Sonographic versus magnetic resonance arthrographic evaluation of full-thickness rotator cuff tears in millimeters

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Preoperative knowledge of full-thickness rotator cuff tear size is important in counseling patients because tear size affects the choice of surgical techniques and the functional outcome of surgery. Twenty-six shoulders of twenty-five consecutive patients were included in a prospective study that compared the preoperative accuracy of magnetic resonance arthrography and ultrasonography for tear size in millimeters with intraoperative findings. No significant differences were found between intraoperative, ultrasonographic, and magnetic resonance arthrographic data for the width of tears. Adoption of a "curved line measurement" for ultrasonographic evaluation of large tears eliminated the tendency of ultrasonography to underestimate tears greater than or equal to 35 mm in width. No significant differences were found between intraoperative, ultrasonographic, and magnetic resonancearthrographic data for retraction of tears. However, a limitation of ultrasonography to evaluate retractions of more than 30 mm was found. Therefore, ultrasound is of equal value for tears less than 30 mm, but magnetic resonance arthrography is more accurate for tears greater than 30 mm. (J Shoulder Elbow Surg 2003; 12:110-16.)

The clinical diagnosis of a full-thickness rotator cuff tear has a sensitivity of up to 91% and a specificity of up to 75%.[15] Preoperative imaging tests have increased the accuracy of the clinical diagnosis. Ultrasonography (US) has a sensitivity of 86% to 100% and a specificity that varies from 67% to 98%.[2,4,8,12,22,24,26] Whereas the sensitivity and specificity of US to detect full-thickness rotator cuff tears are similar to those of magnetic resonance imaging (MRI),[2,3] magnetic resonance arthrography (MRA) further improves the differentiation of rotator cuff lesions when compared with unenhanced MRI.[5,13,17] However, the simple diagnosis of a full-thickness rotator cuff tear is no longer sufficient for surgical management. Preoperative knowledge of tear size is important in counseling patients because tear size is one factor in determining the choice of repair techniques.[6,9-11,20,21,25]

Tear size also affects the functional outcome of the repair.[14,23] A number of studies have recommended that surgical procedures should be based on the size of rotator cuff tears. Arthroscopic repair[6] and arthroscopically assisted mini-open repair[6,11,20,25] are recommended for small- to medium-sized tears, whereas tears with a width of more than 5 cm show only 50% satisfactory results with arthroscopically assisted mini-open repair.[21] A standard open procedure has been recommended for tears greater than 3 cm in width.[6,20] Another criterion for the choice of surgical procedures is the degree of retraction of the tendon.[9-11,18,20,25] Iannotti et al[14] reported on the association between retraction and functional outcome. However, preoperative evaluation of retraction in centimeters is ill-defined. Patte[18] proposed estimating retraction through a classification of 3 grades by preoperative computed tomography. Indirect estimation of retraction through measurement of the acromiohumeral distance in plain radiographs is widely accepted and used.[9,25]

MRA is an imaging method with an in-plane spatial resolution of below 1 mm. However, evaluation of the width and retraction of rotator cuff tears in millimeters has not been verified. US has a spatial resolution of below 1 mm if 7.5-MHz transducers are applied. However, until recently, US evaluation of width was only done for interval steps of 1 to 3 cm.[4,8,12,22,24,26] US evaluation of retraction in millimeters has not been compared with intraoperative findings. It is, therefore, unclear whether US or MRA is adequate as a single method for preoperative evaluation of full-thickness rotator cuff tear size.

The aim of this study was to evaluate the accuracy of MRA and US in millimeters for both width and retraction of full-thickness rotator cuff tears. Surgical findings were used to verify US and MRA data. A new approach to US measurement, which may increase

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the accuracy of large tear evaluation in the future, is presented. We also suggest an economical way to use preoperative imaging tests for the evaluation of full-thickness rotator cuff tears in millimeters.

