Evaluation of Radiographic Changes 5 Years After Arthroscopic Rotator Cuff Repair

Ryogo Furuhata,* MD, PhD, Noboru Matsumura,*† MD, PhD, Tomoki Matsuo,* MD, Hiroo Kimura,* MD, PhD, Taku Suzuki,* MD, PhD, Masaya Nakamura,* MD, PhD, and Takuji Iwamoto,* MD, PhD

Investigation performed at the Department of Orthopaedic Surgery, Keio University School of Medicine, Tokyo, Japan

Background: Radiographic changes in the glenohumeral joint often occur after rotator cuff repair; however, the details of the progression and underlying causes remain unknown.

Purpose: To retrospectively evaluate the timing and frequency of radiographic changes after arthroscopic rotator cuff repair and to clarify the predictive factors that affect the onset of such changes using multivariate analysis.

Study Design: Case-control study; Level of evidence, 3.

Methods: We retrospectively reviewed 100 patients with 5 years of follow-up after arthroscopic rotator cuff repair and evaluated the postoperative shift in radiographic findings on plain radiographs every year during follow-up. Factors related to osteoarthritis, acromial spur re-formation, and greater tuberosity resorption at 5 years after surgery were evaluated using logistic regression analyses. Explanatory variables included preoperative factors, intraoperative factors, and postoperative retear. Baseline variables significant in the univariate analyses were included in the multivariate models.

Results: Of the 100 patients, 12 developed osteoarthritis, 26 developed acromial spur formation, and 16 developed greater tuberosity resorption at 5 years after surgery. The incidence and grade of osteoarthritis and acromial spur gradually increased over time postoperatively. On the other hand, greater tuberosity resorption developed within 2 years after surgery but did not progress later. Multivariate analysis showed that a larger anteroposterior tear size (odds ratio [OR], 1.09; 95% CI, 1.01-1.17; $P = .037$) was a risk factor for postoperative osteoarthritis. Early retear (OR, 10.26; 95% CI, 1.03-102.40; $P = .047$) was a risk factor for acromial spur re-formation. Roughness of the greater tuberosity (OR, 9.07; 95% CI, 1.13-72.82; $P = .038$) and larger number of suture anchors (OR, 3.34; 95% CI, 1.66-6.74; $P = .001$) were risk factors for greater tuberosity resorption.

Conclusion: Our study showed that radiographic changes occurred in 40% of patients within 5 years after arthroscopic rotator cuff repair. While the osteoarthritic changes and acromial spur re-formation gradually progressed postoperatively, the greater tuberosity resorption stopped within 2 years after surgery. Tear size, morphology of the greater tuberosity, and the number of suture anchors can affect radiographic changes. Furthermore, this study suggested that acromial spur re-formation may be an indicator of early retears.

Keywords: acromial spur; arthroscopy; bone resorption; osteoarthritis; radiographic change; rotator cuff repair

Arthroscopic rotator cuff repair for rotator cuff tears provides favorable long-term clinical outcomes.[18,26,38] However, postoperative radiographic changes, such as osteoarthritis of the glenohumeral joint,[1,12,16,25,28,29,36,53] re-formation of the acromial spur,[3,13] and bone resorption of the greater tuberosity,[4] frequently occur after rotator cuff repair. Postoperative glenohumeral osteoarthritis has been reported to be associated with retear and poor long-term clinical outcomes after rotator cuff repair.[12,16] Although the effect of acromial spur re-formation on long-term postoperative outcomes is unclear, there are some reports that acromial spur re-formation after acromioplasty causes shoulder pain or symptoms of subacromial impingement.[3,13] Bone resorption of the greater tuberosity may lose biomechanical fixation for possible revision or resurgery, while rotator cuff repair using biodegradable anchors has the advantage of preserving bone stock after rotator cuff repair.[22,23,37] Several studies to date have reported that bone resorption around the suture anchor has no significant effect on postoperative clinical outcomes[23,27,37]; however, there is 1 report showing the association of this radiological finding with the retear rate.[39]

Previous studies have shown that the frequency of osteoarthritis of the glenohumeral joint >5 years after rotator cuff repair was 17% to 29%[1,12,16,25,28]; however, the timing

The Orthopaedic Journal of Sports Medicine, 10(9), 23259671221126095
DOI: 10.1177/23259671221126095

of its appearance has not been well-documented. The frequency and pathogenesis of re-formation of an acromial spur remain poorly understood. Osteolysis around the suture anchors, which may be a precursor of greater tuberosity resorption, has been reported to occur gradually from 3 months postoperatively and increase up to 2 years postoperatively[45]; however, no studies have evaluated the long-term change of osteolysis around the anchors or greater tuberosity resorption. In addition, few studies have examined the risk factors for glenohumeral osteoarthritis after rotator cuff repair,[12,16,25] and factors affecting the re-formation of an acromial spur and bone resorption of the greater tuberosity remain unknown. Therefore, it is important to identify the timing of the appearance of these radiographic changes following rotator cuff repair and the risk factors for radiographic changes.

The purpose of this study was to determine the timing and frequency of these radiographic changes after arthroscopic rotator cuff repair and to clarify whether these changes progress over time. Further, we examined the factors affecting postoperative radiographic changes using multivariate analysis.

METHODS

Patient Selection

The study protocol was approved by the independent ethics committee of our hospital. This retrospective study involved patients who underwent arthroscopic rotator cuff repair between 2013 and 2017. We included patients who underwent arthroscopic rotator cuff repair for posterosuperior rotator cuff tears. Patients with subscapularis tendon tears were treated by open rotator cuff repair and were not included in this study. In addition, we excluded patients who were unable to continue follow-up with plain radiographs immediately after surgery and every year (once a year) for 5 years after surgery, patients who had undergone surgery of the affected upper extremity, and patients had preoperative osteoarthritic changes in the glenohumeral joint (Samilson-Prieto[12] grade $\geq$2). There were no age-related restrictions; however, the indication for surgery was a healthy patient who could be administered general anesthesia.

We identified 159 patients who met the inclusion criteria. Of these, we excluded 54 patients without follow-up every year for 5 years after surgery, 2 patients with a history of the affected upper limb surgery, and 3 patients with preoperative glenohumeral osteoarthritis. As a result, only 100 patients could be followed up with plain radiographs every year during the 5 years after surgery and were included in this study.

Surgical Procedure and Rehabilitation

Surgery was performed by a single orthopaedic surgeon (N.M.) with over 10 years of experience in shoulder surgery and over 500 surgeries for arthroscopic rotator cuff repair. All patients were placed in the beach-chair position under general anesthesia. First, intra-articular arthroscopy was performed. None of the patients had obvious cartilage lesions in the glenohumeral joint. Degeneration of the long head of biceps brachii was observed in 18 patients; however, additional biceps tenotomy or tenodesis was not performed for any of these patients. The subscapularis tendon was intact in all patients. The coracoacromial release was performed in all cases, regardless of the acromial type, and then the acromion spur was shaved until the trabecular bone was visible under the subacromial bursa view. Footprint preparation was limited to the removal of soft tissue remnants using a sharp curette and did not involve using a burr to shave cortical bone or create bone vents. In all cases, rotator cuff repair was performed using double-row technique with bioinductive suture anchors (Healix Advance BR Anchor; Mitek) [9] None of the patients underwent a transition from arthroscopic to open rotator cuff repair. The mean number of suture anchors used for surgery was 3.3 ± 1.5 (range, 2-8). The number of suture anchors was determined by the respective size of rotator cuff tear.

