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SHOULDER

Tear progression of symptomatic full-thickness and partial-thickness rotator cuff tears as measured by repeated MRI

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Abstract
Purpose The purpose of this study was to analyse the natural course of symptomatic full-thickness and partial-thickness rotator cuff tears treated non-operatively and to identify risk factors affecting tear enlargement.
Methods One hundred and twenty-two patients who received non-surgical treatment for a partial- or full-thickness supraspinatus tear were included in this study. All rotator cuff tears were diagnosed with magnetic resonance imaging (MRI), and the same modality was used for follow-up studies. Follow-up MRI was performed after at least a 6-month interval. We evaluated the correlation between tear enlargement and follow-up duration. Eleven risk factors were analysed by both univariate and multivariate analyses to identify factors that affect enlargement of rotator cuff tears. The mean follow-up period was 24.4 ± 19.5 months.
Results Out of 122 patients, 34 (27.9%) patients had an initial full-thickness tear and 88 (72.1%) patients had a partial-thickness tear. Considering all patients together, tear size increased in 51/122 (41.8%) patients, was unchanged in 65/122 (53.3%) patients, and decreased in 6/122 (4.9%) patients. Tear size increased for 28/34 (82.4%) patients with full-thickness tears and 23/88 (26.1%) patients with partial-thickness tears. From the two groups which were followed over 12 months, a higher rate of enlargement was observed in full-thickness tears than in partial-thickness tears (6–12 months, n.s.; 12–24 months, $P = 0.002$; over 24 months, $P < 0.001$). Logistic regression revealed that having a full-thickness tear was the most reliable risk factor for tear progression ($P < 0.001$).
Conclusions This study found that 28/34 (82.4%) of symptomatic full-thickness rotator cuff tears and 23/88 (26.1%) of symptomatic partial-thickness tears increased in size over a follow-up period of 6–100 months. Full-thickness tears showed a higher rate of enlargement than partial-thickness tears regardless of the follow-up duration. Univariate and multivariate analyses suggested that full-thickness tear was the most reliable risk factor for tear enlargement. The clinical relevance of these observations is that full-thickness rotator cuff tears treated conservatively should be monitored more carefully for progression than partial-thickness tears.
Level of evidence IV.

Keywords Rotator cuff tear · Natural history · Non-operative · Conservative · MRI · Progression

Introduction

Rotator cuff tear is a common pathology of the shoulder joint, affecting approximately 20.7–22.1% of the general population [25, 32]. However, the natural history of symptomatic rotator cuff tears is poorly understood. Yamaguchi et al. [31] reported no decrease in tear size over 5 years in 23 patients evaluated by ultrasound, and they suggested that tendon healing of a rotator cuff tear does not occur over a 5-year period. However, recent studies have indicated that rotator cuff tears do not always progress over time. Safran et al. [27] reported that 5/61 (8%) full-thickness rotator cuff

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tears evaluated with serial ultrasound decreased in size over a 2-year follow-up. Thus, the natural history of rotator cuff tears remains a subject of considerable controversy.

Many studies have investigated the risk factors that potentially affect rotator cuff tendon healing after surgery. Patient factors such as age, diabetes mellitus (DM), smoking status, and osteoporosis have been suggested to negatively impact the clinical outcomes and healing of rotator cuff tears [2, 5, 6, 22, 23]. Furthermore, tear size, fatty infiltration, and muscle atrophy have also been proposed as important prognostic factors influencing rotator cuff healing [3, 7, 13, 19]. A recent study that examined the correlation between tear pattern and tear progression risk suggested that the risk of tear progression does not differ between tears with and without anterior rotator cable disruption [18]. However, few studies have investigated the risk factors affecting the enlargement of rotator cuff tears treated conservatively. Proper analysis of the factors associated with rotator cuff tear enlargement will enable better decision-making in the treatment of rotator cuff tears. Therefore, comprehensive efforts to identify the prognostic factors of tear enlargement are required.

