Long-term Results of Arthroscopic Rotator Cuff Repair: Initial Tear Size Matters

A Prospective Study on Clinical and Radiological Results at a Minimum Follow-up of 10 Years

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Background: Arthroscopic techniques are now considered the gold standard for treatment of most rotator cuff (RC) tears; however, no consensus exists on the maintenance of results over time, and long-term follow-up data have been reported for few cohorts of patients.

Purpose: To present the long-term results associated with the arthroscopic treatment of RC tears and to evaluate associations between preoperative factors and RC integrity at final follow-up.

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

Methods: A total of 169 patients were contacted at least 10 years after arthroscopic RC surgery and were invited to a clinical evaluation. Information on preoperative conditions, tear size, subjective satisfaction, and functional scores was collected; isometric strength and range of motion were also measured; and each patient underwent an ultrasound examination to evaluate supraspinatus integrity and a shoulder radiograph to evaluate osteoarthritis.

Results: A total of 149 patients (88.2% of the eligible patients) were available for a complete telephonic interview, and 102 patients were available for the final evaluation. Ultrasound revealed an intact supraspinatus in 54 patients (53.47%). By adding the 10 patients who underwent revision surgery to the nonintact group, this percentage would drop to 48.65%. Tear size was associated with supraspinatus integrity in univariate analysis (hazard ratio, 3.04; 95% CI, 1.63-5.69; $P = .001$) and multivariable analysis (hazard ratio, 2.18; 95% CI, 1.03-4.62; $P = .04$). However, no significant differences were encountered in the subjective and functional scores collected, with the exception of the Constant-Murley Score, which was significantly higher in patients with smaller tears at the index procedure. Strength testing also revealed significantly superior abduction and flexion strength in this group, and radiographs showed a significantly higher acromion-humeral distance and lower grades of osteoarthritis. Patients with an intact supraspinatus at final follow-up showed superior results in all functional scores, greater satisfaction, superior abduction and flexion strength, higher acromion-humeral distance, and lower grades of osteoarthritis.

Conclusion: RC tear size at the time of surgery significantly affects supraspinatus integrity at a minimum follow-up of 10 years. However, a larger tear is not associated with an inferior subjective result, although it negatively influences abduction and flexion strength, range of motion, and osteoarthritis progression. Intraoperative efforts to obtain a durable RC repair are encouraged, since supraspinatus integrity at final follow-up influences clinical and functional outcomes, patient satisfaction, and osteoarthritis progression.

Keywords: shoulder; rotator cuff repair; arthroscopy; ultrasound; long term

Surgical management of rotator cuff (RC) tears is evolving rapidly, and the number of publications regarding arthroscopic RC repair increases dramatically every year.[32] Arthroscopic techniques are now considered the gold standard for treatment of most RC tears, providing similar functional results to open and mini-open surgery, with a decrease in postoperative complications.[46]

Various treatment modalities can be performed arthroscopically, and most publications report satisfactory results at short-term (<2 years) follow-up evaluation. However, no consensus exists on the maintenance of results over time, and long-term (>5 years) follow-up data have been reported

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only for few cohorts of patients.[46] The goal of this study is to present the long-term results associated with the arthroscopic treatments of RC tears to provide clinicians and researchers with an updated standpoint about the results of arthroscopic RC management.

METHODS

The primary aim of this prospective observational clinical trial on a historical cohort was to measure the proportion of patients who still presented an intact supraspinatus tendon (SSp) at least 10 years after arthroscopic RC repair. The secondary goal was to evaluate associations between preoperative conditions and integrity at a minimum follow-up of 10 years. Finally, functional and radiological outcomes were compared between patients with and without intact SSp and between patients whose tear was classified as small (C1-C2 according to the Southern California Orthopaedic Institute [SCOI] classification system[45]) and large (C3-C4) during procedures for arthroscopic RC repair.

The study protocol was approved by the regional ethical committee (Ospedale San Raffaele–IRCCS, Lombardia, Milan, 98/int/2015, September 10, 2015; amendment 1, March 9, 2017; Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico–Milano Area 2, Lombardia, Milan, 123/2017, February 27, 2017).

Technique

Surgery was performed with the patient under sedation and with a brachial plexus block, and in a lateral decubitus position, with the upper limb kept at about 30° of abduction and 30° of flexion. Diagnostic arthroscopy was performed from standard posterior, midglenoid, and lateral portals; the size of the tear was classified according to the SCOI classification.[45] The tendon was repaired by use of double- or triple-loaded suture anchors (Corkscrew Suture Anchors; Arthrex, Inc). A standard single-row suture anchor repair was used in all patients. Acromioplasty was performed with the Sampson cutting block technique in patients with type 2 or 3 acromial morphology according to the Bigliani classification. A single surgeon (P.S.R.) performed all operations.

After the operation, all patients wore an arm sling day and night for 4 weeks; during that period, the sling was removed only to eat and perform personal hygiene and light exercises for mobilization of the elbow and scapulothoracic joint. From the 29th day, unless otherwise indicated, patients began passive physical therapy to recover the full range of motion of the shoulder joint. From the end of the second month, patients started active physical therapy, lasting 4 weeks, to regain muscle strength.

Patients who underwent arthroscopic treatment of RC tears between January 2002 and July 2007 were prospectively evaluated from January 2014 to July 2017 (D.C., F.M.F., M.M.). Patients who received arthroscopic treatment of degenerative shoulder conditions not including tendon repair (eg, isolated tenotomy or tenodesis of the long head of the biceps tendon, subacromial decompression, removal of loose bodies or articular debridement, arthroscopic needling of calcific tendinitis) were not included in this study, as well as patients with isolated subscapularis tears, patients who received arthroscopic treatment for labral lesion or fracture sequelae, and patients who received arthroscopically assisted mini-open RC repair.

At least 10 years after surgery, a telephone interview was conducted to inquire if the patient had undergone reoperation of the index shoulder; to collect Simple Assessment Numeric Evaluation, Numeric Rating Scale, American Shoulder and Elbow Surgeons,[37] and Simple Shoulder Test[29] scores; to assess satisfaction; and to invite each patient to a functional and radiological evaluation.

During the clinical evaluation, the Constant-Murley Score[9] (CMS) was collected and isometric strength in shoulder forward flexion and abduction was measured. All measures were performed in triplicate with a dynamometer (Kern HCB; Kern & Sohn GmbH).