MATERIALS AND METHODS

In this prospective study, preoperative US and MRA of full-thickness rotator cuff tears were compared with intraoperative findings by blinded observers. Twenty-five consecutive patients (twenty-six shoulders) who were diagnosed as having a full-thickness rotator cuff tear by US at the time of the first contact with our department were included in the study between April 1998 and August 2000. Another 57 patients who were operated on for rotator cuff pathologies in the above-mentioned time frame were excluded from the study because they either presented US images or magnetic resonance (MR) images from outside institutions at the time of the first consultation or had no full-thickness rotator cuff tear. One patient with a full-thickness rotator cuff tear was excluded because he reported a fall on his arm in the time between US and MRA measurements, with suspected enlargement of the tear. None of the patients had previous surgery on the affected shoulder. All patients with suspected full-thickness tears had pain for more than 4 months in duration despite an appropriate trial of conservative therapy. There were no patients with an injury sustained less than 6 months before the time of initial physical examination and US. The time that elapsed between US and MRA was 20 to 52 days (mean, 34 days). Surgery was performed between 65 and 92 days (mean, 78 days) after first contact with the patient. The mean age of the 13 male and 12 female patients was 60 years (range, 43-77 years). For statistical analysis, all data were expressed as mean and SEM. An analysis of variance was performed to compare groups of US, MRA, and intraoperative measurements. Post hoc tests were performed with the Fisher protected least significant difference (PLSD) test with the SPSS 8.0 software package (SPSS Inc, Chicago, Ill).

US

Ultrasonograms were obtained with a real-time 7.5-MHz linear array transducer (Siemens Sonoline SI-400; Siemens Medical Systems, Erlangen, Germany). All sonograms were obtained and evaluated by an orthopaedic surgeon who had conducted more than 1200 examinations during a 4-year period and who also performed the clinical tests. Images of the supraspinatus tendon were made with the shoulder extended, the elbow flexed, and the hand placed behind the back on the contralateral iliac wing. This position was necessary in order to expose as much of the supraspinatus tendon as possible from under the acromion. At first, the transducer was oriented perpendicular to the supraspinatus tendon approximately 45° between the coronal and sagittal plane, defined as the parasagittal plane. It was moved anteriorly to posteriorly to visualize the subscapularis, supraspinatus, and infraspinatus tendons. The transducer was then rotated 90° to examine the tendons in a longitudinal plane (coronal-oblique plane). The examination technique included static and dynamic portions. Documentations were done by a Mitsubishi video printer (Mitsubishi Electric Corporation, Kyoto, Japan) on thermal paper. Images of the contralateral side were not routinely documented in all cases.

A diagnosis of a full-thickness tear was made if a hypoechoic zone that extended through the entire substance of the cuff was seen, if there was a loss of convexity of the outer contour of the rotator cuff with visible margins of a tear, or if cuff tissue could not be visualized. Measurements of tear size were made in two planes, with each of the two images showing the maximum extent of the tear.

For measurement of the width, we used the plane perpendicular to the cuff fibers of the supraspinatus (parasagittal plane). A straight line was used to determine the width in millimeters of the hypoechoic zone, the cuff defect, or the distance between the visualized margins of the cuff as described by Wiener and Seitz.[26] If the tear extended across the bicipital groove and involvement of the cranial part of the subscapularis was suspected, the cranial border of the subscapularis tendon was carefully scanned with the use of planes parallel and perpendicular to the fibers of the subscapularis tendon. Retraction of the subscapularis in millimeters was included in the tear size if a full-thickness subscapularis lesion was found. Measurement of tears that included more than one tendon was always done on a single image of the corresponding parasagittal plane. Retraction was determined by measuring the distance between the greater tuberosity and the visualized cuff margin or the length of the depressed interface between supraspinatus and the overlying deltoid muscle in the coronal-oblique plane. If the torn end could not be visualized distal to the acromion in the coronal-oblique plane, the cuff was defined as "not visible."

MRA

For MR studies, patients were placed in a supine position with the arm by the side and the thumb pointing upward. All MRA studies were performed with a 1.0-T unit (Magnetom Impact Expert; Siemens Medical Systems) with the use of a flexible surface coil.

