

Failure With Continuity in Rotator Cuff Repair “Healing”

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Background: Ten to seventy percent of rotator cuff repairs form a recurrent defect after surgery. The relationship between retraction of the repaired tendon and formation of a recurrent defect is not well defined.

Purpose/Hypotheses: To measure the prevalence, timing, and magnitude of tendon retraction after rotator cuff repair and correlate these outcomes with formation of a full-thickness recurrent tendon defect on magnetic resonance imaging, as well as clinical outcomes. We hypothesized that (1) tendon retraction is a common phenomenon, although not always associated with a recurrent defect; (2) formation of a recurrent tendon defect correlates with the timing of tendon retraction; and (3) clinical outcome correlates with the magnitude of tendon retraction at 52 weeks and the formation of a recurrent tendon defect.

Study Design: Case series; Level of evidence, 4.

Methods: Fourteen patients underwent arthroscopic rotator cuff repair. Tantalum markers placed within the repaired tendons were used to assess tendon retraction by computed tomography scan at 6, 12, 26, and 52 weeks after operation. Magnetic resonance imaging was performed to assess for recurrent tendon defects. Shoulder function was evaluated using the Penn score, visual analog scale (VAS) score for pain, and isometric scapular-plane abduction strength.

Results: All rotator cuff repairs retracted away from their position of initial fixation during the first year after surgery (mean [standard deviation], 16.1 [5.3] mm; range, 5.7-23.2 mm), yet only 30% of patients formed a recurrent defect. Patients who formed a recurrent defect tended to have more tendon retraction during the first 6 weeks after surgery (9.7 [6.0] mm) than those who did not form a defect (4.1 [2.2] mm) ($P = .08$), but the total magnitude of tendon retraction was not significantly different between patient groups at 52 weeks. There was no significant correlation between the magnitude of tendon retraction and the Penn score ($r = 0.01$, $P = .97$) or normalized scapular abduction strength ($r = -0.21$, $P = .58$). However, patients who formed a recurrent defect tended to have lower Penn scores at 52 weeks ($P = .1$).

Conclusion: Early tendon retraction, but not the total magnitude, correlates with formation of a recurrent tendon defect and worse clinical outcomes. “Failure with continuity” (tendon retraction without a recurrent defect) appears to be a common phenomenon after rotator cuff repair. These data suggest that repairs should be protected in the early postoperative period and repair strategies should endeavor to mechanically and biologically augment the repair during this critical early period.

Keywords: rotator cuff repair; tendon healing; tendon retraction

Rotator cuff tears affect 40% or more of patients older than 60 years and are a common cause of debilitating pain, reduced shoulder function, and weakness. In excess of 250,000 rotator cuff repairs are performed annually in the United States.⁶ Despite continuing advances in surgical repair techniques and modification to postoperative rehabilitation strategies, magnetic resonance imaging (MRI) and ultrasonography (US) studies continue to reveal that 10% to 70% of rotator cuff repairs go on to form a recurrent tendon defect after surgery.^{21,30,32} These recurrent tendon defects are believed to form when the repaired rotator cuff tendon retracts away from its initial site of fixation. However, our understanding of the timing,

magnitude, and prevalence of tendon retraction after rotator cuff repair, as well as its relationship to the formation of a recurrent defect, is limited.

Despite consistent improvements in patient-reported outcomes after rotator cuff repair, degenerative muscle changes, abnormal tendon architecture, and shoulder weakness often persist, even in patients without an identifiable recurrent defect.^{**} We propose that tendon retraction after repair may explain, at least in part, these clinical findings and suggest that the absence of a recurrent tendon defect on standard magnetic resonance (MR) or US imaging may not be sufficient to conclude that the tendon has healed at the site of initial fixation.

Hence, the objective of this study was to measure the prevalence, timing, and magnitude of tendon retraction

during the first year after rotator cuff repair and correlate these outcomes with the formation of a recurrent tendon defect and clinical outcomes. We used low-dose computed tomography (CT) imaging of radio-opaque markers to quantify tendon retraction after rotator cuff repair.⁹ Our primary hypotheses were that (1) tendon retraction is a common phenomenon, although not always associated with a recurrent defect; (2) formation of a recurrent tendon defect correlates with the timing of tendon retraction; and (3) clinical outcome correlates with the magnitude of tendon retraction at 52 weeks and the formation of a recurrent tendon defect. As a secondary objective, we sought to determine the extent to which tendon retraction could be estimated from muscle-tendon junction retraction measured from standard MR images.