Each patient also underwent a shoulder radiograph (standard true anteroposterior and lateral views) and an ultrasound examination of the RC (E.N., A.A.), performed with the high-frequency linear transducer (12.5 MHz) of a Samsung RS80A Prestige ultrasound system. Ultrasound was chosen because it is fast, thus increasing patients' compliance with follow-up; it is cost-effective; and its reliability in evaluating RC integrity was already evaluated at midterm follow-up.[18,19,25] Furthermore, ultrasound agreement with magnetic resonance imaging (MRI) was proven to be high in evaluating RCs at midterm follow-up.[25,49]

The ultrasound examination was performed by a dedicated musculoskeletal radiologist (E.N.) and used to define tendon integrity as a dichotomous variable: an intact SSp

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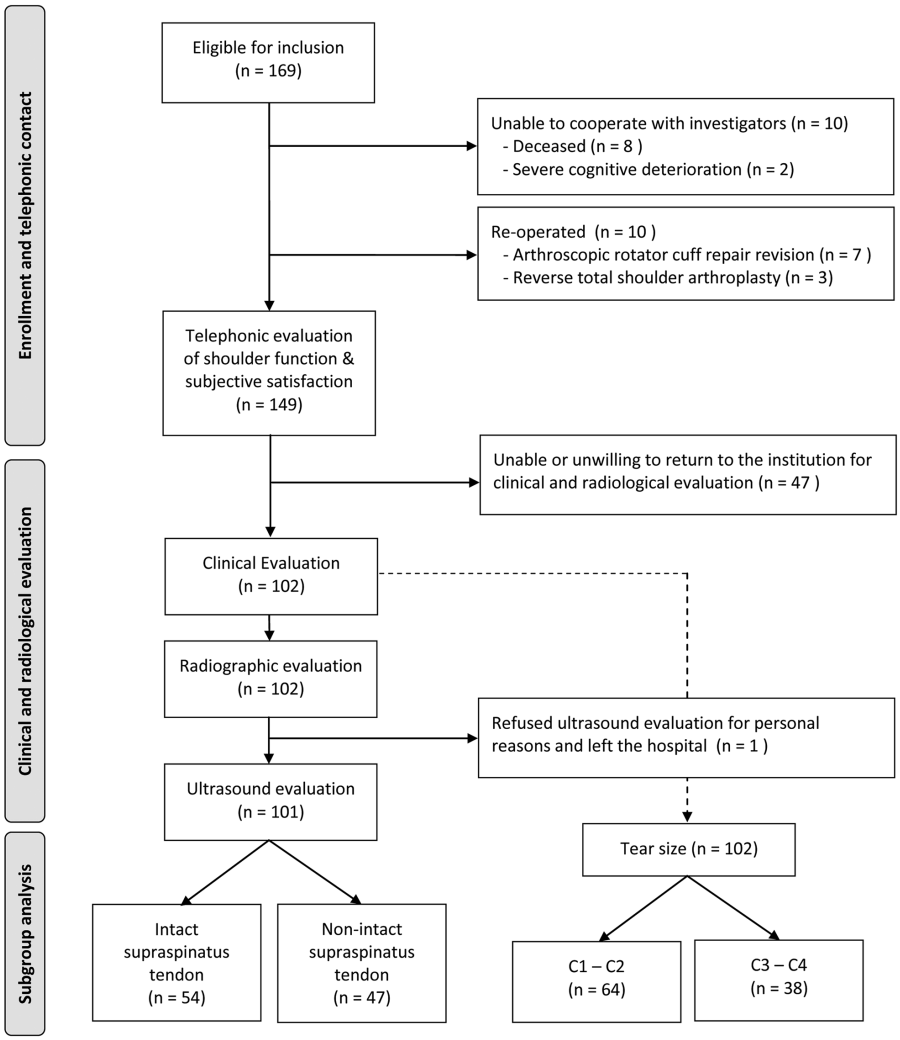

Figure 1. Flow diagram of the study. C1-C2, small tear size; C3-C4, large tear size.

was defined as such if the fibers were continuous for the full tendon thickness and throughout its course, up to the tendon footprint; a tendon presenting with a complete interruption of the fibers or with a hypoechoic area >1 cm was defined as nonintact.

On standard anteroposterior shoulder views, the acromiohumeral distance was measured, and the presence of shoulder osteoarthritis (OA) was classified according to the classifications of Hamada et al[20] and Samilson and Prieto.[42]

Statistical Analysis

A power analysis before the study began indicated that a minimal sample size of 100 patients was sufficient to test the hypothesis that the proportion of patients who still presented an intact SSp at least 10 years after arthroscopic RC repair was ≥70% of the total group, achieving a 2-sided 95% CI with an amplitude of 18% (0.61-0.79; Gaussian approximation). The figure of 70% was chosen per previous reports on midterm follow-up results.[18]

Statistical analysis (A.M., S.B., F.A.) was performed with GraphPad Prism software (v 6.0; GraphPad Software Inc) and SAS software (v 9.4; SAS Institute, Inc).

The differences between the groups of patients for continuous variables were evaluated with the unpaired Student *t* test or Mann-Whitney test according to the characteristics of the data distribution. Categorical variables were evaluated with the chi-square test or Fisher exact test.

The proportional hazards regression model for interval-censored current time-to-event data was used to estimate univariate and multivariate hazard ratios (HRs) for evaluating the association between covariates and SSp integrity.[47] We refer to current status data for patients of this study, as only 1 clinical visit was performed to evaluate the integrity state of SSp after 10 years of follow-up. The exact time of any new lesions is not known. For all analyses, the significance level was set at $P < .05$.

TABLE 1
Patient Characteristics[a]

	Median [Q1-Q3] or Frequency Ratio
Age at surgery, y	60.13 [54.76-65.54]
Body mass index, kg/m^2	25.61 [23.62-28.41]
Female:male	0.54:0.46
Side, left:right	
Operated	0.28:0.72
Dominant	0.02:0.98
Tear size, C1-C2:C3-C4	0.62:0.38
Smoking, yes:no	
At surgery	0.20:0.80
At follow-up	0.15:0.85
Diabetes mellitus, yes:no	
At surgery	0.06:0.94
At follow-up	0.18:0.82
Trauma, yes:no	0.08:0.92

[a]C1-C2, small tear size; C3-C4, large tear size; Q1, first quartile; Q3, third quartile.

RESULTS

A total of 169 patients were eligible for clinical evaluation. A flow diagram illustrates the grouping and flow of patients in our clinical study (Figure 1).

Eight patients died during the follow-up period for reasons not related to the RC pathology, whereas 2 developed severe cognitive deterioration and could not collaborate with data collection; 10 patients underwent a reoperation during the follow-up period (arthroscopic revision of the arthroscopic RC repair in 7 cases and reverse total shoulder arthroplasty in 3). Of these patients, 4 had a small RC tear (C1-C2) and 6 a large one (C3-C4); these patients were not included in the subsequent clinical and radiological analysis.

A total of 149 patients (88.2% of the eligible patients) were available for a complete telephone interview (mean ± SD: Simple Assessment Numeric Evaluation, 80.68 ± 25.35 points; Numeric Rating Scale, 1.79 ± 2.69 points; American Shoulder and Elbow Surgeons, 84.85 ± 26.61 points; Simple Shoulder Test, 10.44 ± 3.45 points), and 102 patients (68% of the patients contacted by telephone and 60.1% of the eligible patients) also agreed to return to our institution for clinical and radiological evaluation (median follow-up, 11.5 years). One patient refused the ultrasound evaluation. Demographic data of the patients who received a clinical assessment are reported in Table 1.