Before arthrography, T_1-weighted (repetition time [milliseconds]/echo time [milliseconds], 500/12) and fat-saturated dual-echo proton density and T_2-weighted (repetition time [milliseconds]/echo time [milliseconds], 3000/15 and 105) oblique-coronal images were acquired. Fluoroscopy-guided shoulder arthrography was performed through an anterior approach. A 23-gauge spinal needle was advanced into the joint, and 1 to 3 mL of iodinated contrast material (Iopamiro 200; Bracco Diagnostics, Milan, Italy) was injected to confirm intracapsular location of the needle tip. Then, 15 mL of a 2-mmol/L gadolinium solution (Magnevist; Schering, Berlin, Germany) was injected to achieve MR contrast.

MRA imaging was initiated within 30 minutes after contrast injection. T_1-weighted spin-echo fat-suppressed imaging (repetition time [milliseconds]/echo time [milliseconds], 588-637/12) in the oblique-coronal and oblique-sagittal plane was then performed. Transverse images were acquired with a T_1-weighted fat-suppressed gradient-echo sequence (FLASH 3d, repetition time [milliseconds]/echo time [milliseconds]/flip angle [degrees], 50/11/60). Transverse imaging was used for better delineation of the rotator interval and the subscapularis tendon lesions.[19] All

imaging was done with a 256 × 256 matrix, 4-mm section thickness, 1-mm skip, two signals acquired, and 18-cm field of view. The total prearthrography MR examination time was 10 minutes, and the MRA imaging time was 18 minutes.

Two radiologists (R.M. and G.P.) independently reviewed MRA images and measured rotator cuff defect size in the paracoronal imaging plane to define the retraction and in the anterior to posterior direction (parasagittal oblique and axial imaging plane) to define the width of rotator cuff defect. Borders of the defect were determined by using margins of contrast material replacing normal tendon or muscle tissue. Transition zones, where tendon or muscle is markedly thinner or irregularly structured, were included in the defect size. Tissues with increased signal intensity with thickness and structure comparable to the surrounding normal cuff, which could be observed in some cases, were not included in the defect size. Evaluation of all MR studies was done with softcopy reading from picture archiving and communication system (PACS) workstations (Siemens Medical Systems, Erlangen, Germany) equipped with high-resolution monochrome CRT monitors (SIENET MagicView 1000, Siemens Medical Systems, Erlangen, Germany). Images of all three imaging planes were displayed simultaneously. The particular image of the parasagittal series showing the largest width of the rotator cuff defect was selected. For measurement of retraction, the particular paracoronal image showing the largest extent of the tear was determined. Window and level adjustment was performed for each of these selected images individually to compensate for contrast differences due to inhomogeneous fat saturation and differences in contrast material concentrations and field inhomogeneity. Window settings were optimized for displaying a maximum of anatomic detail of rotator cuff structures. All measurements were performed with the distance software tool provided by the reporting workstation. Because of the curved contour of the humerus, single straight linear width measurements in the parasagittal plane could not resemble the intraoperative measurement method in large rotator cuff defects. Therefore, large defects were evaluated with up to three linear distance measurements acceptably approximating the curved articular surface of the humerus.

The coronal-oblique scans enabled measurements comparable to the coronal-oblique measurements on US. The spatial orientations of slices were identical to US depicting the tendons of the rotator cuff in the same planes.

Intraoperative measurements

All operative procedures were performed by the same orthopaedic surgeon. Small tears had a mini-open repair and large tears had a standard open repair with the use of modified Mason-Allen stitches and transosseous bone tunnels in all cases. An assisting doctor, who was blinded to the US and MRA data, recorded all findings in a standardized manner. The border of the tear was defined as fully intact tendon, the rim of a full-thickness tear, or the area where the full thickness of the tendon end could be determined. Intratendinous midsubstance extensions in the area of the conjoined tendon of the supraspinatus and infraspinatus were added to the total tear size. The width of the tear was recorded in the parasagittal direction, perpendicular to the long axis of the cuff fibers. Retraction in the coronal-oblique plane was documented as the maximum distance between the area of the original tendon insertion to the free end of full-thickness tendon substance. If the tear included the rotator interval and the long tendon of the biceps (LTB) was exposed with the subscapularis intact, the width of the rotator interval was added to the width of the tear.

RESULTS

Preoperative US diagnosis of full-thickness rotator cuff tears was confirmed by preoperative MRA and by surgical findings in all cases (Table I).