Postoperatively, the arm was immobilized in a brace for 1 month. Passive range of motion training was commenced 1 month after surgery, and active range of motion training was allowed 2 months after surgery. The patients were allowed to return to recreational activity with high demands on the shoulder or manual labor 6 months after surgery. To assess postoperative retear of the repaired rotator cuff, magnetic resonance imaging (MRI) scans were taken at 6, 12, and 24 months after surgery. To assess the radiographic progression of the glenohumeral joint, plain radiographs of the shoulder including anteroposterior and scapular-Y directions were taken immediately (within 2 weeks) and every year for 5 years after surgery. No revision surgery was needed or performed in the present cases.

Outcome Measures

We evaluated the postoperative change in glenohumeral osteoarthritis, acromial spur (anterior spur or lateral spur) re-formation, and bone resorption of the greater tuberosity on plain radiographs immediately and every year during the 5 years after surgery. Osteoarthritis of the

†Address correspondence to Noboru Matsumura, MD, PhD, Department of Orthopaedic Surgery, Keio University School of Medicine, 35 Shinanomachi, Shinjuku-ku, Tokyo, 160-8582, Japan (email: noboru18@gmail.com).

*Department of Orthopaedic Surgery, Keio University School of Medicine, Shinjuku-ku, Tokyo, Japan.

Final revision submitted July 12, 2022; accepted July 27, 2022.

One or more of the authors has declared the following potential conflict of interest or source of funding: This study was supported by Japan Society for the promotion of Science KAKENHI (grant No. JP20K09488). AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

Ethical approval for this study was obtained from the Keio University School of Medicine (ref No. 20130147).

glenohumeral joint was assessed according to the 4-stage Samilson-Prieto classification as modified by Goutallier.[2,41] Osteoarthritis was defined as Samilson-Prieto grade ≥2, similar to a previous study.[12] Consistent with an earlier study,[31] acromial anterior spurs were assessed using a radiograph in the scapular-Y view, and the length of a spur was defined as the distance from the point where the inclusion of the anterior edge of the acromion abruptly increased to the tip of the spur. Spurs of lengths <5, 5 to <10, and ≥10 mm were classified as small, medium, and large, respectively.[34] This study defined acromial anterior spur re-formation as a spur ≥5 mm. Acromial lateral spurs were defined as bony protrusions with a downward peak extending ≥3 mm from the lateral surface of the acromion on a radiograph in the anteroposterior view.[14,54] In addition, this study defined greater tuberosity resorption as flattening or depression of the greater tuberosity on a radiograph in the anteroposterior view.

In the analyses to examine the risk factors for postoperative radiographic changes, the dependent variables were osteoarthritis, acromial spur re-formation, and bone resorption of the greater tuberosity at 5 years after surgery. Since there were many cases in which both anterior and lateral spurs were combined postoperatively in this study, we evaluated patients with anterior or lateral spur as acromial spur re-formation. Explanatory variables included preoperative factors (age, sex, side of the affected shoulder, duration of symptoms, smoking history, presence of diabetes, morphology of the greater tuberosity, superior migration of the humeral head, and the length of the acromial spur), intraoperative factors (tear size and the number of suture anchors used in surgery), and postoperative factor (presence of early retear). One examiner (R.F.) with 10 years of experience in shoulder surgery with >100 rotator cuff repair surgeries, who was not involved in the surgery, evaluated the radiographic outcomes and medical history. Medical history was evaluated using clinical notes. Preoperative morphology of the greater tuberosity was classified into normal, spur, sclerosis, roughness, or femoralization based on a plain radiograph in anteroposterior view.[20] We defined superior migration of the humeral head as an acromohumeral interval of ≤6 mm.[15,30,52] Intraoperative assessment of the tear size was used to reduce any potential error from measurements taken from preoperative imaging. Tear size was measured in the anteroposterior and mediolateral dimensions. Based on a previous study,[25] retears were defined as tears with a severity corresponding to Sugaya type ≥4 on MRI findings within 2 years after surgery.[46] We also analyzed the risk factors for early retear, with early retear as the dependent variable and preoperative and intraoperative factors as the explanatory variables.

Statistical Analysis

All statistical analyses were conducted using SPSS software (Version 27.0; IBM). Cochran *Q* test with Bonferroni correction was used to evaluate the incidence of radiographic findings after rotator cuff repair. Compared with the state immediately postoperatively, radiographic changes at 1, 2, 3, 4, and 5 years after repair were evaluated. In the analyses of the risk factors for postoperative radiographic changes and early retear, Mann-Whitney *U* test was used to compare the average of continuous values (age, duration of symptoms, tear size, spur length, and the number of suture anchors). Fisher exact tests were used to compare the proportion of discrete variables (sex, side of the affected shoulder, duration of symptoms, smoking history, presence of diabetes, morphology of the greater tuberosity, superior migration of the humeral head, and retear). Significant baseline variables in univariate analyses were included in the multivariate models. Multivariate analyses were performed using logistic regression analysis to identify the independent predictors of radiographic changes and early retear after rotator cuff repair. The regression model fit was estimated using the Hosmer-Lemeshow goodness-of-fit test. The threshold for significance was set at $P \leq .05$.

TABLE 1
Patient Demographics (N = 100)[a]

Characteristic	Value
Age, years	63.3 ± 8.3 (46-87)
Female sex	38
Dominant arm affected	69
Duration of symptoms (years)	1.8 ± 3.4 (0.1-20)
History of trauma	73
History of smoking	46
Diabetes	13
Preoperative osteoarthritis[b]	0
Length of acromial spur, mm	
Anterior	2.3 ± 3.7 (0-17)
Lateral	1.2 ± 1.7 (0.8)
Morphology of greater tuberosity	
Sclerosis	35
Spur	7
Roughness	11
Femoralization	8
Superior migration of humeral head	12
Tear size, cm	
Anteroposterior	1.6 ± 1.1 (0-4.8)
Mediolateral	2.0 ± 1.4 (0-4.9)

[a]Data are presented as mean ± SD (range) or No. of patients.
[b]Modified Samilson-Prieto grade ≥2.

RESULTS

The mean patient age at the time of surgery was 63.3 ± 8.3 years, with 38 women and 62 men. The mean time from onset of symptoms to surgery was 1.8 ± 3.4 years. Overall, 73 patients had a history of trauma to the affected shoulder (Table 1).

The preoperative radiographic findings are presented in Table 1. Of the 100 patients, none had osteoarthritic changes in the glenohumeral joint that were higher than Samilson-Prieto grade 1. A preoperative anterior spur ≥5 mm was observed in 23 patients, and a lateral spur ≥3 mm was observed in 19 patients. Early retears (within 2 years after surgery) developed in 7 patients.