MATERIALS AND METHODS

This institutional review board–approved prospective study included 14 patients with preoperative MRI evidence of a 1- to 4-cm full-thickness tear of the supraspinatus and/or infraspinatus tendons that was confirmed at the time of surgery, retracted less than 2 cm, and was repairable using an arthroscopic suture bridge technique. Exclusion criteria were arthritis of the glenohumeral joint, preoperative passive range of motion more than 20° less in any plane of motion than the contralateral shoulder, inflammatory arthritis, cortisone injection within 12 weeks of surgery, or injury of the contralateral shoulder. Other exclusion criteria were muscle atrophy greater than grade 2,^{10,15} a full-thickness tear of the subscapularis requiring repair, patients requiring biceps tenodesis or labral repair, smokers, or patients involved in workers' compensation claims. Patients having a release of the long head of the biceps or an acromioclavicular (AC) joint resection were included.

Operative Technique

All repairs were performed by 1 of 2 shoulder fellowship-trained orthopaedic surgeons at our institution (J.A.M. or J.P.I.). At the time of surgery, the rotator cuff tear was debrided back to a stable edge and then the anterior-posterior length of the tear was measured using a graduated probe along the medial edge of the greater tuberosity footprint. Then, 5.0-mm Fastin anchors, each loaded with a double strand of No. 2 Orthocord suture (DePuy Mitek, Warsaw, Indiana), were inserted at the medial edge of

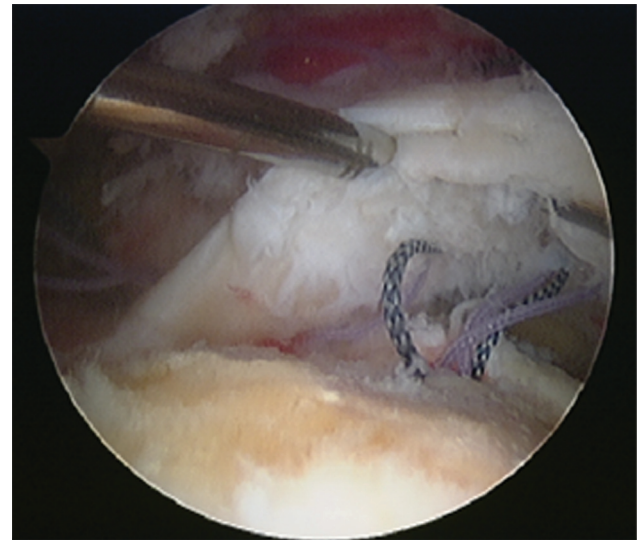


Figure 1. Intraoperative photo showing that the arthroscopic bead delivery device was inserted into the lateral edge of the tendon before the repair sutures were tied, and the beads were deployed 1.5 to 2 cm medial to the lateral edge. (Reprinted with permission from Derwin et al.⁹ © 2012, Elsevier Ltd.)

the repair footprint. Both limbs of each suture were passed through the tendon, approximately 1.5 cm from the lateral edge, for a planned suture-bridge repair.²⁶

After the sutures had been passed through the tendon, but before the medial row of the repair was tied down, one or two 1.6-mm diameter tantalum beads were deployed within the tendon using a custom, cannulated, arthroscopic delivery device. The delivery device was inserted into the lateral edge of the tendon, and beads were deployed 1.5 to 2 cm medial to the lateral edge but not otherwise attached to the tendon (Figure 1). The beads were located medial to the repair suture line but within the tendonous portion of the rotator cuff.

