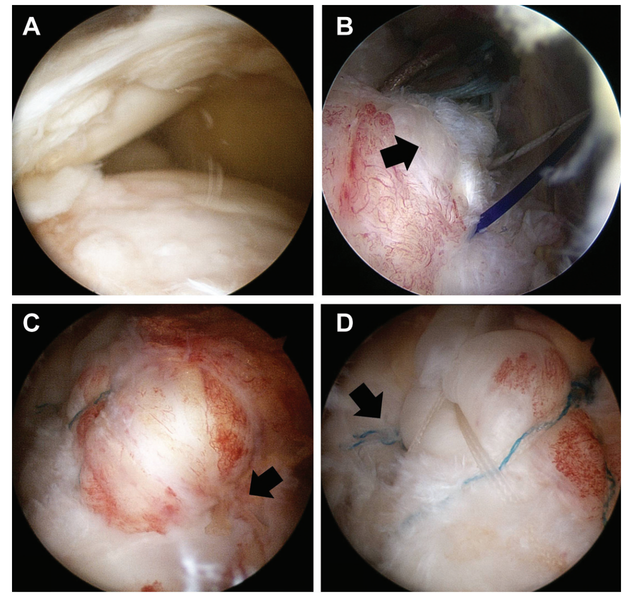

Figure 2. Arthroscopic images of rotator cuff tear and repair. (A) A massive rotator cuff was seen. (B) A large marginal dog-ear deformity was formed at the posterior aspect after repair with a conventional suture-bridge technique (arrow). In a modified suture-bridge technique, a marginal dog-ear deformity was repaired at (C) anterior and (D) posterior aspects of the bridging suture limbs (arrows).

cuff tendon to the footprint.[6,22,30,37] Among these factors, the method of surgical fixation is the only one that the surgeon can control. Several arthroscopic surgical techniques, repair structures, and suture configurations have been developed to increase footprint contact area and pressure, consequently restoring normal cuff tension and reducing retear rate.[5,7,16,28,31,32,34] Among them, suture-bridge repair (transosseous equivalent) has been reported to improve initial fixation strength and decrease gap formation and strain over the footprint, resulting in a significantly higher tendon healing rate compared with a single-row or double-row repair techniques.[14,21,25,32,34,35]

Repair with the suture-bridge technique, however, can lead to the existence of a dog-ear deformity at the anterior and posterior margins of the torn rotator cuff (Figures 1 and 2). A *marginal dog-ear deformity* is defined as a noncompression site at the tendon-to-bone interface that develops at anterior and posterior aspects of the bridging suture limbs after repair with the suture-bridge technique,[24] and its incidence has been reported to be as high as 47% in suture-bridge repair for full-thickness medium-sized to massive tears.[23] It is thought that this deformity may interfere with rotator cuff healing, delay restoration of normal muscle tension, and further provoke a progressive retear initiating at the gap between the unhealed rotator cuff and the tuberosity.[23,24]

The modified suture-bridge technique for marginal dog-ear deformities was first introduced in 2007.[24] In this technical note, the authors used an additional simple repair procedure for dog-ear deformities after rotator cuff repair with suture-bridge technique. When a dog-ear deformity was observed after fixation at the lateral row, the surgeon made a single stitch using 1 end of the suture strand from the lateral row via suture relay with polydioxanone (PDS) through the detached cuff and then seated a nonsliding knot on top of the suture, pressing this area of soft tissue firmly onto the bone.[24] Although the incidence of marginal dog-ear deformity is relatively high, and it may have negative effects on successful healing of the rotator cuff, the structural and functional outcomes of a modified suture-bridge technique for this deformity have never been fully documented.

The purpose of this study was to evaluate the structural and functional outcomes of a modified suture-bridge technique designed to prevent marginal dog-ear deformities in rotator cuff repair with a suture-bridge technique. We divided the study patients into 2 groups (group A, rotator cuff repair with a conventional suture-bridge technique; and group B, rotator cuff repair with a modified suture-bridge technique), and we aimed to compare the structural and functional outcomes between the groups. Our hypothesis was that the outcomes would be superior in group B.

