Original Article

Subscapularis tendon tear detection using axial internal rotation MRI: semiquantitative and quantitative analysis

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Background: Magnetic resonance image (MRI) of the subscapularis tendon plays an important role in preoperative planning. This retrospective study aimed to evaluate the diagnostic value and quantitative measurement of an additional internal rotation sequence in the detection of partial subscapularis tendon tears.

Methods: The study included 76 patients who underwent arthroscopy and magnetic resonance (MR) shoulder between January 2018 to December 2019. Three different sets of images were evaluated in each case to determine the diagnostic value in the detection of partial subscapularis tendon tears including Set 1: standard axial fat-suppressed proton density (PD/FS) image and sagittal fat-suppressed T2 weight image (T2W/FS) images, Set 2: standard axial PD/FS and internal rotation PD/FS images, and Set 3: standard axial PD/FS, sagittal T2W/FS and axial internal rotation PD/FS images. Subscapularis tendon tear was diagnosed by arthroscopy and patients with or without tears were grouped. The coracohumoral distance (CHD), coracoglenoid angle (CGA), coracohumeral angle (CHA), CHD difference and CHD ratio were evaluated and compared between groups using univariate and multivariate analysis. The interreader agreement was assessed. The cut-off point for the prediction of subscapularis tears was calculated.

Results: Twenty-nine shoulders revealed partial subscapularis tendon tears (29/76, 38.2%). Imaging Set 3 provided the highest sensitivity and accuracy {79–83% [confidence interval (CI): 0.60–0.95], 75–76% (CI: 0.63–0.85)}, compared to image Set 2 [31–58% (CI: 0.15–0.76), 67–68% (CI: 0.55–0.79)] and Set 1 [17–21% (CI: 0.06–0.40], 61–66% (CI: 0.54–0.76)], and a moderate level of interobserver agreement (Kappa =0.55). Axial CHD [odd ratio (OR) =1.48, P=0.044], internal rotate CHD (OR =0.68, P=0.02), CHD difference (OR =2.58, P<0.001), and CHD ratio (OR =1.34, P<0.001) were associated with subscapularis tears. A CHD difference and CHD ratio of more than 0.04 mm and 1.01 achieved a 90% sensitivity and 72% specificity, both.

Conclusions: Internal rotation during MRI can increase diagnostic accuracy for subscapularis tendon partial tears. The CHD differences and CHD ratio are useful parameters to indicate subscapularis tears. This technique may improve preoperative management and reduce the consequences of delayed diagnosis and treatment.

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Introduction

Rotator cuff tendon tear is the leading cause of shoulder pain and long-term dysfunction (1). Over the last two decades, rotator cuff injury and arthroscopic-assisted surgery have become increasingly common (2,3). Subscapularis tendon injury is frequently missed at arthroscopy or surgery (4). Specific exploration of the subscapularis tendons under arthroscope increases diagnostic accuracy in subscapularis tendon pathology (5).

The subscapularis is one of the largest and strongest muscles in the rotator cuff (6). The muscle provides approximately 50 percent of rotator cuff force and plays a crucial role in dynamic and static shoulder stabilization (6-10). Subscapularis tendon tears are common. The reported prevalence of subscapularis tears among patients who underwent arthroscopy ranges from 12% to 50% (9,11-13). The most common site of subscapularis tendon tears is at the anterosuperior aspect and is often associated with long head biceps tendons pathology (4,14-20). Because the superior part of the subscapularis tendons adjoins the long head biceps tendons, it also supports long head bicep tendon stability (14,21). Delayed diagnosis or under detection of subscapularis tears may deteriorate shoulder function and provoke shoulder pain (4,22,23).

Magnetic resonance imaging (MRI) provides pathologic details and plays a crucial part in the preoperative diagnosis of subscapularis tendon tear. Axial and sagittal oblique views in fluid sensitive sequences are the most informative views in tendinous abnormality detection (7,10,14). Malavolta *et al.* (9) reported an overall sensitivity of 68% and overall specificity of 90% in the diagnosis of subscapularis tears. The sensitivity and specificity of full-thickness subscapularis tears are approximately 93% and 97%, respectively, while the sensitivity and specificity of partial tears are approximately 74% and 88%, respectively (9). Furukawa *et al.* (14) reported that radial-slice imaging magnetic resonance (MR) techniques improves the diagnostic value for subscapularis tears with a sensitivity of 94.7% and a specificity of 82.4%.

To improve the diagnostic sensitivity for partial-thickness subscapularis tears, we applied an internal rotation position using a fat-suppressed proton density (PD/FS) sequence scan on the axial plane in addition to the routine protocol. We hypothesize that the additional internal rotation position could increase the diagnosis accuracy of the partial subscapularis tendon tear on MRI. Therefore, we explored the advantages of this technique for the diagnosis of partial thickness subscapularis tendon tears and evaluated shoulder variations associated with subscapularis tendon tears and shoulder impingement. We present this article in accordance with the STARD reporting checklist (available at https://qims.amegroups.com/article/view/10.21037/qims-23-273/rc).

Methods

All MRIs of the shoulders between January 1st, 2018 and December 31st, 2019 in Siriraj hospital were retrospectively included in this study. The inclusion criteria were (I) MRI was performed within the 6 months preceding arthroscopy, (II) performed in a 3T MR machine, and (III) all axial PD/FS images, sagittal oblique fat-suppressed T2 weight image (T2W/FS) images and internal rotation axial PD/FS images were available. The exclusion criteria were (I) lack of demographic information or incomplete arthroscopic results; (II) complete tear of the subscapularis tendon in arthroscope; (III) presence of MR artifacts interfering image interpretation (e.g., metallic artifacts and motion artifacts); (IV) MRI with low image quality or improper shoulder position, and (V) MR images of patients with a history of bone or soft tissue tumors, bone fracture, infectious diseases, inflammatory arthritis, and previous surgery at shoulders. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Faculty of Medicine, Siriraj hospital, Mahidol University, Bangkok, Thailand, the Siriraj Institutional Review Board (No. SI039/2021) and individual consent for this retrospective analysis was waived.

A total of 1,011 MR images of the shoulders were

Figure 1 Positioning of the patient during scan. (A) Conventional positioning: patient in supine position, the humerus in the neutral position, the inner aspect of the arms adhering to the torsi, the thumbs pointing laterally, and the palms supinating. (B) Internal rotation position: patient in supine position, the inner aspects of the arms were adhered to the torso with the thumbs pointed medially and palms pronating.

performed between January 1st, 2018 and December 31st, 2019. Eighty-eight shoulder MRIs met the eligibility criteria. Eleven shoulder MRIs were excluded due to history of previous surgery at the shoulders, low image quality, or complete tear on arthroscopy. Another MRI was excluded due to the diagnosis of septic arthritis. As a result, 76 shoulder MRIs of 76 patients were enrolled. All patient underwent arthroscopy and physical examination by a sport medicine orthopedic surgeon (AK) and were grouped into no tear and partial groups. The clinical test data including belly press or lift off test, Jobe test, Neer test and Hawkin test were obtained.

