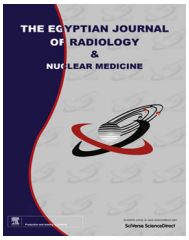
The Egyptian Journal of Radiology and Nuclear Medicine (2015) **46**, 683–693

Egyptian Society of Radiology and Nuclear Medicine

The Egyptian Journal of Radiology and Nuclear Medicine

www.elsevier.com/locate/ejrnm
www.sciencedirect.com



ORIGINAL ARTICLE

The role of oblique axial MR imaging in the diagnosis of ACL bundle lesions

Heba Ahmed Kamal *, **Nagui Abdelwahab, Nevien E. El-Liethy**

Radio Diagnosis, Faculty of Medicine, Cairo University, Egypt

Received 11 March 2015; accepted 8 May 2015
Available online 23 May 2015

KEYWORDS

Magnetic resonance imaging;
Oblique axial;
Knee;
Anterior cruciate ligament

Abstract *Objective:* This study was done to evaluate the accuracy of oblique axial MR imaging in studying individual ACL bundle lesions.

Subjects and methods: This study included forty-one (41) patients; 20 patients with no symptoms or signs of ACL injury and 21 patients in the suspected ACL lesions group. Each patient had a single MRI examination followed by a single indicated arthroscopy. The standard knee protocol (sagittal FSE proton density, coronal FSE T2-fat suppressed, axial FSE T2, sagittal FSE T1 and sagittal STIR) was designated **protocol A**, while the standard knee protocol plus oblique axial imaging was designated **protocol B**.

Results: The comparative study was done using MRI **protocol A** versus **protocol B** for isolated anteromedial and posterolateral bundle as well as for ACL lesions as a whole with comparing these findings with arthroscopy as the gold standard. The addition of oblique axial imaging, increased sensitivity for ACL lesions (as a whole) from 74% to 95% and the accuracy from 76% to 95% while specificity remained similar.

The sensitivity, specificity and accuracy of standard MR imaging for the detection of anteromedial bundle lesions were shown to be 80%, 100% and 86%, while that for posterolateral bundle lesions was 78%, 100% and 81% respectively. However, the addition of oblique axial imaging, increased sensitivity for anteromedial bundle lesions to 88% and accuracy to 90% while specificity remained similar. For posterolateral bundle lesions, the sensitivity increased to 89% and accuracy to 90% while specificity remains similar.

Conclusion: Compared with standard MR imaging, the addition of oblique axial imaging improves the diagnostic accuracy for detecting lesions of the ACL, including both bundles' delineation. This imaging plane seems to provide a useful adjunct to standard MR imaging when ACL lesion is suspected.

* Corresponding author. Mobile: +20 01223600583, +20 01123000552.
E-mail addresses: Hebakamala@yahoo.com (H.A. Kamal), nagui.abdelwahab@gmail.com (N. Abdelwahab), nevienelliethy@yahoo.com (N.E. El-Liethy).

Peer review under responsibility of Egyptian Society of Radiology and Nuclear Medicine.

http://dx.doi.org/10.1016/j.ejrnm.2015.05.007

1. Introduction

The anterior cruciate ligament is composed of the anteromedial and posterolateral bundles. Functionally, these two distinct bundles act in a complementary manner to limit the excessive femoro-tibial movement at the end of flexion and extension (1).

Most anterior cruciate ligament (ACL) tears are complete, with the tear involving all of the anteromedial and posterolateral bundle fibers. Partial ACL tears occur less frequently and may involve both bundles to a variable degree or one bundle completely. Arthroscopic-based studies may reflect an underestimation of true prevalence as patients with complete rather than partial tears are more likely to undergo arthroscopy (2).

Partial tear recognition is clinically relevant and important because:

1. Partial tears, unlike complete ACL tears, may have the capacity to heal with conservative treatment (3).
2. One may be more inclined to opt for a trial of conservative treatment.
3. If surgery is undertaken, partial ACL tears primarily limited to only a single bundle may be amenable to isolated single bundle graft augmentation rather than full ACL graft reconstruction (4).

Currently, multiple surgical reconstruction techniques are available to repair a ruptured ACL. The double bundle ACL reconstruction technique and selective bundle ACL reconstruction technique use the anatomic double-bundle approach of the ACL in order to improve functionality after surgery (5).

Clearly accurate early evaluation of partial ACL tears is relevant to improving the clinical and surgical management of ACL tears (6). Usually, when partial ACL tears are diagnosed on MRI, it is frequently not possible to detect an isolated AM or PL bundle tear reliably using standard MR sequences and imaging planes (7). Oblique sagittal and oblique coronal imaging has been used to delineate the ACL more clearly (8,9).

1.1. The aim of this study

To investigate the diagnostic accuracy of oblique axial intermediate weighting MR imaging in detecting and differentiating tears (complete–partial) as well as degeneration of the ACL bundles.

2. Materials and methods

This prospective study was drawn from 41 patients: 24 males and 17 females with age range from 18 to 60 years (mean age 39 years). Consent was obtained from all the patients before doing this study. All patients were referred to the Radiology department from the outpatient clinic of the Orthopedics department between May 2014 and September 2014.

This study was approved by the ethics committee of the Cairo University.

Patients with history of knee surgery or arthroscopy were not included in the study. All patients were subjected to history taking and clinical provisional diagnosis.

The study included 20 patients with no symptoms or signs of ACL injury (group A; control group) and 21 patients in the suspected ACL lesions group (group B).

As each patient had a single MRI examination followed by a single arthroscopy, 41 MRI examinations and 41 corresponding arthroscopy examinations were analyzed.

Arthroscopy in group A was clinically indicated for suspected injuries other than ACL.

2.1. Magnetic resonance imaging

MR examinations were performed using ACHIEVA 1.5 T scanner (Philips medical systems, Best, the Netherlands) using a phased array knee coil at the radiology department.

Technically, the oblique axial plane is easy to acquire and does not require any knee repositioning. The knee was examined in a supine and extended position.

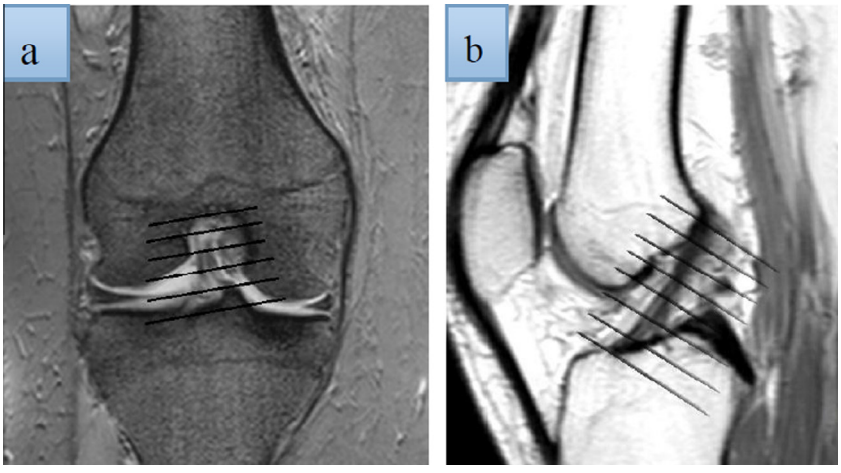


Fig. 1 Oblique axial imaging of ACL was planned using both coronal (a) and sagittal (b) images. (Black lines).

