

Original Article

Diagnosis of anterior cruciate ligament tear: Value of oblique axial MR image

Arin Pisanuwongse, M.D.

Tanaporn Taveepattanangkul, M.D.

Nittaya Lektrakul, M.D.

From Division of Diagnostic Radiology, Department of Radiology, Faculty of Medicine,
Siriraj hospital, Mahidol University, Bangkok, Thailand.

Address correspondence to A.P. (email: arin.pit@mahidol.ac.th)

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Abstract

Background: Accurate magnetic resonance (MR) evaluation of anterior cruciate ligament (ACL) injuries can be challenging due to the oblique orientation of its bundles. Oblique axial MR imaging has been proposed to improve visualization of the ACL bundles and may facilitate the detection of ACL bundle tears.

Objective: To investigate the diagnostic value of adding oblique axial ACL imaging to the routine knee MRI protocol for detecting ACL tears and differentiating partial ACL tears from complete tears.

Materials and Methods: This retrospective study included 144 patients at Siriraj hospital who underwent knee MRI between August 2018 and April 2022 followed by arthroscopy. Protocols A (routine protocol) and B (with additional oblique-axial imaging) were compared for their performance in the detection of ACL tears, differentiation of partial from complete ACL tears and detection of isolated ACL bundle tears. The performances of an inexperienced (reader 1) and an experienced (reader 2) reader were also compared.

Results: The specificity and accuracy for the diagnosis of partial ACL tears were significantly higher for protocol B for reader 2, while for reader 1 these values did not reach statistical significance. With protocol B, the specificity and accuracy of reader 2 were significantly superior to those of reader 1. For the detection of isolated ACL bundle tears, the sample cohort of partial tear cases was too small for statistical evaluation.

Conclusion: The addition of oblique-axial imaging to routine knee MR imaging improves diagnostic accuracy for detecting partial tears of the ACL. However, the extent of its usefulness may also rely on the reader's experience.

Keywords: ACL, ACL tear, Oblique axial MR imaging of the ACL.

Introduction

The anterior cruciate ligament (ACL) plays a crucial role as a primary passive restraint to anterior tibial translation and supports knee rotational stability [1]. The ACL anatomically consists of the anteromedial (AM) and the posterolateral (PL) bundles which are named according to their relative insertion sites on the tibia [2]. ACL tears are common knee injuries, accounting for up to 64% of knee injuries in athletes [2]. Although not as common as complete ACL tears, partial tears account for about 10%-27% of ACL injuries [1,3-5].

Recognizing partial ACL tears has been a challenge using both by clinical and imaging approaches. It requires a combination of examinations such as clinical findings, imaging findings, and sometimes arthroscopic assessment when indicated [3]. Unlike a complete ACL tear, which no longer has the capacity to heal, a partial ACL tear retains a limited blood supply by way of the medial geniculate artery, which may allow healing to occur [6-8]. The treatment approach for ACL partial tears is thus highly individualized for each patient [3]. The conservative method is preferred for patients who are at low risk of progression based on clinical stability and lifestyle activity level. On the contrary, those with high-risk lifestyle activities and clinical instability may be better suited for surgical treatment [3]. Moreover, for management purposes, the associated injuries, the percentage of remaining fibers, and the functionality of those remaining remnants need to be taken into account.

Undoubtedly, MRI plays an important role in aiding the diagnosis and guiding treatment of ACL tears. Additionally, if an isolated bundle tear is present, isolated single-bundle reconstruction instead of full ACL graft reconstruction may be considered [6,11-14].

However, there remains some difficulty in using MRI to diagnose partial ACL tears, to distinguish partial from complete tears [3,13,15-18], and to differentiate between the AM and PL bundles [13]. For instance, previous studies found that the accuracy of MR imaging for the diagnosis of partial ACL tears is much lower than that for complete tears with a sensitivity of about 40-77% and a specificity of about 62-79% [15,18-20, 21-25]. As one strategy to improve the diagnostic accuracy of MRI for ACL injuries, Ng et al. and HL et al. [6,24] reported that the addition of an oblique-axial view of the ACL improved the sensitivity and overall accuracy for detecting partial ACL tears. However, this imaging plane is not routinely included in the standard knee MRI protocol in most hospitals in Thailand. Therefore, this study aims to investigate the value of adding this oblique axial image to the routine sports knee MRI protocol. We hypothesized that the addition of an oblique axial MR image to a standard knee MRI protocol would improve the detection of ACL bundle tears.

Materials and methods

This retrospective study reviewed a total of 144 patient records from Siriraj Hospital of patients who underwent knee MRI between August 2018, and April 2022 followed by arthroscopic examination. The study population consisted of 113 males and 31 females ranging in age from 8 to 75 years (mean age of 34 years). Patients with prior knee surgery or those presenting with suspected knee tumours were excluded from this study. The average time interval between the MRI and arthroscopy was 4.5 months (ranging from 9 days to 16 months).