After the beads were implanted, the medial row of repair sutures was tied down in a mattress configuration, and the suture limbs were crossed and fixed with a knotless Versalok anchor (DePuy Mitek) placed approximately 1 to 1.5 cm distal to the lateral-most aspect of the greater tuberosity. In 2 patients, a single bead was also inserted within their intact subscapularis from the superior border

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One or more of the authors has declared the following potential conflict of interest or source of funding: This work was supported in part by Pfizer Pharmaceuticals; the Department of Orthopedic Surgery, Cleveland Clinic; and the Department of Orthopedic Surgery, Henry Ford Hospital. Dr Derwin has received research funding and materials from Synthesome and The Musculoskeletal Transplant Foundation and was a paid consultant for CollPlant. Drs McCarron, Iannotti, and Derwin receive royalties from The Musculoskeletal Transplant Foundation. Dr Iannotti is a paid consultant and receives royalties from Tornier.

of the tendon. The position of the intact subscapularis tendon would not be expected to change over the course of the study, and therefore these subscapularis beads served as a control for the bead-based measurements made from repaired tendons (described below).

Postoperative Protocol

The postoperative protocol was prospectively defined to include use of a sling or small abduction pillow for 6 weeks. Patients were allowed use of the operative arm at waist level for simple activities of daily living. Active range of motion or weighted use of the arm for lifting, reaching, pushing, or pulling was restricted during the first 6 weeks. Active range of motion and exercises were started at 6 weeks after surgery, and progression of exercises after 12 weeks was individualized based on the patients' pain and function. All patients were seen by the treating surgeon (J.A.M. or J.P.I.) and study team at 2, 6, 12, 16, 26, 39, and 52 weeks. Supervised physical therapy was used based on the surgeons' preferences and the patients' needs or preferences.

Imaging

A low-radiation dose CT scan (100 kV, 45 mAs) of the operated shoulder was performed before the patient was discharged from the hospital at the time of surgery and at 6, 12, 26, and 52 weeks postoperation. The CT scans were performed on either Siemens Sensation 16 or Sensation 64 scanners (Siemens Medical Solutions, Erlangen, Germany) with voxel size ranging from 0.2 to 0.4 mm in the x-y dimension and 0.6 to 0.75 mm in the z dimension. Scans were obtained with the hand of the operated shoulder resting on the umbilicus and the elbow of the operated shoulder resting on the scanner table.

Magnetic resonance imaging was obtained at 6, 12, 26, and 52 weeks after surgery. All MRI examinations were performed using dedicated shoulder coils on 1.5 tesla units (Avanto, Symphony, Siemens Medical Solutions; Philips Inera, Philips, Amsterdam, the Netherlands) or 1.0 tesla units (Harmony; Siemens). Complete MRI examinations—consisting of axial, coronal, and sagittal proton density (PD) images with fat suppression; coronal T2-weighted images without fat suppression; and sagittal T1-weighted images—were performed within 3 months before surgery and at 52 weeks after surgery. At 6, 12, and 26 weeks, a condensed MR examination was performed consisting of coronal PD fat-suppressed images and coronal T2-weighted images without fat suppression.

All images were read by the treating surgeon at the time of each clinical follow-up. Furthermore, at 52 weeks, all MRIs from each patient were assessed in aggregate for (a) the timing and presence of a recurrent, full-thickness tendon defect and (b) the change in the position of the muscle-tendon junction (MTJ) of the supraspinatus tendon between 6 and 52 weeks. Criterion for a postoperative recurrent tendon defect (retear) was a full-thickness region with fluid signal intensity on T2-weighted images in at least 2 sequential images (Figure 2). The change in position of

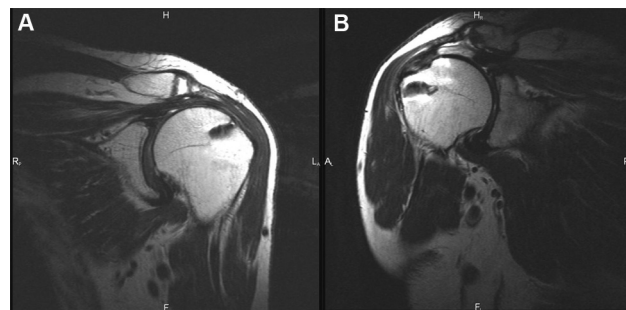


Figure 2. Coronal oblique T2-weighted magnetic resonance images without fat suppression at 52 weeks after surgery: (A) shoulder without a recurrent tendon defect having undergone a 22.5-mm increase in anchor-bead distance since day of surgery (patient 1) and (B) shoulder with a recurrent tendon defect having undergone a 12.3-mm increase in anchor-bead distance since day of surgery (patient 11).

the MTJ was measured relative to the greater tuberosity between 6 and 52 weeks after surgery on coronal images. The MRI assessment was performed by consensus reading of 2 shoulder fellowship-trained orthopaedic surgeons (J.P.I., E.T.R.) and 2 musculoskeletal radiologists (J.M.P., J.P.S.), all of whom were blinded to and not involved with the measurements of anchor-bead distance from the CT scans.