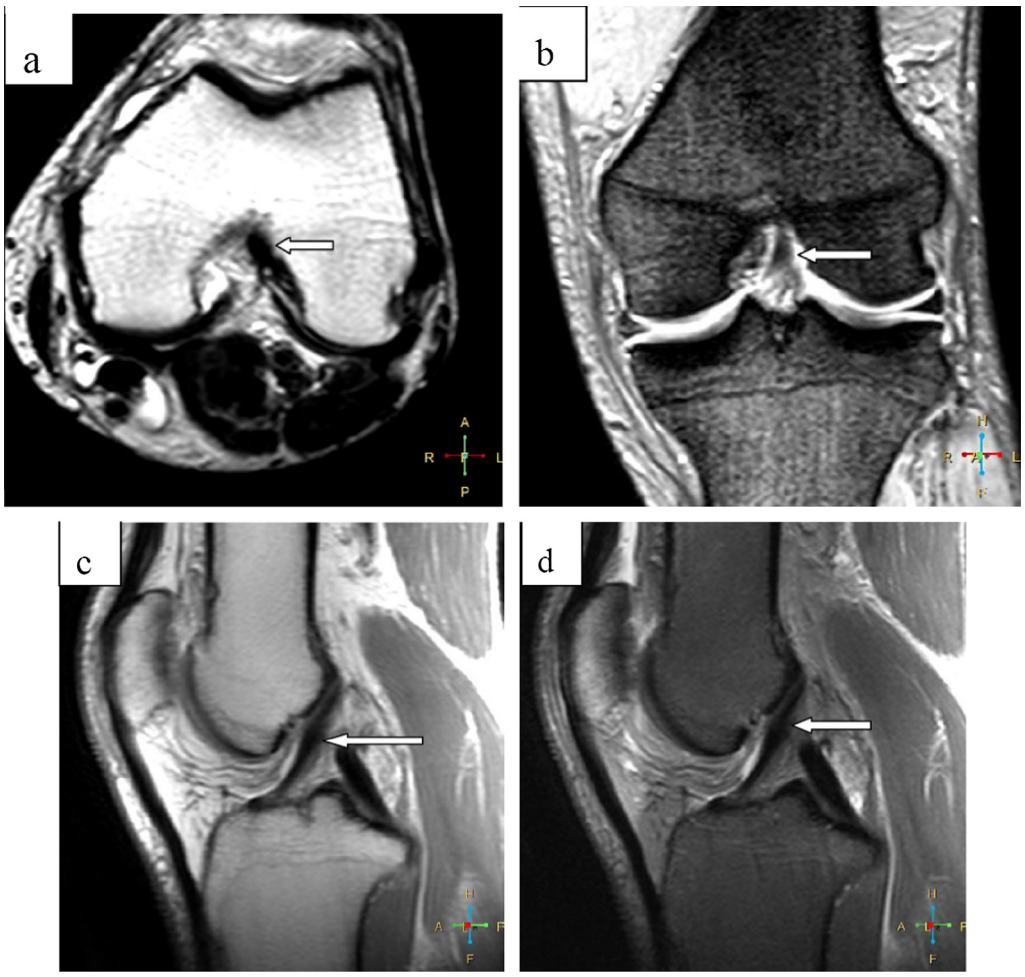


Fig. 2 (a) Axial FSE T2, (b) coronal FSE T2 fat suppression, and (c) sagittal FSE PD and (d) sagittal STIR MRI of the right knee, revealed an intact ACL.

2.1.1. Protocol of MR imaging Table 1

Preliminary scout localizers in axial, coronal and sagittal planes were done. The axial images serve as a localizer for prescribing the coronal and sagittal oblique sections.

Oblique axial images of the ACL were obtained in a plane aligned perpendicular to the course of the ACL using sagittal and coronal images for positioning and alignment Fig. 1.

The standard knee protocol (sagittal FSE proton density, coronal FSE T2-fat suppressed, axial FSE T2, sagittal FSE T1 and sagittal STIR) was designated **protocol A**, while the standard knee protocol plus oblique axial imaging was designated **protocol B**.

2.1.2. MRI analysis

The ability to delineate the anteromedial and posterolateral bundles of the ACL near the tibial insertion, the midportion, and near the femoral origin was assessed.

Two musculoskeletal radiologists who were unaware of arthroscopic findings, reviewed all knee MR examinations and ACL status by consensus. Firstly, the standard imaging planes of the knee were evaluated **(protocol A)** with each ACL bundle being classified as intact, partially torn, or completely torn. Thereafter, these standard planes were evaluated together with oblique axial imaging of the ACL **(protocol B)** and each ACL bundle was again classified as intact, partially torn, or completely torn.

An intact ACL or ACL bundle was one in which all the ACL fibers could be followed on contiguous sections as intact from the tibial to the femoral attachment. A partial ACL tear or ACL bundle tear was defined by high signal intensity within the ACL or individual bundle, focal swelling or thinning of the ACL or ACL bundle and/or a wavy course of the ACL or ACL bundle with maintained continuity. A complete ACL tear or ACL bundle tear was defined as a complete lack of continuity of the ACL or ACL bundle tear.

Together with assessing the individual bundles, the ACL as a whole unit was also classified on MRI as intact, partially torn, or completely torn. Intact ACL was defined by the normal appearance of both ACL bundles. Partial ACL tear was defined by either partial or complete tear in one or other bundle, but not a complete tear of both bundles. Complete ACL tear was defined by complete tear of both bundles. MRI results were compared with arthroscopic findings.

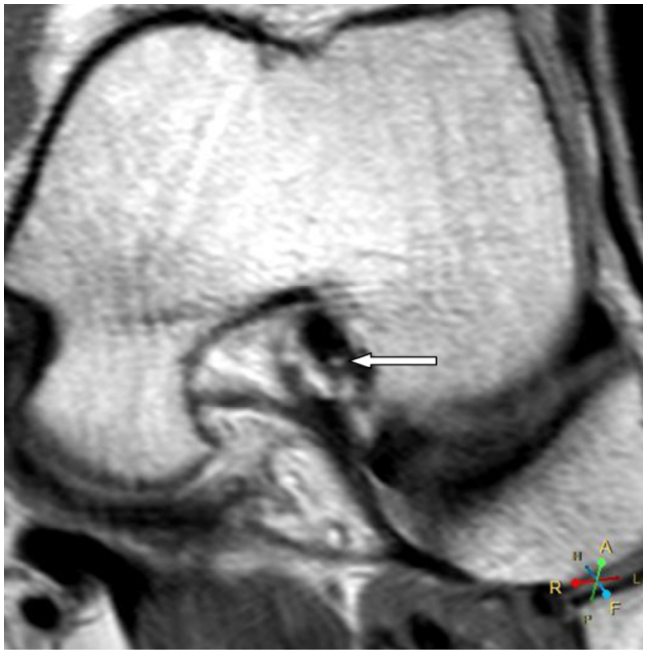


Fig. 3 Axial oblique PD shows an area of hyper-intensity (white arrow) within the anteromedial bundle at the mid-portion of the ACL. The bundle was considered partially torn. It was proved by arthroscopy to be intact (fibrofatty component of the ACL, normal variant).