Imaging acquisition

Three 3.0-T MR machines, including two Ingenia 3.0 T; Philips Healthcare, Best, Netherlands (installed in 2013 and 2014); and one MAGNETOM vida 3.0 T; Siemens, Erlangen, Germany (installed in 2019) were used. Phased array shoulder coils were also applied to the shoulders. For conventional MR images, patients were imaged supine with the humerus in the neutral position, the inner aspect of the arms adhering to the torsi, the thumbs pointing laterally, and the palms supinating. After conventional MR images were obtained, the internal rotation MR images were performed. The affected shoulders were passively flexed for 10–90 degree and the patients were asked to put the arms down and internally rotate the shoulders. The inner aspects of the arms were adhered to the torso with the thumbs pointed medially and palms pronating (*Figure 1*). The scanning parameters were listed as following; axial PD/FS and internal rotate PD/FS: repetition time (TR) =2,500 ms, echo time (TE) =30 ms, field of view (FOV) 140 mm, matrix =256×256; and sagittal T2W/FS: TR =3,870 ms, TE =75–80 ms, FOV 140 mm, matrix =256×256. The example of MR images is shown in *Figure 2*.

Imaging interpretation

All shoulder MRIs were organized into three data sets. Set 1 was composed of axial PD/FS and sagittal T2W/FS images. Set 2 was axial PD/FS and internal rotation axial PD/FS images, and Set 3 was a combination of axial PD/FS, sagittal T2W/FS, and internal rotation axial PD/FS images. Two radiologists with eight and five years of experience in musculoskeletal radiology (PS and AP, respectively) independently reviewed the included MRIs. The three MRI sets were reviewed separately with a one-month gap between each MRI set. The reviewers were blinded to patient information (clinical histories, laboratory investigations and final diagnoses). Disagreements between the two reviewers were resolved by consensus. The morphology of MRIs for subscapularis and biceps tendons were classified as no tear, partial tear, and complete tear. Tendinosis of the subscapularis and biceps tendon were also recorded. Partial tears of the tendons were defined as evidence of fluid or near fluid signal intensity along the course of the tendon, particularly on the articular sides of the subscapularis tendons, without complete disruption of the tendon fibers (*Figure 3*). Complete tears of the tendons were defined as complete disruption of the tendinous course either with or without tendon retraction and were excluded from the study (*Figure 4*). Tendinosis was defined as increased signal intensity (less than fluid signal intensity) along the tendon without discontinuity or interruption of the tendon fibers (*Figures 3,4*).

Coracoid morphology was classified into three types (*Figure 5*). A flat coracoid type (type A) was defined as the

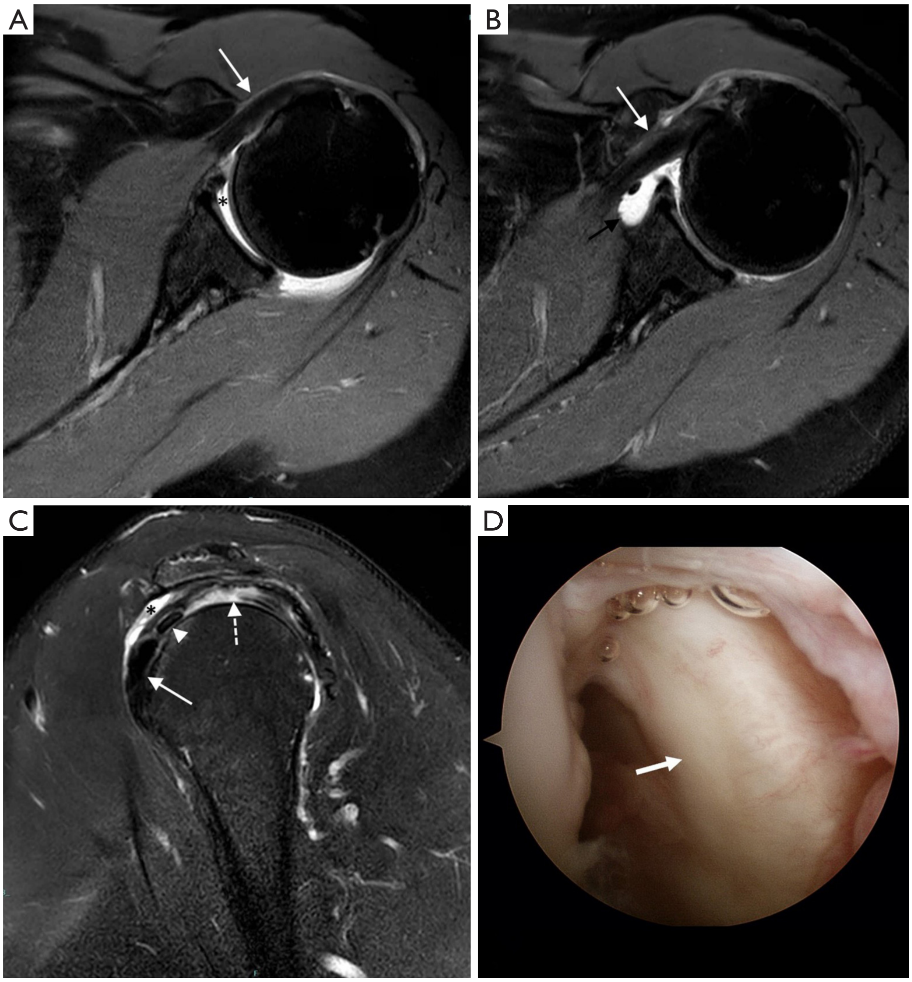

Figure 2 A 63-year-old man with left shoulder pain without subscapularis tendon tear. The shoulder MR images in axial PD/FS (A) and axial internal rotation PD/FS (B) show normal course and signal intensity of subscapularis tendon (white arrow) with small amount of joint effusion (asterisk). Minimal fluid in subscapularis bursa is also visualized (black arrow) (B). Sagittal oblique T2W/FS (C) shows normal subscapularis tendon (white arrow), tendinosis of long head biceps tendon (arrow head) and partial-thickness articular side tear of supraspinatus tendon (dotted arrow) with minimal fluid in subdeltoid bursa (asterisk). (D) Arthroscopy revealed normal appearance of the subscapularis tendon (white arrow). MR, magnetic resonance; PD/FS, fat-suppressed proton density; T2W/FS, fat-suppressed T2 weighted.

axis of the coracoid process in the axial view is straight from the base to the tip. Type B is characterised by a prominent osteophyte at the end of the coracoid process. We defined hooked coracoid (type C) where the axis of coracoid process is laterally deviated a few centimeters at its base.

