Skeletal Radiol
DOI 10.1007/s00256-015-2152-2

SCIENTIFIC ARTICLE

# Long head of the biceps brachii tendon: unenhanced MRI versus direct MR arthrography

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Received: 15 December 2014 / Revised: 13 March 2015 / Accepted: 9 April 2015


**Abstract**
*Objective* We sought to determine the diagnostic accuracy of unenhanced MRI and direct MR arthrography (MRA) for evaluation of the intra-articular long head of the biceps brachii tendon (LHBT) using arthroscopy as the gold standard.
*Materials and methods* A retrospective review of patients who underwent shoulder MRI ($n$=132) and MRA ($n$=67) within 12 months prior to arthroscopy was performed. MR images were independently reviewed by two blinded musculoskeletal radiologists. Routinely recorded arthroscopic photos/videos were reviewed by an orthopedic surgeon. The LHBT was graded as normal, tendinosis, partial thickness tear less or greater than 50 %, and complete tear. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy for tendinosis and tear detection were calculated.
*Results* MRI correctly diagnosed fewer normal LHBTs compared to MRA (39–54 % versus 74–84 %, respectively; $p<0.005$). MRI and MRA did not differ significantly in the diagnosis of tendinosis (18–36 % and 15–38 %, respectively; $p>0.05$) and tears (75–83 % and 64–73 %, respectively; $p>0.05$). For tendinosis, MRI versus MRA showed 18–36 % and 15–38 % sensitivity, 69–79 % and 83–91 % specificity, 22–28 % and 18–50 % PPV, 74–76 % and 80–86 % NPV, and 61–64 % and 70–81 % accuracy; respectively. For tears, MRI versus MRA showed 75–83 % and 64–73 % sensitivity, 73–75 % and 82–91 % specificity, 66–69 % and 41–62 % PPV, 82–87 % and 92–94 % NPV, and 74–78 % and 79–88 % accuracy; respectively.
*Conclusions* No significant difference was found between unenhanced MRI and direct MRA for the detection of tendinosis and tears of LHBTs.

**Keywords** Unenhanced MRI · MR arthrography · Long head of biceps brachii tendon · Arthroscopy · Accuracy

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## Introduction

Although the precise function of the long head of the biceps brachii tendon (LHBT) remains controversial [1], it is a well-recognized source of pain and dysfunction. Often accompanied by other shoulder pathology [2–5], LHBT disorders are challenging for clinicians with examination results that may be inconsistent and bear limited impact on pretest probability [6, 7]. Accurate diagnosis and treatment of LHBT injuries may prevent complete rupture and loss of function as well as offer relief even in the setting of massive rotator cuff tear [8, 9]. Although recent studies have shown ultrasound accurate for certain types of LHBT pathology [10, 11], MR imaging remains the preferred method for evaluation of the LHBT [12].

The ability of MR imaging to detect LHBT abnormalities is known to vary with technique. For example, previous studies have shown suboptimal detection of LHBT tears using unenhanced MRI, with sensitivities ranging from 24 to 56 % [2, 3, 13]. The use of either intravenous or intra-articular gadolinium has also produced mixed results. Zanetti et al. showed adequate diagnosis of long head of biceps tendinopathy and rupture using direct MR arthrography (MRA) with accuracy rates of 79–86 %, suggesting its superiority to unenhanced MRI [9]. Jung et al. found no significant difference between indirect and direct MRA for identifying LHBT tears, with sensitivities of 67–78 % and 78–89 %, respectively [14]. More recently, two studies have shown that the LHBT remains inadequately evaluated by MRI with sensitivities as low as 7 to 43 % [15, 16], although both studies reported the combined results of direct MRA and unenhanced MRI and both reported results which were limited to either normal or abnormal tendons, when it is known that accuracy varies with the specific degree of LHBT tear [3]. To our knowledge, there has been no study critically comparing unenhanced MRI to direct MRA in a large series of patients for the evaluation of the intra-articular LHBT.

The purpose of this investigation was to compare the most frequently used techniques in shoulder MR imaging, unenhanced MRI and direct MRA, for the assessment of the intra-articular LHBT. We sought to determine the diagnostic accuracy of these techniques using arthroscopy as the gold standard.

## Materials and methods

### Subjects

This was a retrospective study of consecutive patients who underwent preoperative shoulder MR imaging and arthroscopy between 2011 and 2014 at one of our ambulatory surgical centers. The study cohort included all patients who underwent arthroscopy. Although there were a variety of indications for shoulder arthroscopy in our cohort, in general, pain that was not responsive to conservative treatment was the most common indication. Patients with suspected internal derangements, including abnormalities of the labrum with or without instability, rotator cuff disease with or without subacromial impingement, adhesive capsulitis, glenohumeral arthritis, and biceps tendon lesions were all included. Patients were excluded if 12 months elapsed between MR imaging and arthroscopy or prior surgical procedure on the LHBT had been performed. Institutional review board approval and waiver of informed consent were obtained prior to chart review.