The purpose of the present study was to evaluate the natural history of symptomatic full-thickness and partial-thickness rotator cuff tears and to identify the risk factors that affect tear enlargement. Patient outcomes were evaluated with serial MRI. Additional factors that could potentially affect rotator cuff tear enlargement, such as comorbidities, activity levels, and structural factors, were also analysed.

It was hypothesized that full-thickness rotator cuff tear would be the best predictor of tear progression over a short-term follow-up period.

Materials and methods

Between 2006 and 2014, patients with either a symptomatic partial- or a full-thickness rotator cuff tear who did not undergo surgical treatment but who underwent follow-up imaging studies were retrospectively reviewed. All rotator cuff tears were diagnosed initially with MRI. Surgical treatment was usually recommended for patients with symptomatic full-thickness rotator cuff tears or partial-thickness rotator cuff tears over 50% in depth despite at least 3 months of conservative treatment. The patients who refused our recommendation for surgical treatment received conservative treatment with medication, physiotherapy, and corticosteroid injection. After at least a 6-month interval, follow-up MRI was performed to identify any changes in the rotator cuff tear. The inclusion criteria were as follows: (1) reparable full-thickness supraspinatus tears [smaller than 4 cm in size along the anterior–posterior (AP) or medial–lateral (ML) length] diagnosed on MRI, (2) partial-thickness supraspinatus tears (>3 mm in size) diagnosed on MRI, (3) follow-up MRI with at least a 6-month interval, and (4) symptomatic rotator cuff tear (initial resting visual analogue scale >3). The exclusion criteria were as follows: (1) irreparable rotator cuff tear (smaller than 7 mm in length for the acromiohumeral distance on a true anteroposterior radiograph, greater than 4 cm in size along the AP or ML length, and stage III or stage IV fatty infiltration according to the modified Goutallier classification [15]), (2) any previous surgery on the affected arm, and (3) glenohumeral joint arthritis.

Of the entire 190 patients, 68 were excluded: 20 had limited MRI images, eight had an irreparable rotator cuff tear, two had undergone previous surgery on the affected arm, and 38 did not undergo follow-up MRI. Thus, of the original 190 patients, 122 were finally included in this study.

Clinical assessment

Each patient visit included a physical examination, which was performed by the same senior surgeon. At this examination, the passive range of motion (ROM) of the affected shoulder, the score for a visual analogue scale (VAS) for pain at rest, the American Shoulder and Elbow Surgeons (ASES) score, and the Constant Shoulder Score (CSS) were evaluated. ROM, including forward flexion, external rotation at the side, external rotation at 90° of abduction, and internal rotation of the treated shoulder, was measured with a goniometer. Internal rotation was evaluated by the tip of the thumb reaching the vertebral level in the sitting position. The vertebral level was numbered serially: 0 for any level below the sacral region, with 1 point added for each level above the sacrum [20].

Each patient's medical history, including DM status, smoking history, osteoporosis status, trauma history, and injection history, was obtained at the initial visit. Telephone surveys were performed by the authors if any patient information was missing. Patients were asked to complete a modified sports activity scale, which was composed of four categories. The categories of the scale included occupation, types of sports enjoyed, frequency of exercise, and duration of exercise [12, 21]. The responses to each of the four categories were converted to points, with values ranging from 1 to 3, according to the degree of performance. Point totals were calculated for each patient, with final scores ranging from 4 to 12 points (Table 1).

Image evaluation

MRI was performed at Seoul St. Mary's Hospital with 3.0-T MRI scanner (Magnetom Verio; Siemens Medical Solution, Erlangen, Germany) with a dedicated shoulder

Table 1 Sports activity scale

	Three (strenuous)	Two (moderate)	One (light)
Occupation	Heavy worker Moving transport Farmer Stockbreeding	Taxi driver Cleaner Restaurant employee	Office job
Type of sports	Tennis Body building Rock-climbing	Jogging, hiking Aerobics, yoga Skiing, swimming Bicycling	Walking Stretching
Frequency	≥4 times/month	2–3 times/month	≤1 time/month
Duration	≥90 min	30–90 min	≤30 min