Functional Evaluation

Shoulder function was evaluated preoperatively and at 6, 12, 26, and 52 weeks after surgery. Pain, activities of daily living, and satisfaction were evaluated using the patient-reported Penn score (100 points).²³ (We note that the commonly used American Shoulder and Elbow Surgeons score uses a subset of the questions on the Penn score to calculate pain and function.) The minimal clinically important difference (MCID) for improvement with the Penn score is 11.4 points.²³ Pain was also assessed using a visual analog scale (VAS) ranging from 0 (no pain) to 10 (severe). Isometric scapular-plane abduction strength was measured in triplicate in the operative and contralateral shoulder using a handheld dynamometer (Manual Muscle Tester 01163; Lafayette Instrument Company, Lafayette, Indiana). Triplicate measures were averaged and strength of the repaired shoulder was normalized by the contralateral.

Analysis of Anchor-Bead Distance (Tendon Retraction)

The CT scans were analyzed using custom software (Vol-Ninja; ImageIQ, Cleveland, Ohio). The 3-dimensional (3D) position of each bead and the superficial end of each suture anchor were determined in a CT scan-based coordinate system.⁹ The scalar distances between each bead and its nearest anchor (anchor-bead distance) were computed for each scan. For each bead, the anchor-bead distance was consistently measured to the same anchor across all scans for a given patient. We have previously shown that

TABLE 1
Patient Demographics, Tear Size, Imaging, and Anchor-Bead Distance Results^a

Patient	Age, y	Sex	Tear Size, cm	MRI	Change in Anchor-Bead Distance Relative to Day of Surgery, mm ^b			
					6 wk	12 wk	26 wk	52 wk
1 ^c	65	M	2	No defect	4.4	20.7	22.5	22.5
2	51	M	3	No defect	4.7	9.3	15.4	14.4
3	44	M	2	No defect	2.4	5.0	6.0	5.7
4	62	M	3.5	No defect	5.1	12.7	21.5	23.2
5	62	M	2.5	No defect	4.8	14.6	20.4	15.7
6	57	M	3	Recurrent defect	17.2	17.0	20.4	21.7
7	72	F	4	Recurrent defect	4.1	13.3	16.3	17.5
8	70	M	3	No defect	3.8	17.1	17.8	17.6
9	55	F	3.5	No defect	3.8	14.2	15.3	16.0
10	63	M	3	Recurrent defect	11.8	18.0	17.1	21.5
11	50	M	4	Recurrent defect	5.6	7.1	12.0	12.3
12	48	F	2	No defect	-0.2	3.5	12.8	11.4
13 ^d	—	—	—	—	—	—	—	—
14	40	M	1.5	No defect	8.0	9.3	10.3	10.0
Mean (SD)	56.8 (9.9)	10:3 (M:F)	2.8 (0.8)		5.8 (4.4)	12.4 (5.3)	16.0 (5.3)	16.1 (5.3)

^aMRI, magnetic resonance imaging.

^bData represent the change in anchor-bead distance of 1 bead (patients 1 [at 26 and 52 weeks], 4, 5, 8, 11, 12) or an average of 2 beads (patients 1 [at 6 and 12 weeks], 2, 3, 6, 7, 9, 10, 14).

^cPatient had 1 bead come out of the tendon and migrate to the axilla between 12 and 26 weeks postoperation.

^dPatient sustained a traumatic injury to the operated arm during the first 6 weeks after surgery and was subsequently removed from the study.

3D distance measurement using low-dose CT imaging in human shoulders is accurate and repeatable to within 0.7 mm for any given CT scan and that ± 3 mm is the uncertainty in anchor-bead distance for rotator cuff repair patients on repeat positioning and rescanning with their hand on the umbilicus.⁹

To determine the magnitude of tendon retraction after surgery, we compared the scalar distance between an anchor-bead pair on a given day with the scalar distance between the same pair on the day of surgery. Anchor-bead distance measurements were performed by a single operator (J.A.M.) who was blinded to the consensus results of the postoperative MRI.

