Diagnostic accuracy of magnetic resonance imaging for subscapularis tendon tears using radial-slice magnetic resonance images

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Background: Magnetic resonance imaging has low diagnostic accuracy for subscapularis tendon tears. This study investigated the utility of radial-slice magnetic resonance images for diagnosing subscapularis tendon tears.

Materials and methods: We investigated 55 shoulders in 54 patients with rotator cuff tears evident during arthroscopic shoulder surgery. The intraoperative finding of a subscapularis tendon tear was compared with the identification of a subscapularis tendon tear on preoperative radial, transverse, and oblique sagittal images using a 3.0-T system. The sensitivity and specificity of diagnostic images generated using different imaging methods for subscapularis tendon tears were investigated.

Results: A subscapularis tendon tear was present in 38 shoulders (69.1%). When the diagnostic accuracy of the magnetic resonance images was compared with the arthroscopic findings, the radial images had 94.7% sensitivity and 82.4% specificity, the transverse images had 57.9% sensitivity and 100% specificity, and the oblique sagittal images had 60.5% sensitivity and 100% specificity.

Conclusion: Radial-slice magnetic resonance images have high sensitivity for subscapularis tendon tears and are useful for diagnosing these lesions. In particular, the sensitivity for tears in the superior part of the subscapularis tendon is higher than that of conventional methods.

Level of evidence: Level III, Diagnostic Study.

Keywords: Radial; MRI; subscapularis tendon; rotator cuff; shoulder; arthroscopy

Recent developments in shoulder arthroscopy have enabled subscapularis tendon tears to be evaluated in detail. The subscapularis has a broad insertion in the lesser tuberosity of the humerus. The subscapularis comprises the anterior portion of the shoulder and is important...
for humeral head stability. The cephalad aspect of the sub-
scapularis tendon adjoins the long head of the biceps tendon
and contributes to its stability.3 Because subscapularis
tendon tears originate from the anterosuperior region,22,24
lesions of the long head of the biceps tendon frequently
occur at the same time.6,23,26,27 Insufficient repair of sub-
scapularis tendon tears may cause decreased glenohumeral
joint stability15,21 or lesions of the long head of the biceps
tendon; therefore, accurate preoperative evaluation of sub-
scapularis tendon tears is important.

Rotator cuff tears have been diagnosed using transverse,
oblique coronal, and oblique sagittal magnetic resonance
(MR) images. Although MR evaluation of supraspinatus and
infraspinatus tendon tears has a sensitivity of greater than
90%,10,16,17 the sensitivity for subscapularis tendon tears is
not particularly high.1,2,5,7,25 The subscapularis tendon is
normally evaluated using transverse and oblique sagittal MR
images,19 but lesions in the anterosuperior region are diffi-
cult to visualize14 because of the partial-volume effect.

We have previously reported that radial-slice MR images,
in which magnetic resonance imaging (MRI) is performed
using radial slices centered on the midpoint of the acetabu-
lum in the hip joint, are useful for evaluating the acetabular
labrum.11,12,14 The rotator cuff tendons attach circum-
ferentially around the humeral head in a circular pattern of
insertion resembling that of the acetabular labrum. Radial-
slice MR images centered on the humeral head provide a
cross slice perpendicular to the rotator cuff insertions,
thereby reducing the partial-volume effect.

The objective of this study was to investigate the value of
radial-slice MR images for diagnosing subscapularis tendon
tears.

Materials and methods

Patients

This study investigated 55 shoulders in 54 patients who underwent
shoulder arthroscopic surgery between March 2011 and December
2012 and in whom rotator cuff tears were arthroscopically
confirmed. The mean age was 62.7 years (range, 26-78 years),
with 27 shoulders in 26 men and 28 shoulders in 28 women. The
affected side was the right shoulder in 41 cases and the left in 14
cases. The exclusion criteria were previous shoulder surgery, age
younger than 18 years, and internal impingement of the shoulder
in an overhead athlete.

