MRI Diagnosis of Anterior Cruciate Ligament Tears: What is the Added Value of Oblique Sagittal Technique?

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Abstract

**Background:** The Anterior Cruciate Ligament (ACL) is a key structure in the knee joint and one of the most frequently injured in clinical practice. Conventional Magnetic Resonance Imaging (MRI) is the preferred method for the diagnosis of ACL and associated injuries. However, the sensitivity and specificity of standard MRI for the detection of partial ACL tears is low.

**Purpose:** To assess the diagnostic efficacy of additional oblique sagittal MR images for MRI diagnosis of Anterior Cruciate Ligament (ACL) tears.

**Patients and Methods:** We prospectively evaluated 51 patients who were referred to the MRI unit because of trauma of knee soft tissue structures. MR images were interpreted using two methods: Standard images (method A); and standard images together with additional oblique sagittal images (method B). The condition of the ACL (normal or tear) was estimated. The findings were compared with the arthroscopic results as a golden standard.

**Results:** Standard knee MR protocol (method A) was positive in 44 out of 51 cases (86.3%), with 18 cases diagnosed as complete tear (35.3%), 26 cases were diagnosed as partial tear (51.0%). Whereas, using method B: 18 cases were diagnosed as complete tear (35.3%), 31 cases were diagnosed as partial tear (60.8%) and two cases were normal (3.9%). Both methods achieved similar results in detection of complete ACL tear. However there was statistically significant difference between the two methods regarding the diagnosis of partial tear of the ACL (p-value <0.016).

**Conclusion:** Adding oblique sagittal technique to the standard MR imaging improved diagnostic accuracy for diagnosing partial ACL tear. However, oblique sagittal technique is as efficient as standard MRI for the evaluation of complete ACL tear. Thus, suggesting the use of additional oblique-sagittal images in cases of suspicion of partial ACL tear.

**Key Words:** MR knee – ACL tear – Sagittal oblique technique.

Introduction

**THE** Anterior Cruciate Ligament (ACL) is considered as one of the major stabilizers of the knee joint [1]. ACL is the most frequently injured large ligament in the knee, with a recorded incidence of 8.1/100,000 every year [2]. Ligament instability may cause significant patient disablement, with subsequent occurrence of degenerative knee joint disease [3].

Magnetic Resonance Imaging (MRI) is the most preferable method for the non-invasive assessment of the ACL [4]. Standard orthogonal MR images cannot view the complete ACL on a single image as the ACL originates from the posteromedial aspect of the lateral femoral condyle, then courses obliquely in an antero-medial direction to insert at the central and medial parts of the tibial intercondylar notch. Thus, 5%-10% of normal ACL is poorly visualized on standard sagittal MR images [5,6].

MRI demonstrates great sensitivity and specificity for the evaluation of acute complete tear of the ACL. Yet, standard MRI protocol is limited for the detection of partial or chronic tears. Partial tears account for 10-16% of all ACL tears and are difficult to diagnose on physical exam [7,8]. Despite that partial ACL tears do not necessitate immediate surgical treatment, diagnosis is crucial for the reason that a significant number of partial tears progress to complete ACL deficiency with development of lax ligament [9,10].

The inferior accuracy of standard MR protocol for partial ACL tear can be promoted by using additional, dedicated MRI techniques [11-13]. These techniques can visualize the ACL along its whole length by slicing along the plane parallel to the long axis of the ligament [6].
The purpose of this study was to assess the diagnostic efficacy of additional oblique sagittal MR images for the evaluation of ACL tears.

**Patients and Methods**

The Hospital Ethical Committee approved this study and informed consents were obtained from all patients. During 6 months duration from November 2014 to April 2015, we prospectively evaluated 51 patients with MRI examination of the knee. They were 11 females and 40 males, with their age range from 10 to 70 years. Median age was 37.65 years. Patients were referred from the Orthopedic Department, Kasr El-Ainy Hospital, Cairo University. MRI examinations were performed for the assessment of the ligaments, the menisci together with the articular cartilage.

**Inclusion criteria:**

Patients with painful knee joint, locking, giving way because of trauma to the knee joint soft tissue structures.