Width of rotator cuff tears

No significant difference was found between each of the methods for evaluation of tear size width in millimeters (Table II). The assessment of MRA data for width by two independent radiologists yielded a concordance rate of 95%.

All 26 shoulders had a tear of the supraspinatus tendon. Of these, 19 had a tear width greater than 15 mm with an additional full-thickness tear of the ventral part of the infraspinatus tendon on intraoperative findings. A concomitant intratendinous cleavage of the infraspinatus tendon was present in 9 of the 19 cases on intraoperative findings. Of these 19 shoulders, 3 (patients 2, 19, and 26) had an additional complete rupture of the cranial part of the subscapularis tendon, a concomitant subluxation of the LTB, and a rupture of the rotator cuff interval (RCI) on intraoperative findings. Both US and MRA identified the subluxation of the LTB and the RCI lesion in these 3 shoulders. Another 4 of the 19 shoulders had a torn RCI without tear of the subscapularis and without subluxation of the LTB on intraoperative findings. US identified 1 of the 4 RCI lesions determined by absence of soft tissue overlying the LTB. MRA identified 2 of the 4 RCI lesions because contrast medium surrounded the interval capsule on three sides in the oblique-sagittal plane. Underestimation of US measurements was suspected in some of the large tears. Therefore, tears smaller than 35 mm and those greater than or equal to 35 mm in width were analyzed separately. In eighteen shoulders (18/26) that showed a tear width of less than 35 mm on intraoperative findings, no significant difference between US, MRA, and operative findings was determined. A straight line was used to measure the distance between torn ends of the cuff in US evaluation (Figure 1, *A*) and MRA evaluation (Figure 1, *B*). In 8 shoulders with a tear width greater than or equal to 35 mm on intraoperative findings, only MRA data showed no significant difference with intraoperative findings. US results of these 8 shoulders were significantly different, with $P = .002$ when compared with intraoperative findings and $P = .01$ when compared with MRA

Table I Absolute values of width and retraction in millimeters

Patient No.	Intraoperative findings		US findings		MRA findings	
	Width	Retraction	Width	Retraction	Width	Retraction
1	20	15	13	17	22	21
2	40	35	30	NV	35	35
3	25	30	25	26	25	22
4	12	18	21	17	21	14
5	10	18	10	15	14	14
6	36	15	21	15	28	23
7	20	16	20	20	16	25
8	32	25	21	18	15	19
9	8	25	13	16	12	10
10	30	25	21	20	45	25
11	35	28	30	23	48	42
12	29	25	20	21	35	35
13	15	12	17	16	15	16
14	30	32	25	NV	6	8
15	12	10	24	12	16	8
16	15	15	20	16	13	14
17	35	35	33	NV	34	36
18	30	30	22	24	37	35
19	42	35	21	NV	32	26
20	40	35	26	NV	40	37
21	15	25	18	18	20	25
22	19	15	24	18	29	29
23	25	22	23	17	29	27
24	38	38	28	NV	32	32
25	28	28	24	24	40	22
26	48	40	41	NV	45	27

Results of MRA measurements of second radiologist (G.P.) are not shown.
US, Ultrasonography; *MRA*, magnetic resonance arthrography; NV, non visible.

Table II Comparison of width of rotator cuff tears in millimeters (mean ± SEM) (n = 26)

	Intraoperative width (26.5 ± 2.1)	MRA width (27.0 ± 2.3)
MRA width (27.0 ± 2.3)	$P = .83$	—
US width (22.7 ± 1.2)	$P = .18$	$P = .12$

findings (Table III). In accordance with established criteria regarding US evaluation of tear sizes, a straight line was again used to measure the distance between torn ends of the cuff (Figure 2, *A*). In contrast in MRA measurements (Figure 2, *B*) and in intraoperative measurements, the curved circumference of the humeral head had been respected and the distance between torn ends of the cuff was measured along a curved line. Retrospective adoption of a curved line measurement technique in US evaluation of tears with a width greater than or equal to 35 mm eliminated the underestimation of these tears. We calculated a second defect size (or distance *b*) from the distances *s* and *h* using the geometric relationships and formulas shown in Figure 3. Points A' and B' were retrospectively determined. The criterion of the margin of the defect was then defined as the visible end of torn rotator cuff at the bottom of the defect close to the US signal of the cortical bone of the humeral head. Results of calculated curved line distances are summarized in Table IV. These data indicated good prediction of defect size in millimeters (Table V).