### MR imaging evaluation

MR imaging was performed with a 1.5-T system (Magnetom Avanto or Symphony; Siemens, Erlangen, Germany) using a standard shoulder coil. At our institution, some referring physicians had a preference for unenhanced MRI while others preferred direct MRA for evaluation of intra-articular pathology and each patient had one exam performed. Although various imaging protocols were used, the following parameters were used most often for unenhanced MRI: coronal spin-echo T1-weighted (TR/TE, 1420/23; echo-train length of 5; 3-mm section thickness, 0.6-mm interslice gap, 320×192 matrix, 12–14-cm field of view, and 1 signal average), coronal fast spin-echo T2-weighted with fat saturation (3570/91, echo-train length of 11, 3-mm section thickness, 0.6-mm interslice gap, 320×192 matrix, 12–14-cm field of view, and 2 signal averages), coronal fast spin-echo intermediate-weighted with fat saturation (2290/46, echo-train length of 7, 3-mm section thickness, 0.6-mm interslice gap, 320×192 matrix, 12–14-cm field of view, and 2 signal averages), sagittal spin-echo T1-weighted (500/12; echo-train length of 3; 3-mm section thickness; 1-mm interslice gap; 256 × 205 matrix; 12–14-cm field of view; and 1 signal average), sagittal spin-echo intermediate-weighted with fat saturation (2290/46; echo-train length of 7; 3-mm section thickness; 1-mm interslice gap; 320×192 matrix; 12–14-cm field of view; and 2 signal averages), and axial spin-echo intermediate-weighted with fat saturation (2220/46; echo-train length of 7; 4-mm section thickness; 1-mm interslice gap; 320×192 matrix; 12–14 cm field of view; and 1 signal average). Direct MRA was performed within 1 h of injection of a mixture of normal saline, Omnipaque (iohexol 300 mg I/ml; GE Healthcare, Princeton, NJ, USA), and Magnevist (gadopentetate dimeglumine; Bayer Healthcare, Wayne, NJ, USA) into the glenohumeral joint using routine fluoroscopic guidance. The final dilution of Magnevist was 1:200 (2.5 mmol/l). Direct MRA was obtained using representative imaging parameters as follows: coronal spin-echo T1-weighted with fat saturation (TR/TE, 689/12; echo-train length of 3; 3-mm section thickness, 0.6-mm interslice gap, 320×192 matrix, 12–14-cm field of view, and 1 signal average), coronal fast spin-echo intermediate-weighted with fat saturation (2230/44, echo-train length of 7, 3-mm section thickness, 0.6-mm interslice gap, 256×154 matrix, 12–14-cm field of view, and 2 signal averages), sagittal spin-echo T1-weighted with fat saturation (689/12; echo-train length of 3; 3-mm section thickness; 1-mm interslice gap; 320×192 matrix; 12–14-cm field of view; and 1 signal average), sagittal spin-echo intermediate-weighted with fat saturation (2000/45; echo-train length of 7; 3-mm section thickness; 1-mm interslice gap; 256×154 matrix; 12–14-cm field of view; and 2 signal averages), and axial spin-echo T1-weighted with fat saturation (653/12; echo-train length of 3; 4-mm section thickness;

**Table 1** Distribution of long head of biceps tendon findings between unenhanced MRI and arthroscopy

| MRI finding | Normal | Tendinosis | Arthroscopy finding | | |
|---|---|---|---|---|---|
| | | | Partial thickness tear<50 % | Partial thickness tear>50 % | Complete tear |
| Normal | 25/18 | 15/7 | 1/2 | 0/1 | 0/0 |
| Tendinosis | 13/21 | 6/12 | 5/7 | 3/2 | 0/1 |
| Partial thickness tear<50 % | 8/5 | 10/11 | 10/8 | 5/5 | 0/0 |
| Partial thickness tear>50 % | 0/2 | 2/3 | 5/4 | 8/10 | 0/1 |
| Complete tear | 0/0 | 0/0 | 0/0 | 2/0 | 14/12 |
| Total | 46 | 33 | 21 | 18 | 14 |

Note: The first number indicates the result from reader 1 and the second number those of reader 2

0.8-mm interslice gap; 320×192 matrix; 12–14-cm field of view; and 1 signal average).

MR images were independently analyzed by two fellowship-trained musculoskeletal radiologists with 3 and 4 years of experience, respectively. The two readers were blind to arthroscopy results. The intra-articular LHBT was graded as normal (grade 0), tendinosis (grade 1), partial thickness tear less or greater than 50 % (grades 2 and 3, respectively), and complete tear (grade 4). Normal tendons are characterized by an absence of caliber change (thickened or attenuated tendon) and smooth contour [9, 17]. Normal tendons demonstrate low signal intensity compared with surrounding tissue, except near the pulley where magic angle artifact can cause increased signal, particularly on shorter TE images [17]. Tendinosis was defined as tendon thickening and/or high signal changes [9, 17]. Partial thickness tear was defined as focal tendon caliber change [2], or high signal (approaching fluid intensity or gadolinium, for non-contrast MRI and direct MRA, respectively) in the tendon substance without complete discontinuity [2, 8]. Tears that resulted in greater than or less than 50 % diameter of the tendon remaining were characterized as<50 % (grade 2) and>50 % (grade 3), respectively. Longitudinal tears, where tendon surrounds the tear [18], were categorized as partial thickness tears<50 % (grade 2), regardless if the tear surfaced or not. Complete tear was defined as complete discontinuity of the intra-articular LHBT [9]. All planes were utilized for the evaluation of the biceps tendon, although the sagittal and coronal planes were deemed the most important. For the biceps tendon near the pulley (distal intra-articular), careful comparison with long TE images (T2-weighted with fat saturation), when available, was performed to avoid over-diagnosing pathologic tendons due to magic angle artifact [8, 19].

### Arthroscopic evaluation

Arthroscopic findings were considered the reference standard. Arthroscopic surgery was performed by two fellowship-trained orthopedic surgeons with 23 and 29 years of experience. Diagnostic arthroscopy was routinely performed with examination of the subacromial space and glenohumeral joint using posterior, anterior, and lateral portals. In addition, each LHBT was pulled into the joint using an arthroscopic probe to evaluate the pulley region. As part of routine clinical practice, both surgeons recorded intra-operative photos and videos for educational purposes, including training of sports medicine fellows. An orthopedic sports medicine fellow who was blinded to the MR grading of the LHBT retrospectively reviewed and graded the LHBT based on the pre-recorded arthroscopic photos and videos. The intra-articular LHBT was arthroscopically graded as normal (grade 0), tendinosis (grade 1), partial thickness tear less or greater than 50 %

**Table 2** Distribution of long head of biceps tendon findings between direct MR arthrography and arthroscopy

| MRI finding | Normal | Tendinosis | Arthroscopy finding | | |
|---|---|---|---|---|---|
| | | | Partial thickness tear<50 % | Partial thickness tear>50 % | Complete tear |
| Normal | 36/32 | 6/5 | 1/2 | 1/0 | 0/0 |
| Tendinosis | 4/7 | 5/2 | 1/2 | 0/0 | 0/0 |
| Partial thickness tear<50 % | 2/3 | 1/4 | 3/1 | 0/1 | 0/0 |
| Partial thickness tear>50 % | 1/1 | 1/2 | 2/2 | 2/2 | 0/0 |
| Complete tear | 0/0 | 0/0 | 0/0 | 0/0 | 1/1 |
| Total | 43 | 13 | 7 | 3 | 1 |

Note: The first number indicates the result from reader 1 and the second number those of reader 2

