

# Does Complete Footprint Coverage Affect Outcomes After Conventional Arthroscopic Repair of Large-Sized Rotator Cuff Tears?

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**Background:** In large-sized rotator cuff tears, tendon repair with incomplete footprint coverage is performed frequently as a way of tension-free or low-tension repair.

**Purpose:** To compare clinical outcomes after arthroscopic repair of large-sized rotator cuff tears between patients with complete versus incomplete footprint coverage.

**Study Design:** Cohort study; Level of evidence, 3.

**Methods:** Among 297 patients who underwent arthroscopic surgery for a large-sized rotator cuff tear, we selected 58 patients (<50% coverage; mean age, 63.34 ± 6.8 years; 34 men and 24 women) with incomplete footprint coverage. Using propensity score matching, another 58 patients with complete footprint coverage (mean age, 63.4 ± 8.03 years; 34 men and 24 women) were selected after 1:1 matching for age, sex, and tear size—the main demographic and prognostic factors of outcomes after rotator cuff repair. Clinical outcomes were compared on magnetic resonance imaging or ultrasonography at minimum of 6 months postoperatively, and functional outcomes were compared using range of motion and pain visual analog scale; American Shoulder and Elbow Surgeons; Constant; University of California, Los Angeles; and Simple Shoulder Test scores at a minimum of 2 years postoperatively.

**Results:** A total of 18 patients in the incomplete footprint coverage group (31.0%) and 20 patients in the complete footprint coverage group (34.5%) showed healing failure, with no significant difference between groups ( $P = .843$ ). In addition, there were no differences in functional outcomes between groups ( $P > .05$  for all).

**Conclusion:** Whether the rotator cuff footprint was completely covered did not affect clinical outcomes in conventional arthroscopic repair of large-sized rotator cuff tears.

**Keywords:** clinical outcome; footprint coverage; healing failure; rotator cuff tear

Rotator cuff tears frequently cause shoulder pain and disability, including weakness and decreased range of motion (ROM) of the shoulder joint.<sup>17,18</sup> Along with population aging and the increase in sports activities, the incidence of rotator cuff tears has increased rapidly.<sup>15</sup> Consequently, arthroscopic rotator cuff repair, a widely accepted treatment for full-thickness rotator cuff tears, is being performed with increasing frequency. If the tear is irreparable, various salvage procedures, such as partial repair, patch interposition, superior capsular reconstruction, or reverse total shoulder arthroplasty may be inevitable<sup>8,14,22</sup>; however, if the tear can be repaired, primary repair should be first considered. In case of

rotator cuff tears, which are repairable but difficult to cover the full length of the footprint, or in case of a rotator cuff tear with a short remnant tendon portion, a rotator cuff repair with incomplete footprint coverage is performed frequently as a way of tension-free or low-tension repair.<sup>23,25</sup>

Few reports exist regarding rotator cuff repair with incomplete footprint coverage. To our knowledge, only 1 study by Koh et al<sup>26</sup> performed a comparative analysis between incomplete and complete footprint coverage; they reported that patients with complete footprint coverage showed better healing rates. However, this comparison has an inherent limitation, as the preoperative variables—such as tear size, fatty infiltration, or age, which could significantly affect the outcomes—were different between groups and may have resulted in a selection bias.

Thus, this study aimed to compare the outcomes of arthroscopic repair of large-sized rotator cuff tears between

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the complete and incomplete footprint coverage groups after matching baseline characteristics.