Supraspinatus Integrity

Ultrasound evaluation of 101 patients revealed an intact SSp prevalence of 53.47%. By adding to the nonintact group the 10 patients who underwent revision surgery, this percentage would drop to 48.65%.

The association between possible risk factors and SSp integrity was evaluated with Cox regression models (Table 2) for current status data. Tear size was associated with SSp integrity in univariate analysis (HR, 3.04; 95% CI, 1.63-5.69; $P = .001$) and multivariable analysis (HR, 2.18; 95% CI, 1.03-4.62; $P = .04$). Concerning age, sex, operated side, body mass index, smoking habits, and diabetes, there was no evidence of association with RC integrity 10 years after repair. The final Hamada grade was also significantly associated with SSp integrity in univariate analysis (HR, 6.32; 95% CI, 3.32-12.03; $P < .001$) and multivariable analysis (HR, 5.07; 95% CI, 2.21-11.64; $P < .001$), while Samilson-Prieto grade and acromiohumeral distance were significant only in the univariate model.

Subgroup Analysis

Tear Size. A stratified analysis of study populations was subsequently performed, and the patients available for clinical follow-up were further divided into 2 groups according to the tear size as classified during surgery (small, C1-C2; large, C3-C4), and their demographic, clinical, and radiological data were compared (Tables 3 and 4). Patients with smaller tears (C1-C2) were younger at the moment of intervention and showed a superior proportion of an intact RC at final follow-up.

However, no significant differences were encountered in the clinical and functional scores collected, with the exception of the CMS and the Simple Shoulder Test (Figure 2; Appendix Figures A1-A10, available in the online version of this article).

Strength testing revealed superior abduction and flexion strength in the C1-C2 group (Appendix Figures A11-A14, available online). A higher acromiohumeral distance and lower grades of OA according to the Samilson-Prieto and Hamada classifications were registered in the C1-C2 group (Figures 3 and 4).

Supraspinatus Integrity at Final Follow-up. According to SSp integrity at final follow-up, patients were subsequently divided in 2 groups (intact, nonintact), and their demographic, clinical, and radiological data were compared (Appendix Tables A1 and A2, available online). Patients with intact SSp were younger at the moment of intervention and showed superior results in all scores, with the exception of the Numeric Rating Scale. Strength testing revealed a superior abduction and flexion strength in the intact SSp group (Appendix Figures A15-A28, available online).

A higher acromiohumeral distance and lower grades of OA according to the Hamada and Samilson-Prieto classifications were registered in the intact SSp group (Figures 5 and 6).

DISCUSSION

This study has 4 main findings. First, tear size at surgery was associated with SSp integrity at a minimum follow-up of 10 years. Specifically, patients with larger (C3-C4) tears, had a 2.18-higher risk of presenting a nonintact RC during follow-up. Second, a difference in CMS, strength, range of motion, and OA progression, but not in subjective scores, was identified between patients with small (C1-C2) and large (C3-C4) RC tears. Third, the proportion of patients who still had an intact SSp at least 10 years after

TABLE 2
Hazard Ratios and 95% CIs for Nonintegrity of the Supraspinatus at Final Follow-up[a]

	Hazard Ratio (95% CI)			
	Univariate	*P* Value	Multivariate	*P* Value
Age at surgery, y				
≤60	Ref			
>60	1.62 (0.88-2.98)	.12		
Sex, %				
Female	Ref			
Male	1.19 (0.64-2.20)	.58		
BMI, kg/m^2				
Normal weight	Ref			
Overweight	1.12 (0.61-2.05)	.72		
Smoking				
No	Ref			
Yes	0.87 (0.39-1.91)	.72		
Diabetes				
No	Ref			
Yes	1.83 (0.61-5.51)	.28		
Side of surgery				
Opposite	Ref			
Dominant	1.02 (0.52-2.01)	.95		
Tear size				
C1-C2	Ref		Ref	
C3-C4	3.04 (1.63-5.69)	**.001**	2.18 (1.03-4.62)	**.04**
ASES score				
≤90	Ref			
>90	0.62 (0.34-1.13)	.12		
Hamada grade				
1	Ref		Ref	
>1	6.32 (3.32-12.03)	<**.001**	5.07 (2.21-11.64)	<**.001**
Samilson-Prieto grade				
0	Ref		Ref	
≥1	1.94 (1.06-3.55)	**.03**	0.91 (0.43-1.97)	.82
AHD				
>8.6	Ref		Ref	
≤8.6	3.63 (1.89-7.01)	<**.001**	0.74 (0.31-1.73)	.48

[a]Bold indicates $P < .05$. ASES, American Shoulder and Elbow Surgeons score; AHD, acromiohumeral distance; BMI, body mass index; C1-C2, small tear size; C3-C4, large tear size; HR, hazard ratio; Ref, reference.

TABLE 3
Subgroup Analysis: Tear Size and Patient Characteristics[a]

	Median [Q1-Q3] or Frequency Ratio		
Group	C1-C2	C3-C4	*P* Value
Age at surgery, y	58.12 [53.03-62.70]	64.56 [57.75-69.10]	**.0004**
Body mass index, kg/m^2	24.62 [23.61-27.44]	25.66 [23.26-29.50]	.4308
Female:male	0.59:0.41	0.47:0.53	.3042
Side, left:right			
Operated	0.27:0.73	0.29:0.71	.8214
Dominant	0.03:0.97	0:1	.5279

[a]Bold indicates $P < .05$. C1-C2, small tear size; C3-C4, large tear size; Q1, first quartile; Q3, third quartile.

arthroscopic RC repair was approximately 50% and was less than the expected. Finally, SSp integrity at final follow-up was associated with clinical and functional outcomes, patient satisfaction, and reduction of OA progression.