Statistical Analysis

The change in anchor-bead distance profiles and Penn scores over time was compared between patients who formed a recurrent tendon defect and those who did not with a quadratic mixed model. The groups were also compared at each time point with the Wilcoxon rank-sum test. Pearson correlation coefficients between change in anchor-bead distance and both the Penn score and normalized scapular-plane abduction strength at 52 weeks were assessed with an *F* test. The normalized scapular-plane abduction strength was compared between patients who formed a recurrent tendon defect and those who did not with the Wilcoxon rank-sum test. Finally, the Pearson correlation between tendon retraction, measured between 6 and 52 weeks by CT imaging of radio-opaque markers, and muscle-tendon junction retraction, measured between 6 and 52 weeks from standard MR images, was tested with

an *F* test. For all analyses, $P < .05$ was considered significant and $.05 < P < .1$ a trend. *P* values were not adjusted for multiple comparisons. Analyses were done with SAS 9.0 (SAS Institute, Cary, North Carolina) and JMP 9.0 (JMP, Cary, North Carolina).

RESULTS

One patient sustained a traumatic injury to the operated arm during the first 6 weeks after surgery and was removed from the study. One bead in 1 patient came out of the tendon and migrated to the axillary pouch between 12 and 26 weeks and was subsequently removed arthroscopically. The mean patient age for the 13 study patients was 56.8 years (standard deviation [SD], 9.9 years; range, 40-72 years), and the mean anterior-posterior rotator cuff tear size at surgery was 2.8 cm (SD, 0.8 cm; range, 1.5-4.0 cm) (Table 1).

Four of 13 patients were considered to have a recurrent tendon defect at 52 weeks by MRI assessment (Figure 2, Table 1). The formation of a full-thickness, fluid-filled gap in the tendon was first identified at 6 weeks in 1 patient, 12 weeks in another, and 26 weeks in 2 patients. We noted that the preoperative tear size in patients who formed a recurrent tendon defect (3.5 ± 0.6 mm) was significantly greater ($P = .04$) than those who did not form a recurrent defect (2.6 ± 0.7 mm).

The anchor-bead distances increased in all study patients over the 52 weeks after surgery (mean [SD], 16.1 [5.3] mm; range, 5.7-23.2 mm) (Table 1), and there was a moderate to strong positive correlation between

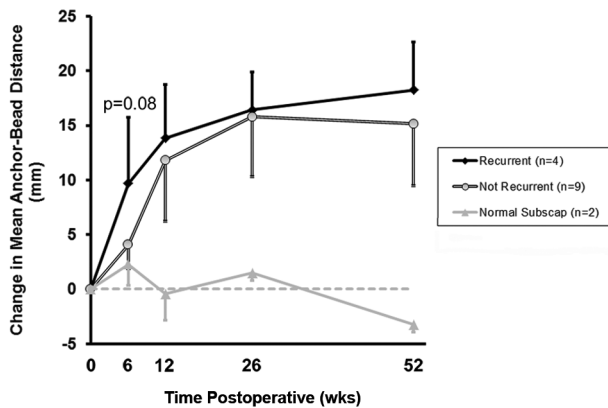


Figure 3. Change in distance between anchors at the repair site and tendon markers within the repaired tendon (relative to the day of surgery). When evaluated over the entire 52-week study period, there was no overall difference in the change of anchor-bead distance between patients who did and those who did not form a recurrent defect (ie, no overall group effect, $P = .12$). However, between the day of surgery and 6 weeks postoperation, anchor-bead distance tended to increase more in patients who formed a recurrent defect than in patients who did not ($P = .08$). Anchor-bead distances in the intact subscapularis tendons over time are also shown.

the change in anchor-bead distance at 52 weeks and patient age ($r = 0.75$, $P = .003$). Over the 52-week study period, there was no overall difference in the change of anchor-bead distance between patients who did and those who did not form a recurrent defect (ie, no overall group effect, $P = .12$). However, between the day of surgery and 6 weeks after operation, anchor-bead distance tended to increase more in patients who formed a recurrent defect (9.7 ± 6.0 mm) than in patients who did not form a recurrent defect (4.1 ± 2.2 mm) ($P = .08$; Figure 3). By 52 weeks, tendon retraction for patients who formed a recurrent defect (18.3 ± 4.4 mm) was not significantly different from patients who did not form a recurrent defect (15.2 ± 5.6 mm) ($P = .5$; Figure 3). Anchor-bead distances in the intact subscapularis tendons varied ± 3 mm over the 52-week study period (Figure 3).