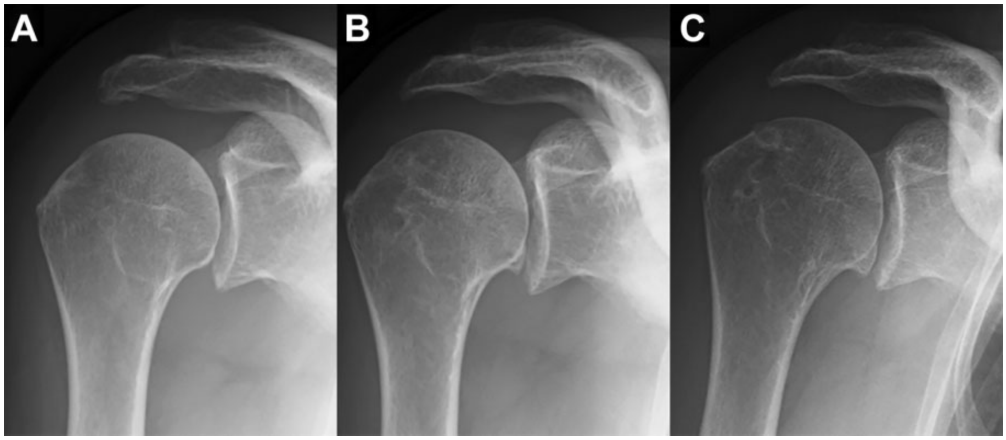

Figure 1. Plain radiographs of the right shoulder of a 57-year-old woman who underwent arthroscopic repair for a supraspinatus tear (A) before, (B) 1 year after, and (C) 5 years after surgery. These radiographs show that the glenohumeral joint, which had no preoperative osteoarthritic changes, developed a spur of the humerus (Samilson-Prieto grade 2) 1 year after surgery with further progression (Samilson-Prieto grade 3) 5 years postoperatively.

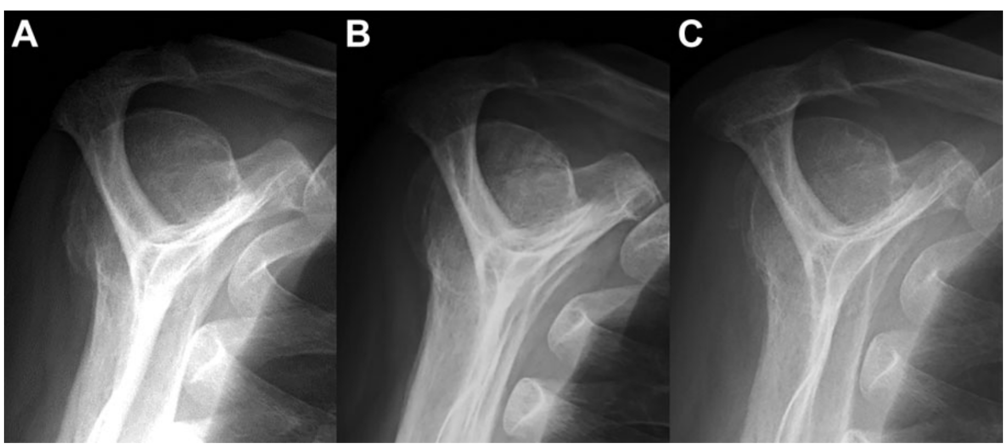

Figure 2. Plain radiographs of the right shoulder of a 67-year-old man who underwent arthroscopic repair for supraspinatus and infraspinatus tears (A) before, (B) 1 year after, and (C) 5 years after surgery. These radiographs show that the acromial anterior spur present preoperatively disappeared 1 year postoperatively but reformed 5 years postoperatively.

Five years after arthroscopic rotator cuff repair, osteoarthritis (Figure 1); anterior spur re-formation (Figure 2); lateral spur re-formation (Figure 3); and bone resorption of the greater tuberosity (Figure 4) occurred in 12, 21, 14, and 16 patients, respectively, and at least 1 of these aforementioned radiographic changes occurred in 40 patients. The incidence of osteoarthritis gradually increased from 1 year postoperatively, as indicated by the proportion of patients with Samilson-Prieto grades 3 or 4. At 5 years postoperatively, 7 patients were classified as having Samilson-Prieto grade 2, 2 patients as grade 3, and 3 patients as grade 4 (Figure 5A).

There were no patients with anterior spur $\geq$5 mm or lateral spur $\geq$3 mm immediately after surgery; however, the incidence of acromial spur re-formation increased gradually from the second postoperative year, and the frequency and mean length of the spur increased over time (Figure 5, B and C). Of the patients with acromial spur at 5 years postoperatively, 15 of 21 (71%) had a larger anterior spur than preoperatively, and 6 of 14 (43%) had a larger lateral spur than preoperatively. The incidence of osteoarthritis and anterior spur increased significantly at 4 years after surgery compared with immediately after surgery ($P < .001$) (Figure 5, A and B). The incidence of lateral spur increased significantly at 3 years after surgery compared with immediately after surgery ($P < .001$) (Figure 5C). Bone resorption of the greater tuberosity developed within 2 years after surgery, but it did not progress after the first 2 postoperative years (Figure 5D).

Risk Factors of Postoperative Osteoarthritis

Univariate analyses demonstrated that older age ($P = .050$), larger anteroposterior tear size ($P = .004$), larger

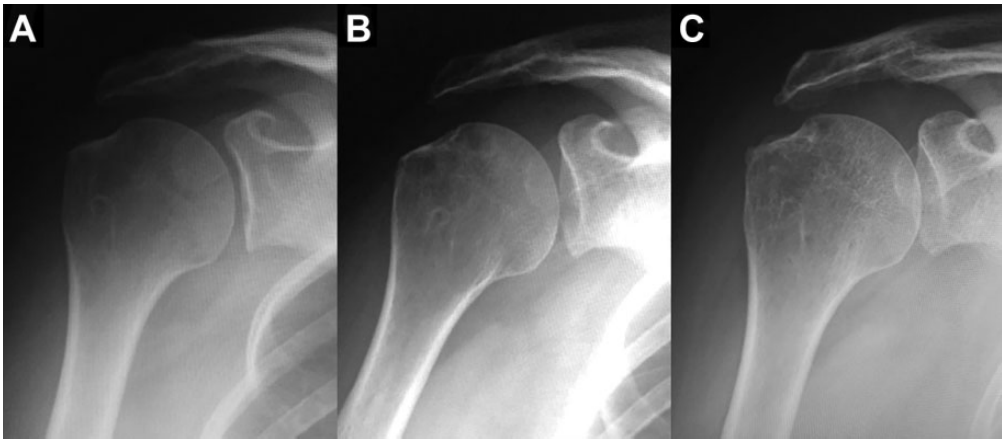

Figure 3. Plain radiographs of the right shoulder of a 50-year-old woman who underwent arthroscopic repair for supraspinatus tear (A) before, (B) 2 years after, and (C) 5 years after surgery. These radiographs show formation of the acromial lateral spur at 2 years postoperatively.

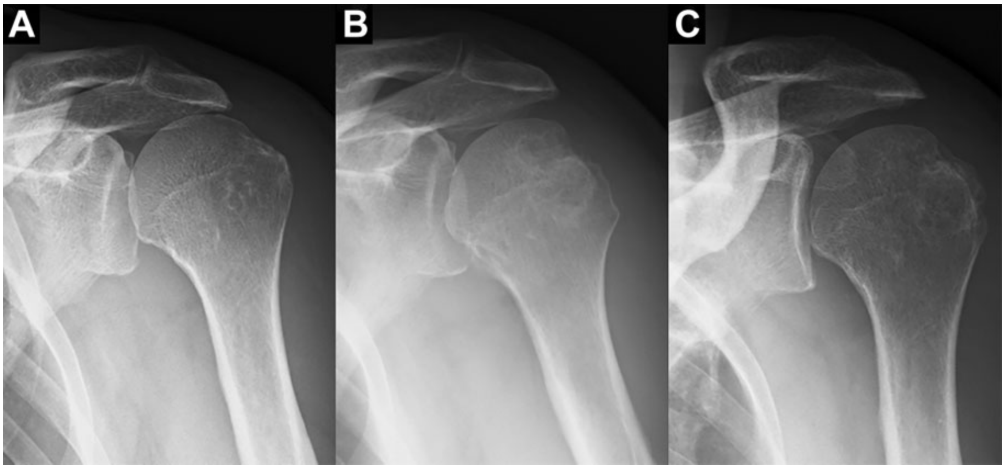

Figure 4. Plain radiographs of the left shoulder of a 51-year-old man who underwent arthroscopic repair for supraspinatus and infraspinatus tears using 6 suture anchors (A) before, (B) 1 year after, and (C) 5 years after surgery. These radiographs show bone resorption of the greater tuberosity at 1 year after surgery, with no further progression at 5 years postoperatively.