MATERIALS AND METHODS

Patient Selection

This study was approved by the institutional review board at the authors' institution. Between January 2008 and

TABLE 1
Demographic Features of the Patients Involved

	Group A (n = 34)	Group B (n = 37)	*P* Value
Age, y, mean ± SD	57.0 ± 4.4	57.6 ± 4.6	.58
Sex, female:male, n	15:19	17:20	.93
Time to operation, mo, mean ± SD	6.8 ± 2.3	7.3 ± 2.6	.68
Involved side, dominant:nondominant, n	21:13	26:11	.61
Medical history, n			
Diabetes mellitus	2	6	.32
Hypertension	6	11	.36
Cerebrovascular accident	0	0	.81
Injury mechanism, n			
Overuse	13	14	.99
Trauma	18	22	.75
Sports	3	1	.55
Concomitant procedures, n			
Acromioplasty	8	5	.43
Distal clavicle resection	3	3	.75
Biceps tenotomy/tenodesis	7	10	.72
Subscapularis repair	9	16	.22
Lafosse[26] grade I:II:III:IV:V	0:4:5:0:0	1:7:8:0:0	

June 2013, all patients who underwent arthroscopic repair for full-thickness rotator cuff tears involving supraspinatus and/or infraspinatus tendons with the following inclusion/exclusion criteria were involved in this study. Inclusion criteria were (1) rotator cuff tears with full-thickness medium-sized to massive tears preoperatively diagnosed by magnetic resonance imaging (MRI), (2) arthroscopic conventional suture-bridge repair or a modified suture-bridge repair with a marginal dog-ear deformity, (3) patient age 50 to 65 years, (4) assessment of structural integrity performed with MRI at a minimum of 3 months postoperatively, and (5) assessment of functional capability at a minimum of 1 year after the surgery. Patients who refused to undertake any postoperative evaluation for structural integrity (n = 15) and who undertook ultrasonography instead (n = 7) were not included in the beginning of the study. Exclusion criteria were (1) partial repair of the torn rotator cuff and (2) additional single- or double-row repair other than a suture-bridge or modified suture-bridge repair. Initially, 78 patients met the inclusion criteria, and among them 7 patients were excluded (4 for partial repair, 3 for additional repairs). Therefore, 71 patients were evaluated for this study.

Group A (conventional suture-bridge technique) consisted of 34 consecutive patients treated between January 2008 and April 2011. Group B (modified suture-bridge technique) consisted of 37 consecutive patients treated between May 2011 and June 2013. We switched the surgical technique in group B from a conventional suture-bridge repair to a modified suture-bridge method to prevent anterior and posterior dog-ear deformities after introduction of this technique,[24] and we further modified the earlier modified technique. We used this technique on all repairs from medium-sized to massive tears for the period we mentioned, not just on cases in which dog-ear deformity developed, because we believed that it would improve rotator cuff healing. The mean ± SD age of patients at the time of surgery was 57.0 ± 4.4 years in group A and 57.6 ± 4.6 years in group B. The female:male ratio was 15:19 in group A and 17:20 in group B. Demographic variables were compared, and there were no significant differences between the 2 groups (Table 1).

Preoperatively, all patients had a full-thickness rotator cuff tear diagnosed on standardized MRI examination with 1.5-T superconducting magnets (Magnetom Vision and Sonata, Siemens Medical Systems) or 3.0-T superconducting magnets (Signa HDxt 3.0T, General Electronic Healthcare). Rotator cuff tear size, extent of retraction of the torn tendon, degree of fatty infiltration to rotator cuff muscles, number of torn tendons, and concomitant abnormalities were assessed. Rotator cuff tear size was measured as the maximum anterior-to-posterior distance of the tear from oblique sagittal views.[10] The extent of retraction of the torn tendon was measured as the maximum medial-to-lateral distance of the tear on oblique coronal views.[10] Fatty infiltration was assessed for each muscle by use of Goutallier staging.[17,18] These preoperative MRI characteristics, when summarized and compared between the 2 groups, showed no differences except degree of fatty infiltration of the infraspinatus tendon (Table 2).