Arthroscopic findings

All arthroscopic examinations were performed by one orthopaedic
surgeon who had 20 years of experience in shoulder surgery. The
morphology of the subscapularis tendon tears was classified as type I
for a partial-thickness tear of the upper third of the subscapularis
tendon, type II for a full-thickness tear of the upper third, type III
for a full-thickness tear of the upper two-thirds, and type IV for a full-
thickness tear of the entire width of the tendon.7,15

The findings regarding the long head of the biceps tendon were
classified as normal, subluxation, dislocation, and disappearance.3

We also investigated the incidence of combined subscapularis
tendon tears and lesions of the long head of the biceps tendon.

MRI protocol

We used a 3.0-T MRI system (Achieva 3.0 T X-series; Philips
Healthcare, Best, Netherlands), with a dedicated 4-channel
shoulder coil. Radial images were acquired using fat-suppressed
T2-weighted imaging (repetition time [TR], 9,428 milliseconds;
echo time [TE], 59 milliseconds; and echo train length [ETL],
17),13,17,20 with a slice thickness of 3.0 mm; field of view (FOV)
of 150 mm × 150 mm; and resolution of 304 × 224. Planning of
the radial axis scan was defined using sagittal and coronal scans to
correct for the complex anatomic angulations of the glenoid and
humeral head and to provide geometric offsets and angulations for
the sequence. We used the axial and coronal MR images that best
demonstrated the midpoint of the glenoid fossa and humeral head
when we planned the radial axis slices. The line passing through the
center of the humeral head and the glenoid was set as an axis.
Radial-slice images were obtained, with slice 1 in the axial or 9-o’
clock position and the following slices rotated incrementally
(Fig. 1). The image acquisition time was approximately 4 minutes.
The transverse images were acquired using fat-suppressed T2-weighted imaging (TR, 4,000 milliseconds; TE, 56 milliseconds; and ETL, 17), with a slice thickness of 3.0 mm, slice gap of 0.3 mm, FOV of 130 mm × 130 mm, and resolution of 304 × 221. Contiguous slices encompassing the entire width of the humeral head were selected on the plane perpendicular to the body axis. The oblique sagittal images were acquired using T2-weighted imaging (TR, 5,800 milliseconds; TE, 100 milliseconds; and ETL, 16), with a slice thickness of 3.0 mm, slice gap of 0.3 mm, FOV of 150 mm × 150 mm, and resolution of 368 × 256. Contiguous slices encompassing the area from the lateral side of the humeral head to the scapular spine were selected on the plane perpendicular to the scapula. The image acquisition time was approximately 4 minutes in both cases.

MRI evaluation of subscapularis tendon

Tendons in which a clear continuity existed between the subscapularis tendon and its insertion and a hypointense signal area was present on the T2-weighted images inside the tendon at the insertion were classified as tear negative. Those in which the continuity of the subscapularis tendon was interrupted or signal hyperintensity such as fluid or near-fluid signal was present on the T2-weighted images inside the tendon were classified as tear positive.

The radial, transverse, and oblique sagittal images were evaluated as either tear negative or tear positive. When there was at least one positive finding for a tear between the transverse images and oblique sagittal images, combined transverse and oblique sagittal images were classified as tear positive.

We investigated the sensitivity, specificity, and accuracy of the MR images using radial-slice images, transverse-slice images, oblique sagittal–slice images, and combined transverse and oblique sagittal images for subscapularis tendon tears, and the arthroscopic findings were used as the gold standard. We also evaluated the sensitivity of each MR image for torn subscapularis tendon morphology.