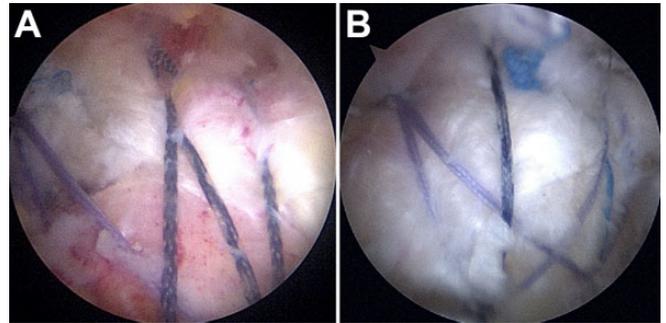
## METHODS

### Patient Selection

This was a retrospective cohort study involving a control group; institutional review board approval was obtained for the study protocol. Between September 2012 and February 2018, a total of 297 patients underwent arthroscopic surgery for large-sized posterolateral full-thickness rotator cuff tears (tear size, 3-5 cm) at our institution.<sup>10</sup> Of these patients, 40 underwent extrasurgical procedures during rotator cuff repair due to high repair tension even after mobilization procedure and poor tissue quality (17 patients underwent repair after medialization of the footprint, 2 partial repair, 5 superior capsular reconstruction, 11 patch augmentation, and 5 biceps augmentation) and were excluded. We reviewed only large-sized rotator cuff tears because the possibility of incomplete footprint coverage during repair surgery was higher than that of smaller tears, but we excluded massive rotator cuff tears because their tissue quality and reducibility may be too poor with advanced fatty infiltration to repair with minimal tension and the glenohumeral mechanics may be disrupted.<sup>3</sup>

Among the 257 patients who underwent conventional arthroscopic repair for large-sized rotator cuff tears, 78 showed incomplete footprint coverage. We defined incomplete footprint coverage as less than 50% repair on the medial half or less of the footprint and complete footprint coverage as complete repair to the lateral end of the greater tuberosity footprint, according to the criteria listed by Koh et al<sup>26</sup> (Figure 1). The remaining 179 patients either had complete footprint coverage or their repaired tendon covered the whole area of the footprint (ie, there was no gray area of footprint coverage, such as 70% or 80%). The tension-free or minimal tension repair was the priority when performing rotator cuff repair; thus, repair with complete footprint coverage was performed only when the repair tension was not high.

The study inclusion criteria were patients who underwent preoperative magnetic resonance imaging (MRI) and postoperative MRI or ultrasonography (US)  $\geq 6$  months after surgery and who completed the required functional outcome measures preoperatively and  $\geq 2$  years after surgery. The exclusion criteria included traumatic tear, workers' compensation status, previous surgery on the same shoulder, and loss to follow-up before 2 years postoperatively.



**Figure 1.** Rotator cuff repair with (A) incomplete and (B) complete footprint coverage.

### Demographic and Clinical Characteristics

The demographic and clinical characteristics of the 78 patients in the incomplete footprint coverage group were compared with those of the remaining 179 patients in the complete footprint coverage group. We evaluated the following characteristics that can affect outcomes: age, sex, symptom duration, hand dominance, steroid injection history, preoperative stiffness, initial pseudoparalysis, bone mineral density, diabetes mellitus, hypercholesterolemia, sports level, work level, tear size, fatty infiltration of each rotator cuff muscle, delamination tear, and concomitant biceps procedures.

Shoulder stiffness was defined as forward elevation  $< 120^\circ$  passively, external rotation  $< 30^\circ$  passively, and internal rotation at a spinal level lower than L3 passively.<sup>31</sup> Pseudoparalysis was defined as active shoulder elevation  $< 90^\circ$  in the presence of full passive forward elevation.<sup>32</sup> Bone mineral density was measured at the last outpatient visit before surgery using dual-energy x-ray absorptiometry (DEXA), and the lowest T-score of the proximal femur and lumbar spine, except the value for the Ward area of the proximal femur, was recorded.<sup>1</sup> Although there has been a concern that the generalized bone mineral density by DEXA may not accurately reflect the bone quality of the greater tuberosity of the proximal humerus where the rotator cuff was torn,<sup>21</sup> we used the bone mineral density assessment by DEXA, as it is an established and widely used method in the general clinical setting. The patient's level of sports activity was defined as high (dynamic or contact sports, such as boxing, basketball, rugby, and tennis), medium (static sports, such as yoga and jogging), or low (mild or no sports activities).<sup>2</sup> Work level was defined as high, medium, or low if the work involved heavy manual labor; manual labor with less physical activity; or sedentary physical activity, respectively.<sup>5</sup> Tear size was measured