The cohort presented in this study is the first one where ultrasound evaluation was performed to assess RC integrity after arthroscopic repair at a minimum follow-up of 10 years and the third one for which such long-term results

TABLE 4
Subgroup Analysis: Tear Size and Clinical and Radiological Results[a]

Group	Mean ± SD, Median [Q1-Q3], or Frequency Ratio			*P* Value
	Overall	C1-C2	C3-C4	
SSp, integrity:nonintegrity	0.53:0.47	0.68:0.32	0.29:0.71	**.0002**
SANE score, 0-100	80 [70-100]	90 [70-100]	80 [60-90]	.0856
NRS score, 0-10	0.00 [0.00-3.25]	0.50 [0.00-2.00]	0.00 [0.00-6.00]	.4803
ASES score, 0-100	90.00 [73.33-100.00]	92.50 [78.33-100.00]	86.67 [51.67-98.33]	.1048
SST score, 0-12	11.00 [9.00-12.00]	12.00 [10.00-12.00]	10.00 [9.00-12.00]	.1015
Satisfaction, 1-4	1 [1-1]	1 [1-1]	1 [1-1]	.4674
CMS total, 0-100	78.05 [65.63-85.20]	81.50 [70.47-86.54]	69.96 [60.17-79.39]	**.0007**
Pain, 0-15	14.75 [10.00-15.00]	15.00 [11.00-15.00]	14.00 [8.75-15.00]	.1458
Daily activities, 0-20	20.00 [16.00-20.00]	20.00 [18.00-20.00]	18.00 [13.00-20.00]	**.0073**
Movement 0-40	38.00 [32.00-40.00]	38.00 [34.00-40.00]	35.00 [26.00-38.00]	**.0084**
Strength, 0-25	7.92 [4.35-13.39]	10.56 ± 5.93	5.94 [2.05-9.76]	**.0007**
Strength, kg				
Abduction	3.60 [1.98-6.09]	4.475 [3.11-7.05]	2.70 [1.06-4.44]	**.0006**
Flexion	4.43 [2.34-6.80]	5.59 ± 2.76	2.55 [1.60-5.29]	**<.0001**
Range of motion, deg				
Abduction	180.0 [143.8-180.0]	180.0 [170.0-180.0]	170.0 [110.0-180.0]	**.0174**
Flexion	180.0 [170.0-180.0]	180.0 [176.3-180.0]	180.0 [140.0-180.0]	**.0164**
AHD, mm	8.63 [5.41-10.50]	9.23 ± 2.63	5.91 ± 3.35	**<.0001**
OA grade				
Hamada, 1:>1	0.72:0.28	0.86:0.14	0.47:0.53	**<.0001**
Samilson-Prieto, 0:>0	0.51:0.49	0.64:0.36	0.29:0.71	**.0009**

[a]Bold indicates $P < .05$. AHD, acromiohumeral distance; ASES, American Shoulder and Elbow Surgeons; C1-C2, small tear size; C3-C4, large tear size; CMS, Constant-Murley Score; NRS, Numeric Rating Scale; OA, osteoarthritis; Q1, first quartile; Q3, third quartile; SANE, Simple Assessment Numeric Evaluation; SSp, supraspinatus tendon; SST, Simple Shoulder Test.

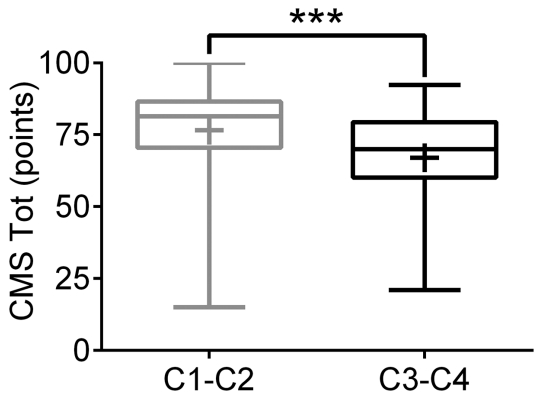

Figure 2. Constant-Murley Score (CMS) in patients with small (C1-C2) and large (C3-C4) rotator cuff tears. Each box represents the interquartile range (from the 25th to the 75th percentile) within which 50% of the values are represented. The plus sign and the line horizontally crossing each box represent the median and the mean of the data, respectively. The error bars show the minimum and maximum values. An unpaired *t* test was used to test for differences between the C1-C2 and C3-C4 groups. Only *P* values <.05 are indicated: ***$P < .001$.

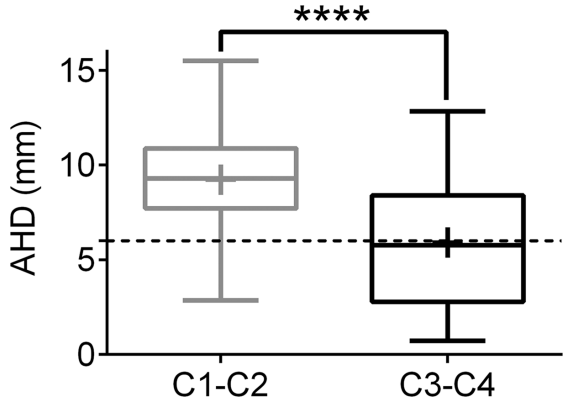

Figure 3. Acromiohumeral distance (AHD) in patients with small (C1-C2) and large (C3-C4) rotator cuff tears. Each box represents the interquartile range (from the 25th to the 75th percentile) within which 50% of the values are represented. The plus sign and the line horizontally crossing each box represent the median and the mean of the data, respectively. The error bars show the minimum and maximum values. The dashed line indicates the cutoff value of 6 mm. An unpaired *t* test was used to test for differences between the C1-C2 and C3-C4 groups. Only *P* values <.05 are indicated: ****$P < .0001$.

are described.[2,8,15,21] Heuberer et al[21] presented in 2017 the results of a case series of 30 patients whose clinical outcomes were collected prospectively 10 years after arthroscopic RC repair with MRI assessment of RC integrity. More recently, several studies originating from the

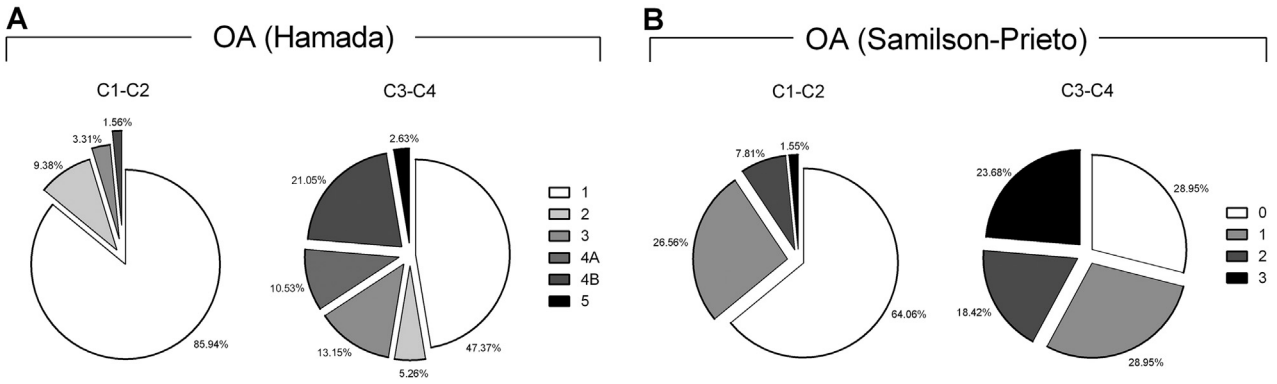

Figure 4. Distribution of patients by grade of shoulder osteoarthritis (OA) per (A) the Hamada classification and (B) the Samilson-Prieto classification in patients with small (C1-C2) and large (C3-C4) rotator cuff tears.