2.2. Arthroscopic analysis

All arthroscopies were performed by orthopedic surgeons, who have experience in knee surgery. At arthroscopy, each bundle was classified as normal, partially torn, or completely torn.

An intact ACL bundle was one in which the fibers were taut and visibly intact from the tibial to the femoral attachment. Partial ACL bundle tear was diagnosed when some, but not all bundle fibers were visibly torn on direct inspection and the remaining fibers exhibited expected resistance to deformation on physical probing. A complete bundle tear was diagnosed when there was no continuity of the ACL bundle and the complete lack of tautness on direct probing.

In addition to the individual bundle assessment, using the same diagnostic criteria, the whole ACL was also classified as normal, partially torn, or completely torn.

2.3. Statistical methods

Data were statistically described in terms of frequencies (number of cases) and percentages. Accuracy was represented using the terms sensitivity, specificity, +ve predictive value, −ve predictive value, and overall accuracy. All statistical calculations were done using computer program SPSS (Statistical Package for the Social Science; SPSS Inc., Chicago, IL, USA) release 15 for Microsoft Windows (2006).

3. Results

3.1. Control group (Group A)

At standard MRI (protocol A), 20 patients (100%) had an intact ACL Fig. 2. At **protocol B**, 2 patients (10%) of the 20 patients had AMB partial tear Fig. 3. However, they were proved to be intact by knee arthroscopy. This difference was due to fibro-fatty component of the tibial attachment of the AMB of the ACL which is a normal variant of the intact ACL (10).

3.2. Clinically suspected ACL lesions group (Group B)

3.2.1. The standard MRI findings (protocol A) compared with arthroscopy

The ACL as a whole was normal in 4 patients (19%), partially torn in 6 patients (28.6%) Fig. 4, and completely torn in 11 patients (52.4%) Fig. 6 (Table 2).

3.2.2. Axial oblique sequences (***protocol B***) compared with arthroscopy

The AMB was normal in 5 patients (23.8%), partially torn in 4 patients (19%) and completely torn in 12 patients (57.1%) Fig. 7 (Table 3).

The PLB was normal in 2 patients (9.5%), partially torn in 7 patients (33.3%) and completely torn in 12 patients (57.1%) Fig. 8 (Table 4).

The ACL as a whole was normal in 2 patients (9.5%), partially torn in 6 patients (28.6%), and completely torn in 13 patients (61.9%) Fig. 5 (Table 5).

3.3. Comparative statistical analysis

The comparative study was done using MRI **protocol A** versus **protocol B** for isolated anteromedial and posterolateral bundles as well as for ACL lesions as a whole with comparing these findings with arthroscopy as the gold standard **(**Table 6 and charts from 1–3).

4. Discussion

The anterior cruciate ligament (ACL) is an important structure in maintaining the normal biomechanics of the knee and is the most commonly injured knee ligament. However, the oblique course of the ACL within the intercondylar fossa limits the visualization and assessment of the pathology of the ligament (11).

The anatomy of the ACL ligament is complex, reflecting its function of providing sagittal and rotational stabilization of the knee joint. MRI nowadays has a central role in the diagnostic strategy. When faced with a clinical suspicion of knee ACL injury, direct and indirect signs of ACL tears must both be sought using MRI to obtain the excellent diagnostic performance described in the literature. Imaging partial tears seems to be more tricky, constituting an important prognostic issue (12).

Anterior cruciate ligament lesions may involve only part of a single bundle or both bundles (3). Correct assessment regarding the presence, severity and location of the lesion is clinically relevant. A bundle specific approach comprises a partial tear of both bundles, a partial tear of a single bundle and/or a complete tear of one bundle. Assessment of individual bundle status is likely to be increasingly relevant to the patient management with the introduction of new reconstructive techniques such as single bundle augmentation surgery, which has