Surgical Procedure: Modified Suture-Bridge Technique for Marginal Dog-Ear Deformities

All surgeries were performed by a single surgeon. Surgeries were performed with patients in the lateral decubitus position. Routine arthroscopic surgical procedures are as follows. After evaluation of the subacromial space and adequate visualization of the torn rotator cuff, debridement was performed to obtain a clear torn margin of the rotator cuff tendons. Tear shape, size, and the extent of retraction were identified intraoperatively. Mobility of the torn and retracted rotator cuff tendons was also evaluated for complete repair. Debridement of the cortical bone at the footprint was performed to expose the underlying cancellous bone. Care was taken not to debride excessive bone at

TABLE 2
Pre- and Postoperative MRI Characteristics of the 2 Groups[a]

	Group A (n = 34)	Group B (n = 37)	*P* Value
Preoperative MRI characteristics			
Tear size, cm	2.91 ± 1.46	2.42 ± 1.01	.11
Extent of retraction, cm	2.23 ± 1.04	2.29 ± 1.18	.82
Degree of fatty infiltration[b]			
Supraspinatus	0.38 ± 0.49	0.30 ± 0.81	.59
Infraspinatus	1.26 ± 0.57	1.73 ± 0.96	.02
Subscapularis	0.41 ± 0.61	0.30 ± 0.78	.49
Global fat infiltration index[c]	0.69 ± 0.40	0.77 ± 0.65	.49
Postoperative MRI findings			
Sugaya classification[38]			
I:II:III:IV:V, n	4:20:2:4:4	20:12:4:0:1	<001
Healed:Retear,[d] n	26:8	36:1	.011
Time between surgery and postoperative MRI, mo	8.23 ± 3.73	6.73 ± 3.67	.46

[a]Values are expressed as mean ± SD unless otherwise indicated. MRI, magnetic resonance imaging.
[b]Goutallier classification.
[c]Defined as the average of the Goutallier stages of the 3 tendons.
[d]"Healed" indicates Sugaya type I, II, or III, whereas "retear" indicates Sugaya type IV or V.

the greater tuberosity. Concomitant procedures included acromioplasty, distal clavicle resection, biceps tenotomy or tenodesis, and subscapularis tendon repair if indicated.

Our modified suture-bridge technique was similar to those described originally,[23,24] but we further modified it for repair of marginal dog-ear deformities. To repair the torn supraspinatus and/or infraspinatus tendons, 2 double-loaded suture anchors (4.5-mm Bio-Corkscrew FT suture anchor; Arthrex) were placed at the junction of the articular cartilage and the medial aspect of the footprint on the greater tuberosity. The medial suture anchors were distanced about 10 mm apart. One suture strand at each double-loaded suture anchor was passed through the torn tendon in a mattress fashion, and the medial row was repaired with sliding knots. Before the suture limbs from each of 2 medial anchors were bridged over the tendon and fixed laterally, the anterior and posterior cuff margins were repaired with the other suture strand at each suture anchor with the following methods. First, one end of the suture strand at each suture anchor that was not used for the medial knots was retrieved through the cannula of the lateral portal. Then a cuff margin was pierced via a curved suture hook (Linvatec) from bursal side to articular side. A PDS monofilament synthetic absorbable suture was fed into the articular side and pulled out through the same cannula at the lateral portal with use of a grasper (Arthrex). After a simple knot was tied with the PDS around the suture that had already been retrieved, the other end of the PDS was pulled to shuttle the braided suture through the cuff margin in a retrograde manner. Then a sliding knot was seated on top of the cuff margin to compress the tissue firmly onto the footprint. The same procedure was applied for both anterior and posterior cuff margins. After cuff margins were repaired, the suture-bridge repair was continued. Each suture limb from the medial mattress suture was placed through the hole at the end of the push-lock device (3.5-mm Bio-PushLock; Arthrex). Pilot holes for the push-lock device were created 2 cm distal to the lateral edge of the footprint via the lateral portal. While constant tension was maintained, a push-lock device (3.5-mm Bio-Push-Lock) was inserted into and engaged in the pilot hole. No additional suture anchors were used (Figures 1 and 2).