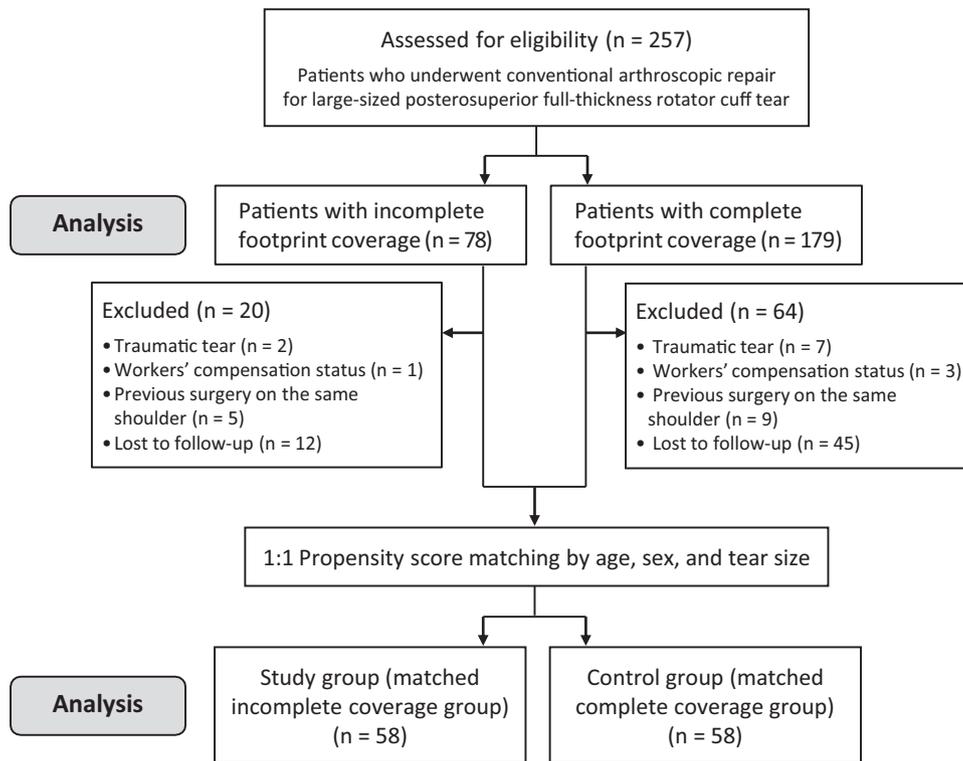
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**Figure 2.** Flowchart of patient exclusion and inclusion in the study.

arthroscopically using a calibrated probe at the time of surgery.<sup>10</sup>

The fatty infiltration of each rotator cuff muscle (supraspinatus, infraspinatus, and subscapularis) was evaluated according to the criteria established by Goutallier et al<sup>20</sup> and modified by Fuchs et al<sup>16</sup> from the preoperative MRI results. Delamination tears were defined as a horizontal retraction of the bursal or articular surface of the tendon, manifested as thickening of the torn retracted edge and/or interstitial splitting of the tendon and confirmed arthroscopically.<sup>40</sup> A musculoskeletal specialized radiologist (not involved in the current study) who was blinded to the patients' characteristics evaluated fatty infiltration. In addition, to assess interrater reliability, another orthopaedic surgeon (S.W.C.) evaluated the fatty infiltration after blinding the ratings of the musculoskeletal specialized radiologist. The interrater agreement of the fatty infiltration grading was evaluated with the intraclass correlation coefficient (ICC), a 2-way random model with absolute agreement. Agreement was generally acceptable, with ICCs of 0.802 for the supraspinatus, 0.713 for the infraspinatus, and 0.645 for the subscapularis.

### Propensity Score Matching

After applying the study inclusion criteria, 58 patients with incomplete footprint coverage and 115 patients with complete footprint coverage remained (Figure 2). From the 115 patients, 58 with complete footprint coverage were selected using 1:1 matching for age, sex, and tear size with the

incomplete footprint coverage group. To reduce bias, we performed propensity score matching (PSM), which is the statistical method of balancing covariates and reducing selection bias by using a propensity score that is the predicted probability of belonging to a certain group.<sup>29</sup>

### Imaging Evaluation

Between the matched incomplete and complete coverage groups, we compared the 6-month clinical outcomes using MRI (SignaHDx 3.0-T system; GE Healthcare) or US (HDI 5000 or IU-22 system; Philips Healthcare). A total of 65 patients underwent postoperative MRI and 51 patients underwent US (35 MRI and 23 US in the incomplete coverage group; 30 MRI and 28 US in the complete coverage group).