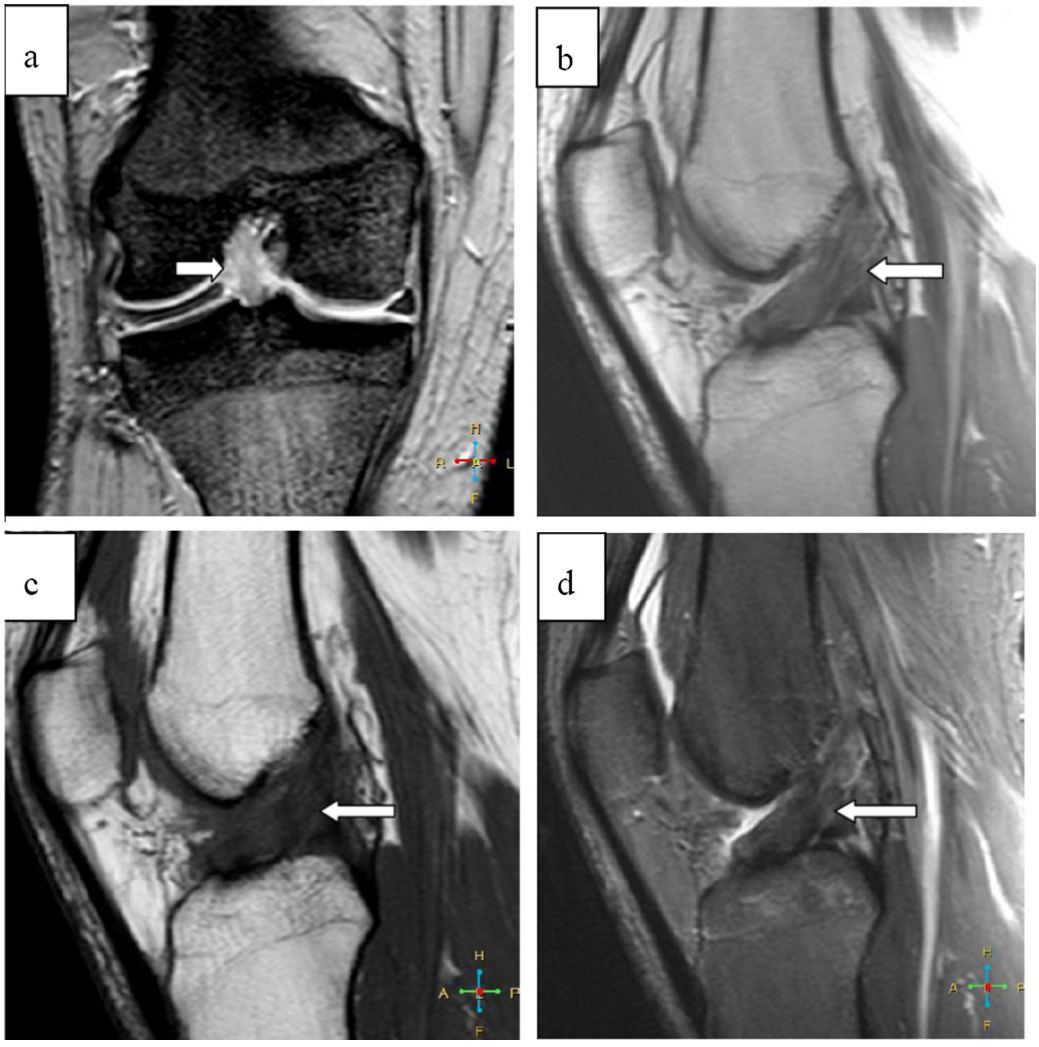


Fig. 4 (a) Coronal FSE T2 fat suppression, (b) sagittal FSE PD, (c) sagittal FSE T2 and (d) sagittal STIR MRI of the right knee. The ACL presented fuzzy outline with areas of intermediate signal intensity in all pulse sequences within its substance, yet its fibers are seen stretched. Findings are those of ACL contusion.

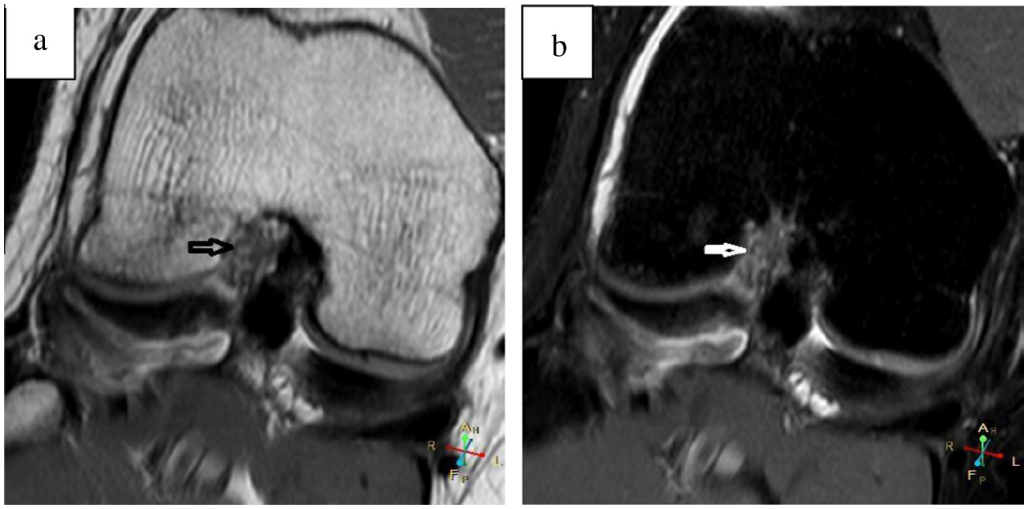


Fig. 5 MR imaging of the ACL of the same patient as Fig. 4. **(Protocol B)** (a) oblique axial intermediate-weighted imaging, (b) with fat suppression, shows complete tear of both bundles (arrow).

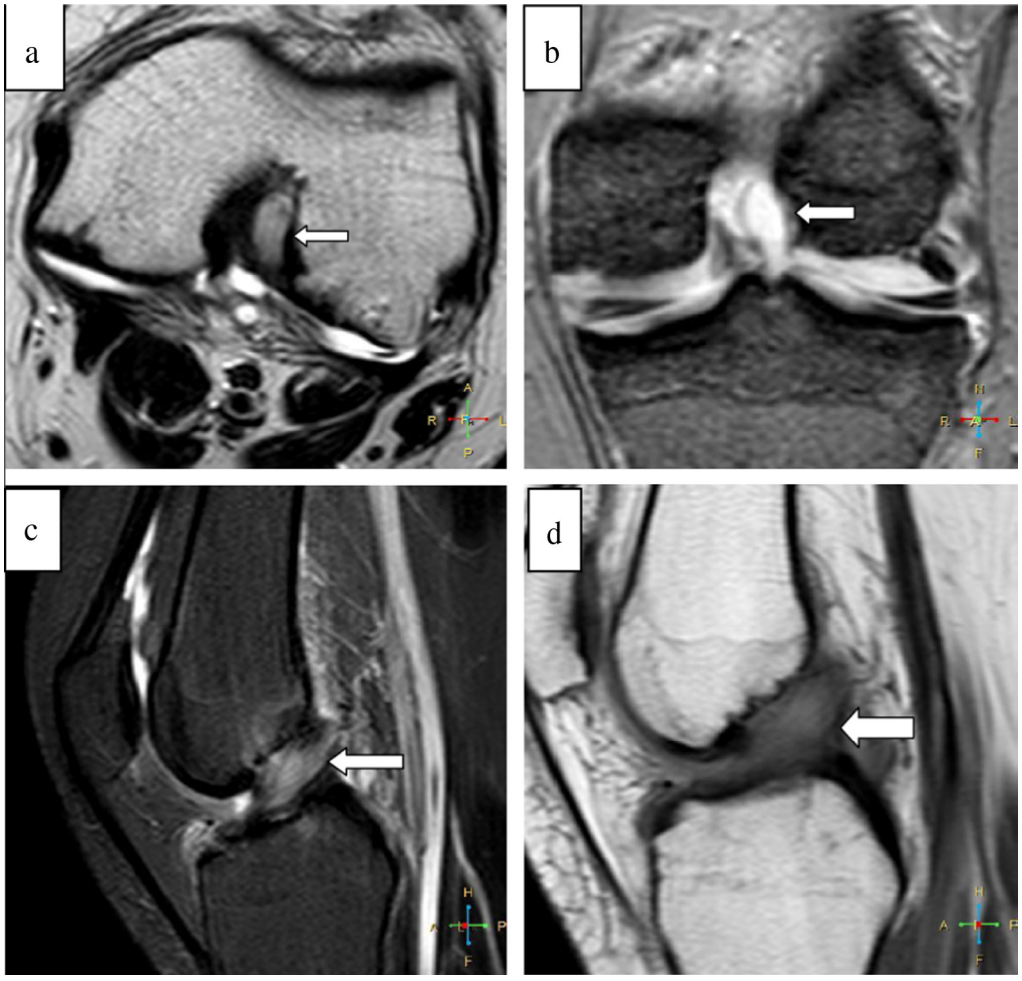


Fig. 6 (a) Axial FSE T2, (b) coronal FSE T2 fat suppression, (c) sagittal STIR and (d) FSE PD MRI of left knee of a female patient, 18 years old who suffered from injury to the knee. It shows intra substance areas of high signal intensity in all pulse sequences, compatible with high grade/complete tear of the ACL.

Table 1 Protocol of MRI.