Across the entire study population, the Penn score increased from a mean (SD) of 39.4 (17.6) preoperatively to 92.0 (10.2) at 52 weeks after surgery. At 52 weeks, there was no significant correlation between the magnitude of tendon retraction (change in anchor-bead distance) and either the total Penn score ($r = 0.01$, $P = .97$) or normalized scapular abduction strength ($r = -0.21$, $P = .58$). Over the entire 52-week study period, the Penn score was significantly lower in patients who formed a recurrent defect ($P = .03$). Specifically, patients who formed a recurrent defect tended to have lower Penn scores at 52 weeks ($P = .1$) (Figure 4). There was no significant difference in normalized scapular abduction strength at 52 weeks between patients who formed a recurrent tendon defect and those who did not ($P = .93$).

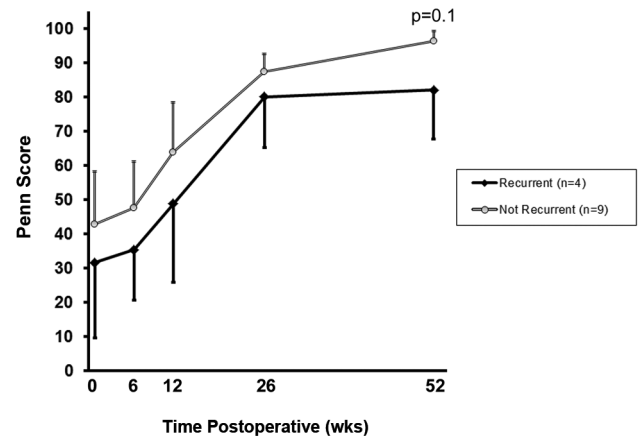


Figure 4. When evaluated over the entire 52-week study period, the Penn score was significantly lower in patients who formed a recurrent defect ($P = .03$). Specifically, patients who formed a recurrent defect tended to have lower Penn scores at 52 weeks ($P = .1$).

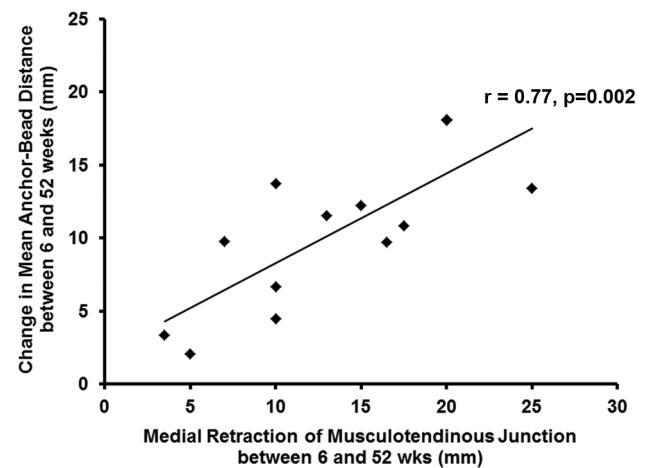


Figure 5. Medial retraction of the muscle-tendon junction between 6 and 52 weeks was moderately to strongly correlated with the change in anchor-bead distance during the same time period ($r = 0.77$, $P = .002$).

Medial retraction of the muscle-tendon junction as measured by MRI between 6 and 52 weeks was moderate to strongly correlated with the change in anchor-bead distance as measured by CT scan during the same time period ($r = 0.77$, $P = .002$) (Figure 5).