<table>
<thead>
<tr>
<th>MR image</th>
<th>Type of subscapularis tendon tear</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
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<td>14 of 14</td>
<td>4 of 4</td>
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<td>Oblique sagittal</td>
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<td>10 of 14</td>
<td>4 of 4</td>
<td>1 of 1</td>
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<td>Combination</td>
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<td>11 of 14</td>
<td>4 of 4</td>
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Intraobserver and interobserver reliability

The MR images were evaluated blindly and independently by 2 orthopaedic surgeons specializing in shoulders with 5 years and 9 years of experience, who were instructed by a musculoskeletal radiologist. The measurements were made a total of 3 times at 1-week intervals. In cases in which the results from the 2 observers were inconsistent, a final consensus decision was made based on discussion between the 2 observers at a later date.

Statistical analysis

Statistical analysis of the diagnostic accuracy of the radial, transverse, oblique sagittal, and combined images was performed by testing for equality of proportions between 2 samples. \( P < .05 \) was considered significant.

Results

Arthroscopic findings

Among the 55 shoulders, a subscapularis tendon tear was present in 38 (69.1%), a supraspinatus tendon tear in 53 (93.6%), and an infraspinatus tendon tear in 23 (41.8%).

Subscapularis tendon tear morphology

A subscapularis tendon tear was not observed arthroscopically in 17 shoulders (30.9%). A tear was evident in 38 shoulders (69.1%), with the tendon tear morphology categorized as type I in 19 (34.5%), type II in 14 (25.5%), type III in 4 (7.3%), and type IV in 1 (1.8%).
Long head of biceps tendon lesion morphology

The findings for the long head of the biceps tendon were normal in 33 shoulders (60%), with subluxation in 11 (20%), dislocation in 6 (9.1%), and disappearance in 5 (9.1%). The incidence of the combination of each type of subscapularis tendon tear and lesion of the long head of the biceps tendon (including subluxation, dislocation, and disappearance) was as follows: 5 shoulders (26.3%) with type I, 12 (85.7%) with type II, 4 (100%) with type III, and 1 (100%) with type IV (Table I).

Diagnostic accuracy of MRI for subscapularis tendon tears

On the radial images, 39 shoulders (70.9%) were positive and 16 (29.1%) were negative for a subscapularis tendon tear. On the transverse images, 22 shoulders (40%) were positive and 33 (60%) were negative. On the oblique sagittal images, 23 shoulders (41.8%) were positive and 32 (58.2%) were negative. On the basis of the combined transverse and oblique sagittal images, 26 shoulders (47.3%) were positive and 29 (52.7%) were negative.

Regarding the diagnostic accuracy of MRI for subscapularis tendon tears, the radial images offered 94.7% sensitivity, 82.4% specificity, and 90.9% accuracy (Table II). The transverse images offered 57.9% sensitivity, 100% specificity, and 70.9% accuracy (Table II). The oblique sagittal images offered 60.5% sensitivity, 100% specificity, and 72.7% accuracy (Table II). The combination of transverse and oblique sagittal images offered 68.4% sensitivity, 100% specificity, and 78.2% accuracy (Table II).

The diagnostic sensitivity of the radial images was significantly higher than that of the transverse ($P < .001$), oblique sagittal ($P < .001$), and combined ($P < .001$) images.

The diagnostic specificity of the radial images was not significantly lower than that of the transverse ($P = .06$), oblique sagittal ($P = .06$), or combined ($P = .06$) images.

The diagnostic accuracy of the radial images was significantly higher than that of the transverse ($P < .01$), oblique sagittal ($P < .01$), and combined ($P = .04$) images.

Regarding the sensitivity of MRI for each torn subscapularis tendon morphologic type (Table III), that of the radial images was 89.5% for type I, 100% for type II, 100% for type III, and 100% for type IV. For the transverse images, the sensitivity was 31.6% for type I, 78.6% for type II, 100% for type III, and 100% for type IV. For the oblique sagittal images, the sensitivity was 42.1% for type I, 71.4% for type II, 100% for type III, and 100% for type IV. For the combination of transverse and oblique sagittal images, the sensitivity was 52.6% for type I, 78.6% for type II, 100% for type III, and 100% for type IV.
Representative cases

A representative case of a partial-thickness tear of the upper third of the subscapularis tendon (type I) is presented in Figure 2. The patient was a 50-year-old woman with left shoulder pain. She had a surgically proven superior partial-thickness subscapularis tendon tear (Fig. 2, A). Radial-slice fat-suppressed T2-weighted images showed signal hyperintensity within the tendon (Fig. 2, B), consistent with a subscapularis tendon tear. On the transverse-slice and oblique sagittal-slice images, a hyperintense signal area was not present inside the tendon, indicating a false-negative finding (Fig. 2, C and D).

