ACL Injuries by MRI: How Can Indirect Signs Confirm our Diagnosis?

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Abstract

Aim of Study: Our study aiming to find a reliable method for ACL injuries diagnosis to minimize the surgical intervention in unneeded cases.

Material and Methods: This study includes 192 individuals with mean age of 29.9 years (age ranging from 14 to 73 years). All of them underwent arthroscopic evaluation for clinically suspected ACL tear at the orthopedic department of our institute. Their MR images were reviewed retrospectively by two radiologists blind to the arthroscopy results, clinical history and the initial MR imaging interpretations. All of those patients were evaluated for the indirect signs including: Bone contusions (either femoral or tibial or both), lateral femoral sulcus sign, ACL orientation (using relation to tibial plateau and to blumensaat line), PCL angle, anterior tibial drawer and Segond fracture.

Results: Femoral and/or tibial bone contusions show high sensitivity and specificity in the diagnosis of complete thickness tear while only tibial contusions were of significant value in the partial tears.

On cut off value of 5 degrees to the ACL Blumensaat angle the sensitivity and the specificity were 100% and 99% respectively in the diagnosis of the full thickness tears while they were 67% and 71% in the partial thickness tears. In addition, the anterior tibial drawer showed sensitivity and specificity of 100% and 85% respectively in full thickness tears when we used a cut off value of 3.5cm.

Alternatively using cut off values of 46.5 degrees for the ACL tibial angle and 111.5 degrees for the PCL angle are conclusive of normal ACL with sensitivity and specificity of 95%, 84% and 100%, 84% respectively.

Conclusion: Indirect signs for assessment of ACL tear are beneficial in the diagnosis of complete tears yet they are not conclusive in the partial tears. Also we can use the PCL and ACL-tibial angles with cut off values of 46.5 degrees and 111.5 degrees respectively to diagnose cases with intact ACL as a trial to reduce unnecessary arthroscopy.

Key Words: ACL injuries – MRI – PCL.

Introduction

THE anterior cruciate ligament (ACL) is an extra-synovial intra-articular structure, running obliquely within the intercondylar groove from the medial aspect of the lateral femoral condyle to the anterior intercondylar region of the tibia. It is formed of two bundles (anteromedial and posterolateral) according to their tibial insertion [1]. At the lateral femoral condyle the anteromedial bundle is inserted at a more medial and superior position while the posterolateral bundle inserts at a more lateral and distal aspect. An additional intermediate bundle is occasionally seen [2]. According to the study done by Girgis et, al., they mentioned that ACL measures approximately 38mm in length and 11mm in width [4]. While Cohen et al., stated that the anteromedial and the posteromedial bundles are 36.9±2.9mm and 20.5±2.5mm in length respectively, while they are almost similar in size measuring about 5.0±0.7mm and 5.3±0.7mm in their mid-substance [5].

Mostly a quick deceleration, hyperextension or rotational injury is the cause of the ACL injury due to a sudden change of direction. A feeling of a popping sensation in the knee is usual complain. Associated injuries to the medial meniscus and medial collateral ligament (MCL) are seen when trauma from the side is reported. In adolescents, avulsion from the tibial spine instead of rupturing usually occurs [6].

In plain Radiography; Anteroposterior (AP), lateral, notch, sunrise, and merchant views are usually used to assess radiographic findings associated with ACL injuries. Additional oblique radiographs may be required to assess tibial plateau fractures. Second fracture (lateral capsular avulsion fracture) is assessed in the AP views acting as a direct sign for lateral capsule injury and an indirect sign for ACL injury. While the lateral notch fracture (assessed in the lateral view) is more commonly seen in chronic ACL injuries [7].
In MRI and MR arthrography; the accuracy, sensitivity and specificity of MRI at ACL tears detection is highly accurate reaching more than 90% [8]. 2D fast spin echo sequences are used to assess the ACL in most centers including: Turbo spin echo (TSE) sagittal intermediate weighted sequence with or without fat suppression. Recently 3D fast spin echo imaging with or without suppression shows same diagnostic accuracy as 2D sequences, allow to decrease the examination time as well as the volume averaging artifacts [9].