The coracohumeral distance (CHD) was measured as the narrowest point between the inner surface of the coracoid process or short head of the biceps tendon to the humeral head at level of mid glenohumoral joint (*Figure 6A,6B*). The coracoglenoid angle (CGA) was defined as an angle between a line from the anterior glenoid rim to the inner surface of the coracoid process and a line drawn perpendicularly to the glenoid surface at the level of the mid glenoid fossa (*Figure 6C*). The coracohumeral angle (CHA) was defined as an angle between a line drawn from the inner surface of the coracoid process to the lateral surface of humeral head and a line from the inner surface of the coracoid process to the medial surface of the humeral head (*Figure 6D*). All the measurements were made at the MRI image at the level that was able to visualize the widest diameter of the mid glenoid fossa. CHD difference was defined as the difference between the CHD measured in axial and internal rotation MR

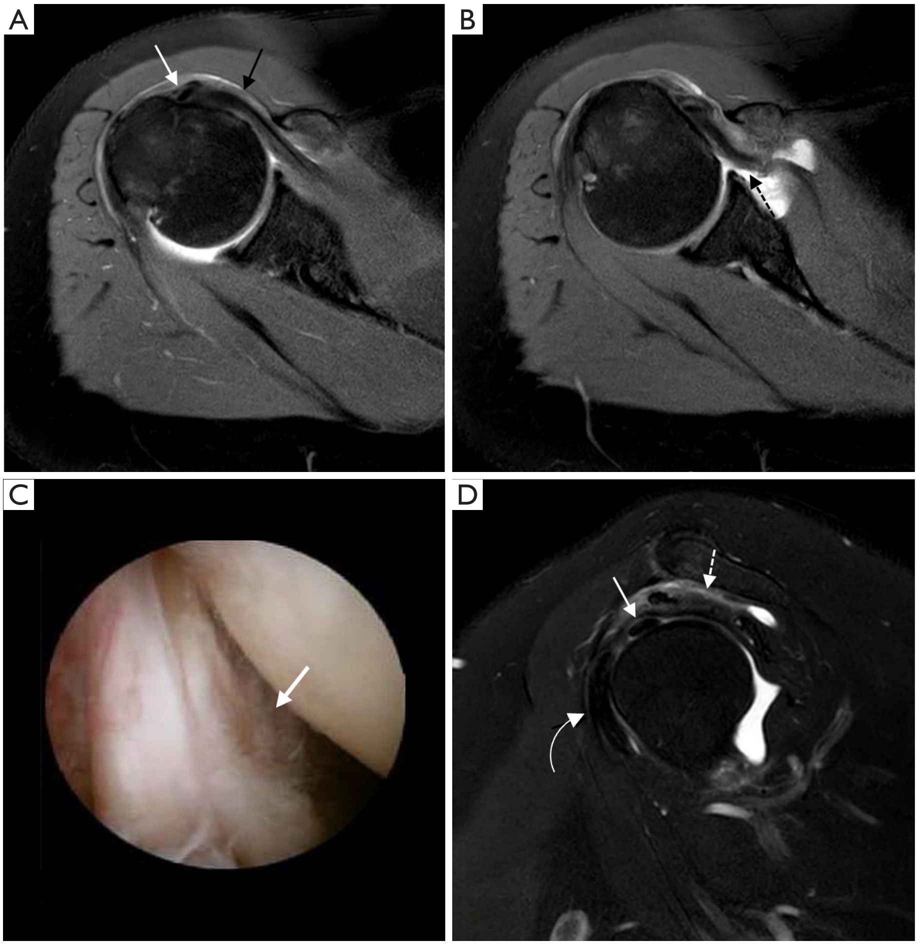

Figure 3 A 52-year-old man with right shoulder pain with partial tear of subscapularis tendon. (A) Axial image PD/FS and show normal subscapularis tendon (black arrow) and longhead biceps tendon (white arrow). (B) Axial internal rotation images in PD/FS show irregular articular surface of subscapularis tendon (dotted black arrow) representing a partial-thickness articular side tear that was confirmed by arthroscopy (white arrow; C). (D) Sagittal oblique T2W/FS shows tendinosis of long head biceps tendon (white arrow) and supraspinatus tendons (dotted white arrow). Normal signal of the subscapularis tendon (curve arrow). MR, magnetic resonance; PD/FS, fat-suppressed proton density; T2W/FS, fat-suppressed T2 weighted.

images. Coracohumeral ratio was defined as a ratio of the CHD measured in axial and internal rotation MR images.

Statistic analysis

Statistical analyses were performed using R version 3.4.3. Continuous data were described using a median and interquartile range, and categorical data were presented with a non-normal distribution and percentage. The Mann-Whiney *U* test was used to estimate the differences of continuous data between the two groups by arthroscopic diagnosis (tears and no tear of the subscapularis tendons). Chi-squared test or Fisher's exact test was used for categorical data. A P value less than 0.05 was considered statistically significant.

Univariate and multivariable logistic regression was performed to determine the association of MRI variation parameters and the arthroscopic diagnosis. Multivariable models were performed to adjust for age, side, belly press or lift off test, Jobe test, CHD axial, CHD internal rotation, CHD different and CHD ratio. The association was presented as odds ratios (OR) with 95% confidence intervals (CI). The metrics for diagnostic performance were accuracy, sensitivity, specificity, positive predictive value, negative

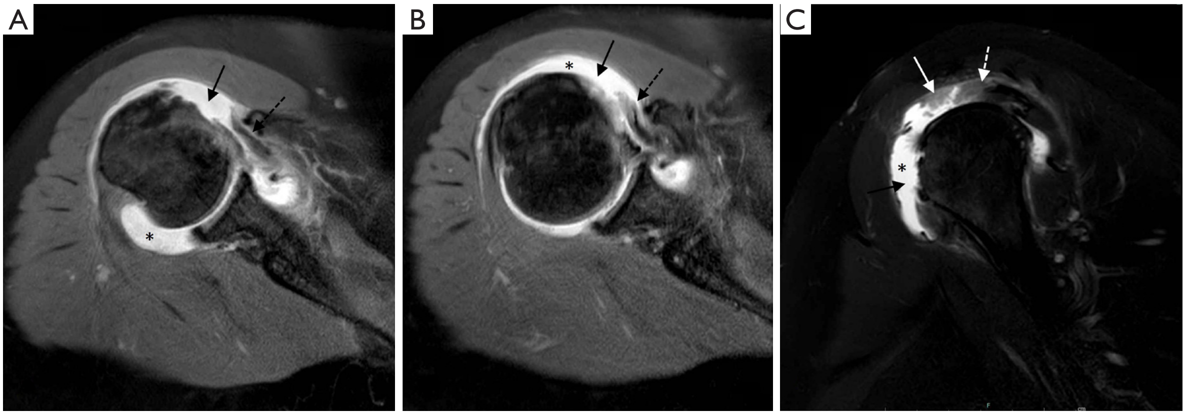

Figure 4 A 61-year-old female with complete tear of the subscapularis tendon. Axial PD/FS image (A) and axial PD/FS in internal rotation image (B) reveals complete disruption of subscapularis tendon (black arrow) with residual retracted subscapularis fibers (dotted black arrow). Sagittal oblique T2W/FS (C) shows absent subscapularis tendon anterior to humeral head (arrow head), as well as articular side tears of supraspinatus (white arrow) and infraspinatus tendons (dotted white arrow). Moderate joint effusion is also observed (asterisk). MR, magnetic resonance; PD/FS, fat-suppressed proton density; T2W/FS, fat-suppressed T2 weighted.

