

Added value of oblique coronal magnetic resonance imaging (MRI) in the diagnosis of anterior cruciate ligament (ACL) single bundle tears

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Abstract

Background

To evaluate the role of the oblique coronal magnetic resonance imaging (MRI) sequence in the study of individual bundle tears of the anterior cruciate ligament (ACL).

Patients and methods

Thirty-two patients with a suspected ACL injury were included in the study (3 women, 29 men). For the standard protocol, all patients underwent routine MRI using the following acquisition parameters: sagittal fast-spin echo (FSE) T2 FSE, coronal short-tau inversion recovery (STIR); and axial FSE T2-weighted images an additional oblique coronal scan protocol was then performed, and the results of the two protocols were compared. The MRI findings were also compared with a gold standard knee arthroscopy, the current.

Results

Oblique coronal MRI showed a better agreement with arthroscopy than standard MRI (weighted kappa = 0.865 and 0.753 respectively).

Conclusion

Oblique coronal MRI provided better visualization of the ACL bundles and increased the accuracy of tear diagnosis. This confirms that oblique coronal MRI should be combined to the routine protocol of the knee as it has several clinically significant effects in the treatment outcome especially in cases of clinically suspected ACL individual bundle tears.

Keywords

Oblique coronal MRI; ACL injury, arthroscopy.

Introduction

The anterior cruciate ligament (ACL) is one of the main stabilizers of the knee joint. It serves to resist anterior translation of the tibia and rotational loads.[1] The ACL consists of two functional bundles that are named based on their insertions in the tibia: the anteromedial (AM) and posterolateral (PL) bundles. Both bundles are biomechanically important for knee stability, with each bundle contributing its own specific mechanical function. The AM bundle stabilizes the flexed knee, and the PL bundle stabilizes the knee in extension. [2]

ACL injuries during sports activity are increasingly common [annual incidence in the US more than 120000 injuries], perhaps because of more participation in the certain sport activities that would be a good reason for seeking better diagnostic methods. [1]

The preferred diagnostic imaging tool for ACL injury

is magnetic resonance imaging (MRI), which accurately confirms the diagnosis of complete ACL tears. However, the sensitivity and specificity of MRI for the detection of partial tears are low. An accurate pre-operative evaluation of the extent of injury is important when planning ACL reconstruction surgery, as partial tears do not always necessitate reconstruction. If one of the ACL bundles is torn and the other is intact, single bundle reconstruction can be undertaken rather than full ACL reconstruction. If single bundle tears can be adequately diagnosed before the surgery, this would enable surgical planning to be more precise. [3]

In addition, it might be useful to indicate that AM and PL bundle injuries are insufficiently identified using the routine imaging. An ideal combination of slice orientation, thickness and pulse sequences may be needed, but results are still only suggestive of the injury in the best-case scenario [4]. To address this, we compared the accuracy of the two MRI protocols

against arthroscopy, the current diagnostic gold-standard in ACL injury diagnosis, aiming to improve the diagnosis and treatment outcome of partial ACL tears.

Patients and methods

Patients:

We conducted a prospective study between February 2016 and January 2017, of thirty-two patients (3 women, 29 men) with clinical signs and symptoms suggestive of ACL injury.

The mean age 36 years (Ranged from 20-45 years). Patients were referred from the orthopedic surgery outpatient clinic, Badr university hospital.

Inclusion criteria: Skeletally mature patients with no signs of knee osteoarthritis and had positive clinical signs of ACL injury.

Exclusion criteria: Patients outside the specified age range; previous knee surgery or endoscopy; ACL intrasubstance ganglion cyst or mucoid degeneration.

This study was approved by the local ethical committee of Helwan University.

MRI methods:

Routine protocol

The MRI scans were performed at the MRI unit of Ain Shams University Hospital. Images were obtained using Philips® Achieva 1.5T with phased array knee coil. The knee was extended inside the coil with the patient in a supine position.