Normally ACL fibers are continuous in all planes and sequences displaying a taut, low to intermediate signal intensity. It is parallel or steeper than the intercondylar line. The posterolateral bundle is of higher signal intensity compared to the anteromedial bundle [10].

ACL tear diagnosis rely on either direct or indirect signs. Direct signs include fiber discontinuity with an empty notch sign denoting complete tear [11], where in acute or subacute injury thickening and increased signal intensity on T2 or intermediate weighted sequences is noted due to associated edema while in chronic cases complete absorption of the ACL fibers may be noted. The remnant fibers may become adherent to the synovial envelope masking the PCL. In partial thickness tear MRI sensitivity (40% to 75%) and specificity (51% to 89%) is low compared to the complete ACL tears. [13] where continuous fibers suggests incomplete tear showing increased signal intensity and fiber laxity leading to ACL bowing. High grade tear is considered when 50% or more of the ACL fibers are torn while a medium grade tear shows 10-50% of fibers torn and a low grade tear is depicted when less than 10% torn fibers detected [10].

Other Indirect signs may be used as aiding factors for diagnosis including: ACL orientation (measured by using either: ACL angle or ACL-Blumensaat line angle) [14], bone contusion [10], osteochondral fracture, PCL line [15], PCL angle [16], PCL buckling [17], deep lateral femoral sulcus sign [15], anterior tibial translation [18], uncovered posterior horns of the medial or lateral meniscus [11]. Second fracture, Bosch-Bock bump [10], buckling of patellar tendon [17], visualization of the whole PCL or lateral collateral ligament in in one coronal image [10] and shearing pad of fat injury [19].

We aimed at this study to find reliable non-invasive method using MRI to diagnose ACL injuries to minimize the unnecessary interventional diagnostic procedures.

Patients and Methods

This retrospective study included 192 patients (129 nine patients were males and 63 were females) underwent arthroscopic evaluation for clinically suspected ACL tear from the orthopedic department of our institute during the period from December 2015 till December 2016. Human ethics committee approval was obtained from the institutional review board of the institute. Their MR images were reviewed retrospectively by two radiologists blind to the arthroscopy results, clinical history and the initial MR imaging interpretations.

MR imaging of the knee was performed with a 1.5-T unit (MSK extreme, GE) with a dedicated extremity coil. The knee was positioned in full extension with approximately 15 degree of external rotation. For all patients sagittal oblique T1, T2, sagittal STIR and PD acquisitions (repetition time msec/echo time=550/7, 2500/40, 2500/35 and 2200/23 respectively) were obtained. Axial T2 (3000/96,2) and coronal T2* (350/9) acquisitions were also obtained.

Image analysis:

All patients were evaluated for the indirect signs including:

a- ACL orientation: Measured by using either:
  I- ACL angle: A reference line is drawn through the mid lateral tibial plateau, then this line is represented on the image showing the ACL. The angle is measured between the represented line and the anterior surface of the ACL.
  II- ACL-Blumensaat line angle: Measured between the posterior surface of the femur and the distal portion of the ACL. A negative value is detected when the apex points superiorly while a positive value occurs when the apex points inferiorly [14].

b- Bone contusion: (Either femoral or tibial or both) the abnormal signal intensity is likely due to edema and/or hemorrhage as well as subcortical micro-fractures [10].

c- PCL angle: It is the angle between two lines, one passing through the center of the proximal portion of the PCL while the other is passing through the center of its distal [16].

d- Deep lateral femoral sulcus sign: It is diagnostic if it exceeds 2mm [15].

e- Anterior tibial translation: Detected at the mid-lateral femoral condyle on sagittal images. More than 5mm anterior translocation of the tibia in relation to the femur indicates ACL tear with
sensitivity of 86% and specificity of 99% according to Chan et al. [18], while an anterior translation of more than 7mm is a sure sign of ACL tear.

f- Segond fracture: Occurs due to avulsion fracture of the iliotibial band, fibular collateral ligament and biceps femoris tendon [10].