mediolateral tear size ($P = .004$), and a larger number of suture anchors ($P = .043$) were significantly associated with postoperative osteoarthritis after rotator cuff repair. Multivariate analysis showed that a larger anteroposterior tear size (odds ratio [OR], 1.09; 95% CI, 1.01-1.17; $P = .037$) was a risk factor for postoperative osteoarthritis. The Hosmer-Lemeshow goodness-of-fit test showed no significant difference from the good model fit ($P = .471$) (Table 2).

Risk Factors for Acromial Spur Re-formation (Anterior or Lateral)

Univariate analyses showed that the roughness of the greater tuberosity ($P = .032$), larger anteroposterior tear size ($P < .001$), larger mediolateral tear size ($P < .001$), a larger number of suture anchors ($P < .001$), and early retear ($P = .001$) were significantly associated with acromial spur formation after rotator cuff repair. Multivariate analysis showed that early retear (OR, 10.26; 95% CI, 1.03-102.40, $P = .047$) was a risk factor for acromial spur. The Hosmer-Lemeshow goodness-of-fit test showed no significant difference from the good model fit ($P = .419$) (Table 3).

Risk Factors of Bone Resorption of the Greater Tuberosity

Univariate analyses showed that the roughness of the greater tuberosity ($P < .001$), larger anteroposterior tear size ($P < .001$), larger mediolateral tear size ($P < .001$), and a larger number of suture anchors ($P < .001$) were significantly associated with bone resorption of the greater tuberosity after rotator cuff repair. Multivariate analysis showed that the roughness of the greater tuberosity (OR, 9.07; 95% CI, 1.13-72.82; $P = .038$) and a larger number of suture

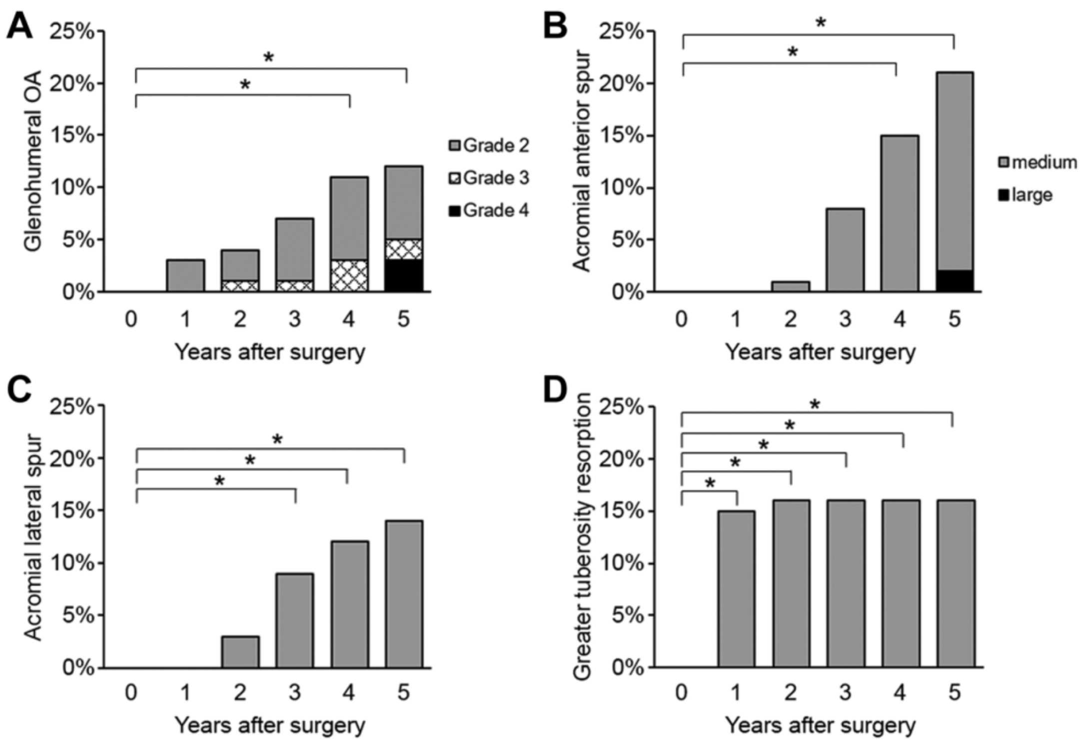

Figure 5. Changes after arthroscopic rotator cuff repair in (A) incidence of OA, (B) re-formation of acromial anterior spur and (C) acromial lateral spur, and (D) bone resorption of the greater tuberosity. OA grade is based on Goutallier modification of the 4-stage Samilson-Prieto classification. Anterior spurs with lengths of 5 to 10 and ≥10 mm were classified as medium and large, respectively. *Statistically significant difference compared with year 0 (time of surgery) ($P < .05$; Cochran *Q* test with Bonferroni correction). OA, osteoarthritis.

anchors (OR, 3.34; 95% CI, 1.66-6.74; $P = .001$) were risk factors for bone resorption of the greater tuberosity. The Hosmer-Lemeshow goodness-of-fit test showed no significant difference from the good model fit ($P = .741$) (Table 4).

Risk Factors of Early Retear

Univariate analyses showed that a shorter duration of symptom ($P = .005$), superior migration of humeral head ($P = .036$), larger anteroposterior tear size ($P = .029$), larger mediolateral tear size ($P = .001$), and a larger number of suture anchors ($P = .011$) were significantly associated with early retear after rotator cuff repair. Multivariate analysis showed that a larger mediolateral tear size (OR, 1.17; 95% CI, 1.01-1.35; $P = .035$) was a risk factor for early retear. The Hosmer-Lemeshow goodness-of-fit test showed no significant difference from the good model fit ($P = .244$) (Table 5).

DISCUSSION

In this study, we investigated the changes in plain radiographic findings during the 5 years after arthroscopic rotator cuff repair and conducted multivariate analyses to identify factors affecting these radiographic changes. As a result, we made 2 important clinical observations. First, osteoarthritis and acromial spurs appeared gradually and progressed after rotator cuff repair, whereas bone resorption of the greater tuberosity occurred within 2 years after rotator cuff repair and did not progress thereafter. Second, these radiographic changes showed significant associations with preoperative bone morphology of the greater tuberosity, tear size of the rotator cuff, the number of suture anchors used in surgery, and the presence of early retear.

This study demonstrated that osteoarthritis after rotator cuff repair developed gradually over time. Moreover, osteoarthritis in 11% of the patients progressed to Samilson-Prieto classification grade ≥2 at 5 years postoperatively. Our results concurred with those of previous studies that evaluated short-term radiological outcomes after rotator cuff repair and which indicated that osteoarthritis develops in 4% to 17% of patients during a follow-up period of 3.6 to 7 years after surgery.[28,29,53] In addition, previous studies that evaluated radiological outcomes for >10 years after surgery showed an increase in the incidence of osteoarthritis (up to 19%-29%) 10 to 20 years after surgery,[1,12,16,25] suggesting that the frequency and grade of osteoarthritis after rotator cuff repair may increase over time, even 5 years postoperatively.