Postoperative MRI scan or US was performed at 6 months and every 6 months thereafter as a routine postoperative protocol for all patients, and every patient included in this study completed more than at least 1 ( $\geq 1$ ) imaging examination including 6-month postoperative imaging. An experienced musculoskeletal radiologist (not involved in the current study) with >17 years of experience who was blinded to the patient and study details performed and interpreted the MRI and US films and further evaluated the healing degree of the rotator cuff to the greater tuberosity. The postoperative cuff healing status on MRI was investigated using the Sugaya classification: type 1, sufficient thickness with homogeneously low intensity; type 2, sufficient thickness with partial high-intensity areas; type

3, less than half the thickness without discontinuity; type 4, minor discontinuity; and type 5, major discontinuity. Types 4 and 5 were defined as healing failures.<sup>37</sup> The US criteria for the diagnosis of a healing failure were as follows<sup>7,43</sup>: no observation of the repaired tendon attributable to retraction, focal defect, or gap in the repaired tendon with consecutive loss of the normal anterior arc of the subdeltoid bursa; loss of the repaired supraspinatus substance with widening of the gap between the supraspinatus and biceps tendons, and hypochoic or anechoic cleft extending through the entire substance of the repaired cuff.

In addition, shoulder ROM along with pain visual analog scale (0-10, with 10 being worst pain); American Shoulder and Elbow Surgeons (100-point system, 50 points for daily function and 50 points for pain); Constant score; Simple Shoulder Test; and University of California, Los Angeles, scores were compared between groups at a minimum of 2 years postoperatively. Shoulder ROM was measured by a single senior investigator (S.W.C.), and the functional outcome scores were measured by a clinical researcher (not involved in the current study). All functional outcome data points from the preoperative and final follow-up assessments were analyzed.

### Surgical Procedures and Rehabilitation

All surgical procedures were performed arthroscopically by a single surgeon (S.W.C.), with the patient in the beach-chair position. Subacromial decompression and acromioplasty were performed to create a flat acromion in all patients. Biceps tenotomy or tenodesis was performed in cases with dislocation, subluxation, and tears involving more than 50% of the long head of the biceps tendon, or for a symptomatic degenerative superior labral anterior and posterior lesion depending on the age or activity level of the patient. None of the patients underwent distal clavicle resection or coracoplasty. The margin of the tear was debrided to obtain better quality tendon tissues. For reattachment of the rotator cuff tendons, a cancellous bone bed was prepared using a bur or ring curette until bleeding occurred. If the mobility of torn cuff was sufficient to pull the torn cuff to the lateral end of the footprint without tension, we performed rotator cuff repair with complete footprint coverage. If the mobility of a tendon was insufficient for tension-free repair, we performed a thorough mobilization procedure, such as tendon release in the bursal and articular sides.

After the mobilization procedure, if the mobility was changed to be sufficient for the complete footprint coverage without much tension, we performed the rotator cuff repair with complete footprint coverage; if the repair tension was still too high to cover the whole length of the footprint even after mobilization procedure, the tendon was repaired on the medial portion of the footprint for the tension-free repair, instead of complete footprint coverage with high tension.

Suture bridge repair was performed in all patients. Suture anchors were inserted at the junction of the articular cartilage and the medial aspect of the footprint from a suture anchor portal just lateral to the acromion for a suture-bridge repair. Sutures were passed through the

tendon in a mattress fashion for suture-bridge repair by using an antegrade suture-passing device (Arthrex Scorpion; Arthrex) and were then tied with a sliding knot (SMC knot) as well as 3 additional half-hitch knots. Then, each suture limb from the medial row was loaded in lateral knotless anchors and, maintaining a constant tension, the suture anchor was then inserted 2 cm distal to the lateral edge of the footprint via the lateral portal. After the device was fully engaged with the bone, the sutures were cut. The arthroscope was then moved into the glenohumeral space, and a tight repair was confirmed.

Immobilization after cuff repair was maintained with an abduction brace for 5 to 6 weeks. Shrugging of both shoulders, active elbow flexion and extension, active forearm supination and pronation, and active hand and wrist motion were encouraged immediately after surgery. Active-assisted ROM exercises were allowed after weaning off the brace. Muscle strengthening exercises were initiated at 9 to 12 weeks postoperatively. Sports activities and heavy labor were allowed after 6 months. The rehabilitation protocol was home based and did not change during the study period.

### Statistical Analysis

The sample size was calculated to detect a significant difference (mean difference of 27%) in the healing failure rate, based on our previous studies that dealt with rotator cuff healing.<sup>3,4,44</sup> A sample size of 58 patients in each group was required for a power of 85% at a type 1 error level of .05 and a dropout rate of 20%.