**Exclusion criteria:**

History of previous knee operation, inflammatory joint disease, active articular infection, metabolic bone disease or absolute contraindications for MR examination as cardiac pacemaker, cochlear implant, aneurysmal clipping and claustrophobia.

MRI examinations were carried out using a 1.5-Tesla MR scanner (Gyroscan Intera, Philips medical systems, Best, Netherlands). A dedicated knee coil was used. The patients were examined in supine position with slight external rotation of the knee joint.

The MRI imaging protocol included standard sequences (Sagittal proton density, Sagittal T1, Sagittal STIR, Coronal fat-suppression T2WI and axial T2 WI) and additional oblique sagittal and oblique coronal images. MRI imaging parameters are demonstrated in Table (1). Sagittal images of standard MRI protocol were used as topogram for planning the 3mm section thickness oblique-coronal plane, parallel to femoral intercondylar roof along the course of the ACL. Obtained oblique coronal images which show the whole course of ACL, were used as a topogram for 3mm section thickness oblique-sagittal images in a plane parallel to the lateral femoral condyle medial border (Fig. 1A-D).

**MR analysis:**

The MRI images were assessed by using two methods: Standard sagittal images only (method A); and standard sagittal with additional oblique sagittal images (method B).

Status of ACL on MR images was classified as intact ACL or torn. The ACL was considered intact, when its fibers could be traced on contiguous sections from the femoral to the tibial attachment. ACL was categorized as completely torn if any of the these signs were detected: Complete disruption of all of ligament fibers; complete absence or atrophy of the ligament with abnormal vertical or horizontal orientation, or complete replacement of the ligament by an edematous mass [6,14]. Partial ACL tear was classified as: Direct presentation of partial ACL rupture (direct visualization of partial fibres disruption), focal or diffuse hyperintense signal (intra-substance high signal intensity), together with the abnormal course of ACL (presented by focal swelling or thinning of the ACL and/or a wavy course of the ACL with maintained continuity) [14,15].

The position of partial rupture of the ACL was also assessed and classified on MRI as upper attachment, middle part and lower attachment rupture. Finally, we compared the number of slices that show the whole course of ACL between standard sagittal images and oblique sagittal images.

**Statistical analysis:**

The results of MRI were compared statistically with arthroscopic findings which were considered the reference standard for diagnosis.

Statistical analyses were performed using Statistical Package for Social Sciences for Windows 15.0 (SPSS Inc., Chicago, IL, USA). Data was summarized using frequencies (number of cases) and percentages for qualitative variables. Statistical difference between standard MRI technique and oblique sagittal technique was done using marginal homogeneity test. \( p \)-value < 0.05 was considered as statistically significant.

**Results**

The standard knee MR imaging protocol (method A) was positive (complete or partial tear of the ACL) in 44 out of 51 cases (86.3%) with normal ACL in seven cases (13.7%).

Using method A, 18 cases were diagnosed as complete tear (35.3%), 26 cases were diagnosed as partial tear (51.0%) (Fig. 2). Whereas, using method B, 18 cases were diagnosed as complete tear (35.3%), 31 cases diagnosed as partial tear (60.8%) and two cases were normal (3.9%) (Figs. 3,4).
Additionally, we compared the findings of partial ACL rupture, position of ACL rupture, as well as, number of tomograms that show the entire length of the ACL between the two methods.

A- Findings of partial rupture of the ACL:

There was statistically significant difference between method A and method B regarding the direct presentation of partial rupture of the ACL (p-value <0.016). The direct presentation of partial ACL tear was higher (77.4%) using method B compared to method A (50%). Method B was slightly more accurate than method A in detecting an intrasubstance hyperintense signal (22.6% in method B compared to 19.2% using method A). However, the presentation of abnormal course of ACL was higher in method A (30.8%) compared to method B (0%) (Table 2).

B- Position of the partial rupture of ACL:

There was no statistically significant difference between methods A and B for the detection of the site of rupture of ACL (upper attachment, middle part or lower attachment) with p-value >0.49 (Table 3).