To date, the relationship between osteoarthritis after rotator cuff repair and postoperative outcomes has not been fully clarified, and no case required additional surgery in the present study. However, some studies have reported

TABLE 2
Univariate and Multivariate Predictors of Osteoarthritis After Rotator Cuff Repair[a]

Variable	Univariate Predictors			Multivariate Predictors	
	Osteoarthritis (+) (n = 12)	Osteoarthritis (-) (n = 88)	P	OR [95% CI]	P
Age, years	68 [62-74]	63 [61-65]	.050[b]	1.08 [0.98-1.18]	.141
Female sex	5 (42)	33 (37)	.762	-	-
Dominant arm affected	9 (75)	60 (68)	.760	-	-
Duration of symptoms, y	2.5 [0-5.0]	1.7 [1.0-2.4]	.991	-	-
Trauma	9 (75)	64 (73)	≥.999	-	-
Smoking	5 (42)	41 (47)	≥.999	-	-
Diabetes	2 (17)	11 (13)	.653	-	-
Morphology of greater tuberosity					
Sclerosis	7 (58)	28 (32)	.105	-	-
Spur	1 (8)	6 (7)	≥.999	-	-
Roughness	2 (17)	9 (10)	.618	-	-
Femoralization	0 (0)	8 (9)	.591	-	-
Superior migration of humeral head	1 (8)	11 (13)	≥.999	-	-
Length of subacromial spur, mm					
Anterior	2.7 [0-5.4]	2.3 [1.5-3.1]	.832	-	-
Lateral	1.8 [0.5-3.2]	1.1 [0.8-1.4]	.178	-	-
Tear size, cm					
Anteroposterior	2.7 [2.1-3.3]	1.4 [1.2-1.6]	.004[b]	1.09 [1.01-1.17]	.037[b]
Mediolateral	3.1 [2.6-3.5]	1.9 [1.6-2.2]	.004[b]	1.01 [0.95-1.08]	.714
Suture anchors used in surgery	4.0 [3.3-4.7]	3.3 [2.9-3.7]	.043[b]	0.98 [0.59-1.63]	.940
Early retear	1 (8)	6 (7)	≥.999	-	-

[a]Values are presented as % [95%CI] or No. (%). Dashes indicated no analyses performed. OR, odds ratio.
[b]Statistically significant ($P \leq .05$).

TABLE 3
Univariate and Multivariate Predictors of Acromial Spur Re-formation After Rotator Cuff Repair[a]

Variable	Univariate Predictors			Multivariate Predictors	
	Spur (+) (n = 26)	Spur (-) (n = 74)	P	OR [95% CI]	P
Age, years	65 [62-68]	63 [61-65]	.311	-	-
Female sex	9 (35)	39 (53)	.170	-	-
Dominant arm affected	18 (69)	51 (69)	≥.999	-	-
Duration of symptoms (years)	2.0 [0.5-3.4]	1.7 [0.9-2.4]	.169	-	-
Trauma	22 (85)	51 (69)	.198	-	-
Smoking	14 (54)	32 (43)	.370	-	-
Diabetes	5 (19)	8 (11)	.321	-	-
Morphology of greater tuberosity					
Sclerosis	8 (31)	27 (36)	≥.999	-	-
Spur	3 (12)	4 (5)	.372	-	-
Roughness	6 (23)	5 (7)	.032[b]	2.44 [0.57-10.42]	.229
Femoralization	2 (8)	6 (8)	≥.999	-	-
Superior migration of humeral head	6 (23)	6 (8)	.074	-	-
Length of subacromial spur, mm					
Anterior	3.4 [1.7-5.2]	1.9 [1.2-2.6]	.661	-	-
Lateral	1.4 [0.6-2.1]	1.1 [0.8-1.5]	.843	-	-
Tear size, cm					
Anteroposterior	2.0 [1.6-2.4]	1.3 [1.0-1.6]	<.001[b]	0.98 [0.92-1.05]	.624
Mediolateral	2.9 [2.3-3.5]	1.7 [1.4-2.0]	<.001[b]	1.05 [0.99-1.11]	.099
Suture anchors used in surgery	4.2 [3.4-5.0]	3.0 [2.7-3.3]	<.001[b]	1.19 [0.80-1.79]	.393
Early retear	6 (23)	1 (1)	.001[b]	10.26 [1.03-102.40]	.047[b]

[a]Values are presented as % [95%CI] or No. (%). Dashes indicated no analyses performed. OR, odds ratio.
[b]Statistically significant ($P \leq .05$).

TABLE 4
Univariate and Multivariate Predictors of Greater Tuberosity Bone Resorption After Rotator Cuff Repair[a]

Variable	Univariate Predictors			Multivariate Predictors	
	Resorption (+) (n = 16)	Resorption (-) (n = 84)	P	OR [95% CI]	P
Age, years	62 [57-67]	64 [62-66]	.605	-	-
Female sex	6 (38)	32 (38)	≥.999	-	-
Dominant arm affected	8 (50)	23 (27)	.084	-	-
Duration of symptoms, years	1.6 [0.2-3.0]	1.8 [1.0-2.6]	.702	-	-
Trauma	13 (81)	60 (71)	.547	-	-
Smoking	8 (50)	38 (45)	.789	-	-
Diabetes	4 (25)	9 (11)	.215	-	-
Morphology of greater tuberosity					
Sclerosis	4 (25)	31 (37)	.409	-	-
Spur	3 (19)	4 (5)	.079	-	-
Roughness	7 (44)	4 (5)	<.001[b]	9.07 [1.13-72.82]	.038[b]
Femoralization	0 (0)	8 (10)	.438	-	-
Superior migration of humeral head	4 (25)	8 (10)	.098	-	-
Length of subacromial spur, mm					
Anterior	1.5 [0-3.0]	2.5 [1.7-3.3]	.180	-	-
Lateral	0.3 [0-0.5]	1.3 [1.0-1.7]	.080	-	-
Tear size, cm					
Anteroposterior	2.6 [2.0-3.2]	1.4 [1.2-1.6]	<.001[b]	1.06 [0.97 -1.15]	.182
Mediolateral	3.2 [2.8-3.6]	1.8 [1.5-2.1]	<.001[b]	0.97 [0.90 -1.06]	.530
Suture anchors used in surgery	5.5 [5.0-6.0]	2.9 [2.6-3.2]	<.001[b]	3.34 [1.66-6.74]	.001[b]
Early retear	2 (13)	5 (6)	.311	—	—

[a]Values are presented as % [95%CI] or No. (%). Dashes indicated no analyses performed. OR, odds ratio.
[b]Statistically significant ($P \leq .05$).