The routine protocol are the knee series having following acquisition parameters (**Table 1**). Sagittal T2-weighted fast-spin echo (FSE), coronal T2-weighted FSE, and axial T2-weighted. The axial images were taken as a localizer for the coronal and sagittal planes. The coronal planes were oriented parallel to a line drawn through the dorsal aspect of the femoral condyles (bicondylar line). The oblique sagittal planes were the planes on the axial localizer images that were 15 degrees from perpendicular to the bicondylar line.

Table 1: Parameters of MRI protocol A and protocol B

		TE	TR	FOV	SL	Gap	Matrix
Routine protocol [protocol A]	Sagittal						
	• T2	100	4200	160x160	3.5	0.5	256x150
	Coronal						
	• T2 fat sat	20	487	170x170	5	1.5	256x150
Axial	• T2						
		100	3.6	160x160	5.5	1.3	256x150
Additional Oblique coronal protocol [protocol B]	Oblique coronal T2	95	3500	150x150	4	1	256x150

Oblique coronal MRI protocol

T2-FSE Images were obtained in the plane parallel to the ACL and the roof of the intercondylar notch (Blumensaat's line) in the midsagittal localizer (**Figure 1**) having acquisition parameters as mentioned in (**Table 1**). The AM and PL bundles of the ACL are clearly differentiated in the oblique coronal images (**Figure 2**) without any knee repositioning in the scanner.

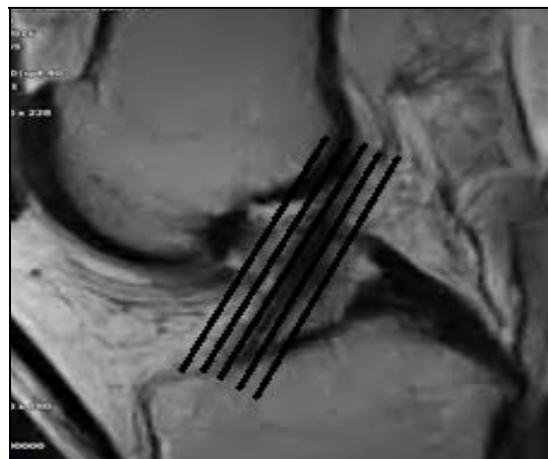


Figure 1: Mid sagittal localizer with black lines parallel to the ACL direction.

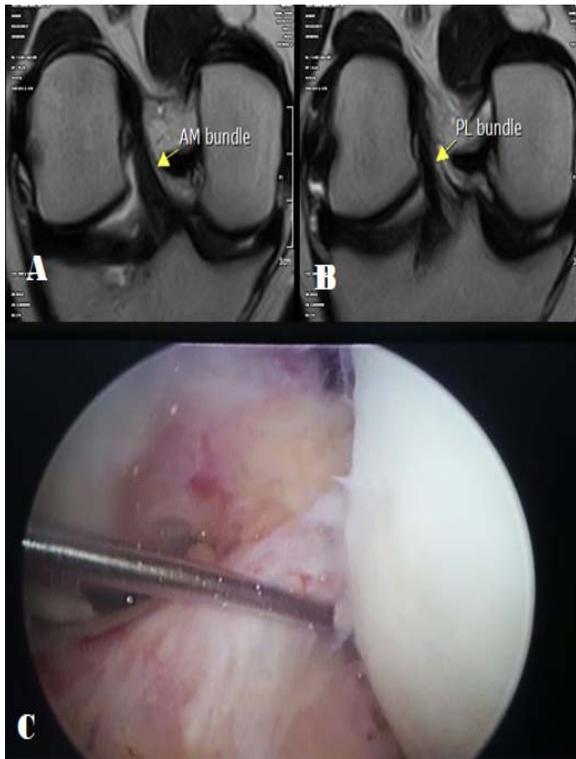


Figure 2: (A) Oblique coronal T2-weighted image of the ACL revealing intact individual AM and PL bundles of the ACL with a thin, bright band of high signal between the bundles. (B) Arthroscopic view of intact ACL fibers. AM=antromedial, PL=posterolateral.