Statistical analysis:

IBM SPSS statistics [V.21.0, IBM Corp., USA. 2012] were used for data analysis.

Results

Our study included 192 patients, 129 males (97.2%) and 63 females (32.8%) with their age ranging from 14 years to 73 years (mean age 29.5).

At arthroscopy 90 patients were diagnosed as normal while 72 patients were diagnosed as complete thickness tear and 30 patients were diagnosed as partial thickness tear.

According to MR reports the following results were detected as detailed in Table (1).

<table>
<thead>
<tr>
<th>MRI findings</th>
<th>Normal</th>
<th>Complete thickness tear</th>
<th>Partial thickness tear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femoral bone contusion</td>
<td>14 cases</td>
<td>44 cases</td>
<td>10 cases</td>
</tr>
<tr>
<td>Tibial bone contusion</td>
<td>12 cases</td>
<td>54 cases</td>
<td>14 cases</td>
</tr>
<tr>
<td>Both femoral and tibial bone contusions</td>
<td>2 cases</td>
<td>30 cases</td>
<td>4 cases</td>
</tr>
<tr>
<td>ACL-tibial plateau angle (mean)</td>
<td>55.18 (±4.069)</td>
<td>35.36 (±9.463)</td>
<td>46.86 (±8.084)</td>
</tr>
<tr>
<td>ACL-blumensaat line angle (mean)</td>
<td>2.711 (±1.515)</td>
<td>22.9 (±9.412)</td>
<td>6.4 (±5.124)</td>
</tr>
<tr>
<td>PCL angle (mean)</td>
<td>124.09 (±5.222)</td>
<td>103.47 (±10.4)</td>
<td>120 (±9.020)</td>
</tr>
<tr>
<td>Anterior tibial drawer (mean)</td>
<td>3.044</td>
<td>9.05</td>
<td>6.46</td>
</tr>
<tr>
<td>Lateral sulcus sign</td>
<td>2 cases</td>
<td>8 cases</td>
<td>2 cases</td>
</tr>
<tr>
<td>Segond fracture</td>
<td>0 cases</td>
<td>2 cases</td>
<td>0 cases</td>
</tr>
</tbody>
</table>

Statistical analysis:

1- Femoral bone contusion:

Out of 90 normal patients 14 patients (15.6%) were positive for femoral bone contusion. While in patients with complete thickness tear out of 72, 44 patients (61.1%) were positive for femoral bone contusion with specificity of 84.4%, sensitivity of 61.1%, PPV of 75.9% and NPV of 73.1% and significant p-value equivalent to <0.0001 according to Pearson Chi-square (significant if below 0.05). But in patients with partial thickness tear 10 patients (33.3%) showed femoral bone contusion with specificity of 84.4%, sensitivity of 33.3%, PPV of 41.7% and NPV of 79.2% and insignificant p-value equivalent to 0.136 according to Pearson Chi-square (significant if below 0.05) for partial thickness tear detection.

2- Tibial bone contusion:

In 90 normal patients 12 patients (13.3%) were positive for tibial bone contusion. While in patients with complete thickness 56 patients (77.8%) showed tibial bone contusion with specificity of 86.7%, sensitivity of 77.8%, PPV of 82.4% and NPV of 83% and significant p value equivalent to <0.0001 according to Pearson Chi-square (significant if below 0.05) for complete thickness tear detection. But in patients with partial thickness tear 14 patients (46.7%) showed tibial bone contusion with specificity of 86.7%, sensitivity of 46.7%, PPV of 53.8% and NPV of 83% and significant p-value equivalent to 0.007 according to Pearson Chi-square (significant if below 0.05) for partial thickness tear detection.

3- Both femoral and tibial bone contusions:

Out of 90 normal patients, 2 patients (2.2%) were positive for both femoral and tibial bone contusions. In patients with complete thickness tear 32 patients (44.4%) showed both femoral and tibial bone contusions with specificity of 97.8%, sensitivity of 44.4%, PPV of 94.1% and NPV of 68.8% and significant p-value equivalent to <0.0001 according to Pearson Chi-square (significant if below 0.05) for complete thickness tear detection. While in patients with partial thickness tear 2 patients (6.7%) showed both femoral and tibial bone contusions with specificity of 97.8%, sensitivity of 6.7%, PPV of 50% and NPV of 75.9% and insignificant p-value equivalent to 0.0406 according to Pearson Chi-square (significant if below 0.05) for partial thickness tear detection.