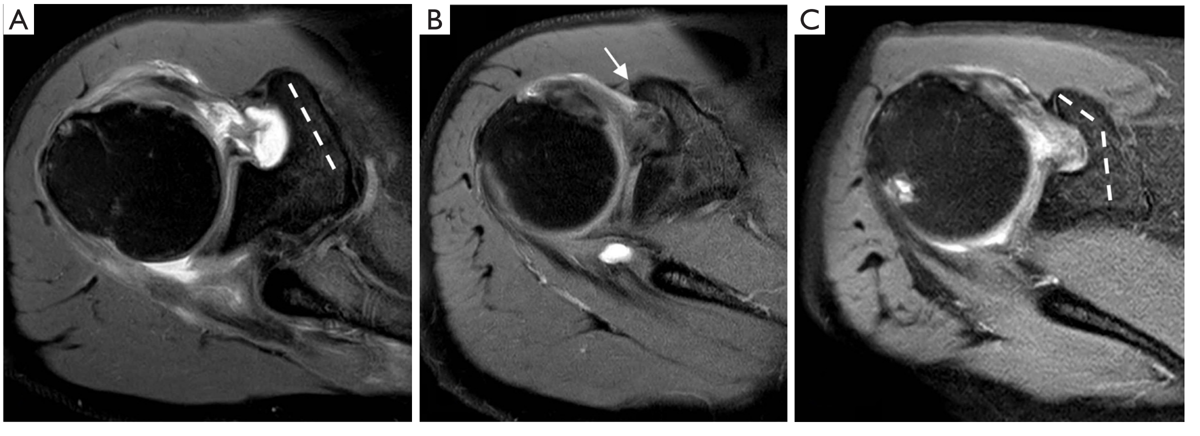

Figure 5 Coracoid morphology in axial PD/FS images. (A) Type A; flat coracoid (dotted line). (B) Type B; osteophyte at the tip of coracoid (white arrow). (C) Type C; hooked coracoid (dotted line). PD/FS, fat-suppressed proton density.

predictive value, and area under the receiver operating characteristics (AUROC). The cut-off value of each measurement parameter for diagnosing subscapularis tears was determined by Youden's index. Agreements between two reviewers were tested with Kappa statistics. The Kappa index interpretation was considered as $k < 0$ for no agreement; $0 \leq k \leq 0.20$ for none to slight agreement; $0.20 < k \leq 0.40$ for fair agreement; $0.40 < k \leq 0.60$ for moderate agreement; $0.60 < k \leq 0.80$ for substantial agreement; and $0.80 < k \leq 1$ for almost perfect agreement for almost perfect agreement.

Results

Seventy-six shoulder MR images were retrospectively reviewed. Twenty-nine patients had a partial subscapularis tear under the arthroscope (38.2%), and 47 patients did not (61.8%) (*Table 1*). The median age of patients in the no tear and tear groups was 58 and 65 years, respectively (P=0.003). Fifty-six (73.6%) of patients underwent arthroscopy on the right shoulder with significant differences between groups (P=0.013). The Belly press or lift off test were found to be significantly positive more in the tear group (34.5%,

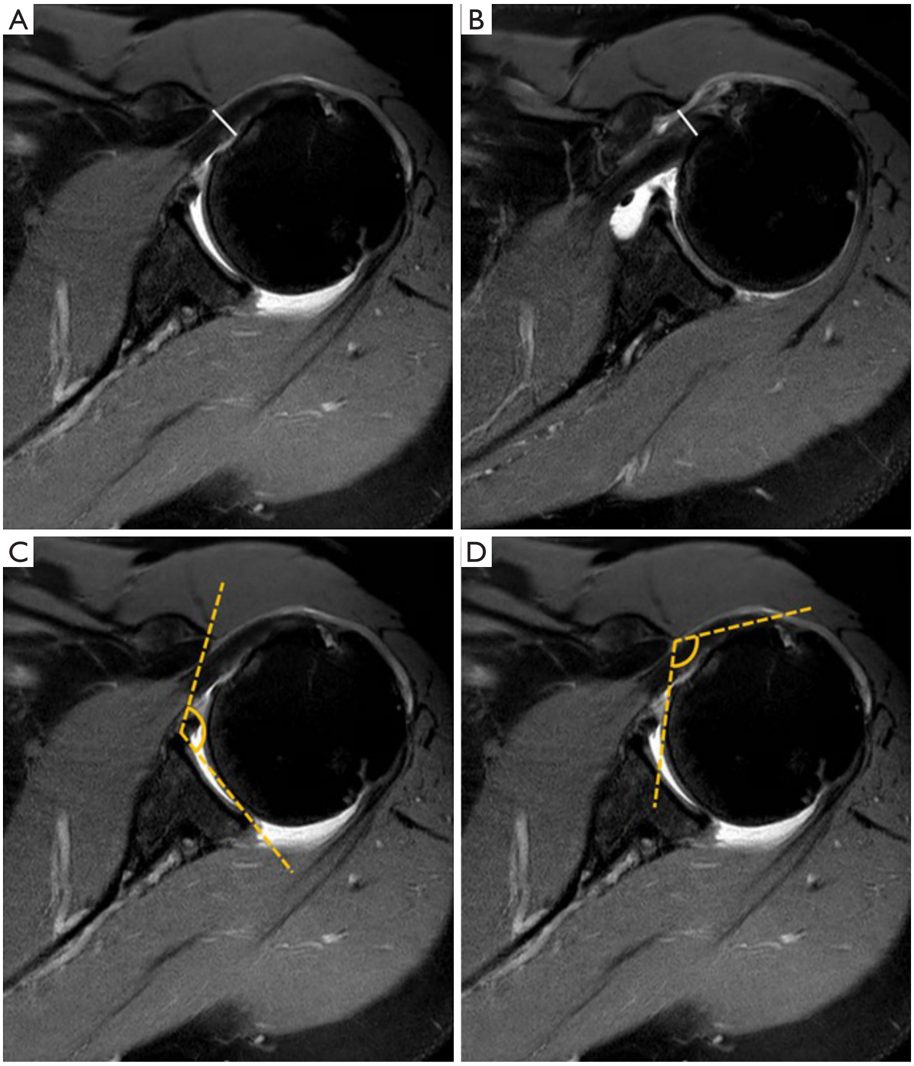

Figure 6 Demonstration of measurements in the study. (A) Axial PD/FS image neutral position; measurement of CHD (white line); (B) axial PD/FS image internal rotation position; measurement of CHD in internal rotation position (white line); (C) axial PD/FS image neutral position; measurement of CGA (dot yellow angle); (D) axial PD/FS image neutral position; measurement of CHA (dot yellow angle). PD/FS, fat-suppressed proton density; CHD, coracohumeral distance; CGA, coracoglenoid angle; CHA, coracohumeral angel.

P=0.011). The Jobe test also revealed significant differences between the tear and no tear groups (P=0.034). The Neer and Hawkins tests showed no significant differences between the groups (P=0.929 and P=0.531, respectively) (*Table 1*). Most patients in our study had a partial or complete supraspinatus tear (28.9% and 53.9%, respectively) without a significant difference between the groups (P=0.220). Most patients did not have a biceps tear (76.3%, P=0.056).