Knee arthroscopy

Standard parapatellar portals were used for diagnostic arthroscopy. Both ACL bundles were identified at the time of arthroscopy with direct visualization and probing, (**Figure 2C**) and accordingly, each bundle was classified as normal or torn. A normal ACL bundle was defined as one that had all fibers intact from the tibial to the femoral attachments. A bundle tear was diagnosed when there was no continuity of the ACL bundle and a lack of tautness was evident by direct probing.

MRI analysis

A consultant musculoskeletal radiologist firstly reviewed the routine imaging planes (protocol A) and classified the ACL as intact, full-thickness tear or suggested partial-thickness tear. Then they reviewed the oblique coronal images (protocol B) of both ACL bundles and reported whether the ACL was intact (Figure 2A&B), or there was a complete tear of both bundles (Figure 3), AM bundle tear (Figure 4) or PL bundle tear (Figure 5).

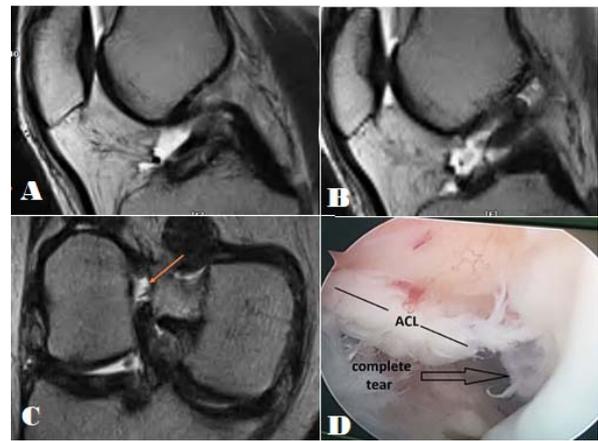


Figure 3: (A, B) Midsagittal consecutive T2-weighted images show mild laxity and apparently fragmented ACL with blunted edges. (C) Corresponding oblique coronal T2-weighted image showing a focal complete tear with a high signal related to the proximal femoral attachment of the ACL, consistent with a proximal complete tear. (D) Knee arthroscopy view shows a complete ACL tear.

Statistical analysis

We used the following terms to represent diagnostic accuracy: sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), positive likelihood ratio (LR+), negative likelihood ratio (LR-) and overall accuracy. Statistical analysis was performed using MedCalc© version 15.8 (**MedCalc© Software bvba, Ostend, Belgium**).

Inter-method agreement regarding the assessment of binary outcomes was examined by calculating Cohen's kappa (κ), bias-adjusted kappa (BAK) and prevalence-adjusted bias-adjusted kappa (PABAK) coefficients. Weighted κ was used to examine the inter-method agreement for assessing outcomes rated on an ordinal scale. The diagnostic accuracy of the oblique coronal protocol for an isolated bundle tear was compared with arthroscopy as the current gold-standard method. Contingency tables were used to calculate the sensitivity, specificity, PPV and NPV; true- and false-positive rates; and correct classification (accuracy) and misclassification rates.

Results

For the diagnosis of an AM bundle tear (**Figure 6**), the oblique coronal protocol had a sensitivity of 90.9 %, specificity of 80.0 %, overall accuracy of 87.5 %, false-positive rate of 20 %, false-negative rate of 9.1 %, prevalence of 68.8 %, PPV of 90.9 %, NPV of 80 %, LR+ of 4.55 and LR- of 0.11. There was strong inter-method agreement as deduced from a κ value of .71, BAK value of .71, and PABAK value of .75.

For diagnosing a PLB tear (**Figure 7**), the oblique coronal protocol had a sensitivity of 95.5 %, specificity of 90 %, overall accuracy of 93.8 %, false-positive rate of 10 %, false-negative rate of 4.5 % prevalence of 68.8 %, PPV of 95.5 %, NPV of 90 %, LR+ of 9.55 and LR- of 0.05. There was very strong inter-method agreement as deduced from the κ value of .85, BAK value of .85, and PABAK value of .88.