The Student *t* test for continuous variables and Fisher exact test and the chi-square test for categorical variables were used before matching, and the Wilcoxon signed-rank test for continuous variables and McNemar test or marginal homogeneity test for categorical variables were used after matching to compare baseline demographic, clinical, and radiologic characteristics and to compare clinical and functional outcomes between the incomplete coverage and complete coverage groups. PSM was used to match age, sex, and tear size, which are the main demographic factors known to be prognostic factors for outcomes after rotator cuff repair. The results of the PSM were evaluated by the value of the c-statistic and the *P* value of the Hosmer-Lemeshow goodness-of-fit test derived from the logistic regression model. PSM is considered appropriate when the value of c-statistics is above 0.7 and the *P* value of the goodness-of-fit is above .05. IBM SPSS Statistics software (Version 23.0; SPSS Inc.) was used for all statistical analyses, and *P* < .05 was considered statistically significant.

### RESULTS

The incomplete coverage group showed larger tear size in both the anteroposterior dimension and retraction (*P* = .003 and *P* < .001, respectively) and higher fatty infiltration of the supraspinatus (*P* < .001) and the infraspinatus (*P* = .003), compared with the complete coverage group. The characteristics of the incomplete coverage group

TABLE 1  
 Characteristics of the Incomplete Coverage Group Versus Complete Coverage Group<sup>a</sup>

	Incomplete Coverage Group (n = 78)	Complete Coverage Group (n = 179)	P
Age, y	63.1 ± 7.1	61.4 ± 8.0	.111
Sex (M:F), n	52:26	119:60	.548
Duration of symptoms, months	20.9 ± 28.6	19.4 ± 25.5	.676
Side of involvement (D:ND), n	61:17	126:53	.224
History of steroid injection, n (%)	34 (43.6)	72 (40.4)	.680
Preoperative stiffness, n (%) <sup>b</sup>	16 (20.5)	30 (16.8)	.483
Preoperative pseudoparalysis, n (%) <sup>c</sup>	14 (17.9)	19 (10.6)	.110
Bone mineral density <sup>d</sup>	-1.34 ± 0.90	-1.25 ± 1.03	.538
Diabetes mellitus, n (%)	12 (15.4)	23 (12.9)	.558
Hypercholesterolemia, n (%)	9 (11.5)	28 (15.6)	.445
Sports level (low:middle:high), n <sup>e</sup>	56:11:11	133:29:17	.533
Work level (low:middle:high), n <sup>f</sup>	21:22:35	57:57:65	.430
Tear size, mm <sup>g</sup>			
AP dimension	38.03 ± 7.08	35.17 ± 7.03	<b>.003</b>
Retraction	36.34 ± 7.79	31.21 ± 10.13	<b>&lt;.001</b>
Fatty infiltration <sup>h</sup>			
Supraspinatus	2.87 ± 0.62	2.49 ± 0.68	<b>&lt;.001</b>
Infraspinatus	2.62 ± 0.94	2.22 ± 0.98	<b>.003</b>
Subscapularis	1.37 ± 1.02	1.33 ± 1.11	.804
Delamination tear, n (%) <sup>i</sup>	24 (30.8)	68 (38.6)	.259
Biceps procedure (To:Td:none), n	40:24:14	85:59:35	.854

<sup>a</sup>Data are reported as mean ± SD unless otherwise indicated. Boldface *P* values indicate statistically significant difference between groups (*P* < .05). AP, anteroposterior; D, dominant; DEXA, dual-energy x-ray absorptiometry; F, female; M, male; ND, nondominant; Td, tenodesis; To, tenotomy.

<sup>b</sup>Defined as forward elevation <120° passively, external rotation <30° passively, and internal rotation at a spinal level lower than L3 passively.<sup>31</sup>

<sup>c</sup>Defined as active shoulder elevation <90° in the presence of full passive forward elevation.<sup>32</sup>

<sup>d</sup>Measured at the last outpatient visit before surgery using DEXA; we recorded the lowest T-score of the proximal femur and lumbar spine, except the value for the Ward's area of the proximal femur.<sup>1</sup>

<sup>e</sup>High, dynamic or contact sports (boxing, basketball, rugby, and tennis); medium, static sports (yoga and jogging); low, mild or no sports activities.<sup>2</sup>

<sup>f</sup>High, heavy manual labor; medium, manual labor with less physical activity; low, sedentary physical activity.<sup>5</sup>

<sup>g</sup>Measured arthroscopically using a calibrated probe at the time of surgery.