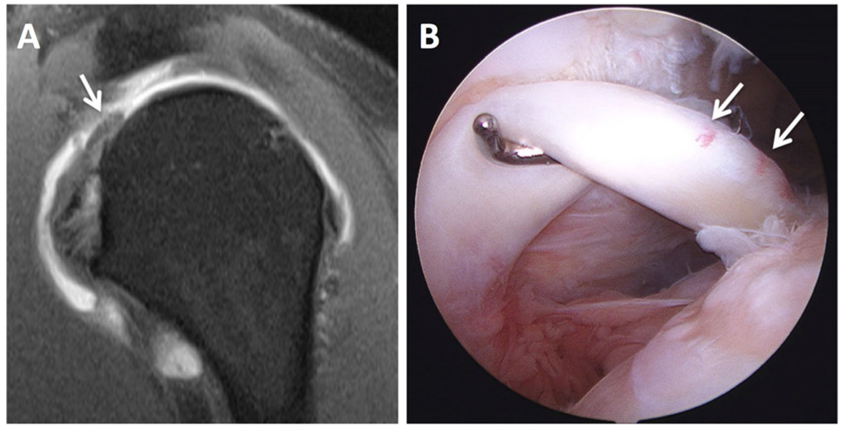


**Fig. 1** A 50-year-old man with discordant imaging and arthroscopic diagnoses near the biceps pulley. Sagittal T1-weighted fat-suppressed MR arthrogram image (**a**) with linear signal diagnosed as a tear less than 50 % near the pulley (*arrow*). However, arthroscopy (**b**) showed tendinosis characterized by mild erythema (*arrows*)

(grades 2 and 3, respectively), and complete tear (grade 4). Tendinosis was defined as tendon thickening and/or erythema.

### Statistical analysis

Descriptive statistics were performed for the study groups and differences between groups were evaluated with the Mann–Whitney *U* or Pearson Chi-square test, as appropriate. True concordance was calculated, defined as the percentage of patients in whom structures were identified exactly according to the classification of pathology on both imaging and arthroscopy. The performance of unenhanced MRI versus direct MRA to detect each category was assessed for each reader. Differences in proportions were evaluated using the Pearson Chi-square test. Additionally, the ability of unenhanced MRI versus direct MRA to detect a partial thickness tear (grades 2 and 3) or any tear (grade 2 or higher) was evaluated. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy for tendinosis and tear detection using unenhanced MRI and direct MRA were calculated.

Inter-observer agreement between reader 1 and reader 2 was assessed using κ statistics. All discordant cases were analyzed in consensus and categorized. Inter-observer agreement was rated as slight for a κ value less than or equal to 0.20, fair for a κ value of 0.21–0.40, moderate for a κ value of 0.41–0.60, substantial for a κ value of 0.61–0.80, and almost perfect for a κ value of 0.81–1.00 [17]. Differences were considered significant at $p<0.05$. Statistical evaluation was performed using the SPSS software package (version 21; SPSS, Chicago, IL, USA).

## Results

The study group consisted of 199 patients (66 females, 133 males). The mean age of patients was 50.5 years (SD=16.5 years). There were 132 unenhanced MRIs and 67 direct MRAs. Mean age of patients who underwent unenhanced MRI versus direct MRA was 56.4 years (SD=14.3 years) and 38.8 years (SD=14.4 years), respectively ($p<0.001$). The median number of days between MR imaging and arthroscopy was 61 (range=1–336). Median days from imaging to surgery for unenhanced MRI versus direct MRA was 63 (range, 1–336) and 56 (range, 7–313), respectively ($p=0.621$).

Arthroscopic surgery diagnosed 89/199 (45 %) of LHBTs as normal, 46/199 (23 %) with tendinosis, 28/199 (14 %) with partial thickness tears less than 50 %, 21/199 (11 %) with

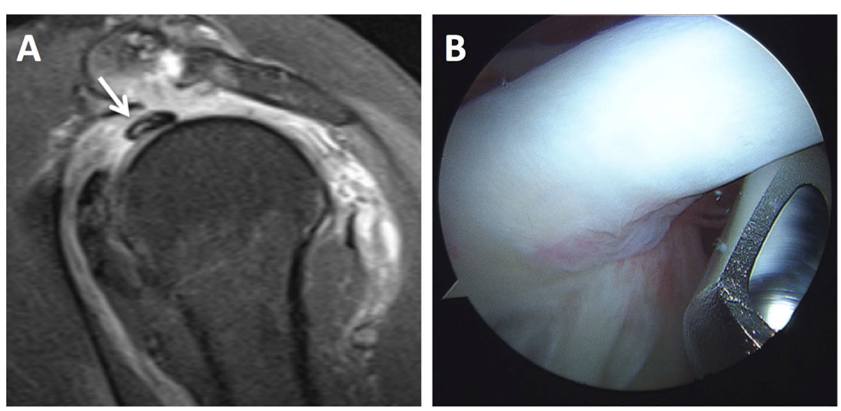


**Fig. 2** A 65-year-old woman with discordant imaging and arthroscopic diagnoses due to longitudinal, intrasubstance tear. Sagittal intermediate-weighted fat-suppressed MR image (**a**) shows linear signal diagnosed as an intra-substance tear less than 50 % (*arrow*). However, diagnosis of a normal tendon was made on arthroscopy (**b**)

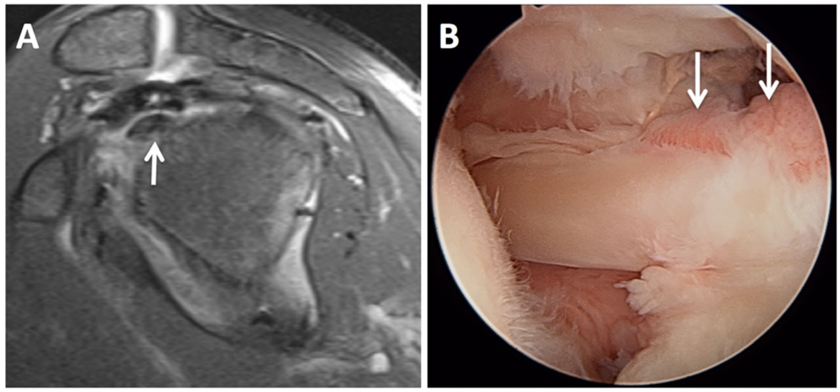

**Fig. 3** A 63-year-old man with discordant imaging and arthroscopic diagnoses due to surrounding synovitis. Sagittal intermediate-weighted fat-suppressed MR image (**a**) shows surface contour irregularity diagnosed as an intra-substance tear less than 50 % (*arrow*). However, arthroscopy (**b**) showed tendinosis characterized by synovitis on the tendon surface (*arrows*)

partial thickness tears greater than 50 %, and 15/199 (8 %) with complete tears.