coil. Fat-suppressed fast spin-echo T2-weighted [2000–5000/76–112 (repetition time ms/echo time ms)] sequences were used in the axial, coronal oblique, and sagittal oblique planes. Fast spin-echo T2-weighted sequences [2000–5000/76–112 (repetition time ms/echo time ms)] were used in the coronal oblique and sagittal oblique planes. T1-weighted images [600–800/13–16 (repetition time ms/echo time ms)] were obtained in the oblique coronal plane. A musculoskeletal radiologist with over 10 years of experience who was blinded to all clinical data reviewed and measured the structural factors of the rotator cuff tears. The measurement of rotator cuff tear size was repeated twice, and the mean value was calculated. For partial- and full-thickness tears, tear size of the supraspinatus was measured in two plane images (oblique sagittal and oblique coronal) to measure tear size. Tear was defined as a hyperintense signal area within the tendon or the presence of a tendon defect filled with fluid on either the T2-weighted or the fat-suppressed, T2-weighted sequence. A full-thickness tear was defined as a tendon that was detached entirely from the greater tuberosity. A partial-thickness tear was defined as a tendon that was partially connected to the greater tuberosity. Since small changes in tear size are difficult to distinguish on MRI scans, changes in tear size were divided into three categories: (1) >2-mm increase, (2) >2-mm decrease, and (3) <2-mm change [24].

The volume of the supraspinatus muscle was determined by calculating the occupation ratio. The percentage of supraspinatus muscle occupying the fossa suprascapularis was measured at the point at which the scapular spine begins to meet the glenoid in the T1-weighted, oblique sagittal plane image [28, 33]. Muscle volume measurements were also categorized into three groups according to the degree of muscle volume change as follows: (1) muscle volume increased by more than 10% on follow-up MRI, compared to initial MRI, (2) muscle volume changed by less than 10%, (3) muscle volume decreased by more than 10%. Since no standard criteria have yet been established to determine whether muscle volume is significantly increased or decreased, a cut-off value of 10% was used. This value was chosen because a study by Chung et al. [4] found that the mean value of intraobserver relative error was ±3.03%; thus, a cut-off of 10% is sufficient to account for measurement error.

Fatty infiltration was also assessed by the method described by Goutallier et al. [15], which was adapted to MRI [10]. Subacromial spur lengths were measured at the supraspinatus outlet view on plain film. Spurs ≥3 mm in length underneath the anterolateral surface of the acromion were considered positive spur changes [24].

For intraobserver reliability, a musculoskeletal radiologist measured the same images a second time, without access to the first measurements. Intraobserver reliabilities were evaluated with the interclass correlation coefficient (ICC).

This study was approved by the Institutional Review Board of our institution (Seoul St. Mary's Hospital, The Catholic University of Korea, IRB No. KC14RISI0288).

Statistical analysis

Depending on the results of normality tests, paired *t* tests or Wilcoxon signed-rank tests were used to compare continuous variables within the same group. The change in the size of the rotator cuff tears was evaluated by comparing tears that increased in size to tears that showed no change or decreased in size [24]. The Chi-square test or Fisher exact test was used to investigate the association between tear enlargement and initial tear size (partial- or full-thickness) at each follow-up. The same test was used to evaluate the relationship between tear enlargement and potential risk factors. Multivariable logistic regression analysis was used to determine the independent predictors of tear progression using the stepwise forward conditional method. The level of significance was set at $P < 0.05$.

Results

Demographic data are shown in Table 2. The ICC was 0.940 for the initial AP size of the supraspinatus tear ($P < 0.001$), 0.961 for the initial ML size of the supraspinatus tear ($P < 0.001$), 0.973 for the follow-up AP size of the supraspinatus tear ($P < 0.001$), and 0.950 for the follow-up ML size of the supraspinatus tear ($P < 0.001$), all of which showed very good ICC agreement.