Structural and Functional Assessment

Postoperatively, all patients were assessed for structural integrity of the repaired tendon via MRI at a minimum of 3 months postoperatively. An MRI was recommended at both 3 months and 1 year postoperatively. In group A, 15 and 19 patients returned for MRI at 3 months and 1 year, respectively (4 patients responded at both time points). In group B, 13 and 24 patients returned for MRI at 3 months and 1 year, respectively (5 patients responded at both time points). Postoperative rotator cuff integrity was categorized as from type I to V according to the classification by Sugaya et al[38]: type I, sufficient thickness compared with normal cuff with homogeneously low intensity on each image; type II, sufficient thickness compared with normal cuff associated with partial high-intensity area; type III, insufficient thickness with less than half the thickness when compared with normal cuff, but without discontinuity, suggesting a partial-thickness delaminated tear; type IV, presence of a minor discontinuity in only 1 or 2 slices on both oblique coronal and sagittal images, suggesting a small full-thickness tear; and type V, presence of a major discontinuity observed in more than 2 slices on both oblique coronal and sagittal images, suggesting a medium or large full-thickness tear. Postoperative retear was defined as either Sugaya type IV or V. The interpretation of the radiographs was performed by the same radiologist using PACS (Picture Archiving and Communication System; Marosis; Infinitti) workstations. The radiologist was blinded to the technique used. Postoperative cuff integrity was summarized and compared between the 2 groups (Table 2).

TABLE 3
Pre- and Postoperative Range of Motion of the Affected Shoulder Joint of the 2 Groups[a]

	Group A (n = 34)	Group B (n = 37)	*P* Value[b]
Forward flexion			
Preoperative, deg	136.2 ± 24.0	128.6 ± 25.5	.36
Postoperative 1 y, deg	174.0 ± 16.8	167.1 ± 21.6	.45
P value[c]	<.001	<.001	
Abduction			
Preoperative, deg	135.6 ± 26.5	129.1 ± 26.7	.49
Postoperative 1 y, deg	170.0 ± 32.4	167.4 ± 36.8	.56
P value[c]	<.001	<.001	
External rotation, arm at side			
Preoperative, deg	45.6 ± 22.7	37.3 ± 28.9	.58
Postoperative 1 y, deg	73.0 ± 17.5	72.1 ± 14.8	.89
P value[c]	<.001	<.001	
Internal rotation, arm at side			
Preoperative, deg	32.9 ± 21.8	31.4 ± 24.5	.86
Postoperative 1 y, deg	64.0 ± 22.3	63.6 ± 25.0	.91
P value[c]	<.001	<.001	

[a]Values are expressed as mean ± SD.
[b]*P* values for comparing group A versus group B.
[c]*P* values for comparing pre- versus postoperative state.

TABLE 4
Pre- and Postoperative Functional Outcome Scores of the 2 Groups[a]

	Group A (n = 34)	Group B (n = 37)	*P* Value[b]
Pain VAS			
Preoperative	5.0 ± 1.8	5.8 ± 2.2	.10
1-year postoperative	2.1 ± 1.3	2.5 ± 0.9	.40
P value[c]	<.001	<.001	
UCLA score			
Preoperative	20.1 ± 5.0	17.9 ± 6.5	.42
1-year postoperative	31.5 ± 5.4	32.6 ± 5.5	.56
P value[c]	<.001	<.001	
Constant score			
Preoperative	53.8 ± 15.9	50.2 ± 13.6	.50
1-year postoperative	73.4 ± 10.3	77.0 ± 9.8	.42
P value[c]	<.001	<.001	
ASES score			
Preoperative	55.4 ± 13.4	50.1 ± 10.0	.30
1-year postoperative	81.6 ± 12.0	85.6 ± 11.4	.41
P value[c]	<.001	<.001	

[a]Values are expressed as mean ± SD. ASES, American Shoulder and Elbow Society; UCLA, University of California, Los Angeles; VAS, visual analog scale.
[b]*P* values for comparing group A versus Group B.
[c]*P* values for pre- versus postoperative state.

For functional assessment, all patients were evaluated for active range of motion (ROM) of the affected shoulder joint including forward elevation, abduction, and external and internal rotations. External and internal rotations were measured with the arm at the side, elbow flexed to 90°, and forearm positioned neutral. A pain visual analog scale (VAS), the University of California, Los Angeles (UCLA) shoulder rating scale,[10] Constant scores,[8,9] and the American Shoulder and Elbow Surgeons (ASES) score[36] were also used in the evaluation. All functional assessments were performed preoperatively and at a minimum of 1 year postoperatively (41.4 ± 18.0 months). These were also summarized and compared between the 2 groups (Tables 3 and 4).