The oblique coronal protocol showed higher inter-method agreement with the arthroscopy (weighted $\kappa = 0.865$, 95% CI 0.718–1.000; very strong agreement) than the routine protocol did (weighted $\kappa = 0.753$, 95% CI 0.586–0.920; strong agreement) (**Figure 8**; **Table 2**).

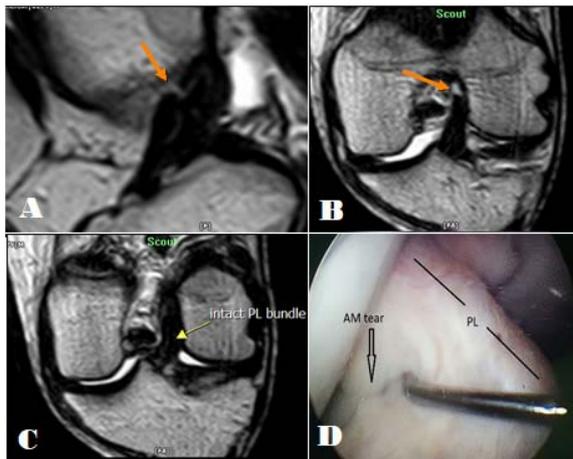


Figure 4: (A) Midsagittal image showing mild laxity and thickening of the ACL with subtle signal alteration close to its proximal femoral attachment. Arrow, (B, C) Corresponding consecutive coronal T2-weighted images show a focal defect with high signal related to the proximal femoral attachment of the AM bundle (B) and mild laxity, but an intact PL bundle (C). (D) Knee arthroscopy shows the AM bundle tear.

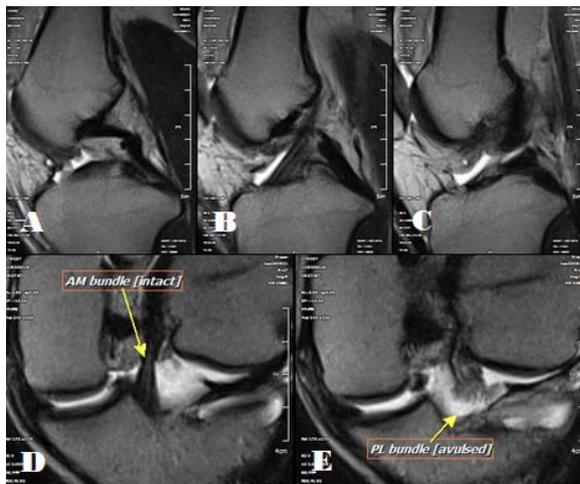


Figure 5: (A, B&C) Three consecutive midsagittal T2-weighted images showing a subtle increased interstitial signal among the ACL fascicles, with an apparently intact ACL maintaining good alignment in relation to the roof of

the intercondylar notch. (D&E) Corresponding specific coronal T2-weighted images showing an intact AM bundle and PL bundle avulsed from its distal tibial attachment. Regional edema is shown with a frayed distal end and slightly retracted/corrugated proximal fibers. Note a displaced inner meniscal fragment in conjunction with a medial meniscus bucket handle tear.

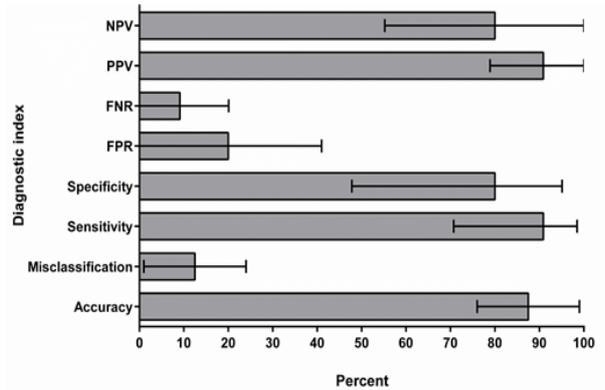


Figure 6. Accuracy of the oblique coronal protocol for the diagnosis of AMB tear. Error bars represent the 95% confidence interval. FNR, false negative rate; FPR, false-positive rate; NPV, negative predictive value; PPV, positive predictive value