Table 2 Demographic data of the patients

	Shoulders ($n = 122$)
Age (years)[a]	63.6 ± 10.0 (37–86)
Gender (men/women)	38:84
Rt./Lt. shoulder	83:39
Isolated supraspinatus (*n*, %)	90 (73.8)
Anterosuperior (SSP[b] + SSC[c]) (*n*, %)	14 (11.5)
Posterosuperior (SSP + ISP[d]) (*n*, %)	11 (9.0)
Three tendons (SSP + SSC + ISP) (*n*, %)	7 (5.7)
Partial-thickness tears ($n = 88$)	
Articular-sided (*n*, %)	20 (22.7)
Bursal-sided (*n*, %)	56 (63.6)
Intratendinous (*n*, %)	12 (13.6)
Number of MRI follow-up (two times/three times)	109:13
Follow-up period (months)[a]	24.7 ± 19.4 (6.0–100.2)

[a] Values given as mean ± SD (range)

[b] Supraspinatus

[c] Subscapularis

[d] Infraspinatus

Table 3 Change in tear size on follow-up

	Increased	No change	Decreased	Total (*n*)
Full-thickness tear (*n*, %)	28 (82.4)	6 (17.6)	0	34
Partial-thickness tear (*n*, %)	23 (26.1)	59 (67)	6 (6.8)	88
Total (*n*, %)	51 (41.8)	65 (53.3)	6 (4.9)	122

Natural history of rotator cuff tears

For full-thickness supraspinatus tears, the average AP and ML tear sizes, as measured on MRI scans, significantly increased during follow-up [AP tear size, initial, 11.4 ± 6.8 mm, follow-up, 15.3 ± 9.1 mm ($P < 0.001$); ML tear size, initial, 16.4 ± 9.6 mm, follow-up, 23.2 ± 12.1 mm ($P < 0.001$)]. For partial-thickness supraspinatus tears, the average AP tear size did not change significantly during follow-up, but average ML tear size increased significantly [AP tear size, initial, 4.8 ± 2.6 mm, follow-up, 4.9 ± 3.4 mm (n.s.); ML tear size, initial, 6.2 ± 3.4 mm, follow-up, 7.0 ± 5.0 mm ($P = 0.015$)].

The changes of tear size for full-thickness and partial-thickness tears are summarized in Table 3. Interestingly, all six patients that showed a decrease in tear size had partial-thickness tears, which were articular in three patients, bursal in two patients, and intratendinous in one patient. Among these six patients, three had a history of trauma, and three did not. Among the 88 patients with partial-thickness tears, tear enlargement was not significantly related to tear location.

Of the 122 patients, 100/122 (90.2%) had fatty infiltration of the supraspinatus at baseline. Changes in fatty infiltration and muscle volume are summarized in Table 4. Patients with initial full-thickness or partial-thickness tears did not differ significantly in the rate of progression of fatty infiltration or the change in muscle volume.

Association between tear enlargement and follow-up duration

For those patients with a follow-up of 12 months or more, the rate of tear enlargement was significantly greater for full-thickness than for partial-thickness tears. Tear enlargement by duration of follow-up for full-thickness and partial-thickness tears is summarized in Table 5.

Factors affecting the enlargement of rotator cuff tears

Univariate analysis did not reveal any significant differences between the two groups with respect to DM status, smoking status, osteoporosis, injection history, trauma history, sports activity level, muscle volume, or fatty infiltration. However, patients older than 60 years ($P = 0.027$) and those with a subacromial spur ($P < 0.001$) on plain film showed significantly more progression compared with patients without these factors. Moreover, tear enlargement occurred significantly more often in the full-thickness tear group than in the partial-thickness group ($P < 0.001$; Table 6). Multivariate logistic regression analysis revealed

Table 4 Change in supraspinatus fatty infiltration and muscle volume

	Fatty infiltration			Muscle volume		
	Improvement	No change	Progression	Increased[a]	No change	Decreased
Full-thickness tear (*n*, %)	0	22 (64.7)	12 (35.3)	0	25 (73.5)	9 (26.5)
Partial-thickness tear (*n*, %)	0	79 (90.0)	9 (10.2)	0	85 (96.6)	3 (3.4)
Total (*n*, %)	0	101 (82.8)	21 (17.2)	0	110 (90.2)	12 (9.8)

[a] Increased more than 10% compared with initial magnetic resonance imaging

Table 5 Tear size enlargement in partial- and full-thickness tears by follow-up period