In addition, healed and retear groups were compared in terms of preoperative characteristics such as rotator cuff tear size, extent of retraction, degree of fatty infiltration of the cuff muscles, postoperative functional outcome scores, and intraoperative surgical techniques (Table 5).

Postoperative Rehabilitation

Postoperatively, regardless of which group they belonged to, all patients underwent a routine rehabilitation protocol under the guidance of the operating surgeon and the assistance of a shoulder physical therapist. Patients wore an immobilizing sling with a supporting abduction pillow at all times for the initial 6 weeks except when patients showered and when they performed rehabilitation exercises. The rehabilitation protocol consisted of 5 phases. In phase I, gentle ROM activities for the shoulder joint were allowed, including shrugging and pendulum exercises. Activities that entailed full ROM of the elbow, wrist, and hand and grip strengthening of the affected side were allowed in this phase. In phase II, passive-assisted ROM of the shoulder joint via pulley or bar exercise was started at the beginning of the phase (bar exercise was not allowed for patients with subscapularis repair for the initial 6 weeks). These exercises were permitted only when tolerable. Active-assisted ROM exercise was gradually started at the end of this phase. In phase III, scapular strengthening exercise was started with isometrics and then advanced to TheraBand exercise as tolerated while subjects continued their phase II exercises. In phase IV, patients were allowed to lift light weights (up to 10 lb) and return to light sports activities. In phase V, full sports activities were permitted as tolerated.

The rehabilitation schedule depended basically on the size of the rotator cuff tear. For medium-sized tears, the phase I protocol was performed for the initial 3 weeks postoperatively, phase II from 3 to 6 weeks, phase III from 6 weeks to 3 months, phase IV after 3 months, and phase V after 6 months. For large to massive tears, phase I was performed for the initial 6 weeks postoperatively, phase II from 6 to 8 weeks, phase III from 8 weeks to 3 months, phase IV after 3 months, and phase V after 6 months. However, the pace of rehabilitation exercises was adjusted individually depending on the patient's subjective feeling of pain and functional capability.

Statistical Analysis

All continuous variables were tested for normality using the Shapiro-Wilk test. Measurements were expressed as

TABLE 5
Preoperative MRI Characteristics, Postoperative Functional Outcome Scores, and Intraoperative Marginal Dog-Ear Repair Status Between Healed and Retear Groups[a]

	Healed Group (n = 62)	Retear Group (n = 9)	*P* Value
Tear size, cm	2.54 ± 1.17	3.40 ± 1.67	.05
Extent of retraction, cm	2.23 ± 1.10	2.52 ± 1.20	.46
Degree of fatty infiltration[b]			
Supraspinatus	0.31 ± 0.67	0.56 ± 0.73	.30
Infraspinatus	1.52 ± 0.86	1.44 ± 0.53	.81
Subscapularis	0.34 ± 0.70	0.44 ± 0.73	.78
Global fat infiltration index[c]	0.72 ± 0.55	0.81 ± 0.51	.64
1-year postoperative outcomes			
UCLA score	34.0 ± 3.1	26.0 ± 1.5	<.001
Constant score	78.9 ± 7.5	61.3 ± 6.5	<.001
ASES score	86.2 ± 6.4	73.2 ± 5.3	.01
Conventional SB:modified SB, n	27:35	8:1	.03

[a]Values are expressed as mean ± SD unless otherwise indicated. Healed group: Sugaya type I, II, or III postoperatively. Retear group: Sugaya type IV or V postoperatively. ASES, American Shoulder and Elbow Society; MRI, magnetic resonance imaging; SB, suture bridge; UCLA, University of California, Los Angeles.

[b]Goutallier classification.

[c]Defined as the average of the Goutallier stages of the 3 tendons.

mean ± SD with 95% CI for continuous variables. Comparisons between groups A and B were made via Student *t* test or Wilcoxon rank sum test (if normality was not assumed) for continuous variables, such as patient age, extent of retraction, global fatty infiltration index, rotator cuff tear size, pre- and postoperative ROM, and functional outcome scores. Comparisons were also was made via chi-square test or Fisher exact test for categorical variables such as preoperative degree of fatty infiltration (Goutallier stage) and postoperative cuff integrity on MRI via Sugaya classification.[18] We also compared healed and retear groups using the same statistical tests. Pre- and postoperative ROM was compared via paired *t* test or Wilcoxon signed rank test (if normality was not assumed). $P < .05$ was considered statistically significant. The statistical software MedCalc (v 11.6, MedCalc Software) and R (v 3.1.0, Comprehensive R Archive Network, GNU General Public License) were used for all statistical analyses.