### Diagnostic accuracy

The distribution of LHBT findings between arthroscopy and unenhanced MRI versus direct MRA is summarized in Tables 1 and 2, respectively. Between unenhanced MRI and direct MRA, there were significant differences in the proportions of arthroscopically diagnosed normal LHBTs (46/132 [35 %] and 43/67 [64 %], respectively; $p<0.001$) and LHBTs with tears (grade 2 and above) (53/132 [40 %] and 11/67 [16 %], respectively; $p=0.001$). The proportion of LHBTs with tendinosis by arthroscopy was not significantly different between unenhanced MRI and direct MRA (33/132 [25 %] and 13/67 [19 %], respectively; $p=0.376$). Overall true concordance for combined unenhanced MRI and direct MRA was 49–55 %. True concordance for reader 1 was significantly different between unenhanced MRI and direct MRA (63/132 [48 %] versus 47/67 [70 %], respectively; $p=0.003$). However, true concordance for reader 2 was not significantly different (60/132 [45 %] versus 38/67 [57 %], respectively; $p=0.133$). Comparison with arthroscopic photos/videos demonstrated causes for discordance to include 15 lesions near the biceps pulley (Fig. 1), five longitudinal tears (Fig. 2), four tendons with surrounding synovitis (Fig. 3), and three biceps anomalies (Fig. 4).

Among normal LHBTs by arthroscopy, 66–69 % were correctly identified. There was a significant difference between the proportions of correctly diagnosed normal cases on unenhanced MRI versus direct MRA for reader 1 (25/46 [54 %] and 36/43 [84 %], respectively; $p=0.003$) and reader 2 (18/46 [39 %] and 32/43 [74 %], respectively; $p=0.001$).

Of LHBTs with tendinosis by arthroscopy, 24–30 % were correctly identified (Fig. 5). There was no significant difference between the proportions of correctly diagnosed tendinosis cases on unenhanced MRI versus direct MRA for reader 1 (6/33 [18 %] and 5/13 [38 %], respectively; $p=0.147$) or reader 2 (12/33 [36 %] and 2/13 [15 %], respectively; $p=0.164$).

Among LHBTs with partial thickness tear less than 50 % by arthroscopy, 32–46 % were correctly identified (Fig. 6). There was no significant difference between the proportions of correctly diagnosed cases with partial thickness tear less than 50 % on unenhanced MRI versus direct MRA for reader 1 (10/21 [48 %] and 3/7 [43 %], respectively; $p=0.827$) or reader 2 (8/21 [38 %] and 1/7 [14 %], respectively; $p=0.243$).

Among LHBTs with partial thickness tear greater than 50 % by arthroscopy, 48–57 % were correctly identified (Fig. 7).

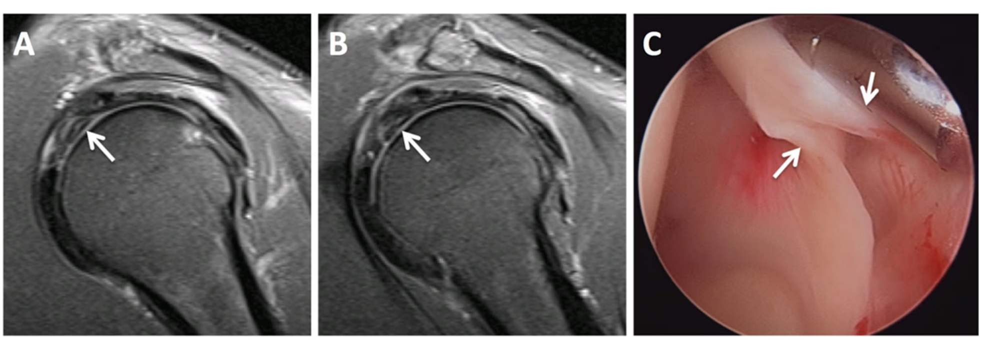

**Fig. 4** A 51-year-old man with discordant imaging and arthroscopic diagnoses due to congenital anomaly. Sagittal intermediate-weighted fat-suppressed MR images (**a** and **b**) shows irregular, linear signal extending through the biceps tendon, diagnosed as an intra-substance tear greater than 50 % (*arrows*). However, arthroscopy (**c**) showed a double origin, split biceps tendon [28] arising from the rotator cuff and joint capsule (*arrows*)

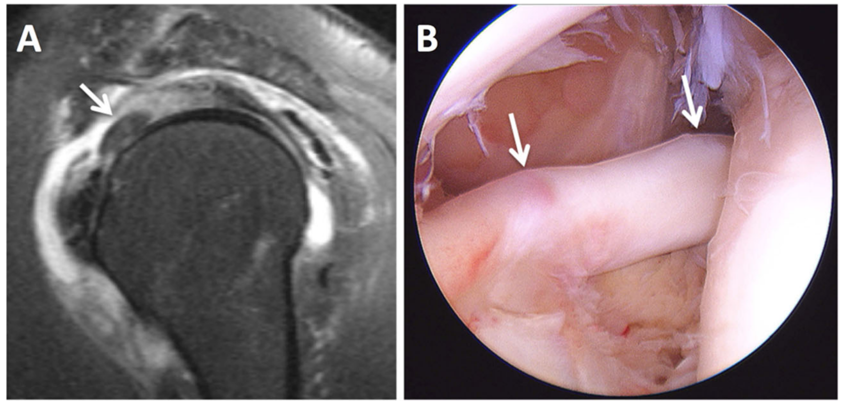


**Fig. 5** A 60-year-old woman with concordant imaging and arthroscopic diagnoses of tendinosis. Sagittal intermediate-weighted fat-suppressed MR image (**a**) shows increased signal and caliber of the biceps tendon, consistent with tendinosis (*arrow*). Arthroscopy (**b**) showed irregular contour and color, confirming tendinosis (*arrows*)

There was no significant difference between proportions of correctly diagnosed cases with partial thickness tear greater than 50 % on unenhanced MRI versus direct MRA for reader 1 (8/18 [44 %] and 2/3 [67 %], respectively; $p=0.476$) or reader 2 (10/18 [56 %] and 2/3 [67 %], respectively; $p=0.719$).