Retraction of rotator cuff tears

Retraction was compared between intraoperative findings and MRA data in all 26 cases. The assessment of MRA data for retraction by two independent radiologists yielded an agreement rate of 95%.

No significant differences were found between MRA data and intraoperative findings (Table VI). In 19 of 26 cases, retraction was compared between US, intraoperative, and MRA data. All of these 19 tears showed a retraction of 30 mm or less on intraoperative evaluation. No significant differences were found between the three methods (Table VI). In 7 cases, torn ends of the cuff were not visible on US images because of the acromion.

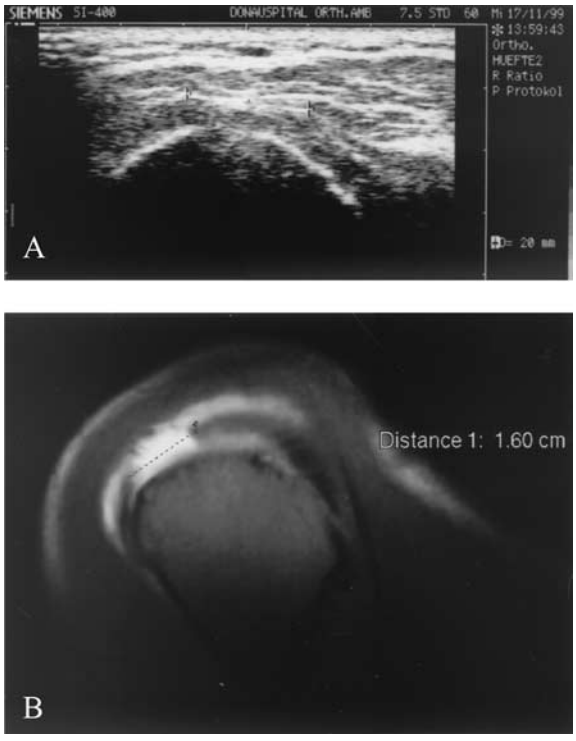

Figure 1 Corresponding ultrasonography (US) and magnetic resonance arthrography (MRA) images of patient 7. **A**, US image to measure width of full-thickness rotator cuff tear (20 mm). **B**, MRA image to measure width of full-thickness rotator cuff tear (16 mm).

Table III Comparison of rotator cuff tears with a width greater than or equal to 35 mm in intraoperative measurements (mean ± SEM) (n = 8)

	Intraoperative width (39.2 ± 1.5)	**MRA width (36.7 ± 2.4)**
MRA width (36.7 ± 2.4)	$P = .41$	—
US width (28.7 ± 2.3)	$P = .002$	$P = .01$