MR examinations were performed on two 3-T scanners available at our institution, including the Ingenia (3.0-T; Philips Healthcare, Best, The Netherlands) and the Magnetom Vida (3.0-T; Siemens Healthineers, Erlangen, Germany). Dedicated phased-array knee coils were used for all examinations. The routine knee MRI protocol used in this study was based on widely accepted musculoskeletal imaging protocols dedicated to sports-related knee injuries at our institution, which typically include multiplanar imaging in the sagittal oblique sequences (T2-weighted, proton density-weighted, and proton density fat-suppressed) and the coronal oblique sequences (T2-weighted with fat suppression and T2-weighted) planes for optimal evaluation of the ACL and other intra-articular structures [9,10] as summarized in Table 1. An additional oblique axial sequence of the ACL was also obtained, with images acquired in a plane perpendicular to the course of the ACL, using sagittal and coronal images as localizers (Figure 1). The MRI acquisition parameters are listed in Table 2.

The routine knee MRI protocol was designated Protocol A while the routine knee MRI protocol in combination with oblique axial imaging was designated Protocol B (Table 1). The images were independently reviewed by two readers who were not aware of the arthroscopic findings. The first reader was a third-year radiology resident while the second reader was a musculoskeletal radiologist with 5 years of experience. Protocols A (routine knee MRI) and B (routine knee MRI plus oblique axial ACL imaging) were acquired during the same examination for each patient. The image sets for each protocol were then evaluated independently by the readers at separate sessions, with a minimum washout period of 3 months between assessments to reduce recall bias.

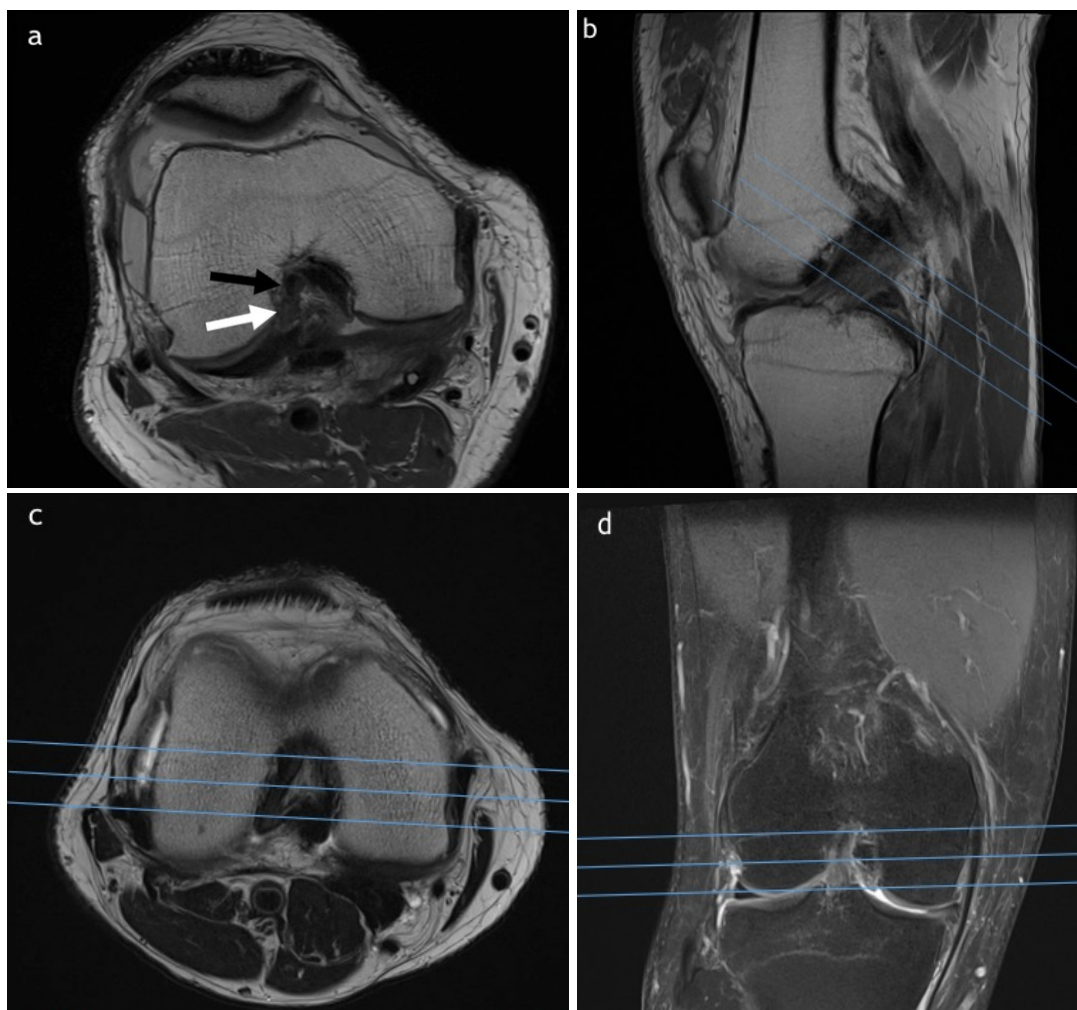


Figure 1. An oblique axial intermediate-weighted MR image of the ACL (a) and its localizations on sagittal T2W (b), true axial T2W (c), and coronal T2W (d) images are shown. The anteromedial (black arrow) and posterolateral (white arrow) bundles are labeled in picture a.