	6–12 months	12–24 months	≥24 months
Full-thickness tear (*n*)	7	9	18
Tear enlargement (*n*, %)	5 (71.4)	8 (88.9)	15 (83.3)
Partial-thickness tear (*n*)	24	41	23
Tear enlargement (*n*, %)	6 (25)	12 (29.3)	5 (21.7)
Total (*n*)	31	50	41
Tear enlargement (*n*, %)	11 (35.5)	20 (40)	20 (48.8)
P value (odds ratio)[a]	n.s.	0.002 (19.3)	<0.001 (18.0)

n.s. not significant

[a] Chi-square test or Fisher exact test comparing tear progression and initial tear size (full-thickness or partial-thickness) in each follow-up period

that initial full-thickness tear was the only significant predictor of the enlargement of the rotator cuff tear ($P < 0.001$, Exp (B), 13.2; 95% confidence interval, 4.8–35.9).

With a sample size of 122 (72.1% with partial-thickness tear and 27.9% with full-thickness tear), logistic regression analysis of tear enlargement for initial full-thickness tears achieved 99.98% power at $\alpha = 0.05$ to detect the effect corresponding to an odds ratio of 13.2 after adjustment for age and subacromial spur.

Clinical outcomes

The average VAS score for pain at the initial visit did not differ significantly from the scores during follow-up (n.s.). Similarly, the ASES and CSS scores at the initial visit did not differ significantly from the scores during follow-up (n.s.). The average values for ROM did not change significantly during follow-up (n.s.). Figures 1 and 2 show the clinical outcomes.

Discussion

The most important finding of the present study was that full-thickness tears showed a higher rate of enlargement than partial-thickness tears. At each follow-up period, full-thickness tears showed a higher rate of enlargement than partial-thickness tears. This suggests that full-thickness tears have a higher risk of enlargement than do partial-thickness tears, irrespective of the length of follow-up. Moreover, multivariate analysis revealed that a full-thickness tear was the only risk factor significantly associated with enlargement of rotator cuff tear. Nakamura et al. [26] reported that medium-sized tears (≥1 cm but <3 cm) are at high risk of tear progression. They also suggested that tears with an initial size of <1 or ≥4 cm are unlikely to get larger. Keener et al. [16, 17] also suggested that the risk of enlargement is 1.5 times greater for full-thickness tears than for partial-thickness tears. Full-thickness tears greater than 4 cm were excluded from our study. Thus, our results demonstrate that full-thickness tears smaller than 4 cm progressed more rapidly than partial-thickness tears.

The present study found that 51/122 (41.8%) of all symptomatic rotator cuff tears increased in size with follow-up ranging from 6 to 100 months. This result is consistent with previously published findings. For instance, Yamaguchi et al. [31] reported tear progression in 9/23 (39.1%) of full-thickness rotator cuff tears monitored by serial

Table 6 Univariate analysis of the relationship between tear enlargement and associated factors

Variable	Tear enlargement ($n = 51$)	No enlargement ($n = 71$)	*P* value	Unadjusted OR (95% CI)
Age (*n*, %)	38 (49.4)	39 (50.6)	0.027[a]	2.4 (1.1, 5.3)
Diabetes (*n*, %)	8 (36.4)	14 (63.6)	n.s.	
Smoking (*n*, %)	21 (40.4)	31 (59.6)	n.s.	
Trauma history (*n*, %)	13 (59.1)	9 (40.9)	n.s.	
Injection history (*n*, %)	27 (39.1)	41 (60.3)	n.s.	
Sports activity level (*n*, %)	35 (37.6)	58 (62.4)	n.s.	
Osteoporosis (*n*, %)	10 (35.7)	18 (64.3)	n.s.	
Subacromial spur (*n*, %)	32 (65.3)	17 (34.7)	<0.001[a]	5.4 (2.4, 11.8)
Initial full-thickness tear (*n*, %)	28 (82.4)	6 (17.6)	<0.001[a]	13.2 (4.8, 35.9)
Fatty infiltration (*n*, %)	22 (51.2)	21 (48.8)	n.s.	
Muscle volume (*n*, %)	13 (59.1)	9 (40.9)	n.s.	