Among LHBTs with complete tears by arthroscopy, 87–100 % were correctly identified. There was no significant difference between proportions of correctly diagnosed cases with complete tear on unenhanced MRI versus direct MRA for reader 2 (12/14 [86 %] and 1/1 [100 %], respectively; $p=0.685$). Differences between proportions for reader 1 could not be calculated due to perfect agreement (14/14 [100 %] and 1/1 [100 %] for unenhanced MRI versus direct MRA, respectively).

When partial LHBT tears (grades 2 and 3) were grouped together, 67–81 % of those diagnosed on arthroscopy were correctly identified. There was no significant difference between proportions of correctly diagnosed partial tear cases on unenhanced MRI versus direct MRA for reader 1 (28/39 [72 %] and 7/10 [70 %], respectively; $p=0.911$) or reader 2 (27/39 [69 %] and 6/10 [60 %], respectively; $p=0.579$). When all LHBT tears diagnosed on arthroscopy were grouped together (grade 2 and above), 73–81 % were correctly identified. There was no significant difference between proportions of correctly diagnosed tear cases on unenhanced MRI versus direct MRA for reader 1 (44/53 [83 %] and 8/11 [73 %], respectively; $p=0.426$) or reader 2 (40/53 [75 %] and 7/11 [64 %], respectively; $p=0.419$). Sensitivity, specificity, PPV, NPV, and accuracy for the detection of tendinosis, a partial tear, and a complete tear of the LHBT by unenhanced MRI versus direct MRA are summarized in Tables 3, 4 and 5, respectively.

### Inter-observer agreement

Inter-observer agreement for LHBT tendinosis and tear detection for combined imaging was fair ($\kappa=0.39$, $p<0.001$) and substantial ($\kappa=0.78$, $p<0.001$), respectively. For unenhanced MRI, inter-observer agreement for LHBT tear detection was almost perfect ($\kappa=0.83$, $p<0.001$) whereas it was moderate for direct MRA ($\kappa=0.57$, $p<0.001$). Across all LHBT findings, inter-observer agreement for combined MR imaging was moderate ($\kappa=0.55$, $p<0.001$).

## Discussion

Despite the prevalence of the LHBT as an important pain generator within the shoulder, the diagnostic role of MR imaging of the LHBT remains unclear. Our study was undertaken to assess the accuracy of unenhanced MRI versus direct MRA for detection of intra-articular LHBT pathology.

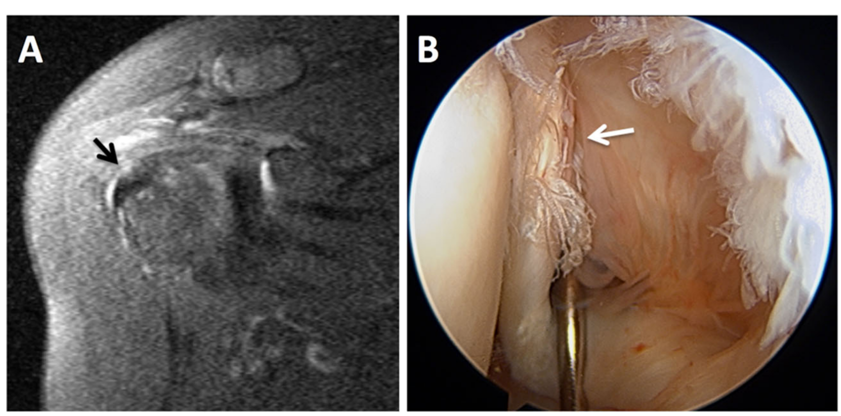


**Fig. 6** A 59-year-old woman with concordant imaging and arthroscopic diagnoses of partial-thickness tear less than 50 %. Coronal intermediate-weighted fat-suppressed MR image (**a**) shows a small tear of the tendon near the pulley (*black arrow*). Arthroscopy (**b**) confirmed the diagnosis as the tendon was pulled into the joint (*white arrow*)

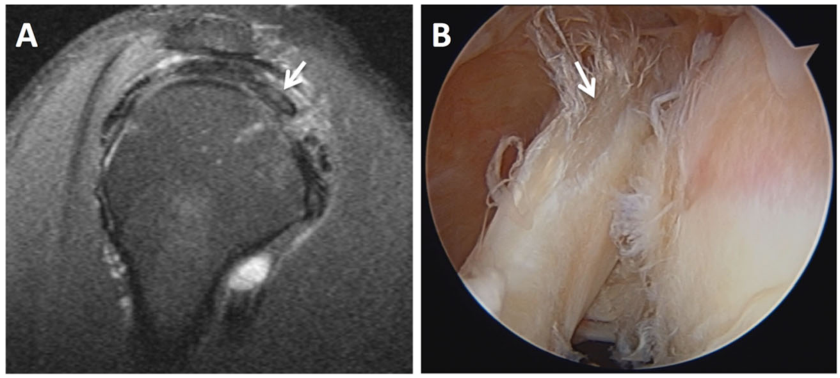


**Fig. 7** A 60-old man with discordant imaging and arthroscopic diagnoses. Sagittal intermediate-weighted fat-suppressed MR image (**a**) shows mild diffuse increased signal of the long head of the biceps tendon interpreted as tendinosis (*arrow*). Arthroscopy (**b**) showed a tendon tear greater than 50 % near the pulley (*arrow*)

Across both MR techniques, the diagnosis of normal LHBTs was moderately accurate with 66–69 % correctly identified. Among false positive findings, the majority was reported as tendinosis (19–31 %). In comparing both MR techniques, direct MRA was superior to unenhanced MRI in correctly diagnosing normal LHBTs for both readers. As the rationale for intra-articular contrast relates to distension of the joint [19], which may help outline the LHBT and reveal tendon surface irregularities [20], this finding may have been related to a lack of native joint fluid in these patients and relative decreased tissue contrast on unenhanced MRI. Further, the use of gadolinium with T1-weighted imaging may have offered improved signal-to-noise ratios, although this is not specific to normal LHBTs.