From the MR images of each protocol, ACL bundles were interpreted as intact, partially torn, or completely torn. Figure 2 shows the normal appearance of the anteromedial and posterolateral bundles on oblique axial imaging. A complete tear was defined as the complete disruption of both ACL's anteromedial (AM) and posterolateral (PL) bundles. On the other hand, a partial ACL tear was defined as an injury involving at least one of the AM or PL bundles without complete tear of both bundles. The injury parameters that were evaluated were included the presence of high signal intensity (SI), focal swelling, thinning, wavy course or discontinuity of each ACL bundle. An intact ACL was defined as having a normal appearance and complete integrity along the course of both ACL bundles running from the proximal femur to the distal tibial attachment.

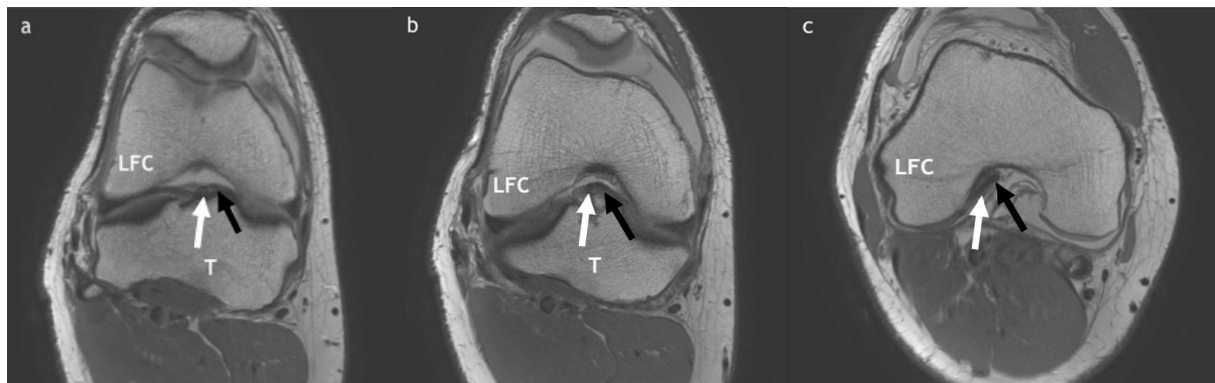


Figure 2. Oblique axial intermediate-weighted MR images of the ACL in a 43-year-old man. Normal appearance of the individual ACL bundles at the distal insertion on the tibia (a), the middle portion (b) and the proximal insertion on the femur (c). The intact anteromedial bundle (black arrow) is located in the more anteromedial position while the intact posterolateral bundle (white arrow) is located in the more posterolateral position. Both ACL bundles show a normal course and signal intensity. LFC, lateral femoral condyle; T, tibia.

MR results were compared with arthroscopic findings. The statistical data were collected as frequencies (number of cases) and percentages. MR imaging Protocols A and B were analyzed for their diagnostic accuracy in detecting ACL lesions, represented by sensitivity, specificity, positive predictive value, negative predictive value and overall accuracy. All statistical calculations were performed using SPSS (Statistical Package for the Social Sciences; SPSS Inc., Chicago, IL, USA) released for Microsoft Windows (2006). The ordinal data in terms of sensitivity, specificity and overall accuracy of Protocols A and B were compared using McNemar's test. A P-value of less than 0.05 indicated a statistically significant difference. Inter-observer agreement between the resident (reader 1) and the musculoskeletal radiologist (reader 2) was then calculated using Cohen's weighted K statistics. A value of less than 0 implied no agreement; values of 0.00-0.20, slight agreement; values of 0.21-0.40, fair agreement; values of 0.41-0.60, moderate agreement; values of 0.61-0.80, substantial agreement; and values of 0.81-1.00, almost perfect agreement [27].

This study was approved by the Institutional Review Board of Siriraj Hospital, Mahidol University (ID No.: SI 351/2022).

Table 1. MR Protocols.

Protocol A (Routine MR knee protocol)	Axial	- Proton density fat-suppressed (PDFS) - T2 weighted (T2W) - 3D_WATS
	Sagittal	- Proton density weighted (PDW)
	Sagittal oblique (parallel to the lateral condyle of the femur)	- Dual PD & T2W - 3D_WATSc
	Coronal oblique (parallel to the medial and lateral condyle of the femur)	- PDFS - T1 weighted (T1W)
	Oblique coronal ACL	- T2W - T2 fat-suppressed (T2-FS)
Protocol B (Routine MR knee protocol + Oblique axial ACL)	Routine MR knee protocol as above	
	Oblique axial ACL	- Proton density weighted (PDW)

Table 2. MR Parameters.