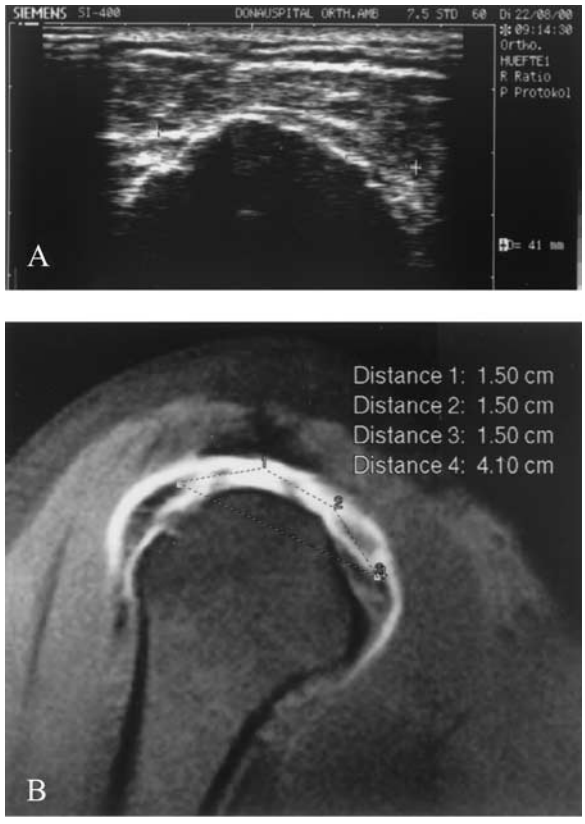

Figure 2 Corresponding US and MRA images of patient 26. **A**, US image to measure width of full-thickness rotator cuff tear (41 mm). A straight line measurement was applied. **B**, MRA image to measure width of full-thickness rotator cuff tear (45 mm). The MRA measurement respects the convex anatomy of the humeral head. Three straight lines, which comprise a total of 45 mm in distance, are used to evaluate the width. A straight line (distance 4) with a length of 41 mm is also shown in order to point out the difference between straight line measurement and curved line measurement.

DISCUSSION

This prospective study shows that MRA provides an accurate evaluation of width and retraction of full-thickness rotator cuff tears in millimeters. Although anatomic details of the rotator cuff can be outlined by MRA in millimeters,[5] no studies to date have compared MRA measurements of width and retraction of full-thickness rotator cuff tears in millimeters with intraoperative findings.

Evaluation of the width of full-thickness rotator cuff tears showed no significant differences between US measurements and intraoperative findings. However, analysis of subgroups revealed a significant difference between US measurements and intraoperative findings for tears with a width greater than or equal to 35 mm. A few studies have quantified the width of full-thickness rotator cuff tear sizes in centimeters with US.[4,8,12,22,24,26] A comparison of these studies is difficult because different systems of classification with interval steps of 10 to 30 mm were used.[1,7,18] Whereas overestimation of rotator cuff tear width has been reported only by Teefey et al,[24] a number of studies have reported that US tends to underestimate the width of full-thickness rotator cuff tears. Farin et al[8] and Wiener and Seitz[26] documented that underestimation pertained to all categories of tear sizes. The findings of the current study are in agreement with those of Read and Perko[22] and Hodler et al,[12] who reported that US tends to underestimate predominantly large tears. Both studies found that US accurately graded small (<20 mm) and moderate (20-40 mm) tears but underestimated the size of tears greater than 40 mm. Further analysis of our data revealed

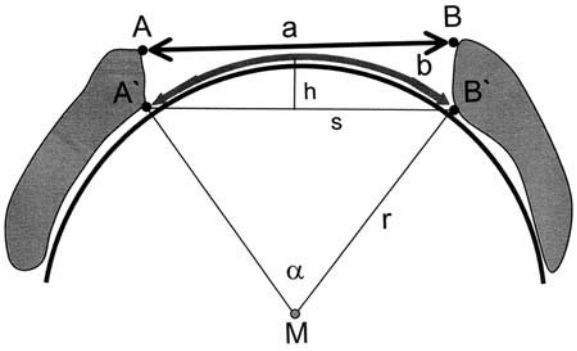

Figure 3 Schematic relationship between the straight line measurement *a* of a given full-thickness rotator cuff tear and the corresponding curved line measurement *b* as it appears in parasagittal US images of the shoulder. For simplification of calculations for distance *b*, the humeral head is assumed to represent a segment of a circle. The formula to calculate *b* is as follows: $b = (\pi/180) \times r \times \alpha$. The formula to calculate radius *r* is as follows: $r = h/2 + s^2/8h$. The formula to calculate α is as follows: $\alpha = \text{arc sin } (s/2r) \times 2$. The complete formula to calculate *b* is as follows: $b = (\pi/180) \times (h/2 + s^2/8h) \times \text{arc sin } (s/2r) \times 2$.