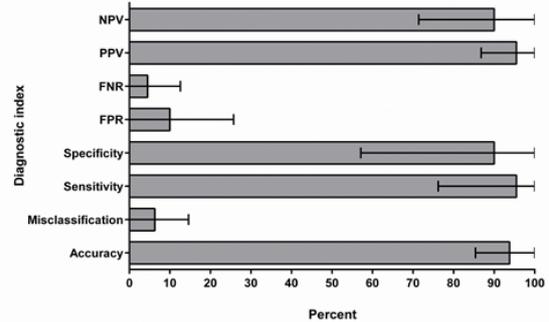


Figure 7. Accuracy of the oblique coronal protocol for the diagnosis of a PLB tear. Error bars represent the 95% confidence interval (95% CI). FNR, false-negative rate; FPR, false-positive rate; NPV, negative predictive value; PPV, positive predictive value

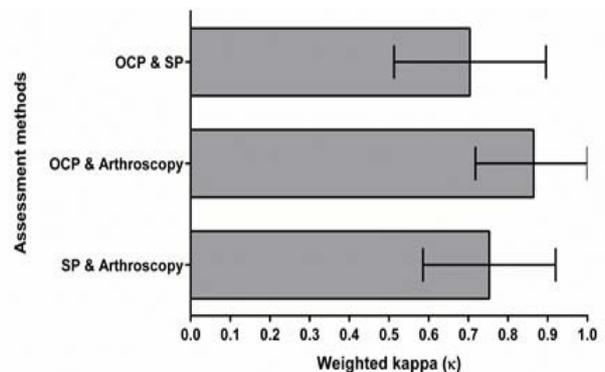


Figure 8. Inter-method agreement for the standard protocol (SP), oblique coronal protocol (OCP) and arthroscopy for the diagnosis of whole ligament tear. Very strong agreement. Error bars represent the 95% confidence interval.

Table 2. Inter-method agreement for the standard protocol, oblique coronal protocol and arthroscopy for diagnosis of whole ligament tear

		Standard protocol						
		Intact	Partial tear	Complete tear	Total	Weighted κ	SE	95% CI
Arthroscopy	<i>Intact</i>	3	1	0	4 (12.5%)	0.753	0.085	0.586 to 0.920
	<i>Partial tear</i>	3	6	2	11 (34.4%)			
	<i>Complete tear</i>	0	0	17	17 (53.1%)			
	<i>Total</i>	6 (18.8%)	7 (21.9%)	19 (59.4%)	32			
		Oblique coronal protocol						
Arthroscopy	<i>Intact</i>	3	1	0	4 (12.5%)	0.865	0.075	0.718 to 1.000
	<i>Partial tear</i>	0	10	1	11 (34.4%)			
	<i>Complete tear</i>	0	1	16	17 (53.1%)			
	<i>Total</i>	3 (9.4%)	12 (37.5%)	17 (53.1%)	32			
		Oblique coronal protocol						
Standard protocol	<i>Intact</i>	3	3	0	6 (18.8%)	0.704	0.098	0.513 to 0.896
	<i>Partial tear</i>	0	6	1	7 (21.9%)			
	<i>Complete tear</i>	0	3	16	19 (59.4%)			
	<i>Total</i>	3 (9.4%)	12 (37.5%)	17 (53.1%)	32			

Discussion

The unique contributions of the AM and PL bundles to knee function has been described in many biomechanical studies, and neither of the individual bundles alone can reproduce the mechanical function of an intact ACL. [5]

Accurate preoperative evaluation of an injury with an assessment of its severity is of utmost clinical importance because it is the first step for a successful management plan. A bundle-specific approach includes the identification of a single bundle tear or complete tear of both bundles. Evaluation of the status of each bundle is relevant to patient management. Single bundle augmentation surgery can be a reliable reconstruc-

tive option for patients who have a single tear of only one rather than both bundles. Therefore, there is a strong motivation to evaluate each of the two bundles on MRI as well as the ACL when an ACL tear is suspected. [6]

Nevertheless, some patients with single bundle ACL tears may be treated conservatively. Conservative management can be tried with patients who lack any clinical examination findings, in low demanding jobs, not involved in activities causing torsional knee strain and having sedentary lifestyles. [7] This adds to the importance of differentiating single bundle from complete ACL injury before deciding the plan of management.