	TR	TE	FOV	SL	Gap	Matrix	NEX
Standard protocol (A)							
Sagittal PD(TSE)	5,000	30	180	4.5	1	512 × 256	3
Coronal T2 FS	472	18	160	5	0.4	512 × 256	2
Axial T2(TSE)	3.6	100	170	5.5	1.5	256 × 192	2
Sagittal T1(TSE)	5.5	30	180	3	0.3	512 × 256	3
Sagittal STIR	5000	30	180	4.5	1	256 × 192	3
Additional sequences. Protocol (B)							
Axial oblique PD and PD FE	5000	30	160	3	0.3	256 × 192	3

been advocated for patients who have a severe tear of only one rather than both bundles. It stands to reason that each bundle should be individually evaluated on MRI as well as the ACL as a whole when an ACL tear is suspected (4).

Almost all previous MR-based studies addressing partial tears of the ACL (13–17,7) have considered the ACL as a whole unit and have not investigated the accuracy of MRI in diagnosing individual ACL bundle tear.

Fetal studies of Ferretti et al. (18) and arthroscopic studies Steckel et al. (19) demonstrated the presence of two functional bundles in the ACL.

Amis and Dawkins identified three bundles during cadaveric knee examinations, named as anteromedial, posterolateral and intermediate bundles (20).

In our study, two bundles were observed using **protocol B**: anteromedial and posterolateral bundles, while they could not be almost separated using protocol A. This agrees with a recent study by Van Dyck et al., who classified ACL into isolated AM and PL bundles (21).

Steckel et al. (22) were able to assess partial ACL tear in a particular bundle using cadaver knees. In another study by Adriaensen who used cadaver knees, MRI with arthroscopic correlation has proven to adequately identify the anteromedial bundle (AMB) and posterolateral bundle (PLB) (23).

Table 2 ACL lesions in protocol (A).

MRI			Arthroscopy			
			Normal	Partial tear	Complete tear	Total
ACL as a whole	Normal(4)	Count	2	2	0	4
		% within Total-A	50.0%	50.0%	0.0%	100.0%
		% within Total-Scope	100.0%	40.0%	0.0%	19.0%
		% of Total	9.5%	9.5%	0.0%	19.0%
	Partial tear(6)	Count	0	3	3	6
		% within Total-A	0.0%	50.0%	50.0%	100.0%
		% within Total-Scope	0.0%	60.0%	21.4%	28.6%
		% of Total	0.0%	14.3%	14.3%	28.6%
	Complete tear(11)	Count	0	0	11	11
		% within Total-A	0.0%	0.0%	100.0%	100.0%
		% within Total-Scope	0.0%	0.0%	78.6%	52.4%
		% of Total	0.0%	0.0%	52.4%	52.4%
Total(21)		Count	2	5	14	21
		% within Total-A	9.5%	23.8%	66.7%	100.0%
		% within Total-Scope	100.0%	100.0%	100.0%	100.0%
		% of Total	9.5%	23.8%	66.7%	100.0%

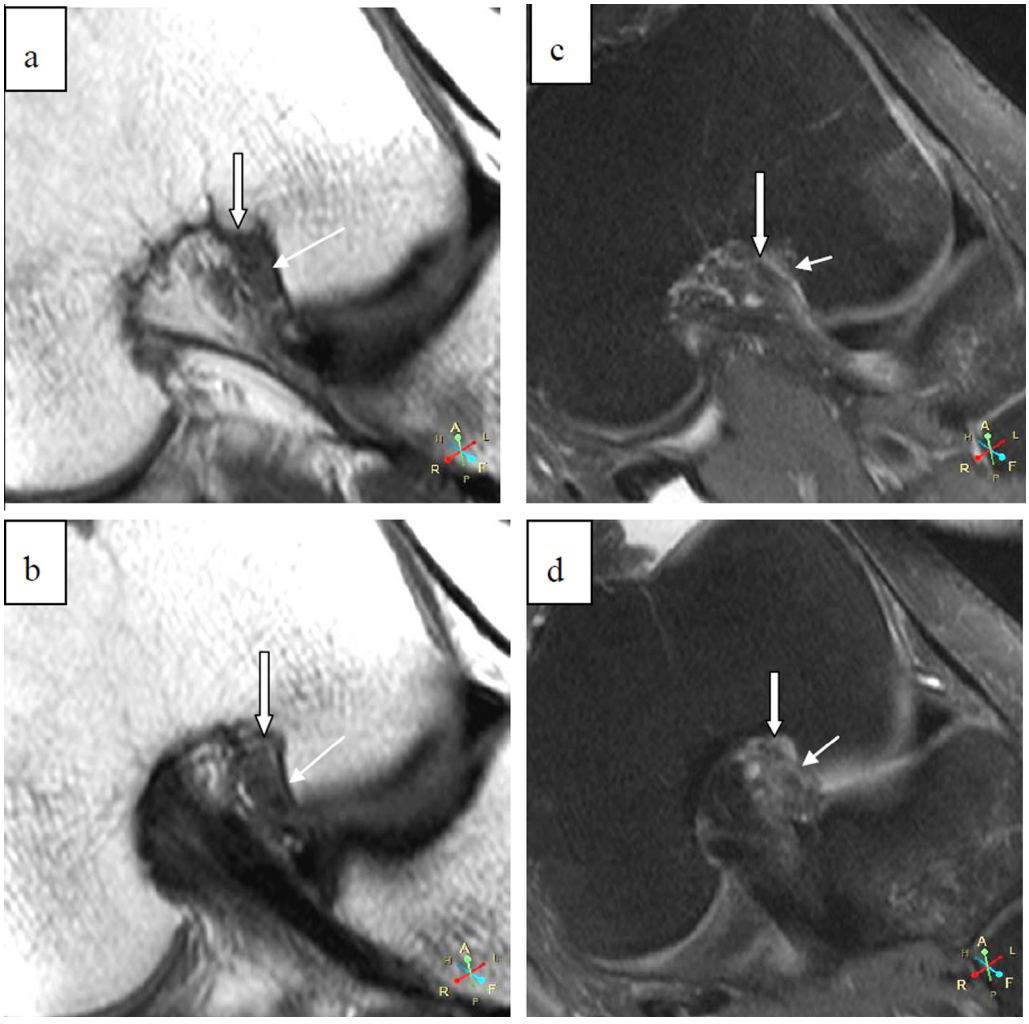


Fig. 7 MR imaging of the ACL (a and b) oblique axial intermediate-weighted imaging, (c and d) with fat suppression, shows a complete tear of the posterolateral bundle at the femoral insertion (a and c) (narrow arrow), and complete tear of the anteromedial bundle at the mid portion of the ACL (b and d) (block arrow), which is compatible with complete tear of both bundles.

Table 3 AMB lesions in protocol (B) compared to the arthroscopy findings.