RESULTS

Preoperatively, rotator cuff tear size, extent of retraction, and degree of fatty infiltration of the cuff muscles showed no significant difference between the 2 groups. However, the postoperative structural integrity evaluated by MRI (the 2 time points combined) showed significant differences (Table 2). The ratio of Sugaya types I:II:III:IV:V was 4:20:2:4:4 in group A and 20:12:4:0:1 in group B. More subjects in group B had a favorable Sugaya type compared with group A ($P < .001$) (Figure 3). The postoperative healed:retear ratio was 26:8 in group A and 36:1 in group B, with a significantly lower retear rate in group B ($P = .011$) (Table 2). Additionally, the 9 patients (4 patients in group A, 5 patients in group B) who undertook postoperative MRI evaluations at 2 different time points (3 months, 1 year) showed no changes in the ratio of Sugaya types I:II:III:IV:V (0:5:2:2:0 at both time points). The average time to undergo postoperative MRI was not significantly different between groups ($P = .46$): 8.2 months for group A and 6.7 months for group B.

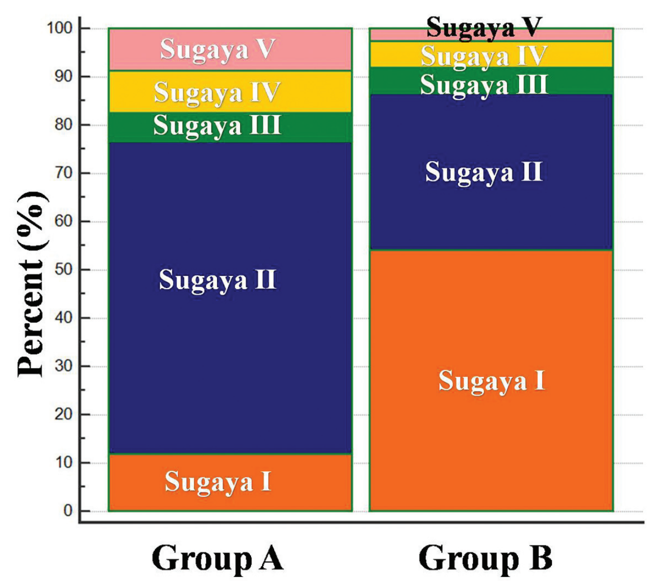

Figure 3. A 100% stacked bar plot showing postoperative rotator cuff integrity of the 2 groups with Sugaya classification.[38] Group A: rotator cuff repair with a conventional suture-bridge technique. Group B: rotator cuff repair with a modified suture-bridge technique for a marginal dog-ear deformity.

All ROM measurements of the affected shoulder joints, pain VAS, and functional outcome scores including the UCLA, Constant, and ASES scores showed significant improvement after the surgery ($P < .001$ for all comparisons between pre- and postoperative state). However, there were no differences between group A and group B both pre- and postoperatively, which meant there were no differences in functional outcomes between the 2 surgical techniques (Tables 3 and 4). Patients were followed up clinically at an average of 58 months (range, 44-77 months) in group A and 26 months (range, 15-35 months) in group B, which was significantly different ($P < .001$).

The healed (n = 62) and retear (n = 9) groups were also compared postoperatively depending on the result of MRI. Preoperative rotator cuff tear size was significantly different ($P = .05$), with larger sized tears in the retear group (3.40 ± 1.67 cm) than in the healed group (2.54 ± 1.17 cm). The extent of retraction of the torn rotator cuff and degree of fatty infiltration showed no differences. Functional outcome scores including the UCLA, Constant, and ASES scores showed significant differences ($P < .001$, $P < .001$, and $P = .01$, respectively), with worse results in the retear group. A comparison of surgical techniques in the healed and retear groups showed significantly fewer modified suture-bridge technique repairs in the retear group ($P = .03$).