With conventional MRI protocols, isolated single bundle ruptures have traditionally been difficult to diagnose because of the oblique direction of these fibers.[8] *Umans et al.(1995)* found that MRI had insufficient sensitivity to accurately diagnose single bundle ACL tears [9], and in a study by *Lawrance et al.(1996)*, MRI was shown to contribute to the diagnosis of only one of nine partial ACL tears confirmed by arthroscopy; MRI could not differentiate between the two bundles of the ACL.[10] However, in another study, *Chang et al. (2013)* found that the overall diagnostic accuracy of MRI for partial ACL tears was 83%, with a better accuracy for AM bundle tears (91%) than for PL bundle tears (78%). [11]

Due to the unique diagonal course of the ACL through the knee joint, many nonorthogonal MRI techniques have been trialed to identify the one that offers the best visualization of the ACL bundles. [12]

Kamal et al. (2015) made a study in which they tried to increase the accuracy of single bundle ACL tear diagnosis by MRI. They used oblique axial MR protocol to do this. Their results revealed an increase in sensitivity for anteromedial bundle lesions to 88% and accuracy to 90% and for posterolateral bundle lesions, the sensitivity increased to 89% and accuracy to 90%. [13]

Volokhina et al. (2015) performed a study in 2015 to assess the accuracy of the “gap” and “foot print” signs in conventional MRI to detect ACL posterolateral bundle tears. They found in their study group of eleven patient with proven PL bundle tears by arthroscopy that the sensitivity of the footprint sign was 75% in the coronal plane and the specificity was 80%. The sensitivity of the gap sign was 72% with a specificity of 68% in the coronal plane. The sensitivity of the gap sign was 52% and the specificity was 53% in the axial plane. The presence of one sign or both had a sensitivity of 82% and a specificity of 58%. [14]

In the present study, we assessed the value of using oblique coronal MRI for identifying single bundle ACL injury. The routinely used sagittal T2 planes have a limited ability to detect single bundle ACL tears, meaning such injuries can be either missed or overestimated preoperatively when using standard techniques.

Perhaps ACL tears are becoming more common with the increasing popularity of certain sports. Patients are rapidly becoming more aware to fully understand the knee condition using more accurate diagnostic tool. Surgeons could be able to make a better preoperative assessment of the injury and develop a better plan. There are many other reasons why improved diagnos-

tic methods are important, reducing preoperative waiting time, improving the success rate of surgery or reducing use of healthcare resources by targeted treatment.

The oblique coronal MRI technique can provide a more informative and detailed view of ACL injury compared to imaging done using conventional MR protocol. Using oblique coronal MRI technique does not add any additional cost or significant time of the investigation. Using this protocol with a 1.5 Tesla MRI scanner can provide more information about an ACL injury than a less available and probably more expensive study performed on a 3 Tesla scanner running only the routine protocol.

Limitations of our study included refusal of some patients with positive MRI findings to undergo knee arthroscopy, these cases have been omitted from the study. Also, the unavailability of a 3 Tesla scanner to do routine protocol and compare it with oblique coronal protocol, so we recommend repeating this study using a high tesla MR machine.

Conclusion

The oblique coronal MRI technique provides better accuracy and specificity for identifying a single band ACL injury than routine sagittal MRI images, without additional cost or time. Precise diagnosis of the type of ACL injury can help to make a more targeted management plan. We recommend that oblique coronal T2 images be added to the standard MRI protocol and validated as a predictive model on a larger sample of patients.

Conflict of interest

The authors have no conflict of interest to declare.

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