MRI			AMB-arthroscopy			
			Normal	Partial tear	Complete tear	Total
AMB-B	Normal(5)	Count	5	0	0	5
		% within AMB-B	100.0%	0.0%	0.0%	100.0%
		% within AMB-Scope	100.0%	0.0%	0.0%	23.8%
		% of Total	23.8%	0.0%	0.0%	23.8%
	Partial tear(4)	Count	0	2	2	4
		% within AMB-B	0.0%	50.0%	50.0%	100.0%
		% within AMB-Scope	0.0%	100.0%	14.3%	19.0%
		% of Total	0.0%	9.5%	9.5%	19.0%
	Complete tear(12)	Count	0	0	12	12
		% within AMB-B	0.0%	0.0%	100.0%	100.0%
		% within AMB-Scope	0.0%	0.0%	85.7%	57.1%
		% of Total	0.0%	0.0%	57.1%	57.1%
Total(21)		Count	5	2	14	21
		% within AMB-B	23.8%	9.5%	66.7%	100.0%
		% within AMB-Scope	100.0%	100.0%	100.0%	100.0%
		% of Total	23.8%	9.5%	66.7%	100.0%

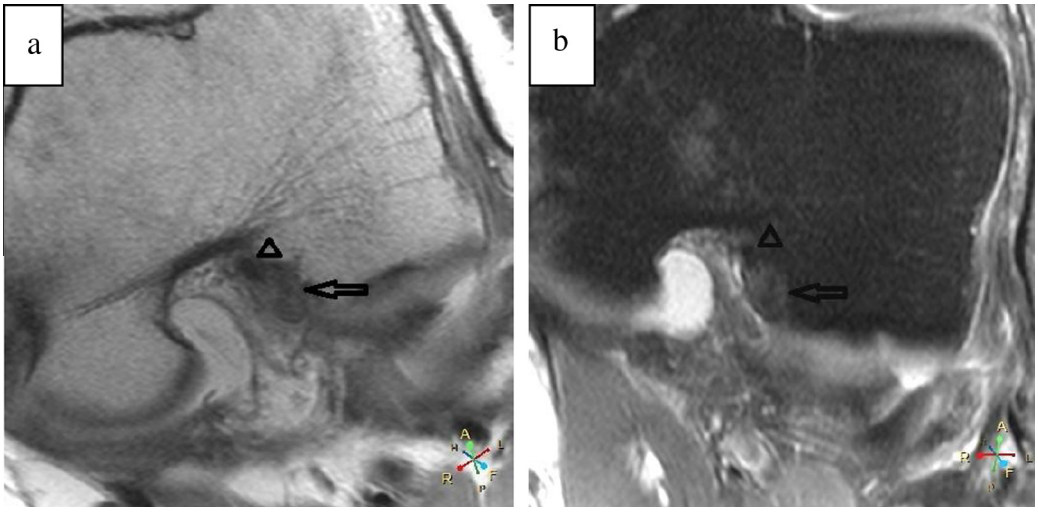


Fig. 8 (a) Oblique axial intermediate-weighted imaging: with (b) fat suppression, of the ACL near its femoral attachment shows a normal anteromedial bundle (open arrow head) and a high-signal swollen posterolateral bundle (long arrow), compatible with a partial tear of the posterolateral bundle, which was proved by arthroscopy.

In our study, we had 41 patients classified into two groups: 20 patients with no signs or symptoms of ACL lesions who underwent knee arthroscopy for other reasons than ACL injury, and 21 patients with clinically suspected ACL lesions. They had no history of knee surgery or previous arthroscopy.

This agrees with Ng et al., who studied a total 60 knees with a normal ACL to help establish the normal appearances of the ACL on oblique axial MR imaging (10).

In the control group of our study, 2 patients (20%) out of 20 were diagnosed to have partial tear of the anteromedial bundle of the ACL, due to a focal area of hyper-intensity in the bundle. It was proved to be intact by arthroscopy. This false positive result was considered to be due to the fibro-fatty component of the ACL.

This agreed with Ng et al., who studied the appearance of individual bundles of the normal ACL and considered this as a normal variant (10).

Oblique axial imaging by Ng et al., improves the visualization of normal ACL bundles over standard MR imaging using 3T magnet. (24).

The current study is to use an oblique axial plane to visualize the ACL on 1.5T MR imaging to study each individual bundle lesion.

Van Dyck et al. classified the patients into normal, complete tear, partial tear, isolated anteromedial or posterolateral bundle tear and mucoid degeneration (7).

In the current study we classified the patients into normal, complete tear, partial tear and mucoid degeneration. Each

Table 4 PMB lesions in protocol (B) compared to arthroscopy findings.

MRI			PLB-arthroscopy			
			Normal	Partial tear	Complete tear	Total
PLB-B	Normal(2)	Count	2	0	0	2
		% within PLB-B	100.0%	0.0%	0.0%	100.0%
		% within PLB-Scope	100.0%	0.0%	0.0%	9.5%
		% of Total	9.5%	0.0%	0.0%	9.5%
	Partial tear(7)	Count	0	5	2	7
		% within PLB-B	0.0%	83.3%	14.3%	100.0%
		% within PLB-Scope	0.0%	83.3%	28.6%	33.3%
		% of Total	0.0%	23.8%	9.5%	33.3%
	Complete tear(12)	Count	0	0	12	12
		% within PLB-B	0.0%	0.0%	100.0%	100.0%
		% within LB-Scope	0.0%	0.0%	85.7%	57.1%
		% of Total	0.0%	0.0%	57.1%	57.1%
Total(21)		Count	2	5	14	21
		% within PLB-B	9.5%	23.8%	66.7%	100.0%
		% within PLB-Scope	100.0%	100.0%	100.0%	100.0%
		% of Total	9.5%	23.8%	66.7%	100.0%

Table 5 ACL lesions in **protocol B** compared to arthroscopy findings.

MRI			Whole ACL-arthroscopy			
			Normal	Partial tear	Complete tear	Total
Whole ACL-B	Normal(2)	Count	2	0.00	0.00	2
		% within Total-B	100.0%	0.00	0.00	100.0%
		% within Total-Scope	100.0%	0.00	0.00	9.5%
		% of Total	9.5%	0.00	0.00	9.5%
	Partial tear(6)	Count	0	5	1	6
		% within Total-B	0.0%	55.6%	16.7%	100.0%
		% within Total-Scope	0.0%	100.0%	7.1%	28.6%
		% of Total	0.0%	23.8%	4.8%	28.6%
	Complete tear(13)	Count	0	0	13	13
		% within Total-B	0.0%	0.0%	100.0%	100.0%
		% within Total-Scope	0.0%	0.0%	92.9%	61.9%
		% of Total	0.0%	0.0%	61.9%	61.9%
Total(21)		Count	2	5	14	21
		% within Total-B	9.5%	23.8%	66.7%	100.0%
		% within Total-Scope	100.0%	100.0%	100.0%	100.0%
		% of Total	9.5%	23.8%	66.7%	100.0%

individual bundle of ACL was assessed separately. Isolated bundle tear was diagnosed as a partial tear of ACL.