There was no statistically significant difference in coracoid morphology between the two groups (P=0.284) (*Table 2*). While type C coracoid was most common in the no-tear group (22/47 patients; 46.8%), type A coracoid was most common in the tear group (12/29 patients; 41.4%). The median of CHD axial were significantly wider in the tear group (6.20 *vs.* 6.94 mm; P=0.044) but the CHD during internal rotation were significantly narrowed in the tear group (6.62 *vs.* 5.78 mm; P=0.02). The measurement of the CGA, and the CHA were not significantly different between the two groups. The CHD difference and CHD ratio were significantly different (P<0.001) (*Table 2*).

Table 1 Baseline characteristics of study subjects

Parameters	Overall	Arthroscopic findings		P value
		Tear negative	Tear positive	
Subjects (%)	76	47 (61.8)	29 (38.2)	
Age (years), median ± SD	60.5±14	58.0±18	65.0±11	0.003
Gender: female, n (%)	41 (53.9)	23 (48.9)	18 (62.1)	0.265
Side: right, n (%)	56 (73.6)	30 (63.8)	26 (89.7)	0.013
Clinical sign, n (%)				
Belly press or lift off test	15 (19.7)	5 (10.6)	10 (34.5)	0.011
Jobe test	49 (64.5)	25 (55.3)	23 (79.3)	0.034
Neer test	37 (49.3)	23 (48.9)	14 (50)	0.929
Hawkin test	34 (45.3)	20 (42.6)	14 (50)	0.531
Subscapularis tendinosis, n (%)	57 (75.0)	31 (66.0)	26 (89.7)	0.020
Supraspinatus tendon, n (%)				0.220
Tear negative	13 (17.1)	12 (25.5)	1 (3.4)	
Partial tear	22 (28.9)	14 (29.8)	8 (27.6)	
Complete tear	41 (53.9)	21 (44.7)	20 (69.0)	
Biceps tendon, n (%)				0.056
Tear negative	58 (76.3)	40 (85.1)	18 (62.1)	
Partial tear	13 (17.1)	5 (10.6)	8 (27.6)	
Complete tear	5 (6.6)	2 (4.3)	3 (10.3)	
Biceps location: subluxation, n (%)	1 (1.3)	0 (0.0)	1 (3.4)	0.382

SD, standard deviation.

Diagnostic values of MRIs for subscapularis tendon tears

The diagnostic accuracy of MRIs for subscapularis tendon tears by the two reviewers using the MRI Sets 1, 2 and 3 was 61–66%, 67–68% and 75–76%, respectively (*Table 3*). With MRI Set 3, the diagnostic accuracy increased by approximately 10–14% when compared with MRI Set 1. The sensitivity of the diagnosis using the MRI Set 3 increased from 17–21% in Set 1 up to 79–83% in Set 3 (*Table 3*). The PPV using the MR image Set 3 slightly decreased from using the image data Set 1 and 2 in both reviewers. The negative predictive value (NPV) using the MRI Set 3 increased from the other two images data sets from both reviewers (*Table 3*).

Observer agreement for MRI interpretation

The interobserver agreement in the interpretation of subscapularis tendon pathologies increased from a slight agreement in the MRI Sets 1 (0.08), to a substantial agreement in the MRI Set 2 and 3 (0.42 and 0.55, respectively) (*Table 4*). Additionally, the agreements in the diagnosis of subscapularis tendinosis increased from 0.47 to 0.55 using the MRI Set 1 and MRI Set 3, respectively.

Association of quantitative parameters

Both the difference and the ratio of CHD between axial and internal rotation images were positively associated with the diagnosis of subscapularis tears with an OR of 2.58 (95% CI: 1.49–4.45) and 1.34 (95% CI: 0.78–2.47), respectively (*Table 2*). These parameters remained significant after multivariate analysis (P<0.001, both) (*Table 5*). Type C coracoid morphology was less likely to be found in the subscapularis tear group compared with the type A [OR =0.41 (95% CI: 0.13–1.24)] (*Table 2*). There were no

Table 2 MR coracoid morphology and quantitative measurements

Parameters	Overall	Arthroscopic findings		Odd ratio (95% CI)	P value
		Tear negative	Tear positive		
Subjects (%)	76	47 (61.8)	29 (38.2)		
Coracoid morphology, n (%)					0.284
Type A (R)	24 (31.6)	12 (25.5)	12 (41.4)	1	
Type B	21 (27.6)	13 (27.7)	8 (27.6)	0.62 (0.19–2.02)	
Type C	31 (40.8)	22 (46.8)	9 (31.0)	0.41 (0.13–1.24)	
CHD axial (mm), median (IQR)	6.48 (1.42)	6.20 (1.16)	6.94 (1.70)	1.48 (1.03–2.11)	0.044
CHD internal rotation (mm), median (IQR)	6.30 (1.53)	6.62 (1.44)	5.78 (1.57)	0.68 (0.48–0.96)	0.020
CHA (degree), median (IQR)	102.50 (10.75)	101.00 (9.00)	104.00 (14.00)	1.03 (0.97–1.09)	0.212
CGA (degree), median (IQR)	130.28 (5.84)	130.57 (4.79)	129.83 (7.31)	0.98 (0.90–1.05)	0.627
CHD diff (mm), median (IQR)	0.11 (1.59)	−0.40 (1.66)	0.63 (1.33)	2.58 (1.49–4.45)	<0.001
CHD ratio, median (IQR)	1.02 (0.27)	0.94 (0.21)	1.14 (0.20)	1.34 (0.78–2.47)	<0.001

CI, confidence interval; MR, Magnetic resonance; IQR, interquartile range; CHD axial, coracohumeral distance measured in axial images; CHD internal rotation, coracohumeral distance measured in internal rotation images; CHA, coracohumeral angle; CGA, coracoglenoid angle; CHD diff, coracohumeral distance difference; CHD ratio, coracohumeral distance ratio; (R), the coracoid morphology type A is considering standard type and use as reference group in calculate odd ratio of other coracoid morphology types.

Table 3 MRI evaluation of subscapularis tendon tears by interpretation of the three MR Images sets: MR Image Set 1 (axial PD/FS and sagittal oblique T2W/FS); MR Image Set 2 (axial PD/FS and internal rotation axial PD/FS); and MR Image Set 3 (axial PD/FS, internal rotation axial PD/FS and sagittal oblique T2W/FS)

Parameters	Reviewer 1 (95% CI)			Reviewer 2 (95% CI)		
	MR Image Set 1	MR Image Set 2	MR Image Set 3	MR Image Set 1	MR Image Set 2	MR Image Set 3
Accuracy	0.66 (0.54–0.76)	0.68 (0.56–0.79)	0.75 (0.63–0.84)	0.61 (0.49–0.72)	0.67 (0.55–0.77)	0.76 (0.65–0.85)
Sensitivity	0.21 (0.80–0.40)	0.31 (0.15–0.51)	0.79 (0.60–0.95)	0.17 (0.06–0.36)	0.58 (0.39–0.76)	0.83 (0.64–0.94)
Specificity	0.94 (0.82–0.98)	0.91 (0.80–0.98)	0.72 (0.57–0.84)	0.87 (0.74–0.95)	0.72 (0.57–0.84)	0.72 (0.57–0.84)
PPV	0.67 (0.35–0.88)	0.69 (0.43–0.87)	0.64 (0.51–0.74)	0.45 (0.22–0.71)	0.57 (0.42–0.69)	0.65 (0.53–0.75)
NPV	0.66 (0.61–0.70)	0.68 (0.63–0.74)	0.85 (0.73–0.92)	0.63 (0.58–0.68)	0.74 (0.64–0.82)	0.87 (0.75–0.94)

MRI, magnetic resonance image; PD/FS, fat-suppressed proton density; T2W/FS, fat-suppressed T2 weighted; CI, confidence interval; PPV, positive predictive value; NPV, negative predictive value; MR, magnetic resonance imaging.

statistically significant associations between subscapularis tears and other MRI measurement parameters. In addition, the Belly press or lift off test were also significant associated with subscapularis tear in multivariate analysis (*Table 5*).