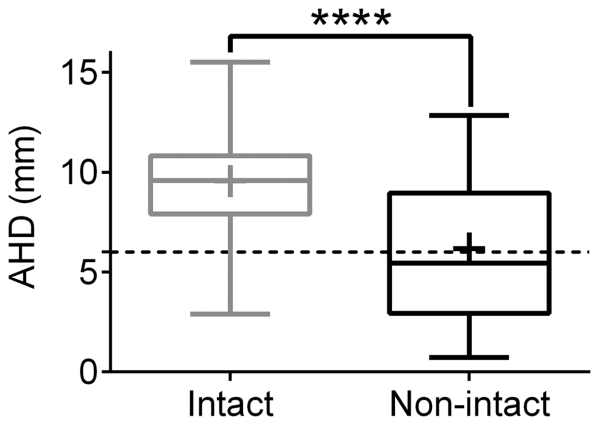

Figure 5. Acromiohumeral distance (AHD) in patients with and without intact supraspinatus tendon at final follow-up. Each box represents the interquartile range (from the 25th to the 75th percentile) within which 50% of the values are represented. The plus sign and the line horizontally crossing each box represent the median and the mean of the data, respectively. The error bars show the minimum and maximum values. The dashed line indicates the cutoff value of 6 mm. Unpaired *t* test was used to test for differences between intact and nonintact groups. Only *P* values $<.05$ are indicated: ****$P < .0001$.

same cohort of patients, enrolled under the direction of the Société Française de Chirurgie Orthopédique et Traumatologique (SOFCOT) in 2003, were published. These studies evaluated different aspects of RC repair and their results, including a relevant fraction of patients who underwent open RC repair.[2,8,15]

Predictive Factors

A relevant finding of this study is that RC tear size at the index procedure was significantly associated with RC integrity at 10-year follow-up. Specifically, patients with C3 and C4 tears had a more-than-double risk of having a nonintact SSp 10 years after surgery (HRs: 3.04 in univariate and 2.18 in multivariate analysis). This information is valuable for patient counseling and to help develop realistic expectations before surgery, since MRI has been demonstrated to predict with high diagnostic accuracy and reproducibility the intraoperative findings as classified by the SCOI system.[3] Previous studies already indicated that RC tear size (dimensions, area, and thickness) is strongly associated with retears at 6 months[27,28] and 9 months[22] after surgery and identified numerous other predictive factors for RC retear, including increased age,[28,48] fatty degeneration[28] and muscle atrophy of the SSp,[22] fatty degeneration of the infraspinatus,[22] and additional biceps or acromioclavicular procedures.[26]

Our analysis could not confirm the role of age in predicting RC integrity at long-term follow-up, and the study design did not include prospective collection of information on fatty degeneration of the RC, since at the moment of surgery, the role of this parameter did not yet have the relevance that it has nowadays as a predictor for RC outcome but also for reparability of the RC.[24]

It is still unclear if a direct correlation between RC integrity and clinical outcome exists, with studies demonstrating that clinical improvements and pain relief after arthroscopic RC repair of large and massive tears can be durable at long-term follow-up, despite early structural failure of repair, especially in older patients.[19,39] The design of this study does not allow us to draw definitive conclusions on the predictive role of RC integrity on functional outcomes; however, between patients with intact and nonintact RCs at final follow-up, significant differences were encountered in favor of patients with an intact RC in terms of strength, range of motion, and all functional scores evaluated.

SSp Integrity at Long-term Follow-up

The SSp integrity ratio documented in the present study (53.5%) approximates closely the one reported by Heuberer et al[21] (50%) but is markedly inferior to that reported in a previous similarly designed prospective study with

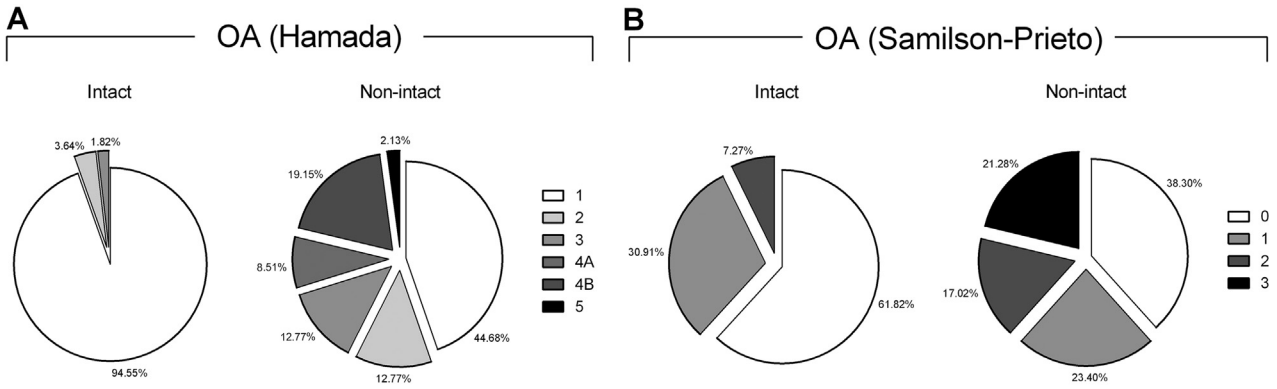

Figure 6. Distribution of patients by grade of shoulder osteoarthritis (OA) per (A) the Hamada classification and (B) the Samilson-Prieto classification in patients with and without intact supraspinatus tendon at final follow-up.

a minimum follow-up of 5 years.[18] Therefore, the conclusions derived from these data support the hypothesis that a proportion of arthroscopic RC repairs can also fail several years after an initially successful repair. This is opposed to what was previously documented for open and mini-open RC repairs, for which survivorship analysis suggested that if RC repairs could survive the early phase, then repair survival over the long-term follow-up would also be likely.[17,25,33]

Both the results of this study and those by Heuberer et al[21] describe a slightly inferior proportion of RC integrity than previous studies in which an open technique was used in all enrolled patients[25] or in approximately half of them.[2,8,15] A possible explanation for these different findings could be the different initial patient selection, technical differences among surgeons, and the fact that arthroscopic repair was, at the time when these surgical procedures were conducted, a relatively new procedure. In its initial phase, this innovation had to dismiss traditional, well-performing techniques (transosseous repair) because they were excessively technically demanding, and surgeons prefer minimally invasive but anatomically less precise strategies (suture anchors).[40] In consideration of this, the results of the present study on the gold standard but "old" technique give reasonable hope that a surgeon performing RC repair with more developed techniques can expect an SSp integrity rate of at least 50% at a long-term follow-up. Of course, this hypothesis should be confirmed by further study with a design similar to this one.