4- Lateral femoral sulcus sign:

In 90 normal patients 2 patients (2.2%) were positive for the lateral femoral sulcus sign. In patients with complete thickness tear 8 patients (11.1%) showed positive sign with specificity of
97.8%, sensitivity of 61.1%, PPV of 80% and NPV of 57.9% and insignificant P value equivalent to 0.099 according to Pearson Chi-square (significant if below 0.05) for complete thickness tear detection. While in patients 2 patients (11.1%) were positive for it with specificity of 97.8%, sensitivity of 6.7%, PPV of 50% and NPV of 75.9% and insignificant p-value equivalent to 0.406 according to Pearson Chi-square (significant if below 0.05) for partial thickness tear detection.

According to kappa agreement test the results was significant (less than 0.05) in cases with complete thickness tears as regards the femoral contusion, tibial contusion, both femoral and tibial contusions as well as the anterior tibial translation.

Table (2): Statistical analysis for the indirect signs in patients diagnosed as full thickness tear.

<table>
<thead>
<tr>
<th>Full thickness tear</th>
<th>Specificity</th>
<th>Sensitivity</th>
<th>PPV</th>
<th>NPV</th>
<th>p-value (significance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femoral bone contusion</td>
<td>84.4%</td>
<td>61.1%</td>
<td>75.9%</td>
<td>73.1%</td>
<td>0.000 (significant)</td>
</tr>
<tr>
<td>Tibial bone contusion</td>
<td>86.7%</td>
<td>77.8%</td>
<td>82.4%</td>
<td>83%</td>
<td>0.000 (significant)</td>
</tr>
<tr>
<td>Both femoral and tibial bone contusions</td>
<td>97.8%</td>
<td>44.4%</td>
<td>94.1%</td>
<td>68.8%</td>
<td>0.000 (significant)</td>
</tr>
<tr>
<td>Lateral femoral sulcus sign</td>
<td>97.8%</td>
<td>61.1%</td>
<td>80%</td>
<td>57.9%</td>
<td>0.099 (insignificant)</td>
</tr>
</tbody>
</table>

Table (3): Statistical analysis for the indirect signs in patients diagnosed as partial thickness tear.

<table>
<thead>
<tr>
<th>Partial thickness tear</th>
<th>Specificity</th>
<th>Sensitivity</th>
<th>PPV</th>
<th>NPV</th>
<th>p-value (significance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femoral bone contusion</td>
<td>84.4%</td>
<td>33.3%</td>
<td>41.7%</td>
<td>79.2%</td>
<td>0.136 (insignificant)</td>
</tr>
<tr>
<td>Tibial bone contusion</td>
<td>86.7%</td>
<td>46.7%</td>
<td>53.8%</td>
<td>83%</td>
<td>0.007 (significant)</td>
</tr>
<tr>
<td>Both femoral and tibial bone contusions</td>
<td>97.8%</td>
<td>6.7%</td>
<td>50%</td>
<td>75.9%</td>
<td>0.0406 (insignificant)</td>
</tr>
<tr>
<td>Lateral femoral sulcus sign</td>
<td>97.8%</td>
<td>6.7%</td>
<td>50%</td>
<td>75.9%</td>
<td>0.406 (insignificant)</td>
</tr>
</tbody>
</table>

Using the ROC curve the ACL angle (blumensaat) angle and anterior drawer sign were significant in detection of either partial or full thickness tears as shown in Tables (4,5) giving high sensitivity and specificity values for the chosen cut off values. While ACL (tibial) angle and PCL angles were efficient in diagnosing values for normal patients as shown in Table (6) with also high sensitivity and specificity for the chosen cut off values.

According to the above results we concluded that indirect signs would be very beneficial in the diagnosis of ACL tears specially when using ACL blumensaat angle and anterior drawer signs due to their high specificity and sensitivity values.