The ratio of CHD on axial and internal rotation MRIs achieved the highest AUC at 0.85 (95% CI: 0.76–0.94), followed by the difference of CHD between the two different MRI views at 0.84 (95% CI: 0.76–0.93) (*Figure 7*). The AUC of the other MRI measurements were fairly low, particularly the measurements of coracohumeral and CGAs.

The cut-off value of each MRI measurement determined using Youden index is presented in *Table 6*. Given the cut-off value of the difference and ratio of CHD between axial and internal rotation positions at 0.04 mm and 1.01, the sensitivity was as high as 90% (0.73–0.98) and 90% (0.73–0.98), respectively. The specificity was also 72% (95% CI: 0.53–0.84) and 72% (95% CI: 0.53–0.84). With CGA more than 127.0 degrees, the specificity of diagnosing subscapularis tendon tears was as high as 85% (95% CI: 0.72–0.94) but low sensitivity 38% (95% CI: 0.21–0.58).

Table 4 Agreement and Kappa values of MRI in the diagnosis of subscapularis pathologies between the two reviewers

MRI diagnosis	MR Image Set 1		MR Image Set 2		MR Image Set 3	
	Agreement	Kappa value	Agreement	Kappa value	Agreement	Kappa value
SSC tears	78.95	0.08	75.00	0.42	77.63	0.55
SSC tendinosis	73.68	0.47	82.89	0.50	84.21	0.55

MRI, magnetic resonance image; SSC, subscapularis tendon; MR Image Set 1, axial fat-suppressed proton density weighted image (PD/FS) and sagittal oblique and sagittal fat-suppressed T2 weight image (T2W/FS) images; MR Image Set 2, axial PD/FS and internal rotation axial PD/FS; MR Image Set 3, axial PD/FS, internal rotation axial PD/FS and sagittal oblique T2WFS.

Table 5 Univariate and multivariate analysis of age, side, clinical signs, and quantitative measurements

Factor	Univariate analysis		Multivariate analysis	
	Odds ratio (95% CI)	P value	Odds ratio (95% CI)	P value
Age (years)	1.064 (1.014–1.117)	0.012	–	
Side: right	0.204 (0.054–0.774)	0.019	–	
Belly press or lift off test	4.421 (1.328–14.716)	0.015	4.795 (1.079–21.309)	0.039
Jobe test	3.096 (1.065–8.997)	0.038	–	
CHD axial	1.476 (1.033–2.108)	0.032	–	
CHD internal rotation	0.678 (0.478–0.962)	0.030	–	
CHD diff	2.576 (1.492–4.449)	0.001	6.074 (2.380–15.500)	<0.001
CHD ratio	1.397 (0.788–2.474)	0.253	0.164 (0.055–0.487)	<0.001

CHD, coracohumeral distance; CHD diff, coracohumeral distance difference; CHD ratio, coracohumeral distance ratio; CI, confidence interval.

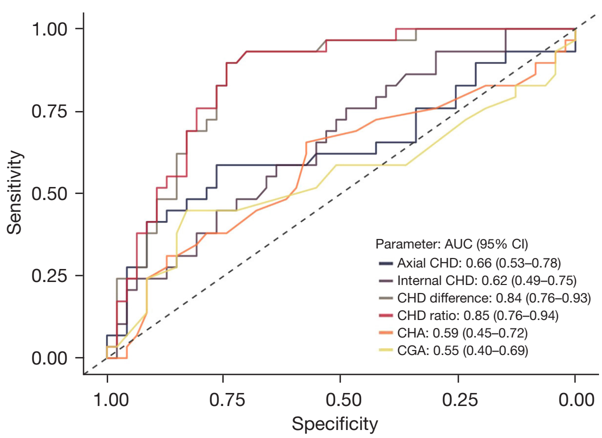

Figure 7 AUC values of MRI parameters are reported with 95% CI. The parameters include CHD measured in axial view, CHD measured in internal rotation position, CHD difference, CHD ratio, CHA and CGA. AUC, area under curve; MRI, magnetic resonance imaging; CI, confident interval; CHD, coracohumeral distance; CHA, coracohumeral angel; CGA, coracoglenoid angle.

Discussion

Semiquantitative evaluation of subscapularis tendons

The reported diagnostic performance of MRIs for subscapularis tendon tears has varied widely. In 2019, a meta-analysis conducted by Malavolta *et al.* (9) based on conventional MRI and MR arthrography using arthroscopy as the gold standard, revealed that the sensitivity and specificity of subscapularis tendon partial-thickness tears were 68% and 90%, respectively. The mean range of the sensitivity in the study were from 25% to 94% representing marked inconsistency of their data pool. Similarly, Furukawa *et al.* in 2014 (14), reported that a low-intermediate sensitivity (68.4%) but high specificity (100%), with 78.2% accuracy. The author suspicious difficulty in diagnosing subscapularis tendon pathologies to be due to oblique orientation of subscapularis tendon on axial plane. The partial volume effect could cause distortion of the tendinous courses (9,14). In our study, the diagnostic performance

Table 6 MRI measurements and cut-off point to predict subscapularis tear

Parameters	Threshold	Sensitivity (95% CI)	Specificity (95% CI)	Accuracy (95% CI)	PPV (95% CI)	NPV (95% CI)
CHD axial	>6.81 mm	0.58 (0.38–0.77)	0.77 (0.62–0.88)	0.70 (0.58–0.80)	0.61 (0.46–0.74)	0.75 (0.65–0.83)
CHD internal rotation	≤6.82 mm	0.76 (0.56–0.90)	0.49 (0.34–0.64)	0.59 (0.47–0.70)	0.48 (0.39–0.56)	0.77 (0.62–0.87)
CHA	>101 degree	0.69 (0.49–0.84)	0.47 (0.32–0.62)	0.55 (0.43–0.67)	0.44 (0.36–0.53)	0.71 (0.57–0.82)
CGA	≤127 degree	0.38 (0.21–0.58)	0.85 (0.72–0.94)	0.67 (0.55–0.77)	0.61 (0.41–0.78)	0.69 (0.62–0.75)
CHD diff	>0.04 mm	0.90 (0.73–0.98)	0.72 (0.53–0.84)	0.79 (0.68–0.88)	0.67 (0.55–0.76)	0.92 (0.79–0.98)
CHD ratio	>1.01	0.90 (0.73–0.98)	0.72 (0.53–0.84)	0.79 (0.68–0.88)	0.67 (0.55–0.76)	0.92 (0.79–0.98)

MRI, magnetic resonance image; CI, confidence interval; CHD axial, coracohumeral distance measured in axial images; CHD internal rotation, coracohumeral distance measured in internal rotation images; CHA, coracohumeral angle; CGA, coracoglenoid angle; CHD diff, coracohumeral distance difference; CHD ratio, coracohumeral distance ratio; PPV, positive predictive value; NPV, negative predictive value.

of conventional MRI using conventional sequences (MRI Set 1) had a low sensitivity (23–26%).