Sequence	Repetition Time (msec)	Echo Time (msec)	Section Thickness (mm)	Field of View (cm)	Matrix (mm x mm)	Echo Train Length (ETL)	Number of Excitations (NEX)	Acquisition time (min)
Axial Oblique PDW FSE	3000-3500	25	2	15x15	350x350	10	1	2.5
Sagittal Oblique T2W FSE	3000-4600	120	3	15x15	450x350	15	1	3
Sagittal Oblique PDW FSE	3000-4600	10	3	15x15	450x350	15	1	3
Sagittal Oblique PDW FSE FS	2400-4000	15	3	19x15	400x350	8	1	2.5
Coronal Oblique T2W FSE	2200-4000	80	2	17x15	400x300	15	1	2.5
Coronal Oblique T2W FSE FS	3100-3600	60	2	15x15	300x300	15	1	2.5

Note. – PDW, proton density-weighted; FSE, fast spin-echo; T2W, T2-weighted. Axial oblique refers to the axial plane of the ACL; sagittal oblique refers to the sagittal plane parallel to the lateral condyle of the femur; coronal oblique refers to the coronal plane parallel to the medial and lateral condyle of the femur.

Results

Under arthroscopy, 37 of the 144 knees (25.7%) had a normal ACL, 8 (5.6%) had a partial ACL tear and 99 (68.8%) had a complete ACL tear. Of the 8 knees with partial ACL tears, 3 cases (37.5%) had an isolated posterolateral bundle (PLb) tear while only 1 case (12.5%) had an anteromedial bundle (AMb) tear.

Based on MR imaging interpretation by the MSK radiologist (reader 2), Protocol A identified 35 knees (24.3%) with a normal ACL, 17 knees (11.8%) with a partial ACL tear, and 64 knees (44.4%) with a complete ACL tear. Using Protocol B, 36 knees (25.0%) were classified as normal, 44 knees (30.6%) as partial ACL tears, and 92 knees (63.9%) as having complete ACL tears (Figure 3 and (Figure 4).

Similarly, the radiology resident (reader 1) reported 35 knees (24.3%) as normal, 27 knees (18.8%) as having partial tears, and 76 knees (52.8%) as having complete tears using Protocol A, whereas Protocol B demonstrated 39 knees (27.1%) with a normal ACL, 33 knees (22.9%) with partial tears, and 79 knees (54.9%) with complete tears.

Of the 36 knees interpreted as normal by reader 2 using Protocol A, 5 knees were found to have ACL tears on arthroscopy (13.9%) (3 partial tears and 2 complete tears). After using Protocol B, the number of arthroscopic-MR finding discrepancies slightly decreased to 4 out of 35 knees (11.4%) (2 partial tears and 2 complete tears) but without a significant difference. Meanwhile, for reader 1, the proportion of MR-arthroscopic findings discrepancies was similar between protocols A and B and was comparatively greater than that of reader 2. Of the 35 knees interpreted as normal by reader 1 using Protocol A, 6 knees had ACL tears on arthroscope (17.1%) (2 partial tears and 4 complete tears). Similarly, the discrepancy proportion was 7 out of 39 knees after using Protocol B (17.9%) (2 partial tears and 5 complete tears).

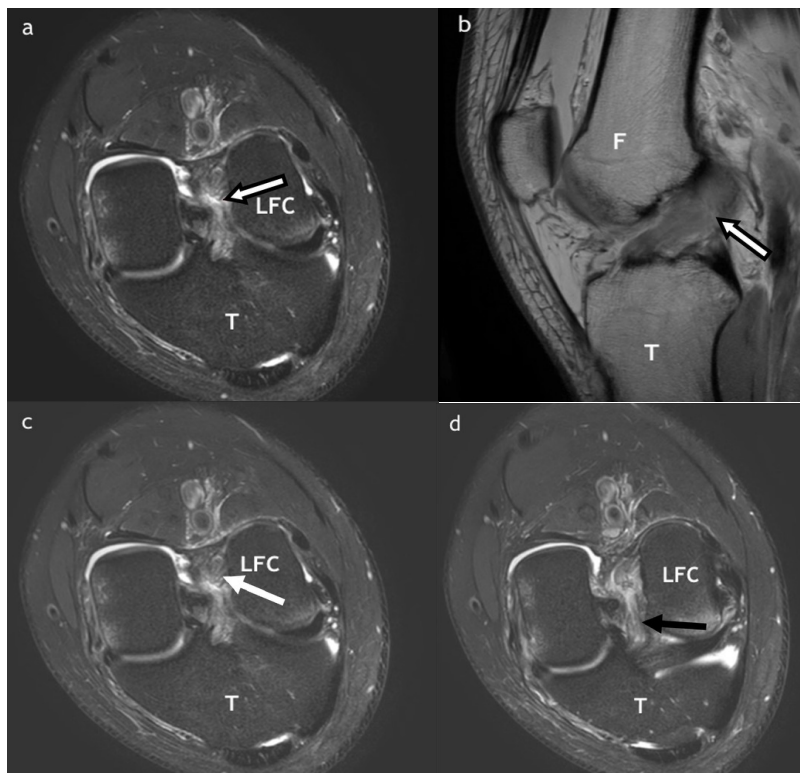


Figure 3. Example of the assessment of a complete ACL tear in a 19-year-old man with a knee injury using the routine knee MRI protocol. MRI findings were confirmed with arthroscopy.