TABLE 5
Univariate and Multivariate Predictors of Early Retear After Rotator Cuff Repair[a]

Variable	Univariate Predictors			Multivariate Predictors	
	Early retear (+) (n = 7)	Early retear (-) (n = 93)	P	OR [95% CI]	P
Age, years	63 [58-69]	63 [62-65]	.882	-	-
Female sex	3 (43)	35 (38)	≥.999	-	-
Dominant arm affected	5 (71)	64 (69)	≥.999	-	-
Duration of symptoms, years	0.4 [0.3-0.6]	1.9 [1.2-2.6]	.005[b]	0.00 [0.00-5.90]	.125
Trauma	7 (100)	66 (71)	.185	-	-
Smoking	4 (57)	42 (45)	.234	-	-
Diabetes	1 (14)	12 (13)	≥.999	-	-
Morphology of greater tuberosity					
Sclerosis	2 (29)	33 (35)	≥.999	-	-
Spur	0 (0)	7 (8)	≥.999	-	-
Roughness	2 (29)	9 (10)	.17	-	-
Femoralization	0 (0)	8 (9)	≥.999	-	-
Superior migration of humeral head	3 (43)	9 (10)	.036[b]	5.33 [0.44-64.12]	.187
Length of subacromial spur, mm					
Anterior spur	3.3 [1.4-5.2]	2.3 [1.5-3.0]	.057	-	-
Lateral spur	0.4 [-0.5 to 1.3]	1.2 [0.9-1.6]	.146	-	-
Tear size, cm					
Anteroposterior	2.3 [1.9-2.8]	1.6 [1.3-1.8]	.029[b]	0.89 [0.77-1.04]	.137
Mediolateral	3.7 [3.2-4.2]	1.9 [1.6-2.2]	.001[b]	1.17 [1.01-1.35]	.035[b]
Suture anchors used in surgery	5.1 [3.5-6.7]	3.2 [2.9-3.4]	.011[b]	1.54 [0.76-3.11]	.234

[a]Values are presented as % [95%CI] or No. (%). Dashes indicated no analyses performed. OR, odds ratio.
[b]Statistically significant ($P \leq .05$).

that postoperative osteoarthritis is associated with poor functional outcomes[12,16]; therefore, it is important to identify factors affecting the onset of postoperative osteoarthritis. Our study showed that only the tear size of the rotator cuff was a risk factor for osteoarthritis 5 years after surgery. The results were similar to those of previous studies in which tear severity factors, such as massive rotator cuff tears and muscle atrophy, affected the progression of postoperative osteoarthritis.[12,16] Further, multivariate analysis performed in the present study showed that the anteroposterior tear size, but not mediolateral tear size, was significantly associated with postoperative osteoarthritis, suggesting that the anteroposterior dimension of tear length has a greater influence on the development of postoperative osteoarthritis than the mediolateral dimension. The number of suture anchors used, which is considered highly correlated with tear size, was also significantly associated with postoperative osteoarthritis in the univariate analysis, but not in the multivariate analysis. This suggests that tear size is a greater contributor to the development of postoperative osteoarthritis than the number of suture anchors. Early retears, older age, and male sex were also identified as risk factors for postoperative osteoarthritis in previous studies[12,16,25,36]; however, multivariate analysis of the present study showed no significant association between these factors and postoperative osteoarthritis. This may be due to the difference in the follow-up period of the patients between this study and the previous studies and the fact that the results of the previous studies were based on univariate analysis only.[12,16,25,36]

Acromial anterior spurs are thought to be traction spurs that developed at the insertion of the coracoacromial ligament to the acromion,[10] whereas lateral spurs are thought to result from mechanical stress caused by impingement of the greater tuberosity on the middle fiber of deltoid.[14] Both spurs have been associated with the presence of acromial impingement and rotator cuff tears.[14,31,32,49,50,54] However, the frequency of re-formation of an acromial spur after rotator cuff repair and its risk factors remain unclear. This study revealed that most acromial spurs gradually appeared since the third postoperative year and that the frequency at 5 years after surgery was 26%. In addition, this study showed an association between re-formation of acromial spurs and early retears within 2 years after surgery. To date, no study has evaluated the mechanism of acromial spur re-formation in patients who experienced retears. Previous studies have shown that patients with retears after rotator cuff repair exhibit a significant decrease in acromiohumeral distance.[19,55] This superior migration of the humeral head causes frequent acromial impingement,[6,34] which may be the underlying mechanism of acromial spur re-formation. While acromial anterior spurs measuring $\geq$5 mm or lateral spurs measuring $\geq$3 mm have been reported to be a diagnostic indicator of rotator cuff tears,[14,31] the present study highlighted the possibility that re-formation of acromial spurs after rotator cuff repair may be a result of early retears.

In addition, we found that 16% of patients experienced bone resorption of the greater tuberosity after rotator cuff repair, most of which appeared within 1 year after surgery. A previous study reported that the greater tuberosity presents with flattened and abnormal morphology after rotator cuff repair.[4] However, the pathogenesis of such radiographic changes in the greater tuberosity has not yet been clarified. We have 2 hypotheses regarding the development of greater tuberosity resorption, the first being inflammatory response to biodegradable anchors that is reflected in T2 signal hyperintensity around the suture anchor in the greater tuberosity on MRI.[4,22,23,27,37,39,42,45] This response lasts postoperatively and is thought to cause the osteolysis around suture anchors.[‡] This bone reaction to suture anchors may have contributed to the resorption of the greater tuberosity in the early postoperative period. Our second hypothesis concerns reduction in bone mineral density of the greater tuberosity in patients with rotator cuff tears. In these patients, the activation of osteoclasts,[11,51] and reduced mechanical stress by the rotator cuff tear,[5,17] caused greater tuberosity osteopenia, which may have contributed to the onset of bone resorption after surgery. The present study showed that the number of suture anchors used in surgery was significantly related to bone resorption in the greater tuberosity. In the cases that required more suture anchors, the bone reaction to suture anchors may have been stronger, which may have affected the greater tuberosity resorption.

Osteopenic changes in the greater tuberosity have been reported to be significantly remarkable in patients with moderate-to-severe retraction of the rotator cuff.[5] This low bone density of the greater tuberosity may be also related to postoperative bone resorption, as more suture anchor is required in cases with severe tendon retraction. In addition, the present study showed a significant association between the bone morphology of the greater tuberosity and greater tuberosity resorption. In patients with rotator cuff tears, chronic tensile overload and heterogeneous strain from the rotator cuff tendons are thought to lead to the formation of spurs and sclerosis of the greater tuberosity.[7,10,40] Furthermore, when the rotator cuff is torn, erosion of bone spurs or the sclerotic cortex gradually progresses due to acromial impingement, resulting in cortical surface roughness.[20] Our study, along with earlier studies, has raised the possibility that this erosion of the greater tuberosity may be further stimulated by inflammation associated with suture anchors, resulting in the progression of bone resorption. Although this bone reaction has been reported to occur in absorbable anchors more frequently than in nonabsorbable anchors,[27] the anchors used in this study, which contained 25% β-tricalcium phosphate, an osteoconductive material, were relatively less prone to bone reaction.[23] Further, there was no significant difference in the frequency of bone reaction around suture anchors compared to polyether ether ketone–type anchors[39]; therefore, the type of suture anchor (bioinductive anchor) has little influence on the results of this study. However, further studies are needed to clarify the effects of bone morphology of the greater tuberosity on postoperative bone resorption.

[‡]References 4, 22, 23, 27, 37, 39, 42, 44, 45.

Despite concerns about the adverse effects of greater tuberosity osteopenia and postoperative bone resorption on tendon healing,[5,39] the present study revealed that, unlike osteoarthritis changes or acromial spur re-formation, progression of bone resorption stopped 1 to 2 years after surgery and showed no significant association with early retears, suggesting that the number of suture anchors and bone morphology of the greater tuberosity may not adversely affect the postoperative outcomes.