To our knowledge, our study is the first to use an internal rotation position on MRI to improve diagnostic performance for subscapularis tendon tears. Few previous studies mentioned that the internal rotation position may improve the detection of subscapularis pathologies, however, there is no consensus for the position yet (24,25). We found that using internal rotation combined with standard MR images (MRI Set 3) markedly improved the diagnostic accuracy to 75–76%, with moderate interobserver reliability (Kappa =0.55), compared to standard MR images alone (MRI Set 1, accuracy of 66–68%, and Kappa =0.08). The increased sensitivity of the internal rotation position we observed could have several explanations. First, the contraction of subscapularis muscles during internal rotation causes tension to the subscapularis tendons, generating a stress view of the tendon on internal rotation MR images. Second, the articular surfaces of the subscapularis tendons provide less contact area to the humoral heads while internal rotated, resulting in increased visualization of the tendinous articular surfaces. Third, when internally rotated the joint fluid accumulates in the anterior joint spaces outlining the articular surfaces of the subscapularis tendons (*Figures 2B*,*3B*), creating an arthrographic effect to the articular surface of subscapularis tendon. Finally, the subscapularis tendons glide beneath the coracoid processes and the short head biceps tendons when the shoulder is internally rotated, causing stress to the inner surfaces of subscapularis tendons. This might assist in evaluation of subcoracoid impingement. Example of MR images of cases with partial subscapularis tear were demonstrated in *Figure 8*.

We found no significant association between the type of coracoid morphology and subscapularis tendon tears (P=0.284). The coracoid type C was the most frequent type (40.8%), which is consistent with an anatomical study by Dugarte *et al.* (26) and Asal *et al.* (27). Both studies found hooked type coracoid process to be most common among elderly subjects (37.5-49%). Asal *et al.* (27) reported that type C is correlated with subscapularis tendon pathologies. This difference could be due to the younger age of subjects in the Asal study, while our subjects were mostly elderly persons.

Parametric measurements

The average CHDs in our study (mean CHD axial =6.48 mm) were lower than the CHD in earlier studies (24,28,29) (9.9–11.0 mm). This could be due the shorter statures and lower muscle mass in the Asian population, especially among the elderly, that leads to smaller bone-tendon structures compared to European and US populations (30,31).

Our study found the CHD in the tear group to be wider than in the no-tear group (6.94 *vs.* 6.20 mm, P=0.044) and mostly has subscapularis tendinosis. This result is consistent with other studies reporting that alteration of the subcoracoid spaces is associated with subcoracoid impingement (24,27,28,32-35). However, some of these studies reported smaller CHD in the impingement group (9.9–11.0 *vs.* 5.5–8.6 mm) (24,28). This may be due to the different age groups and definitions of impingement versus tendon tear used in different studies. Most reports use "subcoracoid impingement" and "subscapularis tendon tears" interchangeably, without a clear definition. Subcoracoid impingement typically presents as shoulder