A representative case of a full-thickness tear of the upper third of the subscapularis tendon (type II) is presented in Figure 3. The patient was a 71-year-old woman with right shoulder pain. She had a surgically proven superior partial-thickness subscapularis tendon tear (Fig. 2, A). Radial-slice fat-suppressed T2-weighted images showed signal hyperintensity within the tendon (Fig. 2, B), consistent with a subscapularis tendon tear. On the transverse-slice and oblique sagittal-slice images, a hyperintense signal area was not present inside the tendon, indicating a false-negative finding (Fig. 2, C and D).

Figure 3  Representative case of full-thickness tear of upper third of subscapularis tendon (SSC) (type II). (A) Arthroscopic image. Complete tear of subscapularis tendon (arrowheads) and dislocation of biceps tendon (arrow). (B) Radial-slice MR images (i and ii). Interrupted subscapularis tendon insertion and mediorotation of biceps tendon (arrows). (C) Transverse-slice MR images (i and ii). Hyperintensity on articular side of subscapularis tendon insertion (arrows). (D) Oblique sagittal-slice MR images (i and ii). Hypointensity in subscapularis tendon (arrowheads) showing negative findings. A, acromion; C, coracoid; G, glenoid; HH, humeral head; LHB, long head of biceps.

A representative case of false-positive findings on the radial-slice images is presented in Figure 4, A. The patient was a 59-year-old woman with right shoulder pain, showing synovitis of the rotator interval (Fig. 4, A-1) and an intact subscapularis tendon. Radial-slice fat-suppressed T2-weighted images showed hyperintensity within the subscapularis tendon (Fig. 4, A-2).

A representative case of false-negative findings on the radial-slice images is presented in Figure 4, B. The patient was a 67-year-old man with right shoulder pain. He had a surgically proven partial-thickness articular-side tear of the subscapularis tendon (Fig. 4, B-1). On the radial-slice fat-suppressed T2-weighted images, a hyperintense signal area was not present inside the tendon, indicating a false-negative finding (Fig. 4, B-2).

Reliability

The results concerning interobserver agreement for the MRI findings and intraobserver reliability of the 2 observers are provided in Table IV.
The subscapularis tendon has a broad insertion into the lesser tuberosity of the humerus. The cephalad aspect of the subscapularis tendon adjoins the long head of the biceps tendon and contributes to its stability.3 Because subscapularis tendon tears originate from the anterosuperior part of the shoulder,2,22 lesions of the long head of the biceps tendon frequently occur concurrently.8,23,26,27 In this study, lesions of the long head of the biceps tendon occurred concurrently with 26.3% of type I subscapularis tendon tears, which were limited to the anterosuperior region. This rate increased to 85.7% for type II subscapularis tendon tears, and a lesion of the long head of the biceps tendon was present in all type III and IV tears. In the case of type II full-thickness tears or worse tears, the instability of the long head of the biceps is considered to increase because of rupture of the pulley structure, thereby causing irreversible damage to this tendon. An accurate evaluation of the early stage of a subscapularis tendon tear is therefore important to prevent damage to the long head of the biceps caused by this tendon. It is necessary to evaluate the instability of the long head of the biceps and the association of subscapularis tendon tears because the incidence of lesions increased with the extent of the subscapularis tendon tear.