Regarding early retear, contrary to the risk factor for postoperative osteoarthritis, mediolateral tear size, but not anteroposterior tear size, were identified as significant risk factors in the multivariate analysis results, which is consistent with previous reports.[8,21,24,33,35] It has been thought that rotator cuff retraction increases tension on the repaired tendon, resulting in poor footprint coverage, or reflects longer and worse tendon quality.[24,43,47] The results of this study suggest that patients with a large, intraoperatively observed mediolateral tear should be followed up with caution for retears.

Strengths and Limitations

This study has 2 major strengths. First, assessment of postoperative radiographic changes over time following rotator cuff repair was feasible in this study because imaging evaluation was performed every year for 1 to 5 years after surgery. Most of the previous studies examining radiographic outcomes after rotator cuff repair evaluated patients only at 1 point in the postoperative period.[1,12,16,25,29,53] Second, this study is novel in that it involved only patients who underwent arthroscopic rotator cuff repair using bioinductive anchors, while most of the previous studies only evaluated cases of open rotator cuff repair[16,25,29] and mixed cases of open and arthroscopic rotator cuff repair.[12]

This study had several limitations. First, this was an observational study; therefore, the results could be affected by residual confounding bias as the result of differences in factors that were not measured. For example, the shape of the tear (crescent tear, L- or U-shaped tear, or massive contracted tear) and muscle atrophy of the torn tendon can also influence the postoperative radiographic outcome; however, we could not evaluate these factors in this study. Second, we did not evaluate postoperative functional outcomes in this study. Since no patient with postoperative radiographic changes required reoperation, statistical significance may not imply clinical significance. Thus, the association between postoperative radiologic changes and functional outcomes remains unclear. Third, 54 patients were excluded because of inadequate follow-up, which may have affected the results of this study. Fourth, rotator cuff tears are generally atraumatic degenerative tears[48]; however, 73 cases in this study had a history of trauma. Although most of the traumas were minor, it may reduce the generalizability of the results. Fifth, identifying immediate postoperative radiographic changes suggestive of early retears would also be significant clinically, but we could not evaluate them due to a lack of frequent follow-up with plain radiography immediately after surgery (especially within 2 years postoperatively).

CONCLUSION

The results of our study showed that radiographic changes occurred in 40% of patients within 5 years after arthroscopic rotator cuff repair. While the osteoarthritic changes and acromial spur re-formation gradually progressed postoperatively, the greater tuberosity resorption stopped within 2 years after surgery. Tear size, the morphology of the greater tuberosity, and the number of suture anchors can affect radiographic changes. Furthermore, this study suggested that acromial spur re-formation may be an indicator of early retears.

REFERENCES

1. Adamson GJ, Tibone JE. Ten-year assessment of primary rotator cuff repairs. *J Shoulder Elbow Surg*. 1993;2(2):57-63.
2. Allain J, Goutallier D, Glorion C. Long-term results of the Latarjet procedure for the treatment of anterior instability of the shoulder. *J Bone Joint Surg Am*. 1998;80(6):841-852.
3. Anderson K, Bowen MK. Spur reformation after arthroscopic acromioplasty. *Arthroscopy*. 1999;15(7):788-791.
4. Beltran LS, Bencardino JT, Steinbach LS. Postoperative MRI of the shoulder. *J Magn Reson Imaging*. 2014;40(6):1280-1297.
5. Cadet ER, Hsu JW, Levine WN, Bigliani LU, Ahmad CS. The relationship between greater tuberosity osteopenia and the chronicity of rotator cuff tears. *J Shoulder Elbow Surg*. 2008;17(1):73-77.
6. Cholewinski JJ, Kusz DJ, Wojciechowski P, Cielinski LS, Zoladz MP. Ultrasound measurement of rotator cuff thickness and acromiohumeral distance in the diagnosis of subacromial impingement syndrome of the shoulder. *Knee Surg Sports Traumatol Arthrosc*. 2008;16(4):408-414.
7. Chuang HC, Hong CK, Hsu KL, Kuan FC, Lin CL, Su WR. The radiographic morphology of the greater tuberosity is associated with muscle degeneration in patients with symptomatic rotator cuff tears. *J Shoulder Elbow Surg*. 2019;28(10):1964-1970.
8. Chung SW, Oh JH, Gong HS, Kim JY, Kim SH. Factors affecting rotator cuff healing after arthroscopic repair: osteoporosis as one of the independent risk factors. *Am J Sports Med*. 2011;39(10):2099-2107.
9. Collin P, McCoubrey G, Lädermann A. Posterosuperior rotator cuff repair by an independent double-row technique. Technical note and radiological and clinical results. *Orthop Traumatol Surg Res*. 2016;102(3):405-408.
10. Cone RO III, Resnick D, Danzig L. Shoulder impingement syndrome: radiographic evaluation. *Radiology*. 1984;150(1):29-33.
11. Ditsios K, Boyer MI, Kusano N, Gelberman RH, Silva MJ. Bone loss following tendon laceration, repair and passive mobilization. *J Orthop Res* 2003;21(6):990-996.
12. Flurin PH, Hardy P, Valenti P, et al. Osteoarthritis after rotator cuff repair: a 10-year follow-up study. *Orthop Traumatol Surg Res*. 2017;103(4):477-481.
13. Friedman RL, Morrison DS. Recurrent acromial bone spur after open subacromial decompression. *J Shoulder Elbow Surg*. 1995;4(6):468-471.
14. Fujisawa Y, Mihata T, Murase T, Sugamoto K, Neo M. Three-dimensional analysis of acromial morphologic characteristics in patients with and without rotator cuff tears using a reconstructed computed tomography model. *Am J Sports Med*. 2014;42(11):2621-2626.
15. Gruber G, Bernhardt GA, Clar H, Zacherl M, Glehr M, Wurnig C. Measurement of the acromiohumeral interval on standardized anteroposterior radiographs: a prospective study of observer variability. *J Shoulder Elbow Surg*. 2010;19(1):10-13.
16. Herve A, Thomazeau H, Favard L, et al. Clinical and radiological outcomes of osteoarthritis twenty years after rotator cuff repair. *Orthop Traumatol Surg Res*. 2019;105(5):813-818.