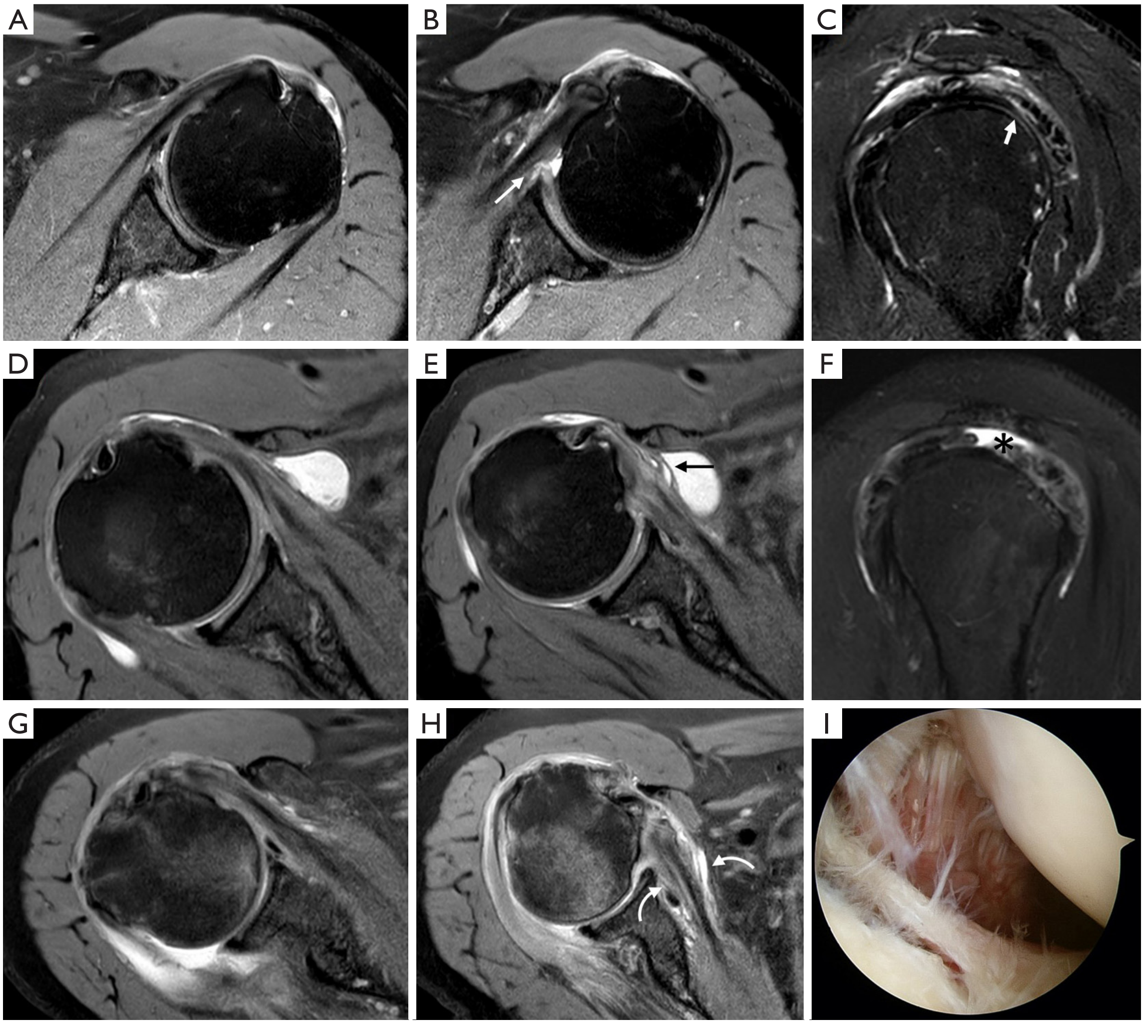

Figure 8 Demonstration of partial subscapularis tendon tears in three patients (A-C, D-F, and G-I) confirmed by arthroscopy. The first patient (A-C), a 67-year-old man found normal appearance of the subscapularis tendon on axial PD/FS image (A). The axial PD/FS internal rotation image (B) revealed deep articular surface tear of the subscapularis tendon (arrow) located anterior to the glenoid rim. The sagittal T2W/FS (C) showed normal appearance of subscapularis tendon. High grade articular side partial thickness tear of the infraspinatus tendon (short arrow). The second patient (D-F), a 58-year-old woman revealed tendinosis of the subscapularis tendon on axial PD/FS image (D). The axial PD/FS internal rotation image (E) revealed irregularity of the bursal surface (black arrow) representing partial tear. The sagittal T2W/FS (F) showed tendinosis without gross tear of the subscapularis tendon. Complete tear of the supraspinatus and marked tendinosis of the infraspinatus tendon (black asterisk). The third patient (G-I), a 58-year-old man found tendinosis and thickening of the subscapularis tendon and suspicious of bursal surface irregularity on axial PD/FS image (G). The axial PD/FS internal rotation image (H) revealed high-grade articular and bursal surface tear of the subscapularis tendon (curve arrows). Arthroscope of subscapularis tendon (I) confirmed the high-grade partial tear of subscapularis tendon. MR, magnetic resonance; PD/FS, fat-suppressed proton density; T2W/FS, fat-suppressed T2 weighted.

pain, which occurs due to narrowing of the space between the coracoid process and the humerus. Most subcoracoid impingement cases are diagnosed clinically without imaging studies. On the other hand, tearing of subscapularis tendons can be related to subcoracoid impingement or isolated to such condition.

In our study, the mean CHD in conventional MR of more than 6.81 mm was the best cut-off point to predict subscapularis tendon tears, with a sensitivity of 58%, a specificity of 77%, and an accuracy of 70%. The AUC value of the CHD was 0.66 (95% CI: 0.53–0.78) (*Figure 7*).

The effect of internal rotation to CHD might reflect subscapularis tendon quality. During internal rotation, the CHD becomes narrow in patients with tears, creating a greater difference and ratio between CHD in conventional images and the internal rotation position (mean CHD diff =0.63 mm; mean CHD ratio = 1.14; P value <0.001, both). The odd ratios were 2.58 (95% CI: 1.49–4.45) for CHD difference and 1.34 (95% CI: 0.78–2.47), for the CHD ratio. The AUC values were 0.84 (95% CI: 0.74–0.92) for CHD difference and 0.85 (95% CI: 0.75–0.92), for the CHD ratio (*Figure 7*). Our results were consistent with previous studies that reported that the CHD became narrowest during maximal internal rotation (25,33). Gerber *et al.* (36) established that the distance between the coracoid and the humeral head decreased when the shoulder was positioned in 90–100 degrees forward flexion with internal rotation. Therefore, the internal rotation position generates a pressure (provocation) view of the subscapularis tendons. The greater CHD difference might reflect a decrease in stiffness of the subscapularis tendons, representing worsened tendinous quality. In addition, we found a significant difference in number of tendinosis cases between the no-tear and tear groups (P=0.02). Therefore, we suspect that the overall quality of the tendinosis in the tear group was poorer. Friedman *et al.* (28) conducted cine MRI of the internal rotation position and reported that impingement resulted in decreased thickness of soft tissue beneath the subcoracoid space, which was not seen in asymptomatic subjects. Our results confirm that internal rotation enhances visualization of the subscapularis tendons and improves detection of subscapularis abnormalities even when the tendons are redundant or folding at the subcoracoid regions.

CGA and CHA have been described as parameters in the prediction of subcoracoid impingement (27,34,36). However, neither angle had a significant difference between the no-tear and tear groups in our study (P=0.627 for CGA, P=0.212 for CHA). Gerber *et al.* (36) studied subcoracoid spaces in 47 shoulders and found that there was a positive correlation between subcoracoid impingement and small CGA, particularly when a small coracoid overlap was present. Watson *et al.* (34) revealed that mean CGA measured in the axial view in subscapularis tears group was smaller than in the control group (CGA 37.02 degrees and CHA 40.56 degrees; P>0.05). Asal *et al.* (27) reported a significant decrease in the CGA value in patients with subscapularis tendon pathologies. We also found that the mean CGA value in patients with subscapularis tears was smaller than in the normal tendon group (129.83 *vs.* 130.57 degrees; P=0.627). CHA has been reported to be associated with subscapularis tendon pathologies (27). Consistent with our findings, Asal *et al.* (27) established that the CHA value significantly increased in patients with subscapularis tendon pathologies. However, the difference we observed was not statistically significant (P=0.212). This could be explained by the fact that CGA and CHA represent coracoid position in relation to glenoid and humerus. These relationships may be altered in the presence of impingement. Our subjects included those with shoulder pain who had an MRI performed and did not focus on subcoracoid impingement patients.

Our retrospective study has several limitations. First, the retrospective design of our study caused the population in our study to not focused on subscapularis impingement and the MR studies were done by two model of MR machines. We enrolled all patients who had shoulder pain, who suspicious of any rotator cuff pathologies and underwent arthroscopy. Therefore, their clinical could be worsen as compared to general population. Second, the arthroscopy is an operator-dependent examination and there may be considerable variability between surgeons in the interpretation of shoulder abnormalities, especially for the subscapularis tendon, however, the study currently serves as the best gold standard for the evaluation of internal derangement of the shoulder. Third, the surgeons in our institute, who performed arthroscopy were aware of the MRI reports and may have been influenced by these reports in their assessment of shoulder pathology. Forth, the subscapularis itself is a major internal rotator of the shoulder. Therefore, it may not be technically possible for the patient with subcoracoid impingement to actively and fully internally rotate the shoulder, and the range of motion and chronicity of the partial tear further contribute to the variability of internal rotation degree for each patient. This limitation can significantly impact the clinical use of this method. However, in our study, all patients were able to successfully achieve active or passive internal rotation during scanning. Fifth, the position used in our study was not maximally internal rotation but instead followed the elbow position. However, using such position revealed increased consistency in internal rotation degree and was more favorable when the patient had shoulder pain. Finally, the interobserver agreement result between the two radiologists was only 0.08-0.55. This reflects the high dependence of the diagnostic method on observer capabilities in the diagnostic performance of axial internal rotation MRI.

Conclusions

The internal rotation position during MRI of the shoulder can significantly improve the diagnostic accuracy for partial subscapularis tendon tears. The use of internal rotation PD/FS images in combination with standard axial PD/FS and sagittal T2W/FS images provides the highest sensitivity and accuracy for the detection of partial subscapularis tears. The measurement of CHD axial, CHD internal rotation, CHD difference, and CHD ratio can be useful parameters to indicate subscapularis tears. The findings of this study may contribute to improved preoperative planning and management, as well as reducing the risk of delayed diagnosis and treatment of subscapularis tears.

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Footnote

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://qims.amegroups.com/article/view/10.21037/qims-23-273/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Faculty of Medicine, Siriraj hospital, Mahidol University, Bangkok, Thailand, the Siriraj Institutional Review Board (No. SI039/2021) and individual consent for this retrospective analysis was waived.

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