(a) Oblique coronal T2W SPAIR and (b) sagittal T2W MR images show increased signal intensity and disruption of the ACL near the femoral insertion site (white arrow with a black outline). (c, d) Oblique coronal images demonstrating the posterolateral bundle (PLb) (white arrow) and the anteromedial bundle (AMb) (black arrow), respectively.

LFC, lateral femoral condyle; T, tibia; F, femur.

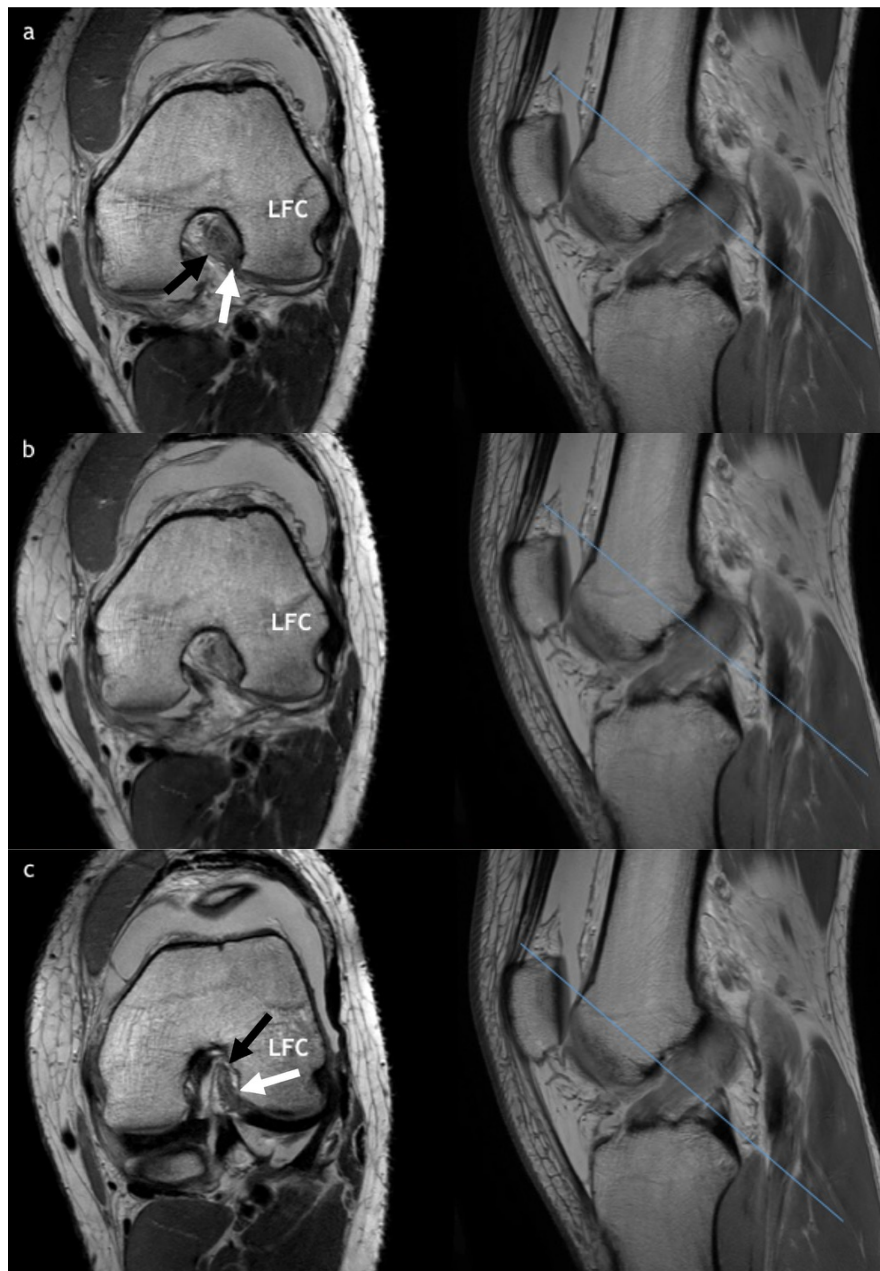


Figure 4. Three consecutive oblique axial intermediate-weighted MR images of the ACL show the same case as Figure 3. Image b shows the level of disruption of both the posterolateral bundle (white arrow) and the anteromedial bundle (black arrow) just below the femoral insertion. Images a and c show the ACL just above (a) and just below (c) the level of disruption.
LFC, lateral femoral condyle, respectively.

Accuracy for the diagnosis of complete or partial tears of the ACL (as a whole):

The sensitivity, specificity, PPV, NPV and accuracy of Protocols A and B for the diagnosis of ACL tears are shown in Table 3. The overall diagnostic accuracy of MR imaging using Protocol B was slightly higher than that of Protocol A for both readers (91.7 VS 90.3 % for reader 1 and 93.1% VS 92.4% for reader 2 respectively). Compared with Protocol A, Protocol B improved reader 1's specificity for detecting ACL tears (to 86.5 % in Protocol B from 78% in Protocol A) but with the cost of lower sensitivity (to 93.5 % in Protocol B from 94.3% in Protocol A). In contrast, Protocol B provided better sensitivity for reader 2 to detect ACL tears (to 96.3 % in Protocol B from 95.3% in Protocol A) while the other parameters, including specificity remained constant. Nonetheless, none of these differences between Protocols A and B parameters reached statistical significance.