C- Number of tomograms showing the whole course of ACL:

The number of slices showing the entire length of the ACL was compared between the standard sagittal images and oblique sagittal images. The number of slices showing the entire length of the ACL using standard sagittal technique (2.38), was statistically significantly lower than the number of slices obtained by oblique-sagittal technique (3.45) with (p<0.001).

Fig. (1): Oblique coronal and sagittal MR images of a normal ACL.

A 30 years old patient complaining of painful knee, orthogonal sagittal image used as a topogram for planning the 3mm section thickness coronal oblique images in a plane parallel to the roof of femoral intercondylar notch (A). An oblique coronal T2WI showing straight fibers of an intact ACL in its entire length (B). Both femoral (arrow heads) and tibial (arrows) attachment sites are clearly identified. Obtained oblique coronal image used for planning 3mm section thickness sagittal oblique image in the plane parallel to the lateral femoral condyle medial border from superolateral to inferomedial (C). An oblique sagittal T2WI demonstrates the ACL in its entire length (D).
Fig. (2): Partial tear of ACL of the left knee joint in a 36-year-old female patient after trauma.

Standard sagittal T2 (A) and sagittal STIR (B) MR images of the left knee, revealed an intact ACL (white arrows). Oblique coronal PD with fat suppression (C) and oblique sagittal T2 with fat suppression (D) demonstrate an intraligamentous hyperintense MRI signal along the proximal substance of the ACL (white arrows), but with some fibers intact. Note trabecular bone injury of the posterior surface of the lateral femoral condyle (arrow heads). Partial tear of the ACL was diagnosed which was confirmed at arthroscopy.

Fig. (3): Partial ACL tear in a 23-year-old male patient with left knee pain and locking after playing football.

Standard sagittal PD (A) and sagittal STIR (B) MR images of the left knee demonstrate acute intrasubstance tear of the ACL evident by thickening of the ligament and oedematous high signal of its fibres (white arrows). The fibres are still in continuity suggestive of partial ACL tear. Oblique coronal T2 (C), oblique sagittal PD (D) and oblique sagittal T2 (E) MR images demonstrate partial disruption of ACL fibres with an area of high signal intensity (blue arrows) at its mid-substance in all pulse sequences, but with some fibres still intact (white arrows), indicating partial tear of the ACL.
Fig. (4): Complete ACL tear in a 24-year-old male patient with left knee pain and giving way after football playing.

Standard sagittal PD (A) and sagittal STIR (B) MR images of the left knee demonstrate fuzzy outline of the ACL with total discontinuity and an area of increased signal intensity, extending completely across the ACL (white arrows) denoting complete tear of the ACL. Oblique coronal PD with fat suppression (C), oblique sagittal PD with fat suppression MRI (D & E) demonstrate a total discontinuity with an area of increased signal intensity extending completely across the mid-substance of ACL (blue arrows) denoting complete tear of ACL. Residual stumps at femoral and tibial attachments (white arrows) are thickened and show increased MR signal intensity. Note associated trabecular bone injury of the posterior aspect of the lateral collateral ligament and edematous subcutaneous tissue at the lateral aspect of the knee.

Table (1): Imaging parameters for MRI examination.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>TR</th>
<th>TE</th>
<th>FOV</th>
<th>SL</th>
<th>Gap</th>
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<td><strong>Standard protocol (A):</strong></td>
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<td>Sagittal PD (TSE)</td>
<td>5,000</td>
<td>30</td>
<td>180</td>
<td>4.5</td>
<td>1</td>
<td>512 X 256</td>
<td>3</td>
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<tr>
<td>Coronal T2 FS</td>
<td>472</td>
<td>18</td>
<td>160</td>
<td>5</td>
<td>0.4</td>
<td>512 X 256</td>
<td>2</td>
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<tr>
<td>Axial T2 (TSE)</td>
<td>3.6</td>
<td>100</td>
<td>170</td>
<td>5.5</td>
<td>1.5</td>
<td>256 X 192</td>
<td>2</td>
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<tr>
<td>Sagittal T1 (TSE)</td>
<td>5.5</td>
<td>30</td>
<td>180</td>
<td>3</td>
<td>0.3</td>
<td>512 X 256</td>
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<td>Sagittal STIR</td>
<td>5,000</td>
<td>30</td>
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<td>4.5</td>
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<td>256 X 192</td>
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<td><strong>Additional sequences protocol (B):</strong></td>
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Table (2): Comparison of the findings of partial ACL tear between method A and method B (number of patients=51).