Table IV Calculated sonographic curved line distances in 8 shoulders with tears greater than or equal to 35 mm in width

Patient No.	Calculated US width
2	36
6	27
11	36
17	33
19	35
20	40
24	33
26	45

Table V Comparison of mean values of rotator cuff tears with a width greater than or equal to 35 mm after calculation of curved line distance "b" from US images (n = 8)

	Intraoperative width (39.2 ± 1.5)	MRA width (36.7 ± 2.4)
MRA width (36.7 ± 2.4)	*P* = .38	—
US width (35.6 ± 1.8)	*P* = .21	*P* = .69

that the method of drawing a straight line between visualized margins of the cuff[8,12,24,26] cannot be used to evaluate the actual size of large tears correctly because the line cuts through the anatomic convexity of the humeral head. After a curved line distance was used, which was then similar to the measurement technique used in MRA and intraoperative tear size evaluation, no underestimation of large tears remained. Reasons for the underestimation of large tears, such as intratendinous cleavages of the infraspinatus or RCI lesions, which have been discussed in previous studies,[22,24] turned out not to be statistically relevant in the current study.

Table VI Comparison of mean values of retraction of rotator cuff tears

	Intraoperative retraction (n = 26) (24.8 ± 1.7)	MRA retraction (n = 19) (22.4 ± 2.0)	Intraoperative retraction (n = 19) (20.8 ± 1.4)
MRA retraction (n = 26) (24.1 ± 1.8)	*P* = .76	—	—
US retraction (n = 19) (18.5 ± 0.8)	—	*P* = .08	*P* = .29
MRA retraction (n = 19) (22.4 ± 2.0)	—	—	*P* = .48

The retraction of the tendon was accurately identified by US in all cases in which the margin of the cuff was visualized lateral to the acromion. Literature regarding evaluation of retraction with US is rare.[24,26] Wiener and Seitz[26] estimated that in cases in which the supraspinatus tendon had not been visualized in the coronal-oblique extension, the tear was assumed to be greater than 30 mm. The current study confirms their estimations because in all cases with a retraction of more than 30 mm on intraoperative measurements, US was unable to visualize the margin of the tendon in the coronal-oblique plane.

The clinical relevance of preoperative knowledge of retraction for the choice of repair techniques has been pointed out by several authors.[9-11,18,20,25] Patients with excessive tendon retraction are supposed to be poor candidates for entirely arthroscopic repair[12] or arthroscopically assisted mini-open repair.[10,11,25] Pollock and Flatow[20] proposed a limit of 2 cm of retraction for arthroscopically assisted mini-open repair, whereas standard open procedures should be chosen for tears with a retraction of 5 cm.[10,20] Massive retraction is considered to be a potential limit to standard tendon-to-bone repair.[9] The findings of Iannotti et al[14] highlight the clinical relevance of evaluating both width and retraction of the rotator cuff tears preoperatively. In their study the square dimension of the tear, calculated from width and retraction, was shown to be a better predictor for functional outcome in terms of Constant score, symptoms of fatigue, and shoulder strength of rotator cuff repairs than was the width of the tear alone. Because standardized criteria by which to evaluate tendon retraction in millimeters preoperatively are lacking, we propose that Patte and Goutallier's[18] classification of 3 grades of retraction measured on preoper-

ative computed tomography might be improved in the future by evaluating retraction on a millimeter basis with US and MRA.

Several limitations pertain to the current study. Patients who had no full-thickness rotator cuff tear on primary US investigation were not included in the study. Hence, it is possible that full-thickness rotator cuff tears were missed. However, all patients with conservative treatment and persistent symptoms underwent MRA or arthroscopy, and no full-thickness rotator cuff tear was found then. Operator dependence is generally regarded as a limitation of US. However, operator dependence has also been found to be significant in unenhanced MRI[16] and has not been verified for MRA investigation of rotator cuff tear sizes thus far. Although a curved line measurement as suggested in this study seems to be highly effective in increasing the accuracy of US evaluation of large tears, this finding is based on the analysis of only 8 cases. Curved line measurement, therefore, should be prospectively tested in a larger series of full-thickness rotator cuff tears in future.

In summary, this study showed that US, which has the advantage of being noninvasive, allowed only limited access to the quantification of width and retraction of full-thickness rotator cuff tears in millimeters whereas MRA provided accurate data for all tear sizes. US underestimates the size of tears with a width greater than or equal to 35 mm. US cannot be used to evaluate retraction of more than 30 mm. Therefore, it is of equal value for tears less than 30 mm, but MRA is better for tears greater than 30 mm.

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