Accuracy for the diagnosis of partial tears of the ACL:

The sensitivity, specificity, PPV, NPV and accuracy of Protocols A and B for the diagnosis and differentiation of partial from complete ACL tears are shown in Table 4. The specificity, PPV and accuracy of MR imaging using Protocol B for the diagnosis of partial tears were higher than those obtained with Protocol A for both readers, with the specificity and accuracy for reader 2 reaching statistical significance ($P=0.000$). Nevertheless, the differences in PPV and the other accuracy parameters between Protocol A and B for reader 1 did not reach statistical significance. Figures 5 and 6 illustrate an example of a case with an isolated partial ACL bundle tear.

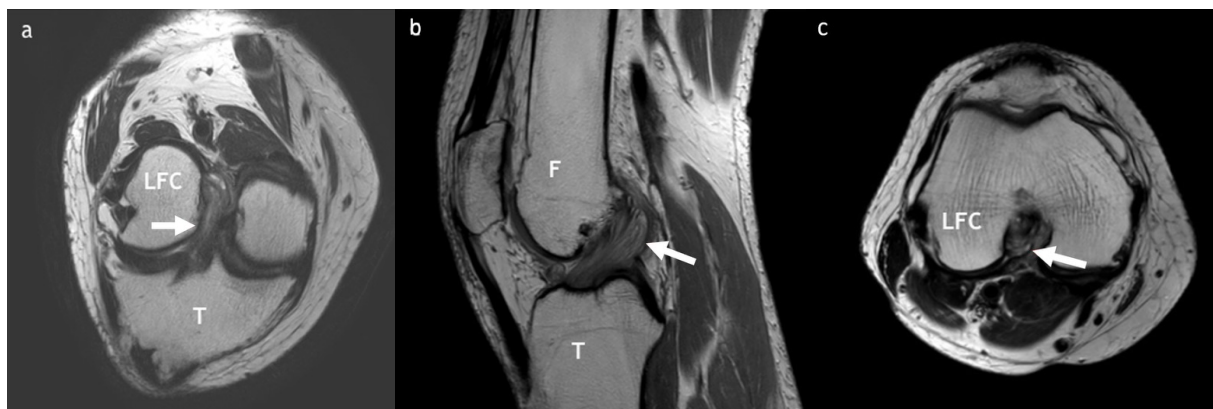


Figure 5. Example of the assessment of an isolated ACL bundle tear demonstrated on MRI and confirmed by arthroscopy. (a) Oblique coronal T2-weighted image, (b) sagittal proton density-weighted image, and (c) true axial T2-weighted image demonstrate increased signal intensity (SI) along the posterolateral bundle (PLb) (white arrows). LFC, lateral femoral condyle; T, tibia; F, femur.



Figure 6. The same case as shown Figure 5 showing three consecutive oblique axial intermediate-weighted MR images of the ACL at different levels along the ligament course: (a) the proximal, (b) the middle, and (c) the distal portion of the ACL. Increased SI along the PLb (white arrows) without fiber course disruption suggests a partial tear. The anteromedial bundle (AMB) demonstrates a normal course and SI (black arrows). LFC = lateral femoral condyle.

Accuracy for the diagnosis of isolated ACL bundle tear:

From a total of 8 knees with partial ACL tears identified on arthroscopy, 3 cases (37.5%) were reported to have an isolated posterolateral bundle (PLb) tear while only 1 case (12.5%) had an anteromedial bundle (AMb) tear. The retrospective arthroscopic reports of the remaining 4 cases with partial ACL tears did not specifically state the bundle tear in detail.

The sensitivity, specificity, PPV, NPV and accuracy of Protocols A and B for the diagnosis of isolated ACL bundle tears are shown in Table 5. The specificity and overall accuracy of MR imaging using Protocol B for the diagnosis of isolated PLb tears were higher than those obtained with Protocol A for both readers, although these differences did not reach statistical significance. Meanwhile, the accuracy parameters for the diagnosis of isolated AMb tears were similar between Protocols A and B for both readers.

Inter-observer agreement:

Using weighted kappa statistics, there was substantial agreement for the MR findings in both Protocols A and B between the readers. With the addition of oblique axial imaging in Protocol B, the interobserver agreement slightly increased from a kappa value of 0.651 to 0.752.

There was no significant difference between the readers' MR interpretations for the diagnosis of ACL tears overall whether they used Protocol A or B ($p > 0.05$). However, when it came to differentiating partial from complete ACL tears, reader 1 statistically had better specificity ($p=0.001$) and accuracy ($p=0.003$) than reader 2 using Protocol A. In contrast, with the addition of oblique axial MR imaging in Protocol B, reader 2's diagnostic performance in differentiating partial from complete ACL tears was statistically better than that of reader 1 in terms of both specificity ($p=0.000$) and accuracy ($p=0.000$).

Table 3. MR detectability for ACL tear (as a whole).