17. Jiang Y, Zhao J, van Holsbeeck MT, Flynn MJ, Ouyang X, Genant HK. Trabecular microstructure and surface changes in the greater tuberosity in rotator cuff tears. *Skeletal Radiol*. 2002;31(9):522-528.
18. Johannsen AM, Arner JW, Elrick BP, et al. Minimum 10-year outcomes of primary arthroscopic transosseous-equivalent double-row rotator cuff repair. *Am J Sports Med*. 2021;49(8):2035-2041.
19. Jost B, Zumstein M, Pfirrmann CWA, Gerber C. Long-term outcome after structural failure of rotator cuff repairs. *J Bone Joint Surg Am*. 2006;88(3):472-479.
20. Kawashima K, Sugaya H, Takahashi N, et al. Relationship between the morphology of the greater tuberosity and radiological and clinical outcomes after arthroscopic rotator cuff repair. *JSES Int*. 2021;5(3): 493-499.
21. Kim IB, Jung DW. A rotator cuff tear concomitant with shoulder stiffness is associated with a lower retear rate after 1-stage arthroscopic surgery. *Am J Sports Med*. 2018;46(8):1909-1918.
22. Kim SH, Oh JH, Lee OS, Lee HR, Hargens AR. Postoperative imaging of bioabsorbable anchors in rotator cuff repair. *Am J Sports Med*. 2014;42(3):552-557.
23. Kim SH, Kim DY, Kwon JE, Park JS, Oh JH. Perianchor cyst formation around biocomposite biodegradable suture anchors after rotator cuff repair. *Am J Sports Med*. 2015;43(12):2907-2912.
24. Kim YK, Jung KH, Kim JW, Kim US, Hwang DH. Factors affecting rotator cuff integrity after arthroscopic repair for medium-sized or larger cuff tears: a retrospective cohort study. *J Shoulder Elbow Surg*. 2018;27(6):1012-1020.
25. Matsuba T, Hata Y, Ishigaki N, Nakamura K, Kato H. Osteoarthritis progression of the shoulder: a long-term follow-up after mini-open rotator cuff repair. *J Orthop Surg (Hong Kong)*. 2018;26(2): 2309499018768106.
26. Millett PJ, Horan MP, Maland KE, Hawkins RJ. Long-term survivorship and outcomes after surgical repair of full-thickness rotator cuff tears. *J Shoulder Elbow Surg*. 2011;20(4):591-597.
27. Micic I, Kholinne E, Kwak JM, Koh KH, Jeon IH. Osteolysis is observed around both bioabsorbable and nonabsorbable anchors on serial magnetic resonance images of patients undergoing arthroscopic rotator cuff repair. *Acta Orthop Traumatol Turc*. 2019;53(6):414-419.
28. Neer CS II, Craig EV, Fukuda H. Cuff-tear arthropathy. *J Bone Joint Surg Am*. 1983;65(9):1232-1244.
29. Nich C, Mütschler C, Vandenbussche E, Augereau B. Long-term clinical and MRI results of open repair of the supraspinatus tendon. *Clin Orthop Relat Res*. 2009;467(10):2613-2622.
30. Nové-Josserand L, Edwards TB, O'Connor DP, Walch G. The acromiohumeral and coracohumeral intervals are abnormal in rotator cuff tears with muscular fatty degeneration. *Clin Orthop Relat Res*. 2005; 433:90-96.
31. Ogawa K, Yoshida A, Inokuchi W, Naniwa T. Acromial spur: relationship to aging and morphologic changes in the rotator cuff. *J Shoulder Elbow Surg*. 2005;14(6):591-598.
32. Oh JH, Kim JY, Lee HK, Choi JA. Classification and clinical significance of acromial spur in rotator cuff tear: heel-type spur and rotator cuff tear. *Clin Orthop Relat Res*. 2010;468(6):1542-1550.
33. Oh JH, Kim SH, Kang JY, Oh CH, Gong HS. Effect of age on functional and structural outcome after rotator cuff repair. *Am J Sports Med*. 2010;38(4):672-678.
34. Park HJ, Lee SY, Choi YJ, Park JH, Kim E. Association between subacromial impingement and acromiohumeral distance on MRI. *Iran J Radiol*. 2018;15(2):e13811.
35. Park JH, Oh KS, Kim TM, et al. Effect of smoking on healing failure after rotator cuff repair. *Am J Sports Med*. 2018;46(12):2960-2968.
36. Paxton ES, Teefey SA, Dahiya N, Keener JD, Yamaguchi K, Galatz LM. Clinical and radiographic outcomes of failed repairs of large or massive rotator cuff tears: minimum ten-year follow-up. *J Bone Joint Surg Am*. 2013;95(7):627-632.
37. Pilge H, Spang J, Rose T, Wolter H, Woertler K, Imhoff AB. Osteolysis after rotator cuff repair with bioabsorbable anchors. *Arch Orthop Trauma Surg*. 2012;132(3):305-310.
38. Plachel F, Traweger A, Vasvary I, Schanda JE, Resch H, Moroder P. Long-term results after arthroscopic transosseous rotator cuff repair. *J Shoulder Elbow Surg*. 2019;28(4):706-714.
39. Ro K, Pancholi S, Son HS, Rhee YG. Perianchor cyst formation after arthroscopic rotator cuff repair using all-suture-type, bioabsorbable-type, and PEEK-type anchors. *Arthroscopy*. 2019;35(8):2284-2292.
40. Rockwood CA, Lyons FR. Shoulder impingement syndrome: diagnosis, radiographic evaluation, and treatment with a modified Neer acromioplasty. *J Bone Joint Surg Am*. 1993;75(3):409-424.
41. Samilson RL, Prieto V. Dislocation arthropathy of the shoulder. *J Bone Joint Surg Am*. 1983;65(4):456-460.
42. Samim M, Beltran L. The postoperative rotator cuff. *Magn Reson Imaging Clin N Am*. 2020;28(2):181-194.
43. Shin YK, Ryu KN, Park JS, Jin W, Park SY, Yoon YC. Predictive factors of retear in patients with repaired rotator cuff tear on shoulder MRI. *AJR Am J Roentgenol*. 2018;210(1):134-141.
44. Spielmann AL, Forster BB, Kokan P, Hawkins RH, Janzen DL. Shoulder after rotator cuff repair: MR imaging findings in asymptomatic individuals–-initial experience. *Radiology*. 1999;213(3):705-708.
45. Stahnke K, Nikulka C, Diederichs G, Haneveld H, Scheibel M, Gerhardt C. Serial MRI evaluation following arthroscopic rotator cuff repair in double-row technique. *Arch Orthop Trauma Surg*. 2016; 136(5):665-672.
46. Sugaya H, Maeda K, Matsuki K, Moriishi J. Functional and structural outcome after arthroscopic full-thickness rotator cuff repair: single-row versus dual-row fixation. *Arthroscopy*. 2005;21(11):1307-1316.
47. Tashjian RZ, Hollins AM, Kim HM, et al. Factors affecting healing rates after arthroscopic double-row rotator cuff repair. *Am J Sports Med*. 2010;38(12):2435-2442.
48. Tashjian RZ. Epidemiology, natural history, and indications for treatment of rotator cuff tears. *Clin Sports Med*. 2012;31(4):589-604.
49. Tucker TJ, Snyder SJ. The keeled acromion: an aggressive acromial variant–-a series of 20 patients with associated rotator cuff tears. *Arthroscopy*. 2004;20(7):744-753.
50. van der Reijden JJ, Nienhuis SL, Somford MP, et al. The value of radiographic markers in the diagnostic work-up of rotator cuff tears, an arthroscopic correlated study. *Skeletal Radiol*. 2020;49(1):55-64.
51. Waldorff EI, Lindner J, Kijek TG, et al. Bone density of the greater tuberosity is decreased in rotator cuff disease with and without full-thickness tears. *J Shoulder Elbow Surg*. 2011;20(6):904-908.
52. Werner CM, Conrad SJ, Meyer DC, Keller A, Hodler J, Gerber C. Intermethod agreement and interobserver correlation of radiologic acromiohumeral distance measurements. *J Shoulder Elbow Surg*. 2008;17(2):237-240.
53. Yamaguchi H, Suenaga N, Oizumi N, Hosokawa Y, Kanaya F. Open repair for massive rotator cuff tear with a modified transosseous-equivalent procedure: preliminary results at short-term follow-up. *J Orthop Sci*. 2011;16(4):398-404.
54. Yoon TH, Choi CH, Kim SJ, Choi YR, Yoon SP, Chun YM. Attrition of rotator cuff without progression to tears during 2-5 years of conservative treatment for impingement syndrome. *Arch Orthop Trauma Surg*. 2019;139(3):377-382.
55. Zingg PO, Jost B, Sukthankar A, Buhler M, Pfirrmann CW, Gerber C. Clinical and structural outcomes of nonoperative management of massive rotator cuff tears. *J Bone Joint Surg Am*. 2007;89(9): 1928-1934.