Table (4): Statistical analysis using ROC curve for the indirect signs in patients diagnosed as complete thickness tear.

<table>
<thead>
<tr>
<th>Complete thickness tear</th>
<th>Area under the curve</th>
<th>Cut off value</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACL angle blumensaat</td>
<td>100%</td>
<td>5</td>
<td>100%</td>
<td>99%</td>
<td>1-1</td>
</tr>
<tr>
<td>Anterior drawer</td>
<td>99.5%</td>
<td>3.5</td>
<td>100%</td>
<td>85%</td>
<td>0.98-1</td>
</tr>
</tbody>
</table>

Table (5): Statistical analysis using ROC curve for the indirect signs in patients diagnosed as partial thickness tear.

<table>
<thead>
<tr>
<th>Partial thickness tear</th>
<th>Area under the curve</th>
<th>Cut off value</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACL angle blumensaat</td>
<td>71.6%</td>
<td>2.9</td>
<td>67%</td>
<td>71%</td>
<td>0.53-0.89</td>
</tr>
<tr>
<td>Anterior drawer</td>
<td>65.8%</td>
<td>2.5</td>
<td>73%</td>
<td>45%</td>
<td>0.48-0.83</td>
</tr>
</tbody>
</table>

Table (6): Statistical analysis using ROC curve for the indirect signs in normal patients.

<table>
<thead>
<tr>
<th>Normal</th>
<th>Area under the curve</th>
<th>Cut off value</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACL angle tibial plateau</td>
<td>98.7%</td>
<td>46.5</td>
<td>95%</td>
<td>84%</td>
<td>0.9-1</td>
</tr>
<tr>
<td>PCL angle</td>
<td>97.1%</td>
<td>111.5</td>
<td>100%</td>
<td>84%</td>
<td>0.93-1</td>
</tr>
</tbody>
</table>
Fig. (1): A–E In normal cases: sagittal oblique images: A,B: ACL-tibial angle. C: ACL-blumensaat angle. D: PCL angle. E: Anterior tibial translation:

Fig. (2): Sagittal oblique T2 WI’s showing multiple cases diagnosed by arthroscopy as partial thickness tear upper row: Shows variable ACL-tibial angles while the lower row shows variable ACL-blumensaat angle.
Fig. (3): Sagittal oblique T2 WI’s showing multiple cases diagnosed by arthroscopy as complete thickness tear with variable ACL-tibial angles.

Fig. (4): Sagittal oblique T2 WI’s showing multiple cases diagnosed by arthroscopy as complete thickness tear with variable ACL-blumensaat angles.

Fig. (5): Sagittal oblique T2 WI’s showing multiple cases diagnosed by arthroscopy as complete thickness tear with variable PCL angles.
Fig. (6): Sagittal oblique T2 STIR WI’s showing anterior tibial drawer in cases diagnosed as complete thickness tears by arthroscopy.

Fig. (7): Sagittal T2 STIR WI’s showing bone contusions at both femoral and tibial subarticular regions.

Discussion

Unnecessary arthroscopy is reduced when proper MRI evaluation used in assessing the severity of the ACL tear and coexisting injuries as it can delineate anatomy in multiple planes in addition to being a non-invasive procedure [20].

ACL tears are mainly complete (approximately 80%) mostly occurring at its middle third (90%), while only around 7% occur close to the femoral attachment and 3% occur at its tibial attachment. Less frequently (around 20%) partial disruption of the ACL fibers occurs causing partial tears which may involve only one or both of its bundles [21].

Indirect signs for ACL tear have been used to enhance the accuracy of the diagnosis. The indirect signs include ACL orientation of the ACL, PCL line, PCL angle, PCL bowing, bone contusions and osteochondral fractures, deep lateral femoral sulcus, anterior drawer sign, and posterior displacement of the lateral meniscus [14].

According to our results we found that either femoral and/or tibial bone contusions show high sensitivity and specificity in the diagnosis of complete thickness tear (p-values <0.05) while only tibial contusions were of significant value in the partial tears.