<sup>h</sup>According to Goutallier classification.<sup>20</sup>

<sup>i</sup>Defined as a horizontal retraction of the bursal or articular surface of the tendon, manifested as thickening of the torn retracted edge and/or interstitial splitting of the tendon and confirmed arthroscopically.<sup>40</sup>

compared with those of the complete coverage group are listed in Table 1.

The PSM results were acceptable, with a c-statistic of 0.977 and a *P* value of .990 for the goodness-of-fit test from the logistic regression model.<sup>28</sup>

After 1:1 PSM for the 58 patients who were selected after applying exclusion criteria in the incomplete coverage group, we acquired similar baseline characteristics between the matched groups for all variables (Table 2).

Regarding the clinical outcomes, 18 patients (31.0%) showed healing failure in the matched incomplete coverage group and 20 patients (34.5%) showed healing failure in the matched complete coverage group; the difference between the groups was not statistically significant (*P* = .843) (Table 3). Regarding functional outcomes, the 2-year postoperative ROM and outcome measures revealed there were no significant differences between the matched groups (Table 4).

## DISCUSSION

In the current study, we found that whether the footprint was covered completely or incompletely did not affect outcomes, including the healing rate. Previously, Koh et al<sup>26</sup> reported that the retear rate was higher in the incomplete footprint coverage group than in the complete footprint coverage group. This was inconsistent with our results, which showed no differences in the retear rate between groups after matching (31.0% in the matched incomplete coverage group vs 34.5% in the matched complete coverage group, *P* = .843). We think that this difference was due to the difference in the study design. In the study by Koh et al,<sup>26</sup> the baseline characteristics between the groups were varied, with significant differences in age, tear size, and fatty degeneration between groups, which are known to be important prognostic factors for outcomes after rotator cuff repair.<sup>3,27</sup> These differences in the baseline characteristics may cause selection biases.

TABLE 2  
Comparison of Matched Incomplete Coverage and Matched Complete Coverage Groups<sup>a</sup>

	Matched Incomplete Coverage Group (n = 58)	Matched Complete Coverage Group (n = 58)	P
Age, y	63.3 ± 6.8	63.4 ± 8.0	.980
Sex (M:F), n	34:24	34:24	>.999
Duration of symptoms, months	20.5 ± 31.5	15.1 ± 23.5	.291
Side of involvement (D:ND), n	48:10	45:13	.642
History of steroid injection, n (%)	27 (46.6)	21 (36.2)	.346
Preoperative stiffness, n (%)	12 (20.7)	5 (8.6)	.113
Preoperative pseudoparalysis, n (%)	13 (22.4)	9 (15.5)	.478
Bone mineral density	-1.37 ± 0.85	-1.63 ± 1.06	.200
Diabetes mellitus, n (%)	7 (12.1)	6 (10.3)	>.999
Hypercholesterolemia, n (%)	8 (13.8)	13 (22.4)	.335
Sports level (low:middle:high), n	43:8:7	40:12:6	.611
Work level (low:middle:high), n	18:15:25	17:17:24	.917
Tear size, mm			
AP dimension	38.39 ± 7.09	38.32 ± 7.80	.901
Retraction	36.89 ± 7.06	34.56 ± 8.94	.123
Fatty infiltration			
Supraspinatus	2.87 ± 0.62	2.74 ± 0.60	.230
Infraspinatus	2.67 ± 0.94	2.56 ± 0.93	.555
Subscapularis	1.39 ± 1.05	1.63 ± 1.23	.262
Delamination tear, n (%)	17 (29.3)	22 (37.9)	.324
Biceps procedure (To:Td:none), n	32:13:13	25:18:15	.405

<sup>a</sup>Data are reported as mean ± SD unless otherwise indicated. Boldface *P* values indicate statistically significant difference between groups (*P* < .05). See Table 1 footnotes for definition of variables. AP, anteroposterior; D, dominant; F, female; M, male; ND, nondominant; Td, tenodesis; To, tenotomy.