	TP	FP	FN	TN	Sensitivity	Specificity	PPV	NPV	Accuracy (%)	p-value
Reader1										
Pro A	101	8	6	29	94.3	78	92.7	82.9	90.3	1.0 (sense) 0.25 (spec)
Pro B	100	5	7	32	93.5	86.5	95	82	91.7	0.69 (accu)
Reader2										
Pro A	102	6	5	31	95.3	83.8	94.4	86.1	92.4	1.0 (sense) 1.0 (spec)
Pro B	103	6	4	31	96.3	83.8	94.5	88.6	93.1	1.0 (accu)

Note-- P-values represent the comparison of diagnostic performance between Protocol A and Protocol B for each reader in detecting ACL tears and differentiating partial from complete ACL tears.

Table 4. MR differentiation of ACL partial tears from complete tears.

	TP	FP	FN	TN	Sensitivity	Specificity	PPV	NPV	Accuracy (%)	p-value
Reader1										
Pro A	2	22	6	77	25	77.8	8.3	92.8	73.8	1.0 (sense) 0.69 (spec)
Pro B	2	20	6	79	25	79.8	9.1	92.9	75.7	0.69 (acc)
Reader2										
Pro A	3	35	5	64	37.5	64.7*	7.9	92.8	62.6**	1.0 (sense) 0.000(spec)
Pro B	3	9	5	90	37.5	90.9*	25	94.7	86.9**	0.000(accu)

**, ** statistical significant p=0.000*

Note-- P-values represent the comparison of diagnostic performance between Protocol A and Protocol B for each reader in detecting ACL tears and in differentiating partial from complete ACL tears.

Table 5. MR Diagnostic performance for detecting isolated ACL bundle tears.

Bundle	Reader	Protocol	TP	FP	FN	TN	Sensitivity	Specificity	Accuracy (%)	p-value
PL	Reader1	A	1	10	2	131	33.3	92.9	91.7	73.8
PL		B	1	8	2	133	33.3	94.5	93.2	73.8
PL	Reader2	A	0	4	3	137	0	97.2	95.1	73.8
PL		B	0	1	3	140	0	99.3	97.2	73.8
AM	Reader1	A	0	1	1	142	0	99.3	98.6	73.8
AM		B	0	1	1	142	0	99.3	98.6	73.8
AM	Reader2	A	0	0	1	143	0	100	99.3	73.8
AM		B	0	0	1	143	0	100	99.3	73.8

PL, posterolateral bundle; AM, Anteromedial bundle; TP, True positive; FN, False negative; TN, True negative; FP, False positive.

Discussion

Diagnosing partial ACL tears with conventional MRI has traditionally been challenging, mainly because of the oblique course of this bundle. Early studies [6,13,16-19,26] advocated the diagnostic value of the oblique-axial MR imaging for detecting partial ACL tears and suggested its potential role in surgical planning.

Ng AWH et al [6] reported in 2011 that oblique axial intermediate-weighted imaging improved the visualization of the ACL bundles in the majority of cases. The same author also found that the addition of this view to the standard knee MRI protocol increased the sensitivity and accuracy for the diagnosis of partial ACL tears from 33% to 87% and from 74% to 87% respectively while the specificity remained unaltered [19].

A few later studies on the oblique axial view for the diagnosis of isolated AM and PL bundle tears also obtained similar supporting evidence. For instance, a prospective study by Ng AWH et al in 2013 demonstrated that adding this view increased the sensitivity of AM bundle tear detection from 29% to 71% and that of PL bundle tear detection from 30% to 60%. Similarly, Kamal HA et al. in 2015 reported an increase in sensitivity from 80% to 88% and accuracy from 86% to 90% for detecting AM bundle tears. The sensitivity and accuracy for diagnosis of PL bundle tears also improved from 79% to 89% and from 81% to 90% respectively.

To our knowledge, oblique axial ACL imaging is not currently part of the standard knee MRI protocol in Thailand. Some centres have incorporated this view into routine practice because it can be easily acquired without the need for knee repositioning.

In our study population, both readers reported a similar proportion of partial ACL tear cases (11.8%-30.6% and 18.8%-22.9%) based on MR images compared with the incidence reported in prior studies (11-27%) [1,3-5]. However, an important issue to address is that the proportion of partial ACL tears retrieved from arthroscopic records at our institution was only 5.6%. One possible explanation for this low number is that the treatment option for this group of partial ACL tears is highly individualized and depends on multiple clinical factors. Nonetheless, this number also reflects that our institution's preferred treatment method for partial ACL tears is mostly conservative.

With the addition of oblique axial imaging of the ACL, our study found no diagnostic benefit over the standard knee MRI protocol for the diagnosis of ACL tears overall (Table 3). Both protocols demonstrated a high diagnostic accuracy of over 90% for both readers. These high accuracy values are consistent with previous studies using the standard knee MRI protocol for detecting overall ACL tears [15,18-19,21-25]. Additionally, with the standard MRI protocol, our study also found a similar specificity for the diagnosis of partial ACL tears (64.7%-77.8%) as compared to that reported in prior studies whose specificity ranged about 62-79%. However, the sensitivity in this study (25%-37.5%) for diagnosis of the same group is less than the previous studies (40%-77%). This low sensitivity value may be attributed to the small sample size of partial tear cases diagnosed by arthroscope, which served as the gold standard reference.