Currently, transverse and oblique sagittal MR images are used to evaluate the subscapularis tendon.1,19 Garavaglia et al7 reported that subscapularis tendon tears were present in 129 of 348 shoulders (37%) undergoing rotator cuff repair and that the sensitivity of MRI diagnostic imaging
was 25%, which indicates that using MRI to diagnose subscapularis tendon tears is difficult. Foad and Wijdicks\(^5\) evaluated subscapularis tendon tears using MRI and MR arthrography and reported relatively low sensitivities of 40% and 36%, respectively, that were not different between these two techniques. Therefore, the low sensitivity of MRI evaluation of subscapularis tendon tears is problematic. This low sensitivity arises because lesions of the superior part of the subscapularis tendon insertion are visualized obliquely on transverse MR images and in parallel on oblique sagittal MR images, which leads to distortion from the partial-volume effect.

Radial-slice MR images have been successfully applied to visualize the acetabular labrum of the hip.\(^1,11,12,14\) However, the only reported use of radial-slice MR images for the shoulder was in the preliminary work described by Munk et al\(^18\) in 1989, with the objective of visualizing the glenoid labrum. For the rotator cuff, radial-slice MR images centered on the head of the humerus provide a cross slice perpendicular to the insertion in all slices, thereby achieving a reduction in the partial-volume effect and potentially offering clear visualization of the subscapularis tendon. In our study, the sensitivity of diagnostic radial MR images for subscapularis tendon tears was high (94.7%), which suggests that this technique is diagnostically useful.

Among subscapularis tendon tears, early lesions arising from the superior part of the subscapularis tendon are closely connected to the long head of the biceps tendon, and early diagnosis is important. According to Adams et al.,\(^1\) the sensitivity of diagnostic MRI for subscapularis tendon tears on transverse and oblique sagittal images is lower for small tears (<30%) at the superior part of the tendon than for larger tears. In this study, we also found that the sensitivity was 78.6% and 71.4% for larger type II tears on the transverse and oblique sagittal MR images, respectively, and 100% for types III and IV. Thus, the clinically important early lesions on the cephalad aspect of the subscapularis tendon are highly affected by the partial-volume effect and are difficult to diagnose using conventional MR images. However, by use of radial MR images, the sensitivity for type I subscapularis tendon tears was 89.5%, and the values for type II, III, and IV tears were similarly high, with greater sensitivity than transverse or oblique sagittal MR images. Actually, as shown in Figure 2, type I subscapularis tendon tears could be diagnosed using only the radial MR images, and the transverse and oblique sagittal MR images yielded false-negative findings. Subscapularis tendon tears severe than type II could be diagnosed using conventional MR images; however, the radial MR images made the findings more conspicuous (Fig. 3).

Our findings suggest that because radial MR images are capable of imaging sections perpendicular to the anterosuperior tendon insertion, early lesions can be more clearly visualized. The use of radial MR images for the accurate diagnosis of not only supraspinatus and infraspinatus tendon tears but also subscapularis tendon tears may be important for determining surgical indications and surgical planning for tendon–insertion point tears.

There were several limitations of this study. The radial-slice MR images for diagnosing subscapularis tendon tears yielded false-negative and false-positive results. The false-positive cases involved patients with synovitis of the rotator interval; synovitis of the long head of the biceps and rotator interval may lead to a signal that is hyperintense to the subscapularis tendon on radial-slice MR images. The evaluation of patients with inflammation of the anterosuperior region, such as in frozen shoulder, requires attention because of the possibility of false-positive findings. The false-negative cases involved patients with partial-thickness articular-side tears of the subscapularis tendon. Because the subscapularis tendon tears were very small, the radial-slice MR images might have been unable to show them. To increase the diagnostic precision for subscapularis tendon tears, radial-slice MR images may have to be acquired at a lower slice angle.

**Conclusion**

According to our study, subscapularis tendon tears including early lesions consisting of partial tears at the superior part of the subscapularis tendon can be accurately evaluated using radial MR images. Radial-slice MR images are highly sensitive and offer a useful method for diagnosing subscapularis tendon tears.

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