In the SOFCOT cohort, RC repair was open in one-half of the patients and arthroscopic in the other. Here the percentage of tendon healing was reported as ranging between 68% and 81%, depending on the initial type of tear,[2] and a separate study by the same study group on massive tears indicated a retear rate of 34%.[8] Interestingly, the differences in the retear rate between isolated SSp tears and larger tears with different extension were not found to be significant, although the failure rate was higher in the group with posterior extension.[2] This is in contrast to the results of the present study, where a significant difference in the proportion of intact RC was documented in C1-C2 tears versus C3-C4 (68% vs 29%, $P = .0002$). Our study strongly supports the hypothesis that initial tear dimension influences the chances of maintaining integrity at long-term follow-up. This hypothesis is also supported by studies reporting long-term results of open RC repair, which are more numerous than those investigating the recently introduced arthroscopic technique.[36,50] These results approximate well those of the SOFCOT cohort for the isolated SSp group (19% retear).[2] On the contrary, regarding massive tears assessed by MRI at 9.9 years postoperatively, Zumstein et al[53] reported a much higher retear rate (57%), which comes closer to the figures reported in our studies for C3-C4 tears (SSp nonintegrity, 71%).

This study could not confirm the detrimental effects of smoking on tissue degeneration, tissue repair, and healing failure previously reported.[38,51]

Clinical Outcomes

Good clinical outcomes of arthroscopic RC repair at long-term follow-up have been shown both in the present study (see Table 4) and in the work by Heuberer et al[21] (CMS, 77.5 ± 15.6; University of California, Los Angeles [UCLA] score, 89.7% ± 15.9%). Slightly inferior clinical results were described by Agout et al[2] for the SOFCOT cohort (total weighted CMS: 60.4 ± 19.3 to 70.6 ± 19.4, depending on tear type).

Few other studies reported results of arthroscopic RC repair with medium to long follow-up: Marrero et al[30] evaluated 33 tears of different sizes at a minimum follow-up of 9 years, reporting a mean UCLA score of 31.8, with 87.7% excellent and good outcomes. Similar results were also reported by Miyazaki et al[34] on 35 arthroscopic repairs of massive RC tears, which maintained good functional results (UCLA score, 31.31) and satisfaction after a minimum follow-up of 9 years. Denard et al[10] reported 78% good to excellent outcomes at a minimum 5-year follow-up after arthroscopic RC repair of massive RC tears (mean UCLA, 30.7; mean American Shoulder and Elbow Surgeons, 85.7), further suggesting that double-row repair can provide a superior UCLA score compared with single-row technique.

Other long-term results available refer to open or mini-open techniques: early studies on long-term outcomes of open RC repair suggested satisfactory results with a decrease in pain after surgery and a return to preinjury activities,[1,5] and more recent ones confirmed maintenance of good strength and high CMS score at 10 years after open repair.[4,7,16,25,43] In a mixed series of arthroscopic and mini-open repairs of small- to medium-size RC tears in 44 patients after a mean follow-up of 11.3 years, van Deurzen et al[50] showed satisfaction in 80% of the cases and 76% good to excellent functional outcomes (median CMS, 82 [range, 29-95]; median Disabilities of the Arm, Shoulder and Hand score, 5.0 [range, 1.0-54]; median Oxford Shoulder Score, 19 [range, 13-39]). Finally, Collin et al[8] reported a mean CMS of 78.5 in a mixed series of arthroscopic and open repairs of massive tears at 10-year follow-up, documenting an association between the preoperative tendon retraction of the infraspinatus and the CMS.

Muscle Strength

After arthroscopic RC repair, muscle strength demonstrates the slowest recovery as compared with pain and shoulder function. To reach the strength of the uninjured contralateral shoulder in all 3 planes of motion, recovery can take 6 months in patients with small tears and 18 months in patients with medium tears, whereas in patients with large to massive tears, strength can remain inferior to the contralateral shoulder after 18 months of follow-up. However, strength did not appear to significantly correlate with postoperative patient satisfaction.[44] A similar finding was reported by Dodson et al,[11] who noted that at a mean follow-up of 7.9 years, patients with recurrent RC defects showed progression of tear size and strength deficits and improvement in terms of pain, function, and satisfaction. Our study was not designed to correlate strength deficits with clinical outcomes. However, we could observe that patients with smaller lesions had superior strength in flexion and abduction at final follow-up, but this finding correlated only with a significantly superior CMS and not with superiority in other functional scores or to satisfaction level or pain scale. These findings are in accordance with those of Dodson et al and suggest that patients with recurrent defects can remain asymptomatic over the long term but will predictably lose strength in the involved extremity.[11]

Osteoarthritis

The loss of the RC's stabilizing function can lead to joint degeneration and RC tear arthropathy,[6,13] and tear size appears to be the strongest predictor for proximal humeral migration.[23] Therefore, especially in the case of large symptomatic tears, RC repair can slow down OA progression. This was recently confirmed in a retrospective analysis of mini-open RC repairs over a minimum of 10 years of follow-up.[31]

However, even if RC tears are repaired, the progression of osteoarthritic changes cannot be halted, with the rate of OA progression after primary RC ranging between 18% and 20% (all types of lesions)[1,17] and 61% (massive RC tears).[53]

The progression of cuff tear arthropathy can be represented by the Hamada classification: in our cohort, >70% of our patients maintained the lowest grade according to this classification, with this percentage being higher in patients with initially small lesions (86%) as compared with patients with larger lesions (47%). These figures are, as expected, higher than those reported by Paxton et al[39] in failed repairs of large or massive RC tears at 10-year follow-up and than those reported by Ranebo et al[41] in patients with full-thickness RC tear treated with acromioplasty without tendon repair at 22-year follow-up. However, the last author reported a 93% Hamada grade 1 in patients with partial-thickness RC tear, who also received the same minimal treatment. These findings support the hypothesis that RC tear is a potentially progressive disease in which cuff integrity is an important determinant for progression.[23,41]

The SOFCOT study group also provided an analysis of OA progression after RC repair, including 401 patients treated by open and arthroscopic techniques. In this study, 45% of the patients had a Samilson-Prieto grade 0, and the CMS was significantly higher in this group than in patients with OA. Furthermore, RC integrity was significantly associated with the absence of OA such that the authors concluded that an unhealed or retorn cuff increases the risk of developing OA.[15] Similar findings were encountered in our cohort, with a prevalence of 50% Samilson-Prieto grade 0 patients and a significant association between RC integrity and absence of OA (Figure 6; Appendix Table A2, available online).

When only patients treated by arthroscopic repair by the SOFCOT study group were analyzed, a 14% rate of glenohumeral OA (defined as Samilson-Prieto grade 2-4) was identified, which was slightly less than our percentage of 21.8%. This difference can probably be explained by the fact that, in the SOFCOT cohort, patients with larger tears were more frequently allocated to open surgery treatment.[15] The fact that open repair could be associated with higher OA progression is supported by the results presented at 10-year minimum follow-up by Elia et al,[14] who reported Samilson-Prieto grade 0 in only 21% of their cases.