Among tendinotic LHBTs, only 24–30 % were correctly identified with no significant difference between both techniques. The sensitivity for detection of LHBT tendinosis was poor at 18–36 % for unenhanced MRI and 15–35 % for direct MRA. The PPV for LHBT tendinosis was similarly low at 22–28 % for unenhanced MRI and 18–50 % for direct MRA. These results are consistent with published data examining the challenges of diagnosing tendinosis of the LHBT. For example, Zanetti et al. studied direct MRA in 19 patients with tendinopathy and found the most reliable findings to include caliber changes and signal abnormalities [9]. More recent data comparing gross anatomic and histologic findings of the LHBT with MRI showed abnormal tendon diameter as the primary, though not sole criterion, for the diagnosis of tendon degeneration, whereas signal changes were less reliable [17]. These findings were related to partial volume artifacts due to the curved course of the LHBT, magic-angle artifact, and fatty infiltration of the tendon [17]. For similar reasons, it is recognized that partial tears of the LHBT at or within one centimeter of the bicipital groove entrance are problematic on MRI [8, 18]. Expectedly, several discordant cases had imaging findings in the region of the biceps pulley, which were almost all over-diagnosed by either reader compared with normal or tendinosis by arthroscopy. Interestingly however, among incorrectly diagnosed tendinotic LHBTs, most were reported as normal. This may be related to differences in grading criteria on imaging versus arthroscopy. In particular, the diagnosis of tendinosis by arthroscopy is frequently based on the presence of erythema involving the thin layer of synovium covering the intra-articular LHBT [21]. This finding however is likely below the resolution of MR imaging. Similarly, arthroscopy may have a limited ability to detect non-surface tendon abnormalities that are readily seen as abnormal intrasubstance signal on MR imaging. Wu et al. recently demonstrated that the macroscopic appearance of the LHBT at arthroscopy does not necessarily reflect its histopathologic grade [5]. This was most notable among macroscopically normal LHBTs, which had various degrees of tendinopathy [5]. Although these specimens were obtained from patients with chronic rotator cuff tears, this may explain the low PPV seen with both MR techniques and potentially challenge the reference standard of arthroscopy used in this study.

The sensitivity of unenhanced MRI for detecting LHBT tears was higher than previous reports (75–83 % compared

**Table 3** Unenhanced MRI and direct MR arthrography compared with arthroscopy for detection of long head of biceps tendinosis

| | Reader 1 | | Reader 2 | |
|---|---|---|---|---|
| | Unenhanced MRI (%) | Direct MRA (%) | Unenhanced MRI (%) | Direct MRA (%) |
| Sensitivity | 18 | 38 | 36 | 15 |
| Specificity | 79 | 91 | 69 | 83 |
| PPV | 22 | 50 | 28 | 18 |
| NPV | 74 | 86 | 76 | 80 |
| Accuracy | 64 | 81 | 61 | 70 |

*MRA* MR arthrography, *PPV* positive predictive value, *NPV* negative predictive value

**Table 4** Unenhanced MRI and direct MR arthrography compared with arthroscopy for detection of long head of biceps tendon partial tears (grades 2 and 3 combined)

| | Reader 1 | | Reader 2 | |
|---|---|---|---|---|
| | Unenhanced MRI (%) | Direct MRA (%) | Unenhanced MRI (%) | Direct MRA (%) |
| Sensitivity | 72 | 70 | 69 | 60 |
| Specificity | 78 | 91 | 76 | 82 |
| PPV | 58 | 58 | 55 | 38 |
| NPV | 87 | 95 | 86 | 92 |
| Accuracy | 77 | 88 | 74 | 79 |

*MRA* MR arthrography, *PPV* positive predictive value, *NPV* negative predictive value

to 24–56 %) [2, 3, 13], whereas it was slightly lower for direct MRA (64–73 % compared to 78–92 %) [9, 14]. The specificity of both techniques was in the range of published data (73–75 % for unenhanced MRI and 82–91 % for direct MRA) [2, 3, 9, 13–16]. The proportion of correctly identified LHBT tears, by each tear classification and when grouped together as partial tears or any tear type, did not significantly differ between unenhanced MRI and direct MRA. This may be a corollary of the findings seen among normal LHBTs. In particular, given the high association of abnormal LHBTs with other shoulder pathology [2–5], sufficiently large joint effusions in these patients may have provided comparable tissue contrast on unenhanced MRI relative to a contrast-distended joint. This remains open to speculation however as the presence of a joint effusion was not recorded in this study. In comparison to prior reports suggesting improved detection of LHBT pathology using direct MRA, the potential benefit of intra-articular contrast may have been outweighed by the current use of high field strength unenhanced MRI. Specifically, in the two previous studies evaluating direct MRA, field strength ranged from 0.5 to 1.5 T [9, 16]; whereas shoulder exams in this study were performed solely on 1.5-T scanners. Given these findings, unenhanced MRI may even be considered advantageous because it is non-invasive, less expensive, and can be performed offsite or during off hours [22].

Accounting for all LHBT findings, reader 1 showed a significant difference between unenhanced MRI and direct MRA (48 % versus 70 %) however this was not seen for reader 2 (45 % versus 57 %). True concordance for combined unenhanced MRI and direct MRA was higher than published data [3], though moderate at 49–55 %. Overall, evaluation of the LHBT may potentially be improved through the use of dedicated MR sequences aimed at overcoming the challenges generated by its curved course. For example, prior studies have suggested evaluation of the LHBT near the bicipital groove entrance on T2 sequences to avoid magic-angle artifact [8, 19], the use of improved out-of-plane spatial resolution, and different arm positions to increase the tendon's extra-articular location and thereby improve interpretation [23].

In addition to lesions near the biceps pulley, discordant imaging and arthroscopic findings included longitudinal tears, tendons with surrounding synovitis, and biceps anomalies. Among discordant patients with synovitis, nearly all were over-diagnosed by both readers as tears compared with normal or tendinosis by arthroscopy. Of the three patients with biceps anomalies, two were graded as partial thickness tears greater than 50 % by one or both readers compared with normal or tendinosis by arthroscopy. This is consistent with several previous studies reporting variations in the intra-articular LHBT that can resemble tendon tears or retraction [24] and are often not diagnosed prospectively [25–27]. In such cases, the LHBT will often appear adherent to the superior joint capsule with absent normal glenoid origin or a "split" intra-articular tendon with a bifurcate or Y-shaped origin [24, 28]. It has been suggested that direct MRA is superior to unenhanced MRI for diagnosing biceps anomalies [29], however there were too few cases in this series to adequately evaluate this.