<table>
<thead>
<tr>
<th>ACL partial rupture</th>
<th>Protocol A</th>
<th>Protocol B</th>
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<tbody>
<tr>
<td>Direct presentation</td>
<td>13 (50.0%)</td>
<td>24 (77.4%)</td>
</tr>
<tr>
<td>Course of ACL</td>
<td>8 (30.8%)</td>
<td>0</td>
</tr>
<tr>
<td>Hyperintense signal</td>
<td>5 (19.2%)</td>
<td>7 (22.6%)</td>
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<tr>
<td>Total</td>
<td>26 (100.0%)</td>
<td>31 (100.0%)</td>
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<tr>
<th>Position of the partial rupture of ACL</th>
<th>Method A</th>
<th>Method B</th>
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<tr>
<td>Upper attachment</td>
<td>9 (34.6%)</td>
<td>10 (32.3%)</td>
</tr>
<tr>
<td>Middle part</td>
<td>6 (23.1%)</td>
<td>7 (22.6%)</td>
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<tr>
<td>Lower attachment</td>
<td>11 (42.3%)</td>
<td>14 (45.2%)</td>
</tr>
<tr>
<td>Total</td>
<td>26 (100.0%)</td>
<td>31 (100.0%)</td>
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Discussion

Nowadays, MRI diagnostic protocols and technical abilities have almost completely excluded the use of diagnostic arthroscopy [7]. However, the diagnosis of partial tears is problematic due to striated appearance of a normal ACL together with increased signal on fluid-sensitive sequences. Furthermore, mucinous degeneration of the ACL with or without ganglion cyst development lead to diffuse intra-ligamentous increased signal intensity, which can be confused with a ligament tear [10].

Dedicated MR protocols, including imaging the knee joint in a slightly flexed position or obtaining images in an oblique sagittal and oblique coronal planes, can improve the diagnostic accuracy of partial ACL tears [11,12,16]. Imaging the knee joint in a flexed position improves the diagnostic accuracy of MRI due to loss of volume averaging in the intercondylar notch. Additionally, the unstretched ligament is wider and thus can be precisely evaluated [16,17]. However, the need for patient’s repositioning in order to perform flexion technique, lessens its reproducibility [11].

Additional oblique sagittal and oblique coronal imaging planes have been employed to improve the accuracy of MRI for the diagnosis of ACL tear [11,13]. The use of oblique sagittal technique follows the orientation and course of the ACL, reducing volume averaging and also permitting visualization of most of the ligament fibers in a single slice [19]. Technically, the oblique sagittal plane is easy to acquire and does not necessitate repositioning of the knee joint. Similar to other investigators [6,11,13] in this study, the knee joint was examined in a supine extended position with slight external rotation.

Various particular techniques for acquiring oblique sagittal MR images have been described in literature. Do-Dai and his colleagues obtained oblique sagittal images for the ACL with the imaging plane parallel to the medial border of the lateral femoral condyle [18]. Another method was presented by Buckwalter and Pennes who recommended an imaging plane angled 15 degree from the orthogonal sagittal plane [8]. On the other hand, Nakanishi et al., acquired oblique sagittal images from an axial localizing sequence at an angle of 10 [17]. Lastly, Barberie et al., compared the use of coronal vs axial planes as localizing sequences to obtain oblique sagittal images of the ACL. Best performance was attained with oblique sagittal images acquired from the coronal sequence in a plane parallel to a line between the medial border of the lateral femoral condyle in the intercondylar notch and the intercondylar eminence [19]. In this study, we obtained oblique sagittal images oriented parallel to the lateral femoral condyle medial border.

In the current presented study, both standard MRI technique (method A) and oblique sagittal technique (method B) achieved similar results in detection of complete ACL tear. However, there was statistically significant difference regarding the detection of partial tear of the ACL between the two methods. The lower accuracy of standard MR imaging in diagnosing partial tear of the ACL is caused by the oblique course of the ligament, its relatively fine fibrillar structure, together with swelling, oedema and hemorrhage that impede precise delineation of a partial ligament tear [20].