Limitations of this study include the relatively high rate of patients unwilling or unable to return to the institution for the clinical evaluation (only 68% of the patients contacted by telephone and 60.1% of the eligible patients). This is explained by the fact that arthroscopic RC repair was not widely available across the country at the time when surgery was conducted and, >10 years later, many patients did not agree to travel again over a long distance for a follow-up evaluation.[12] To gather as much information as possible, an interview was conducted to collect validated outcome scores: the fact that these scores were initially designed to be completed by patients independent of any examiners (not by telephone) could have created a small bias of results. Furthermore, the study design (prospective observational clinical trial on an historic cohort) did not allow us to include a preoperative evaluation or a short-term follow-up point. The latter could have been interesting to evaluate the rate of late RC failures, which is not clearly defined yet. However, for the clinical

evaluation, a single long-term follow-up point appears sufficient, since clinically significant improvement in patient-reported outcomes, range of motion, and strength occurs mostly up to 1 year after surgery and rarely beyond this point.[52]

Another limitation of this study is the fact that a power analysis to evaluate the precision of the estimates could be conducted only on the primary study outcome: all the supplementary analyses presented to compare subgroups of patients lacked this and therefore need to be interpreted with caution. Finally, the study was not designed to evaluate the effects of specific working or leisure activities on RC repair survival and could not consider constitutional differences among the study population—all factors that can affect short- and long-term results.[35]

CONCLUSION

RC tear size at the time of surgery significantly affects SSp integrity at a minimum follow-up of 10 years after a full arthroscopic RC repair. However, a larger tear size is not associated with an inferior subjective result, although it negatively influences abduction and flexion strength, range of motion, and OA progression.

Given that the results of this study are based on an arthroscopic traditional single-row technique, RC repair integrity can be expected in about 50% of patients at 10 years after surgery. This information is valuable for patient counseling and to help develop realistic expectations. Intraoperative efforts to obtain a durable RC repair are encouraged, since SSp integrity at final follow-up influences clinical and functional outcomes, patient satisfaction, and OA progression.

REFERENCES

1. Adamson GJ, Tibone JE. Ten-year assessment of primary rotator cuff repairs. *J Shoulder Elbow Surg*. 1993;2:57-63.
2. Agout C, Berhouet J, Bouju Y, et al. Clinical and anatomic results of rotator cuff repair at 10 years depend on tear type. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(8):2490-2497.
3. Aliprandi A, Messina C, Arrigoni P, et al. Reporting rotator cuff tears on magnetic resonance arthrography using the Snyder's arthroscopic classification. *World J Radiol*. 2017;9(3):126-133.
4. Bell S, Lim Y-J, Coghlan J. Long-term longitudinal follow-up of mini-open rotator cuff repair. *J Bone Joint Surg Am*. 2013;95(2):151-157.
5. Bigliani LU, Cordasco FA, McLIveen SJ, Musso ES. Operative repair of massive rotator cuff tears: long-term results. *J Shoulder Elbow Surg*. 1992;1:120-130.
6. Chalmers PN, Salazar DH, Steger-May K, et al. Radiographic progression of arthritic changes in shoulders with degenerative rotator cuff tears. *J Shoulder Elbow Surg*. 2016;25(11):1749-1755.
7. Cofield RH, Parvizi J, Hoffmeyer PJ, Lanzer WL, Ilstrup DM, Rowland CM. Surgical repair of chronic rotator cuff tears: a prospective long-term study. *J Bone Joint Surg Am*. 2001;83(1):71-77.
8. Collin P, Colmar M, Thomazeau H, et al. Clinical and MRI outcomes 10 years after repair of massive posterosuperior rotator cuff tears. *J Bone Joint Surg Am*. 2018;100(21):1854-1863.
9. Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. *Clin Orthop Relat Res*. 1987;214:160-164.
10. Denard PJ, Jiwani AZ, Lädermann A, Burkhart SS. Long-term outcome of arthroscopic massive rotator cuff repair: the importance of double-row fixation. *Arthroscopy*. 2012;28(7):909-915.
11. Dodson CC, Kitay A, Verma NN, et al. The long-term outcome of recurrent defects after rotator cuff repair. *Am J Sports Med*. 2010;38(1):35-39.
12. Dunn WR, Schackman BR, Walsh C, et al. Variation in orthopaedic surgeons' perceptions about the indications for rotator cuff surgery. *J Bone Joint Surg*. 2005;87(9):1978-1984.
13. Eajazi A, Kussman S, LeBedis C, et al. Rotator cuff tear arthropathy: pathophysiology, imaging characteristics, and treatment options. *AJR Am J Roentgenol*. 2015;205(5):W502-W511.
14. Elia F, Azoulay V, Lebon J, Faraud A, Bonnevialle N, Mansat P. Clinical and anatomic results of surgical repair of chronic rotator cuff tears at ten-year minimum follow-up. *Int Orthop*. 2017;41(6):1219-1226.
15. Flurin P-H, Hardy P, Valenti P, Meyer N, Collin P, Kempf J-F. Osteoarthritis after rotator cuff repair: a 10-year follow-up study. *Orthop Traumatol Surg Res*. 2017;103(4):477-481.
16. Galatz LM, Griggs S, Cameron BD, Iannotti JP. Prospective longitudinal analysis of postoperative shoulder function: a ten-year follow-up study of full-thickness rotator cuff tears. *J Bone Joint Surg Am*. 2001;83(7):1052-1056.
17. Goutallier D, Postel JM, Radier C, Bernageau J, Zilber S. Long-term functional and structural outcome in patients with intact repairs 1 year after open transosseous rotator cuff repair. *J Shoulder Elbow Surg*. 2009;18:521-528.
18. Gulotta LV, Nho SJ, Dodson CC, Adler RS, Altchek DW, MacGillivray JD. Prospective evaluation of arthroscopic rotator cuff repairs at 5 years: part I—functional outcomes and radiographic healing rates. *J Shoulder Elbow Surg*. 2011;20(6):934-940.
19. Gulotta LV, Nho SJ, Dodson CC, Adler RS, Altchek DW, MacGillivray JD. Prospective evaluation of arthroscopic rotator cuff repairs at 5 years: part II—prognostic factors for clinical and radiographic outcomes. *J Shoulder Elbow Surg*. 2011;20(6):941-946.
20. Hamada K, Yamanaka K, Uchiyama Y, Mikasa T, Mikasa M. A radiographic classification of massive rotator cuff tear arthritis. *Clin Orthop Relat Res*. 2011;469(9):2452-2460.
21. Heuberer PR, Smolen D, Pauzenberger L, et al. Longitudinal long-term magnetic resonance imaging and clinical follow-up after single-row arthroscopic rotator cuff repair: clinical superiority of structural tendon integrity. *Am J Sports Med*. 2017;45(6):1283-1288.
22. Jeong HY, Kim HJ, Jeon YS, Rhee YG. Factors predictive of healing in large rotator cuff tears: is it possible to predict retear preoperatively? *Am J Sports Med*. 2018;46(7):1693-1700.
23. Keener JD, Wei AS, Kim HM, Steger-May K, Yamaguchi K. Proximal humeral migration in shoulders with symptomatic and asymptomatic rotator cuff tears. *J Bone Joint Surg Am*. 2009;91(6):1405-1413.
24. Kim JY, Park JS, Rhee YG. Can preoperative magnetic resonance imaging predict the reparability of massive rotator cuff tears? *Am J Sports Med*. 2017;45(7):1654-1663.
25. Kluger R, Bock P, Mittlböck M, Krampla W, Engel A. Long-term survivorship of rotator cuff repairs using ultrasound and magnetic resonance imaging analysis. *Am J Sports Med*. 2011;39(10):2071-2081.
26. Lambers Heerspink FO, Dorrestijn O, van Raay JJAM, Diercks RL. Specific patient-related prognostic factors for rotator cuff repair: a systematic review. *J Shoulder Elbow Surg*. 2014;23(7):1073-1080.
27. Le BTN, Wu XL, Lam PH, Murrell GAC. Factors predicting rotator cuff retears: an analysis of 1000 consecutive rotator cuff repairs. *Am J Sports Med*. 2014;42(5):1134-1142.
28. Lee YS, Jeong JY, Park C-D, Kang SG, Yoo JC. Evaluation of the risk factors for a rotator cuff retear after repair surgery. *Am J Sports Med*. 2017;45(8):1755-1761.
29. Marchese C, Cristalli G, Pichi B, et al. Italian cross-cultural adaptation and validation of three different scales for the evaluation of shoulder pain and dysfunction after neck dissection: University of California–Los Angeles (UCLA) Shoulder Scale, Shoulder Pain and Disability Index (SPADI). *Acta Otorhinolaryngol Ital*. 2012;32(1):12-17.
30. Marrero LG, Nelman KR, Nottage WM. Long-term follow-up of arthroscopic rotator cuff repair. *Arthroscopy*. 2011;27(7):885-888.