Two studies showed that MR images of the knees in flexion can provide more space around the ACL within the intercondylar area, helping to decrease volume-averaging artifact and thereby allowing better visualization of the femoral end of the ligament (25,26).

In our study, the knee was examined in a supine and extended position. This agreed with many authors like Ng et al. (24) and Van Dyck et al. (7) so that the technique of the examination would be easier.

In a study primarily addressing partial tears of the ACL, Roychowdhury et al. described the appearances of the normal ACL on true axial imaging. They found wide variability in the shape of the ACL at the tibial insertion with the mid- to proximal portion of the ACL tending to be of smooth ellipse or oval configuration. This study also first described the ''isolated ACL bundle sign'' as a sign of partial ACL tear (27).

Casagranda et al. studied double bundle ACL grafts and found oblique coronal imaging useful when assessing the integrity of the ACL bundles (5).

Kwon et al. (28) reported that additional oblique planes would be useful in the evaluation of ACL tears; they found no significant difference in terms of sensitivity between the findings of normal sections and oblique coronal and sagittal sections, but specificity and accuracy increased significantly with the oblique images.

In our study we used oblique axial MR imaging of the ACL. The addition of oblique axial imaging, increased sensitivity for ACL lesions (as a whole) from 74% to 95% and the accuracy from 76% to 95% while specificity remained unchanged.

Table 6 Shows the comparative study between protocols A and B regarding different ACL lesions (Group B) with the arthroscopy as the gold standard.

Item		TP	FN	TN	FP	Sensitivity	Specificity	(+)ve PV	(−)ve PV	Accuracy
Protocol A										
AMB-A	Partial tear	1	0	6	0	100.00	100.00	100.00	100.00	100.00
	Complete tear	10	3	6	0	77.00	100.00	100.00	67.00	84.00
	Overall	12	3	6	0	80.00	100.00	100.00	67.00	86.00
PLB-A	Partial tear	3	2	2	0	60.00	100.00	100.00	50.00	71.00
	Complete tear	12	2	2	0	86.00	100.00	100.00	50.00	88.00
	Overall	15	4	2	0	79.00	100.00	100.00	33.00	81.00
Whole	Partial tear	3	2	2	0	60.00	100.00	100.00	50.00	71.00
ACL-A	Complete tear	11	3	2	0	79.00	100.00	100.00	40.00	81.00
	Overall	14	5	2	0	74.00	100.00	100.00	29.00	76.00
Protocol B										
AMB-B	Partial tear	2	0	5	0	100.00	100.00	100.00	100.00	100.00
	Complete tear	12	2	5	0	86.00	100.00	100.00	71.00	89.00
	Overall	14	2	5	0	88.00	100.00	100.00	71.00	90.00
PLB-B	Partial tear	5	0	2	0	100.00	100.00	100.00	100.00	100.00
	Complete tear	12	2	2	0	86.00	100.00	100.00	50.00	88.00
	Overall	17	2	2	0	89.00	100.00	100.00	50.00	90.00
	Partial tear	5	0	2	0	100.00	100.00	100.00	100.00	100.00
Whole	Complete tear	13	1	2	0	93.00	100.00	100.00	67.00	94.00
ACL-B	Overall	18	1	2	0	95.00	100.00	100.00	67.00	95.00

TP: true positive, FN: false negative, TN: true negative, FP: false positive, +ve PV: positive predictive value, and −ve PV: negative predictive value.

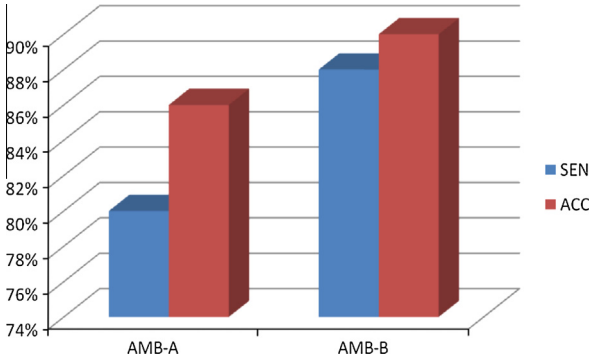


Chart 1 Comparison between the sensitivity (SEN) and the accuracy (ACC) of protocols **A** and **B** (correlated with arthroscopy) regarding anteromedial bundle (AMB), posterolateral bundle (PLB) and the ACL as a whole. AMB lesions.

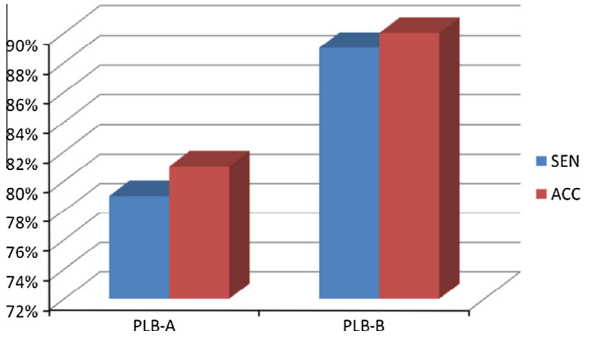


Chart 2 PLB lesions.

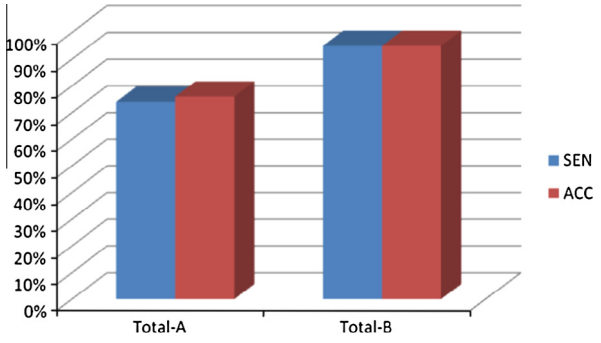


Chart 3 ACL lesions as a whole.

A study by Ng et al., has studied the diagnostic accuracy of oblique axial intermediate weighting MR imaging in detecting partial thickness anterior cruciate ligament (ACL) bundle tears (24).

This study showed the sensitivity, specificity and accuracy of standard MR imaging for the detection of anteromedial bundle partial tears to be 29%, 86% and 79%. The addition of oblique axial imaging, increased sensitivity to 71% while specificity and accuracy remained unchanged (24).

In our study the sensitivity, specificity and accuracy of standard MR imaging for the detection of anteromedial bundle lesions were shown to be 80%, 100% and 86%, however, the addition of oblique axial imaging to standard views increased sensitivity to 88% and accuracy to 90% while specificity remained unchanged.

The study conducted by Ng et al., showed the sensitivity, specificity and accuracy of standard MR imaging for posterolateral bundle tears to be 30%, 94% and 84% respectively. The addition of oblique axial imaging increased the sensitivity to 60%, while specificity and accuracy remained unchanged (24).

While in our study the sensitivity, specificity and accuracy of standard MR imaging for posterolateral bundle lesions were 78%, 100% and 81% respectively, the addition of oblique axial imaging to standard views increased the sensitivity to 89% and accuracy to 90% while specificity remained unchanged.