n.s. not significant, *OR* odds ratio, *CI* confidence interval

[a] Statistically significant

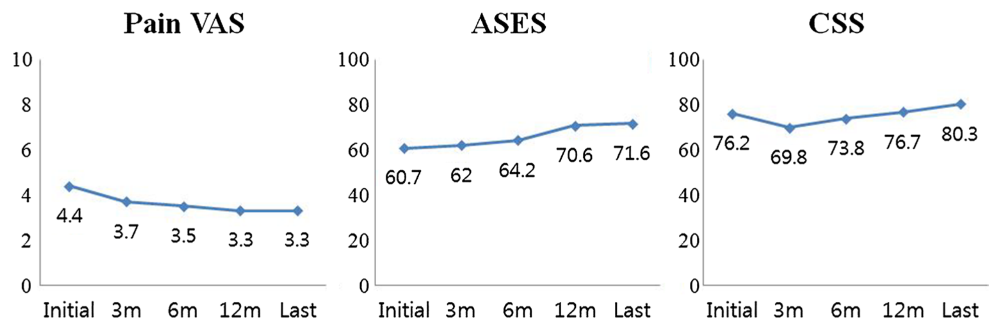

Fig. 1 The average VAS score for pain, ASES and CSS scores at the initial visit did not differ significantly from the scores during follow-up