TABLE 3  
Comparison of Rotator Cuff Healing Between the Matched Incomplete and Complete Coverage Groups<sup>a</sup>

	Matched Incomplete Coverage Group (n = 58)	Matched Complete Coverage Group (n = 58)	P
Failed healing (rotator cuff retear)	18 (31.0)	20 (34.5)	.843
Successful healing	40 (69.0)	38 (65.5)	

<sup>a</sup>Data are presented as n (%). The postoperative cuff healing status was evaluated by either MRI scan or US. For MRI, Sugaya types 4 and 5 were defined as healing failures.<sup>37</sup> For US, the criteria for the diagnosis of a healing failure were as follows<sup>7,43</sup>: no observation of the repaired tendon attributable to retraction, focal defect, or gap in the repaired tendon with consecutive loss of the normal anterior arc of the subdeltoid bursa; loss of the repaired supraspinatus substance with widening of the gap between the supraspinatus and biceps tendons, and hypoechoic or anechoic cleft extending through the entire substance of the repaired cuff. MRI, magnetic resonance imaging; US, ultrasonography.

Another study by Lee et al<sup>27</sup> supports the results of the current study. Lee et al evaluated factors associated with retear after rotator cuff repair and concluded that the completeness of rotator cuff repair based on the extent of footprint coverage was not a risk factor for retear, in contrast to age, initial tear size, and fatty infiltration of the supraspinatus, which were independent risk factors for retear.

Many authors have reported that minimal tension during rotator cuff repair is critical for successful healing, especially in larger-sized tears.<sup>9,19,24</sup> Clinically, rotator cuff tendon repairs placed at the medial portion of the greater tuberosity (medialized repair) have significantly lower construct tensions. Thus, several authors recommend medialized repair to decrease tension on the repaired tendon when significant tension is observed.<sup>12,13,33</sup> Dierckman et al<sup>12</sup> showed a significant 5.4-fold increase in tension

when the tendon was placed laterally compared with the medial footprint. Similarly, Domb et al<sup>13</sup> reported a 2.8-fold increase in tension required to reduce the torn tendon from the medial to the lateral footprint. It is reasonable to expect that more tension would be required to pull the torn tendon back to the lateral end of the footprint, and the medialized repair would have a clear biomechanical advantage of less repair tension. Given this, medialized repair would be a reasonable option to relieve tension and improve healing after rotator cuff repair, especially in chronic retracted tears. The chronic tear is defined as an age-related degenerated tear with ≥3 months of symptoms without definite trauma history.<sup>41</sup>

In this study, we attempted to increase tendon mobility by thoroughly releasing adhesions on both the capsular and the bursal sides. If the repair tension was still high enough to cover the entire extent of the footprint despite the

TABLE 4  
Functional Outcomes After Surgery: Comparison of Matched Incomplete Coverage and Matched Incomplete Coverage Groups<sup>a</sup>

Evaluation	Preoperative			Postoperative (>1 y)		
	Matched Incomplete Coverage Group	Matched Complete Coverage Group	P	Matched Incomplete Coverage Group	Matched Complete Coverage Group	P
ROM						
FF	152.36 ± 28.56	150.01 ± 30.19	.671	164.22 ± 21.20	167.15 ± 14.57	.388
ER	57.19 ± 20.61	53.72 ± 18.78	.355	57.32 ± 13.38	59.12 ± 13.02	.468
IR	10.96 ± 3.58	10.74 ± 3.20	.731	8.31 ± 2.45	8.27 ± 1.97	.934
Pain VAS	5.77 ± 2.10	5.87 ± 2.06	.790	1.77 ± 1.81	1.85 ± 1.65	.819
ASES	46.76 ± 16.35	48.80 ± 18.00	.524	79.39 ± 14.95	77.27 ± 13.86	.430
Constant	50.50 ± 14.94	48.10 ± 16.65	.417	73.72 ± 13.29	72.94 ± 12.80	.749
SST	3.74 ± 2.48	4.20 ± 2.57	.323	8.91 ± 2.05	8.39 ± 2.16	.190
UCLA	22.65 ± 5.59	21.50 ± 5.24	.254	29.82 ± 5.75	29.31 ± 4.57	.593

<sup>a</sup>Values are presented as mean ± SD. ASES, American Shoulder and Elbow Surgeons; ER, external rotation at the side; FF, forward flexion; IR, internal rotation at the back; ROM, range of motion; SST, Simple Shoulder Test score; UCLA, University of California, Los Angeles; VAS, visual analog scale.

thorough mobilization process, we chose medialized repair (incomplete footprint coverage) to relieve repair tension instead of repair with complete footprint coverage but with high tension. We believe that this effort to decrease repair tension may bring comparably satisfactory outcomes despite incomplete footprint coverage. A study by Steinhilber et al<sup>36</sup> reported that the retear rate after patch use in rotator cuff repair was higher in the augmentation graft than in the interposition graft (34% vs 12%, respectively), suggesting that tension-free repair by interposition graft is more important for tendon healing, also supporting the importance of repair tension in rotator cuff repair.