This was in agreement with Nenezic and Kocijanic, who studied the value of the oblique sagittal MRI technique for ACL tears in a total of 149 patients. They found that the additional oblique sagittal imaging upgraded the diagnostic accuracy of partial ACL tear, however, the oblique sagittal MRI was just as accurate as the standard MR protocol for the diagnosis of complete ACL tear [11].

Similarly, Kosaka and his colleagues had concluded that additional oblique sagittal MRI technique significantly increased the diagnostic accuracy of MRI for the detection of partial ACL tear compared with the standard MRI protocol [6].

In this study, there was statistically significant difference between method A and method B regarding the direct presentation of partial rupture of the ACL (p-value <0.016). The direct presentation of partial ACL tear was higher (77.4%) using method B compared to using method A (50%). We also found that additional oblique sagittal MR technique are slightly more precise (22.6%) than standard MRI (19.2%) in detecting ACL abnormal focal intraligamentous hyperintense signal on T2WI, a sign of edema due to microruptures of the ACL fibres. This was in line with previous findings of Nenezic and Kocijanic [11].

We also assessed the location of ACL partial tear. Similar to the findings of previous study by Kwon et al., [12], we found that the most common site of ACL partial tear was its lower attachment.

Additionally, there was statistically significant difference between standard sagittal images and oblique sagittal images regarding the number of MR slices that showed the whole course of ACL.
Oblique sagittal images allowed the ACL to be assessed in larger number of slices compared to standard sagittal images. This was previously explained due to angulations in two planes with two phases of paracoronal and sagittal tomograms which represent the true axis of the ACL ligament. This coincided with the findings of the previous studies [16,18,20].

Our study had few limitations: First, inconsistent time period between onset of symptoms or knee trauma and the MRI examination. Second, relatively small number of patients with partial ACL tears included in the study.

In conclusion, the addition of oblique sagittal technique to the standard MR imaging improved the diagnostic accuracy for the diagnosis of partial ACL tear. However, oblique sagittal technique is as efficient as standard MRI for the evaluation of a complete ACL tear. Thus, suggesting the use of additional oblique-sagittal images in cases of suspicion of partial ACL tear.

Conflict of interests:
The authors declare no conflicts of interests.

Acknowledgment:
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References


تشخيص تمزق الرباط الصليبي الأمامي لمفصل الأركية: ما هي القيمة المضافة للتصوير السهيمي المائل؟

الفرض: تقييم كفاءة التصوير السهيمي المائل في تشخيص تمزق الرباط الصليبي الأمامي.

المرضى والطريقة: شملت هذه الدراسة الاستكشافية أحد وخمسين (51) مريضاً يعانون من أعراض أو علامات إصابة الرباط الصليبي الأمامي. كل مريض ضعف للتصوير بالرنين المغناطيسي القياسي (طريقة B) ثم تبعه تصوير بالرنين المغناطيسي السهيمي المائل (طريقة B).

تمت مقارنة نتائج فحوصات الرنين بنتيجات الفحص بالمنظور الجراحي.

النتائج: باستخدام الرنين المغناطيسي القياسي (طريقة A)، تم تشخيص 18 حالة قطع كامل في الرباط الصليبي الأمامي، و36 حالة تمزق جزئي. بينما بإضافة التصوير السهيمي المائل (طريقة B)، تم تشخيص 18 حالة تمزق جزئي، 31 حالة تمزق جزئي. كلا الطرقتين أدت لنفس التشخيص بالنسبة للتمزق الكامل للرباط الصليبي، بينما كان هناك فرق إحصائي في تشخيص تمزق جزئي بعد إضافة التصوير السهيمي المائل.

الخلاصة: إضافة التصوير السهيمي المائل يحسن الكفاءة التشخيصية للتصوير الرنين المغناطيسي في حالات تمزق الرباط الصليبي الأمامي، ولكن لديه نفس كفاءة التصوير القياسي في حالات تمزق الكامل.