Similar to what is advocated in the literature [30], at our institution, indications for treatment of LHBT pathology include tearing, instability, and tenosynovitis. In our study, we

**Table 5** Unenhanced MRI and direct MR arthrography compared with arthroscopy for detection of all long head of biceps tendon tears (grades 2 and above)

| | Reader 1 | | Reader 2 | |
|---|---|---|---|---|
| | Unenhanced MRI (%) | Direct MRA (%) | Unenhanced MRI (%) | Direct MRA (%) |
| Sensitivity | 83 | 73 | 75 | 64 |
| Specificity | 75 | 91 | 73 | 82 |
| PPV | 69 | 62 | 66 | 41 |
| NPV | 87 | 94 | 82 | 92 |
| Accuracy | 78 | 88 | 74 | 79 |

*MRA* MR arthrography, *PPV* positive predictive value, *NPV* negative predictive value did not include evaluation of LHBT instability. However, for tearing and tenosynovitis (represented as tendinosis in our study), we did not see any benefit for direct MRA over unenhanced MRI. There are several limitations to this study. First, our study was a retrospective review rather than a prospective design. Second, there may have been a bias related to inclusion of only patients with arthroscopy performed. Indeed, the prevalence of LHBT disease was relatively high in our series of patients (55 % compared to 21–25 %) [8, 31]. Third, our study included a variable and sometimes lengthy time between MR imaging and arthroscopy. However, other radiology-surgical comparison studies have utilized similar methods with similar average number of days between imaging and surgery [2, 14, 15, 32–34]. Of the 199 enrolled subjects, 169 had less than 180 days (6 month) time lapse between imaging and arthroscopy. Fourth, there was a higher frequency of abnormal LHBTs among patients who underwent unenhanced MRI compared to direct MRA. Given our institution's referring physician preference to perform unenhanced MRI over direct MRA in older patients (56.4 years versus 38.8 years of age, respectively), these findings are consistent with previous work showing a direct relationship between abnormal histologic LHBT findings and patient age [4]. Fifth, arthroscopy was used as a reference standard and recent studies have suggested that the LHBT near the pulley region cannot be entirely evaluated by pulling the tendon into the joint [35]. As previously discussed, arthroscopy may also have been subject to diagnostic error as the macroscopic appearance of the LHBT has been shown to unreliably reflect its histopathologic grade [5]. Finally, the results from this study likely represent one of the best-case scenarios. Unlike prior studies in which MRIs were prospectively interpreted in routine practice [3, 36], the interpretations in this current study were performed without interruptions or time constraints, used all three imaging planes to score the LHBT, and only evaluated the LHBT rather than all structures in the field of view.

In summary, both unenhanced MRI and direct MRA are fairly accurate for the diagnosis of LHBT pathology. No significant difference was found between unenhanced MRI and direct MRA for the detection of tendinosis and tears of LHBTs, and therefore the addition of intra-articular contrast may not add any significant benefit to unenhanced MRI for the evaluation of LHBT pathology. Both MR techniques show poor sensitivity and PPV for detecting tendinosis, which may be related to differences in grading criteria on imaging versus arthroscopy. Knowledge of potential pitfalls and strategies for improving evaluation of the LHBT may allow the radiologist to be confident when appropriate.

**Acknowledgments** Eric Y. Chang, MD gratefully acknowledges salary support from the VA Clinical Science Research and Development Career Development Award (1IK2CX000749).

**Conflict of interest** The author(s) declare that they have no competing interests.

## References

1. Khazzam M, George MS, Churchill RS, Kuhn JE. Disorders of the long head of biceps tendon. J Shoulder Elbow Surg. 2012;21(1): 136–45.
2. Beall DP, Williamson EE, Ly JQ, Adkins MC, Emery RL, Jones TP, et al. Association of biceps tendon tears with rotator cuff abnormalities: degree of correlation with tears of the anterior and superior portions of the rotator cuff. AJR Am J Roentgenol. 2003;180(3): 633–9.
3. Dubrow SA, Streit JJ, Shishani Y, Robbin MR, Gobezie R. Diagnostic accuracy in detecting tears in the proximal biceps tendon using standard nonenhancing shoulder MRI. Open Access J Sports Med. 2014;5:81–7.
4. Murthi AM, Vosburgh CL, Neviaser TJ. The incidence of pathologic changes of the long head of the biceps tendon. J Shoulder Elbow Surg. 2000;9(5):382–5.
5. Wu PT, Jou IM, Yang CC, Lin CJ, Yang CY, Su FC, et al. The severity of the long head biceps tendinopathy in patients with chronic rotator cuff tears: macroscopic versus microscopic results. J Shoulder Elbow Surg. 2014;23(8):1099–106.
6. Ben Kibler W, Sciascia AD, Hester P, Dome D, Jacobs C. Clinical utility of traditional and new tests in the diagnosis of biceps tendon injuries and superior labrum anterior and posterior lesions in the shoulder. Am J Sports Med. 2009;37(9):1840–7.
7. Holtby R, Razmjou H. Accuracy of the Speed's and Yergason's tests in detecting biceps pathology and SLAP lesions: comparison with arthroscopic findings. Arthroscopy. 2004;20(3):231–6.
8. Gaskin CM, Anderson MW, Choudhri A, Diduch DR. Focal partial tears of the long head of the biceps brachii tendon at the entrance to the bicipital groove: MR imaging findings, surgical correlation, and clinical significance. Skelet Radiol. 2009;38(10):959–65.
9. Zanetti M, Weishaupt D, Gerber C, Hodler J. Tendinopathy and rupture of the tendon of the long head of the biceps brachii muscle: evaluation with MR arthrography. AJR Am J Roentgenol. 1998;170(6):1557–61.
10. Armstrong A, Teefey SA, Wu T, Clark AM, Middleton WD, Yamaguchi K, et al. The efficacy of ultrasound in the diagnosis of long head of the biceps tendon pathology. J Shoulder Elbow Surg. 2006;15(1):7–11.
11. Skendzel JG, Jacobson JA, Carpenter JE, Miller BS. Long head of biceps brachii tendon evaluation: accuracy of preoperative ultrasound. AJR Am J Roentgenol. 2011;197(4):942–8.
12. Morag Y, Jacobson JA, Shields G, Rajani R, Jamadar DA, Miller B, et al. MR arthrography of rotator interval, long head of the biceps brachii, and biceps pulley of the shoulder. Radiology. 2005;235(1): 21–30.
13. Ostor AJ, Richards CA, Tytherleigh-Strong G, Bearcroft PW, Prevost AT, Speed CA, et al. Validation of clinical examination versus magnetic resonance imaging and arthroscopy for the detection of rotator cuff lesions. Clin Rheumatol. 2013;32(9):1283–91.
14. Jung JY, Yoon YC, Yi SK, Yoo J, Choe BK. Comparison study of indirect MR arthrography and direct MR arthrography of the shoulder. Skelet Radiol. 2009;38(7):659–67.
15. Halma JJ, Eshuis R, Krebbers YM, Weits T, de Gast A. Interdisciplinary inter-observer agreement and accuracy of MR imaging of the shoulder with arthroscopic correlation. Arch Orthop Trauma Surg. 2012;132(3):311–20.