DISCUSSION

Our study showed that our modified suture-bridge technique for a marginal dog-ear deformity provided significantly lower Sugaya stages and lower retear rate than a conventional suture-bridge technique for repair of full-thickness medium-sized to massive rotator cuff tears. Although functional outcome scores were not different between the 2 techniques postoperatively, patients with retear showed significantly worse functional results than the patients with healed cuff. In this respect, our modified suture-bridge technique provides superior structural outcomes and may provide better functional results by decreasing the retear rate. To our knowledge, this study is the first to describe structural and functional outcomes of a modified suture-bridge technique compared with a conventional suture-bridge repair.

Recently, structural integrity after rotator cuff repair has been investigated vigorously both biomechanically and clinically, and retear rates have been reported and compared in terms of surgical technique (single-row vs double-row). A biomechanical comparison of single-row and double-row repairs showed that a footprint reconstruction of the rotator cuff using a double-row repair improved initial strength and stiffness and also decreased gap formation and strain over the footprint when compared with a single-row repair.[21] A systematic review of clinical studies (level 1 or 2 evidence) on the rates of radiographically proven retear concluded that there may be a trend toward a higher retear rate with single-row repair.[11] The review found that the complete retear rate was 8% to 40% for single-row repair and 4% to 26% for a double-row method.[11] Since the suture-bridge repair technique was introduced, several biomechanical studies have shown that the suture-bridge method provides more firm repair constructs than do double-row or single-row repair methods.[2,32-35] However, clinical results regarding structural healing following suture-bridge repair have been reported in only 2 studies, to our knowledge.[6,25] Choi et al,[6] who conducted a retrospective case series regarding the suture-bridge technique, reported a 17% retear rate in medium-sized to massive rotator cuff tears. Kim et al,[25] in a cohort study comparing double-row repair to a suture-bridge technique, showed that retear rates were 24% and 20%, respectively, with no significant difference. In our study, the retear rate was 23.5% for conventional suture-bridge repair and 2.7% for modified suture-bridge repair for a marginal dog-ear deformity. We think that this significantly lower retear rate is attributable to the initial surgical fixation, although some factors should be considered: Only patients aged 50 to 65 years were included, and postoperative MRIs were taken at an average of 6.73 months. Biomechanical reasons may explain such a low retear rate: For example, this repair technique increased contact surface and pressure at the footprint by adding a suture at each marginal dog-ear deformity. In addition to the marginal dog-ear deformity associated with the suture-bridge method, the "central bird beak deformity" is known to be quite common in large to massive tears.[23] However, we have not seen many cases of central bird beak deformity, because we place the 2 medial suture anchors close to each other (about 10 mm apart) and use 2 lateral row fixations.

Our modified suture-bridge technique is a bit different in suture configuration from the one introduced in the original technique[24] in that additional stitches were made for anterior and posterior cuff margins where a dog-ear deformity would occur. Then, suture bridges with suture limbs from the medial row were made and fixed at the lateral row. We believe that this provided increased tendon-to-bone interface and a better load-sharing at the repaired tendon, consequently resulting in superior structural healing.

There is general consensus among shoulder surgeons that functional outcome scores improve after arthroscopic rotator cuff repair, regardless of the repair technique.[6,11,16,21,30,37,38] In addition, scores improve regardless of patients' demographic characteristics and preoperative cuff conditions—tear size, extent of retraction, degree of fatty infiltration, muscle atrophy, delamination—although these might be related to structural failure after repair.[3,22] In many clinical studies, when functional outcomes were compared postoperatively depending on repair technique, no significant differences were found.[6,11,16,21,30,37,38] Even though a suture-bridge technique has been proven to have better structural outcomes than other arthroscopic repair techniques, the functional outcomes are not different.[5,14,16,25] This observation is consistent with the result of this study. The ROM, pain VAS, UCLA score, Constant score, and ASES scores showed no differences between the 2 repair techniques. However, most of the studies, including the current study, were based on relatively small samples, thus having low statistical power. The possibility of type II error always exists—that is, that these clinical data failed to detect a difference in functional capability depending on different surgical repair technique, although such a difference really exists.