Many authors had used knee arthroscopy as a gold standard to study the normal appearance of the ACL (10,19,23) and to study ACL lesions (7,14,24).

This agreed with our study. MR interpretations were compared with the arthroscopic results as the standard of reference.

Limitation of our study included mucoid degeneration of the ACL; it was a rare entity. It was not diagnosed in our sample.

In conclusion, compared with standard MR imaging, the addition of oblique axial imaging improves diagnostic accuracy for detecting lesions of the ACL, including both bundles' delineation. This imaging plane seems to provide a useful adjunct to standard MR imaging when ACL lesion is suspected.

Conflict of interest

We have no conflict of interest to declare.

References

(1) Amis AA, Dawkins GP. Functional anatomy of the anterior cruciate ligament. Fibre bundle actions related to ligament replacements and injuries. J Bone Joint Surg Br 1991;73:260–7.
(2) Ochi M, Adachi N, Deie M, Kanaya A. Anterior cruciate ligament augmentation procedure with a 1-incision technique: anteromedial bundle or posterolateral bundle reconstruction. Arthroscopy 2006;22(463):e1–5.
(3) Sommerlath K, Odensten M, Lysholm J. The late course of acute partial anterior cruciate ligament tears. A nine to 15-year follow-up evaluation. Clin Orthop Relat Res 1992;281:152–8.
(4) Siebold R, Fu FH. Assessment and augmentation of symptomatic anteromedial or posterolateral bundle tears of the anterior cruciate ligament. Arthroscopy 2008;24:1289–98.
(5) Casagranda BU, Maxwell NJ, Kavanagh EC, Towers JD, Shen W, Fu FH. Normal appearance and complications of double-bundle and selective-bundle anterior cruciate ligament reconstructions using optimal MRI techniques. AJR Am J Roentgenol 2009;192(5):1407–15.
(6) Cohen SB, VanBeek C, Starman JS, Armfield D, Irrgang JJ, Fu FH. MRI measurement of the 2 bundles of the normal anterior cruciate ligament. Orthopedics 2009;32, 9.
(7) Van Dyck P, De Smet E, Veryser J, Lambrecht V, Gielen JL, Vanhoenacker FM, et al. Partial tear of the anterior cruciate ligament of the knee: injury patterns on MR imaging. Knee Surg Sports Traumatol Arthrosc 2012;20:256–61.
(8) Hong SH, Choi JY, Lee GK, Choi JA, Chung HW, Kang HS. Grading of anterior cruciate ligament injury. Diagnostic efficacy of oblique coronal magnetic resonance imaging of the knee. J Comput Assist Tomogr 2003;27:814–9.
(9) Smith DK, May DA, Phillips P. MR imaging of the anterior cruciate ligament: frequency of discordant findings on sagittal oblique images and correlation with arthroscopic findings. AJR 1996;166:411–3.
(10) Ng WHA, Griffith JF, Law KY, Ting JW, Tipoe GL, Ahuja AT, et al. Oblique axial MR imaging of the normal anterior cruciate ligament bundles. Skeletal Radiol 2012;40:1587–94.
(11) Chambat P et al. Orthop Traumatol: Surg Res 2013;99S:S43–52.
(12) Guenoun D et al. The contribution of MRI to the diagnosis of traumatic tears of the anterior cruciate ligament. Diagn Inter Imag 2012;93:331–41.
(13) Umans H, Wimpfheimer O, Haramati N, et al. Diagnosis of partial tear of the anterior cruciate ligament of the knee: value of MR imaging. AJR Am J Roentgenol 1995;165:893–7.
(14) Van Dyck P, Vanhoenacker FM, Gielen JL, Dossche L, Van Gestel J, Wouters K, et al. Three tesla magnetic resonance imaging of the anterior cruciate ligament of the knee: can we differentiate complete from partial tears? Skeletal Radiol 2011;40:701–7.
(15) DeFranco MJ, Bach Jr BR. A comprehensive review of partial anterior cruciate ligament tears. J Bone Joint Surg Am 2009;91:198–208.
(16) Yao L, Gentili A, Petrus L, Lee LK. Partial ACL rupture: an MR diagnosis? Skeletal Radiol 1995;24:247–51.
(17) Brandser EA, Riley MA, Berbaum KS, el-Khoury GY, Bennett DL. MR imaging of anterior cruciate ligament injury: independent value of primary and secondary signs. Am J Roentgenol 1996;167:121–6.
(18) Ferretti M, Levicoff EA, Macpherson TA, Moreland MS, Cohen M. The fetal anterior cruciate ligament: an anatomic and histologic study. Arthroscopy 2007;23:278–83, FH.
(19) Steckel H, Fu FH, Baums MH, Klinger HM. Arthroscopic evaluation of the ACL double bundle structure. Knee Surg Sports Traumatol Arthrosc 2009;17:782–5.
(20) Amis AA, Bull AMJ, Lie DTT. Biomechanics of rotational instability and anatomic anterior cruciate ligament reconstruction. Oper Tech Orthop 2005;15:29–35.
(21) Van Dyck P, Gielen JL, Vanhoenacker FM, Wouters K, Dossche L, Parizel PM. Stable or unstable tear of the anterior cruciate ligament of the knee: an MR diagnosis? Skeletal Radiol 2012;41(3):273–80 [Medline] [Full Text].
(22) Steckel H, Vadala G, Davis D, Musahl V, Fu FH. 3-T MR imaging of partial ACL tears: a cadaver study. Knee Surg Sports Traumatol Arthrosc 2007;15:1066–71.
(23) Adriaensen ME, Hogan B, Al-Bulushi HI, Kavanagh EC. Double-bundle depiction of the anterior cruciate ligament at 3 Tesla. Skeletal Radiol Jul 2012;41(7):831–4.
(24) Ng WHA, Griffith JF, Law KY, Yung PSH, Hung EHY, et al. MRI diagnosis of ACL bundle tears: value of oblique axial imaging. Skeletal Radiol 2013;42:209–17.
(25) Pereira ER, Ryu KN, Ahn JM, Kayser F, Bielecki D, Resnick D. Evaluation of the anterior cruciate ligament of the knee: comparison between partial flexion true sagittal and extension sagittal oblique positions during MR imaging. Clin Radiol 1998;53:574–8.
(26) Niitsu M, Ikeda K, Fukubayashi T, Anno I, Itai Y. Knee extension and flexion: MR delineation of normal and torn anterior cruciate ligaments. J Comput Assist Tomogr 1996;20:322–7.
(27) Roychowdhury S, Fitzgerald SW, Sonin AH, Peduto AJ, Miller FH, Hoff FL. Using MR imaging to diagnose partial tears of the anterior cruciate ligament: value of axial images. AJR Am J Roentgenol 1997;168:1487–91.
(28) Kwon JW, Yoon YC, Kim YN, Ahn JH, Choe BK. Which oblique plane is more helpful in diagnosing an anterior cruciate ligament tear? Clin Radiol 2009;64:291.