DISCUSSION

The purpose of this study was to measure the prevalence, timing, and magnitude of tendon retraction during the first year after rotator cuff repair and correlate these outcomes with the formation of a recurrent tendon defect and clinical outcomes. Our results showed that all rotator cuff tendon

repairs retracted away from their position of initial fixation during the first year after surgery (mean [SD], 16.1 [5.3] mm; range, 5.7-23.2 mm), yet only 4 of 13 (30%) patients formed a recurrent tendon defect. There was a positive correlation between the magnitude of tendon retraction at 52 weeks and patient age. Patients who formed a recurrent defect had a larger preoperative tear size and tended to have more tendon retraction during the first 6 weeks after surgery than those patients who did not form a defect, but the total magnitude of tendon retraction was not significantly different between these patient groups at 1 year. Although the presence of a recurrent defect did correlate with worse clinical outcomes for the patient, the total magnitude of tendon retraction did not.

In this study, low-dose CT imaging was used to measure the 3D distance between implanted markers in the rotator cuff, a technique that is conceptually similar to radiostereometric analysis (RSA). Derwin et al⁹ have previously shown that 3D distance measurement using low-dose CT imaging in human shoulders is accurate and repeatable to within 0.7 mm. Furthermore, these authors showed that ± 3 mm is the uncertainty in anchor-bead distance for rotator cuff repair patients on repeat positioning and scanning with their hand on the umbilicus.⁹ In the current study, we demonstrated that the anchor-bead distance of beads implanted in the normal, intact subscapularis tendon varied ± 3 mm over the current 52-week study period. These data corroborate the previously reported uncertainty of the measurement technique,⁹ as well as support the conclusion that implanted tendon beads do not migrate appreciably within the tendon over time.

To further assess the potential for bead migration within a repaired tendon, we performed a pilot study on 10 cadaveric rotator cuff tendon repairs, cyclically loaded from 5 to 50 N at 0.25 Hz for 1000 cycles. Intratendinous beads were deployed within the repaired tendon in the exact manner as used for the patients in this study, and surface markers were affixed to the tendon as the gold standard. The change in tendon-to-bone distance after cycling was not significantly different between the surface-affixed and intratendinous markers ($P = .15$, paired t test), and the Pearson correlation of the surface-affixed and intratendinous marker distances after cycling was $r = 0.98$ ($n = 10$, unpublished data). This cadaver study demonstrates that intratendinous beads behave similarly to surface-affixed markers under in vitro cyclic loading conditions and also suggests that migration of deployed tantalum beads within the rotator cuff tendon in human patients over time is minimal. In addition, the moderate to strong positive correlation between bead movement away from the suture anchors and the medial retraction of the muscle-tendon junction (Figure 5) further supports the conclusion that the change in anchor-bead distance measured in this study reflects a medial retraction of the tendon rather than a medial migration of the beads within the tendon.

Medial retraction of a repaired rotator cuff tendon away from its position of initial fixation at the greater tuberosity has been recently described by other authors as well. Baring et al² reported on tendon retraction after open rotator cuff repair using a transosseous modified Mason-Allen suture technique in 10 patients using RSA. Similar to

our findings, repaired rotator cuff tendons retracted medially an average of 8.7 mm during the first year after surgery. All patients demonstrated some degree of medial tendon retraction, yet only 4 of 10 (40%) demonstrated a partial or full recurrent tendon defect. Together with our study, these results suggest that tendon retraction could be a common phenomenon after rotator cuff repair, yet not always associated with a recurrent defect. We have used the term *failure with continuity* to describe this process of tendon retraction away from its position of initial fixation without the formation of a recurrent defect.

Our data demonstrate that ~80% of tendon retraction occurs in the first 12 weeks after operation. Likewise, Baring et al² showed that ~80% of the retraction of their repairs occurred between 3 and 14 weeks after the operation. This timeline correlates with other literature reporting that rotator cuff retears occur by 3 to 6 months after surgery.^{13,20,25} Although the total magnitude of tendon retraction was not significantly different between patient groups at 1 year, patients who had a recurrent tendon defect at 52 weeks had a larger preoperative tear size and tended to have more tendon retraction during the first 6 weeks after surgery than those patients who did not. These results suggest that tear size as well as the timing and rate of tendon retraction may be influencing defect formation, rather than the cumulative magnitude of retraction during the postoperative period. In addition, 3 of the 4 patients who formed a recurrent defect in this study had the majority of their tendon retraction precede defect formation, suggesting that tendon retraction and the formation of a recurrent defect do not necessarily occur simultaneously.