Generally, structural failure after rotator cuff repair does not always coincide with poor functional outcomes. Many studies have proven no significant differences in functional outcomes between patients with successful healing and patients with structural failure.[1,4,20,27] However, other studies reported the opposite—that patients who experienced retear showed poorer functional outcomes than patients with successful healing, suggesting a positive relation between successful structural integrity of the repaired tendon and better functional outcomes.[1,3,4,19,20,22] Recently, researchers have been more concerned about postoperative structural integrity and have attempted to reduce the retear rate by modifying their surgical techniques in various ways.[23,24] In this study, patients with a retear showed significantly poorer functional outcomes than patients with healed cuff. Surgical technique and rotator cuff tear size were found to be the factors affecting the structural outcomes. The extent of retraction and degree of fatty infiltration were not significant. We believe that a surgical technique, that is, how mechanically firm the construct is between a torn tendon and a footprint, is the most important factor for successful structural healing, consequently possibly resulting in better functional outcomes. Also, the surgical technique is the factor that the surgeon can control.

Several limitations should be mentioned. First, a small sample size can carry inadequate statistical power and produce a large type II error. Our study included only 34 patients with a conventional suture-bridge repair and 37 patients with a modified suture-bridge method; only 9 patients had a retear. However, we limited patient age to 50 to 65 years to exclude other factors that can influence structural and functional outcomes. These include poor bone quality leading to failure of the fixation construct, cuff tissues that are degenerated and delaminated to variable degrees, and a low compliance with rehabilitation, all of which are more likely in elderly patients versus younger patients. We believe that more homogeneous data were obtained because of this age restriction, although the sample size was relatively small. Second, this study has a selection bias. Twenty-two patients who did not undertake postoperative MRI were not involved in the study. If they exhibited results different than those of the involved patients, this could bias our conclusion significantly. However, a study with a single postoperative evaluation scheme for structural integrity may provide more authentic results than a study with different evaluation methods even though the latter has a larger sample size. Third, the time at which the postoperative MRI was performed differed between groups (8.2 months in group A and 6.7 months in group B). Since a retear could occur during this time interval postoperatively, it could bias our conclusion. However, Miller et al[29] reported that recurrent rotator cuff tears occur more frequently in the early postoperative period (within the first 3 months) after arthroscopic repair of large and massive tears. This is consistent with our earlier report on the timing of a retear, in which we concluded that a retear occurs infrequently in the late postoperative period (after 3 months). Also, 9 patients who undertook 2 postoperative MRI evaluations at 6 months in this study showed no changes in their Sugaya types. Fourth, 2 kinds of surgeries were performed at 2 different periods within the study—a conventional suture-bridge technique from January 2008 to April 2011 and a modified suture-bridge technique for a marginal dog-ear deformity from May 2011 to June 2013—because we switched the technique. As surgical experience accumulates, surgeons are likely to perform more efficiently and accurately. However, because the senior surgeon (J.H.K.) in this study has sufficient experience (17 years currently) performing shoulder arthroscopy, we believe that this bias is minimal. Also, the durations of clinical follow-up were different between groups (58 months in group A vs 26 months in group B, $P < .001$), so we compared postoperative functional outcomes at a given time point (1 year) consistently for both groups. Fifth, marginal dog-ear deformities can be avoided with 3×3, 3×2, or even more complex suture configurations. To determine the effect of a marginal dog-ear deformity on rotator cuff healing, these suture configurations should be included. However, placement of more suture anchors can create other biases, such as increased surgical time or pullout of the suture anchors. Sixth, other factors could have affected the healing pattern and functional outcome, such as the presence of concomitant subscapularis repair. In our study, the rate of subscapularis tendon repair was 26% (9/34) in group A and 43% (16/37) in group B. Although this difference was not statistically significant ($P = .22$), it might have influenced the results because the rehabilitation protocol was different for those who underwent subscapularis repair (external rotation using a bar was not allowed for 3-6 weeks postoperatively).

CONCLUSION

The modified suture-bridge technique for marginal dog-ear deformities provided superior structural outcomes compared with a conventional suture-bridge technique in arthroscopic repair of medium-sized to massive rotator cuff tears. This technique may provide better functional outcomes by decreasing the retear rate. Since initial surgical fixation of the torn rotator cuff to the footprint is the only controllable factor to prevent a retear, from the surgeon's perspective, efforts should be made to develop various suture configurations to decrease such deformity. Our modified suture-bridge technique can be one of them; however, longer follow-up and further studies are needed to confirm these results.

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