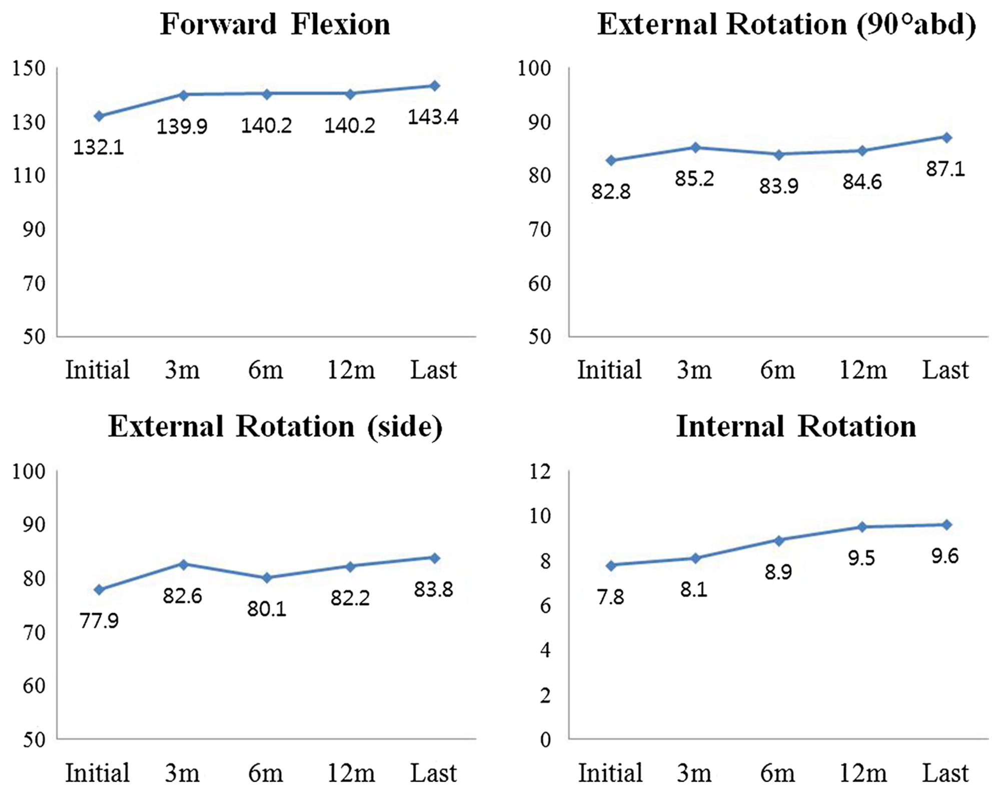

Fig. 2 The average values for ROM did not change significantly during follow-up

ultrasound over 2.8 years. Another study by Safran et al. [27] found that 30/61 (49.2%) of all full-thickness rotator cuff tears had increased in size after 29 months, as measured by ultrasound. Keener et al. [17] used serial ultrasound to demonstrate that tear progression occurred in 108/219 (49%) of shoulders with a median follow-up of 5.1 years. Studies using MRI scans have obtained similar results. Fucentese et al. [9] demonstrated that 6/24 (25%) with full-thickness supraspinatus tears showed increased tear size after a mean follow-up of 42 months. Another study found that 19/59 (32.2%) of all partial- and full-thickness rotator cuff tears had progressed after 20 months, as monitored by serial MRI scans [24]. Together, these studies suggest that 25–49.2% of all rotator cuff tears progress over time, which is consistent with our findings. Furthermore, our study analysed 34 full-thickness and 88 partial-thickness rotator cuff tears, making it the largest study to date that uses MRI to assess tear progression. Thus, our results may provide the most accurate estimate of tear progression to date.

Univariate analysis revealed that patients older than 60 years [38/77 (49.4%)] had significantly more tear progression than patients younger than 60 years [13/45 (28.9%)]. Similarly, a recent study by Maman et al. [24] found that patients older than 60 years had a significantly higher progression rate than younger patients. However, multivariate analysis did not identify age as a significant predictor of tear progression. Patients with a subacromial spur on plain film [32/49 (65.3%)] showed significantly more progression than patients without a subacromial spur [19/73 (26.0%)] in our study. A larger subacromial spur might be related to a thicker and shorter coracoacromial ligament and increased pressure in the subacromial space, causing subacromial impingement [1, 8, 14, 29]. However, subacromial spur was not related to tear progression in multivariate analysis.

Although a large number of rotator cuff tears progressed in our study, tear size decreased in six patients on follow-up MRI. Although this result appears to contradict the conventional wisdom that rotator cuff tears do not heal [11, 30, 31], a few studies have reported results similar to ours. Fucentese et al. [9] found that the tear was no longer visible on follow-up MRI in 2/24 (8%) with full-thickness tears. Another study reported that the size of the rotator cuff tear was reduced by more than 5 mm on follow-up MRI in 5/59 (8%) patients [24]. However, whether the reduction in size of the rotator cuff tears in our study indicates true healing of the rotator cuff remains unclear. A possible explanation for the apparent decrease in tear size may be that the tear site became filled with scar tissue or synovial proliferation from normal tissue [11, 27].

There are several limitations in this study. First, the study had a high dropout rate, which may have introduced a degree of bias. The present study was designed as a retrospective review of tear progression on serial MRI. Second, there were a smaller number of patients with full-thickness tears than with partial-thickness tears. The small sample size for full-thickness tear may have led to bias in our comparison of the progression of tear types and may have affected our ability to detect risk factors for tear enlargement. Third, the follow-up duration was relatively short, and the time interval between follow-up imaging was somewhat variable. Since it was speculated that the length of follow-up was a significant factor affecting tear enlargement, patients were classified into three groups according to the follow-up period. This analysis may have helped to compensate for errors associated with a variable follow-up. Although longer-term studies are needed to fully understand tear progression, our 2-year follow-up is still a meaningful time frame for observing the natural history of rotator cuff tears.

Conclusion

This study found that 28/34 (82.4%) of symptomatic full-thickness rotator cuff tears and 23/88 (26.1%) of symptomatic partial-thickness tears increased in size over a follow-up period of 6–100 months. The present study suggests that tear enlargement occurs more frequently in full-thickness tears than in partial-thickness tears. Moreover, a full-thickness tear was the most reliable predictor of tear enlargement.

Compliance with ethical standards

Conflict of interest Yang-Soo Kim, Sung-Eun Kim, Sung-Ho Bae, Hyo-Jin Lee, Won-Hee Jee, and Chang kyun Park declare that they have no conflict of interest.

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Ethical approval This study was approved by the Institutional Review Board of our institution (Study No: KC14RISI0288).

Informed consent Informed consent was obtained from all individual participants included in this study.

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