The mechanisms by which tendon retraction and recurrent tendon defect formation occur are unclear. Cummins and Murrell⁷ have reported that at the time of revision surgery in 19 of 22 rotator cuff repairs, failure had occurred by the tendon pulling through the sutures used for fixation. Schepull et al²⁸ noted elongation of Achilles tendon repairs during the first postoperative year. In the current study, we noted that the appearance of the repaired tendons at their site of fixation to the greater tuberosity was consistently more normal on MRI than tendon signal medial to the site of fixation. For the 4 patients who went on to form recurrent defects, soft tissue was frequently seen to persist at the greater tuberosity attachment site, with the fluid gap medial to the repair line. These observations suggest that the arthroscopic suture-bridge technique may be achieving its intended goal of maintaining the repaired tendon at the greater tuberosity footprint but also precipitating repair elongation or gap formation medial to the suture line within the tendon mid-substance.⁵ Together, these studies suggest that tendon retraction after rotator cuff repair could occur as a result of the tendon pulling through sutures, elongation of the newly formed repair tissue itself, and/or elongation of the tendon medial to the repair sutures. The extent to which intrinsic factors (eg, mechanical or biologic characteristics of the repaired tendon) or extrinsic factors (eg, type of surgical repair, activity level) influence the timing or magnitude of tendon retraction is not known. However, the finding that patient age is significantly correlated with the tendon retraction may

highlight the importance of intrinsic factors on tendon healing after rotator cuff repair. Further study in larger sample sizes is needed to conclusively demonstrate that early tendon retraction correlates with the formation of a recurrent tendon defect and to define the underlying mechanisms and relationships between these 2 events.

The presence of a recurrent tendon defect did correlate with worse clinical outcomes (Penn scores), consistent with previous studies.^{1,3,4,8,11,12,16-19} However, neither Penn score nor scapular-plane abduction strength correlated with the total magnitude of tendon retraction at 1 year. Given the relatively large magnitudes of tendon retraction observed across all patients in this study, we expected tendon retraction to have an adverse effect on clinical outcome. This lack of correlation may be due to the small sample size and/or the small- to medium-sized tears treated in this study. Another explanation may be the fact that our measurement technique only determines tendon retraction relative to the position of tendon fixation at surgery, not necessarily relative to the normal muscle-tendon length prior to developing a tear, which may limit its direct correlation with these clinical outcomes postoperatively.

Limitations of our study include the small sample size, which does not allow for robust statistical power or defining all potential mechanisms and timing of tendon retraction in all types of patients, surgical repair techniques, or size and configuration of tears. Second, our CT scan measurement technique only determines tendon retraction relative to the position of tendon fixation at surgery, not necessarily relative to the normal muscle-tendon length, which may limit its direct correlation with clinical outcomes. Third, the use of only 1 or 2 beads in the repaired tendons limited our ability to discriminate regional variation in tendon retraction and led us to report only an average retraction for the entire tendon repair. Fourth, 1 bead did dislodge from the tendon in 1 patient. We speculate that the bead migrated laterally out of the tendon after significant medial retraction as *lateral* bead migration out of its initial delivery tunnel might be possible if suture cutting through tendon results in a frayed or loose tendon edge. Although second-look surgery to remove the loose bead from the axilla confirmed no adverse consequence for the patient, this event does underscore the potential risk of using untethered beads in this application.

In summary, the most significant and conclusive finding from this study is that all 13 patients demonstrated some degree of medial tendon retraction after rotator cuff repair, whether or not they went on to form a recurrent tendon defect. Specifically, failure with continuity (tendon retraction without a recurrent defect) should be appreciated as a common phenomenon after rotator cuff repair. Tendon retraction in all patients may explain, at least in part, why degenerative muscle changes, abnormal tendon architecture, and shoulder weakness persist after rotator cuff repair in human patients.^{††} Since about 80% of the tendon retraction occurs in the first 12 weeks after surgery, these data also suggest that repairs should be protected in the early postoperative period, and repair strategies should

endeavor to mechanically augment and improve the rate and quality of the repair in this critical early period. Future work will use a second-generation tendon marker to explore the relationships between tendon healing/retraction and muscle function. We also intend to use this technique for monitoring outcomes in rotator cuff tendon repair with and without a scaffold augmentation.

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