Interestingly, unlike the increased sensitivity reported by Ng AWH et al. [6], our study found that the addition of oblique axial imaging to the standard knee MRI protocol significantly improved specificity and overall diagnostic accuracy for the experienced musculoskeletal radiologist (reader 2) in detecting partial ACL tear lesions and distinguishing them from complete tears ($p=0.000$). The specificity rose from 64.7% to 90.9% while the accuracy rose from 62.6% to 86.9%. Moreover, the performance of the MSK radiologist appeared to be significantly superior to that of the radiology resident after the addition of the oblique axial image ($p=0.000$ for both specificity and accuracy). Meanwhile, the specificity and accuracy of the less experienced radiology resident after the addition of oblique axial imaging were only slightly higher than those of the standard knee MRI protocol and did not reach statistical significance ($p=0.69$). We speculate that this finding may differ in a larger cohort study. Nonetheless, these results suggest that the experience of the interpreter may play an important role in maximizing the diagnostic value of the oblique axial view.

For the detection of a normal ACL, the addition of oblique axial imaging did not show significant diagnostic value over the standard protocol as shown by the NPV in the Tables 3 and 4. However, it is noteworthy that most of the arthroscopic-MR discrepancy cases identified by reader 2 were partial tear cases (50-60%), considering that this group of patients made up a small proportion of the study population (5.6%). After the addition of oblique axial imaging, reader 2 correctly identified an arthroscopic-proven partial ACL tear case that had previously been interpreted as normal using Protocol A (Fig.5). In a larger cohort study, this additional imaging plane may potentially be helpful to a certain extent for delineating partially torn ACLs from normal ones. In clinical practice, MRI findings should also be interpreted in conjunction with clinical examination and arthroscopic correlation. Evaluation of ligament alignment and signal intensity may provide additional information for assessing functional ACL insufficiency.

This study has several limitations. Although the addition of oblique axial imaging improved specificity and accuracy for the experienced reader, the increase in diagnostic performance for the less experienced reader did not reach statistical significance. This finding may be related to the relatively small cohort size, and different results may be observed in a larger study population.

In addition, our investigation of individual ACL bundle tears was limited by several factors. The number of isolated bundle tear cases obtained from retrospective arthroscopic reports in our institution over the selected 3-year period was small. While most partial ACL tears at our institution underwent conservative management, detailed documentation regarding the degree of partial tear or the specific bundle involved was often lacking in the reports. As a result, only 4 out of 8 partial ACL tear cases in the study population were specifically identified as isolated AM or PL bundle tears.

Another limitation of our study relates to the imperfection of the arthroscopic reports used as the gold standard. Since this was a retrospective study, not all patients with MRI-detected partial ACL tears underwent arthroscopy and thus were excluded from the study population. It was also not possible to require all patients with ACL tears detected on MRI to further undergo arthroscopy within a short time interval. While the average time interval between MRI and arthroscopy in the study by Ng AWH et al [6] study was 46 days (range 5-80 days), the time interval in this study ranged from 9 days to 1 year and 4 months. One possible explanation for this wide interval is that part of the study period coincided with the COVID-19 pandemic, during which many elective surgeries were rescheduled and delayed accordingly. The longer the interval between MRI and arthroscopy, the greater the possibility that partial ACL tears initially identified from MRI to progress to complete tears or heal. These limitations due to the retrospective nature of the study are similar to those in other retrospective studies by Ng AWH

et al in 2012 [6] and Volokhina et al in 2015 [13], which also faced limitations from little statistical power from their small cohorts. Another reason why arthroscopy is an imperfect gold standard is its inability to detect intrasubstance tears, which would otherwise be seen as partial ACL tears on MR imaging. A prospective study with a larger cohort would be helpful for further validation of our results.

Regarding the MRI interpretation process, we only analyzed images on a qualitative basis. Although our inter-reader agreement was substantial, the visual analysis may lead to subjective interpretation by the inexperienced radiologists. Besides, due to the retrospective nature of our work, along with the absence of a control group, this could have led to bias by positively influencing the interpretation of cases of uncertainty. Lastly, the two readers in this study may not be enough to represent the performance of other MSK radiologists or radiology residents in routine clinical practice as a whole. Further studies with more readers both from the MSK radiologists and the radiology residents would be desirable.

Conclusion

While the current routine knee MRI protocol presents high accuracy for the detection of ACL tears as a whole, the addition of oblique axial ACL imaging improves diagnostic performance in detecting partial ACL tears, particularly by increasing sensitivity for less experienced readers. This additional sequence is easy to acquire and may be considered a useful adjunct to routine knee MRI protocols for ACL evaluation.

Author contributions

(I) Conception and design: A Pisanuwongse, T Taveepattanangkul, N Lektrakul; (II) Administrative support: A Pisanuwongse; (III) Provision of study materials or patients: A Pisanuwongse, T Taveepattanangkul, N Lektrakul; (IV) Collection and assembly of data: A Pisanuwongse, T Taveepattanangkul; (V) Data analysis and interpretation: A Pisanuwongse, T Taveepattanangkul; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

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