16. Houtz CG, Schwartzberg RS, Barry JA, Reuss BL, Papa L. Shoulder MRI accuracy in the community setting. J Shoulder Elbow Surg. 2011;20(4):537–42.
17. Buck FM, Grehn H, Hilbe M, Pfirrmann CW, Manzanell S, Hodler J. Degeneration of the long biceps tendon: comparison of MRI with gross anatomy and histology. AJR Am J Roentgenol. 2009;193(5): 1367–75.
18. Tuckman GA. Abnormalities of the long head of the biceps tendon of the shoulder: MR imaging findings. AJR Am J Roentgenol. 1994;163(5):1183–8.
19. Chung CB, Dwek JR, Cho GJ, Lektrakul N, Trudell D, Resnick D. Rotator cuff interval: evaluation with MR imaging and MR arthrography of the shoulder in 32 cadavers. J Comput Assist Tomogr. 2000;24(5):738–43.
20. Resnick D, Kang HS, Pretterklieber ML. Internal derangements of joints. 2nd ed. Philadelphia: Saunders/Elsevier; 2007.
21. Nho SJ, Strauss EJ, Lenart BA, Provencher MT, Mazzocca AD, Verma NN, et al. Long head of the biceps tendinopathy: diagnosis and management. J Am Acad Orthop Surg. 2010;18(11):645–56.
22. Steinbach LS, Palmer WE, Schweitzer ME. Special focus session. MR arthrography. Radiographics. 2002;22(5):1223–46.
23. Polster JM, Schickendantz MS. Shoulder MRI: what do we miss? AJR Am J Roentgenol. 2010;195(3):577–84.
24. Vinson EN, Wittstein J, Garrigues GE, Taylor DC. MRI of selected abnormalities at the anterior superior aspect of the shoulder: potential pitfalls and subtle diagnoses. AJR Am J Roentgenol. 2012;199(3):534–45.
25. Gaskin CM, Golish SR, Blount KJ, Diduch DR. Anomalies of the long head of the biceps brachii tendon: clinical significance, MR arthrographic findings, and arthroscopic correlation in two patients. Skelet Radiol. 2007;36(8):785–9.
26. Wahl CJ, MacGillivray JD. Three congenital variations in the long head of the biceps tendon: a review of pathoanatomic considerations and case reports. J Shoulder Elbow Surg. 2007;16(6):e25–30.
27. Moser TP, Cardinal E, Bureau NJ, Guillin R, Lanneville P, Grabs D. The aponeurotic expansion of the supraspinatus tendon: anatomy and prevalence in a series of 150 shoulder MRIs. Skelet Radiol. 2015;44(2):223–31.
28. Dierickx C, Ceccarelli E, Conti M, Vanlommel J, Castagna A. Variations of the intra-articular portion of the long head of the biceps tendon: a classification of embryologically explained variations. J Shoulder Elbow Surg. 2009;18(4):556–65.
29. Yeh L, Pedowitz R, Kwak S, Haghighi P, Muhle C, Trudell D, et al. Intracapsular origin of the long head of the biceps tendon. Skelet Radiol. 1999;28(3):178–81.
30. Creech MJ, Yeung M, Denkers M, Simunovic N, Athwal GS, Ayeni OR. Surgical indications for long head biceps tenodesis: a systematic review. Knee Surg Sports Traumatol Arthrosc Off J ESSKA. 2014. doi:10.1007/s00167-014-3383-9.
31. Nidecker A, Guckel C, von Hochstetter A. Imaging the long head of biceps tendon–a pictorial essay emphasizing magnetic resonance. Eur J Radiol. 1997;25(3):177–87.
32. Schaeffeler C, Waldt S, Holzapfel K, Kirchhoff C, Jungmann PM, Wolf P, et al. Lesions of the biceps pulley: diagnostic accuracy of MR arthrography of the shoulder and evaluation of previously described and new diagnostic signs. Radiology. 2012;264(2):504–13.
33. Chang CY, Gill CM, Huang AJ, Simeone FJ, Torriani M, McCarthy JC, et al. Use of MR arthrography in detecting tears of the ligamentum teres with arthroscopic correlation. Skelet Radiol. 2015;44(3):361–7.
34. Petchprapa CN, Rybak LD, Dunham KS, Lattanzi R, Recht MP. Labral and cartilage abnormalities in young patients with hip pain: accuracy of 3-Tesla indirect MR arthrography. Skelet Radiol. 2015;44(1):97–105.
35. Festa A, Allert J, Issa K, Tasto JP, Myer JJ. Visualization of the extra-articular portion of the long head of the biceps tendon during intra-articular shoulder arthroscopy. Arthroscopy. 2014;30(11): 1413–7.
36. Mohtadi NG, Vellet AD, Clark ML, Hollinshead RM, Sasyniuk TM, Fick GH, et al. A prospective, double-blind comparison of magnetic resonance imaging and arthroscopy in the evaluation of patients presenting with shoulder pain. J Shoulder Elbow Surg. 2004;13(3):258–65.