Furthermore, in a chronic retracted tear, the native tendon may be short because of tendon loss.<sup>38</sup> Previously, Kim et al<sup>25</sup> stressed the importance of the remnant tendon length for outcomes in patients with larger than medium-sized rotator cuff tears and reported that the medialized single row repair, when the remnant tendon length is short and the mobility of the tendon is insufficient, provides superior rotator cuff integrity. We think that medialized repair with incomplete footprint coverage may be a reasonable option for chronic large-sized tears, which are more likely to have short remnant tendons with stiff and less compliant muscle tissue.

The similar outcomes of the incomplete footprint coverage compared with the complete footprint coverage in this study may in part come from the neotendon formation on the exposed footprint of the incomplete footprint coverage group. Previously, Yamakado<sup>42</sup> reported that in most patients (93%) who underwent medially based rotator cuff repair, neotendon regeneration was found on MRI scan at 1 year after surgery. Similarly, Dierckman et al<sup>11</sup> also reported that, in a patient who underwent medially based rotator cuff repair with bone marrow vents, the footprint was completely covered lateral to the repair site with a neotendon in a second-look arthroscopic examination. The exposed footprint seemed to be covered with collagen fibers

and connected to the repaired cuff tendon, which may further relieve the force applied to the repaired tendon. In addition, Milano et al<sup>29</sup> showed that the healing rate was higher in patients who underwent microfractures in the footprint lateral to the medially based repair site than in those who did not (60% vs. 12.5%) in larger rotator cuff tears. The egress of blood from the microfracture placed in the footprint lateral to the repair may contain various growth factors or even mesenchymal stem cells, which contribute to the formation of a super clot and establish new vascular channels for cuff vascularization, which may improve rotator cuff healing.<sup>35</sup> In the current study, footprint preparation was performed sufficiently until the subchondral cancellous bone of the entire footprint was exposed in every patient. We think this thorough footprint preparation process may be one of the reasons for the increase in biological healing potential in the incomplete footprint coverage group, similar to the microfracture process.

### Limitations

This study has several limitations. First, this was a retrospective study. Although we used PSM to carefully eliminate the influence of confounding factors and overcome the limitations of the retrospective study, we cannot deny that the possibility of selection bias still existed. Second, not all patients who underwent arthroscopic large-sized rotator cuff repair were included, and the loss at follow-up (57/257; 22.2%) might have caused a risk of selection bias of which we were not aware. For example, if patients who were doing extremely well did not return for follow-up, this would adversely affect the outcomes. Conversely, if the patients who were extremely dissatisfied did not return for follow-up, there would be an improvement in the outcomes.

A third limitation was that we used 2 evaluation methods (either MRI or US) to assess postoperative cuff integrity,

which could decrease the consistency of interpretation. However, the diagnostic accuracy of MRI and US in the characterization of full-thickness rotator cuff tears is known to be comparably high with overall estimates of sensitivity and specificity over 0.90,<sup>34</sup> and the concordance between MRI and US to assess rotator cuff repair integrity after surgery is known to be very high (92%).<sup>6</sup> We think that the use of 2 different evaluation methods (either MRI scan or US) would not gravely compromise our ability to analyze the cuff healing status. Moreover, to minimize the examiner dependency and avoid surgeon prejudice, experienced musculoskeletal radiologists who were unaware of the present study performed MRI or US and interpreted cuff integrity using the same strict criteria.

As another limitation, the evaluation time of 6 months may have been early for the final diagnosis of cuff healing. However, findings from preclinical and clinical studies have indicated that a 6-month period after surgery is enough time to evaluate rotator cuff healing, and we do not believe there would be a large enough difference in the cuff healing rate in a later evaluation period to compromise the reliability of this study.<sup>30,39</sup> Finally, even though we tried to repair with minimal tension, we cannot be sure whether the repair tension was not actually high, as we did not directly measure the repair tension during rotator cuff repair surgery. A well-designed prospective study that measures the repair tension may be warranted to generalize the findings of this study.

## CONCLUSION

Whether the footprint was covered completely or not did not affect clinical outcomes in conventional arthroscopic repair of large-sized rotator cuff tears.

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