31. 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*. 2018;26(2):230949901876810.
32. McElvany MD, McGoldrick E, Gee AO, Neradilek MB, Matsen FA. Rotator cuff repair: published evidence on factors associated with repair integrity and clinical outcome. *Am J Sports Med*. 2015; 43(2):491-500.
33. 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.
34. Miyazaki AN, Santos PD, da Silva LA, do Val Sella G, Checchia SL, Yonamine AM. Are the good functional results from arthroscopic repair of massive rotator cuff injuries maintained over the long term? *Rev Bras Ortop*. 2016;51(1):40-44.
35. Namdari S, Donegan RP, Chamberlain AM, Galatz LM, Yamaguchi K, Keener JD. Factors affecting outcome after structural failure of repaired rotator cuff tears. *J Bone Joint Surg Am*. 2014;96(2):99-105.
36. Nich C, Dhiaf N, Di Schino M, Augereau B. Does partial tear repair of adjacent tendons improve the outcome of supraspinatus tendon full-thickness tear reinsertion? *Orthop Traumatol Surg Res*. 2014; 100(7):721-726.
37. Padua R, Padua L, Ceccarelli E, Bondi R, Alviti F, Castagna A. Italian version of ASES questionnaire for shoulder assessment: cross-cultural adaptation and validation. *Musculoskelet Surg*. 2010; 94(suppl 1):S85-S90.
38. Park JH, Oh K-S, Kim TM, et al. Effect of smoking on healing failure after rotator cuff repair. *Am J Sports Med*. 2018;46(12):2960-2968.
39. 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.
40. Randelli P, Cucchi D, Ragone V, de Girolamo L, Cabitza P, Randelli M. History of rotator cuff surgery. *Knee Surg Sports Traumatol Arthrosc*. 2015;23(2):344-362.
41. Ranebo MC, Björnsson Hallgren HC, Norlin R, Adolfsson LE. Clinical and structural outcome 22 years after acromioplasty without tendon repair in patients with subacromial pain and cuff tears. *J Shoulder Elbow Surg*. 2016;26:1262-1270.
42. Samilson RL, Prieto V. Dislocation arthropathy of the shoulder. *J Bone Joint Surg Am*. 1983;65(4):456-460.
43. Saraswat MK, Styles-Tripp F, Beaupre LA, et al. Functional outcomes and health-related quality of life after surgical repair of full-thickness rotator cuff tears using a mini-open technique. *Am J Sports Med*. 2015;43(11):2794-2799.
44. Shin S-J, Chung J, Lee J, Ko Y-W. Recovery of muscle strength after intact arthroscopic rotator cuff repair according to preoperative rotator cuff tear size. *Am J Sports Med*. 2016;44(4):972-980.
45. Snyder SJ. Arthroscopic classification of rotator cuff lesions and surgical decision making. In: Snyder SJ, Ed. *Shoulder Arthroscopy*. Philadelphia, PA: Lippincott Williams & Wilkins; 2003:201-207.
46. Spennacchio P, Banfi G, Cucchi D, D'Ambrosi R, Cabitza P, Randelli P. Long-term outcome after arthroscopic rotator cuff treatment. *Knee Surg Sports Traumatol Arthrosc*. 2015;23(2):523-529.
47. Sun J. Regression analysis of current status data. In: *The Statistical Analysis of Interval-Censored Failure Time Data*. New York, NY: Springer New York; 2006:97-123.
48. 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.
49. Teefey SA, Rubin DA, Middleton WD, Hildebolt CF, Leibold RA, Yamaguchi K. Detection and quantification of rotator cuff tears: comparison of ultrasonographic, magnetic resonance imaging, and arthroscopic findings in seventy-one consecutive cases. *J Bone Joint Surg Am*. 2004;86(4):708-716.
50. van Deurzen D, Scholtes V, Willems W, et al. Long-term results of arthroscopic and mini-open repair of small- to medium-size full-thickness rotator cuff tears. *Shoulder Elbow*. 2019;11(1)(suppl):68-76.
51. Yamamoto N, Mineta M, Kawakami J, Sano H, Itoi E. Risk factors for tear progression in symptomatic rotator cuff tears: a prospective study of 174 shoulders. *Am J Sports Med*. 2017;45(11):2524-2531.
52. Zuke WA, Leroux TS, Gregory BP, et al. Establishing maximal medical improvement after arthroscopic rotator cuff repair. *Am J Sports Med*. 2018;46(4):1000-1007.
53. Zumstein MA, Jost B, Hempel J, Hodler J, Gerber C. The clinical and structural long-term results of open repair of massive tears of the rotator cuff. *J Bone Joint Surg Am*. 2008;90:2423-2431.