When we used cut off value of 5 degrees to the ACL Blumensaat angle the sensitivity and the specificity were 100% and 99% respectively in the diagnosis of the full thickness tears while they were 67% and 71% in the partial thickness tears. So we concluded that this angle could be used as a definite sign for the diagnosis of the complete tears. In addition, the anterior tibial drawer showed sensitivity and specificity of 100% and 85% respectively in full thickness tears when we used a cut off value of 3.5cm.
Alternatively we realized that using cut off values of 46.5 degrees for the ACL tibial angle and 111.5 degrees for the PCL angle are conclusive of normal ACL with sensitivity and specificity of 95%, 84% and 100%, 84% respectively.

Many old studies had discussed the efficiency of the indirect signs in the ACL tears diagnosis suggesting different cut off values. Most of them had lower sensitivity and specificity values than ours for example in the study done by Robertson et al. [22] they stated that the sensitivity and specificity to tibial bone contusion, femoral contusion, ACL blumensaat angle and anterior drawer sign were 40.5%/97.5%, 37.5%/98.5%, 79%/86% and 60%/88% respectively. While Gentili et al. [14] results declared the following sensitivity and specificity for the angle between lateral tibial plateau and ACL less than 45 degree, angle between Blumensaat line and ACL more than 15 degree, bone contusions in lateral compartment, PCL angle less than 107 degrees and anterior displacement of tibia more than 7mm (90%, 97%); (89%, 100%); (54%, 100%); (52%, 94%) and (41%, 91%) respectively.

So they concluded that indirect signs could be used as an assistant factors to determine the integrity of the ACL and their absence do not exclude the presence of tear.

In our study according to our results we can rely upon the ACL blumensaat angle as well as the tibial anterior drawer sign for the diagnosis of complete tears but partial thickness tear is still a challenging diagnosis that may need arthroscopy for definite evaluation.

Conclusion:

Indirect signs for assessment of ACL tear are beneficial in the diagnosis of complete tears yet they are not conclusive in the partial tears. Also we can use the PCL and ACL-tibial angles with cut off values of 46.5 degrees and 111.5 degrees respectively to diagnose cases with intact ACL as a trial to reduce unnecessary arthroscopy.

References


19- ROBERTSON P.L., SCHWEITZER M.E., BARTOLOZZI


الملخص العربي

الهدف من الدراسة: دراستنا تهدف إلى إيجاد طريقة يمكن الاعتماد عليها لتشخيص إصابات الرباط الصليبي الأمامي للحد من التدخل الجراحي في الحالات غير الضرورية.


النتائج: تظهر كميات العظام الفخذيه و/ أو التقويم الفيزيائي حساسية عالية وخصوصية في تشخيص التمزق الكامل للرباط الصليبي الأمامي في حين أن كميات الفيزيائي فقط ذات قيمة كبيرة في التمزق الجراحي.

عند استخدام 6 درجات كنسبة قاطعة لاتجاه الرباط الصليبي الأمامي (استخدام خط بلومنسات) كانت الحساسية والخصوصية 100% و99% على التوالي في تشخيص القطع الكلي في حين كانت 77% و71% في تشخيص القطع الجراحي. بالإضافة إلى ذلك، أظهرت زوجة الرباط الصليبي الأمامي، حساسية وخصوصية 100% و85% على التوالي في تشخيص القطع الكلي عندما استخدمنا قيم قاطعه 0.5 نم.

وقد تم استنتاج ان استخدام القيم النازل 6.5 درجة لاتجاه الرباط الصليبي الأمامي (بالاستخدام الفيزيائي) و111.5 درجة لزاوية الرباط الصليبي الخلفي يمكن تشخيص رباط صليبي طبيعي مع حساسية وخصوصية 95% و95% على التوالي.

الاستنتاج: الفحص المباشرة لتشخيص الرباط الصليبي الأمامي مفيدة في تشخيص القطع الجراحي كما يمكننا استخدام اثاث الرباط الصليبي الأمامي (بالاستخدام الفيزيائي) وزاوية الرباط الصليبي مع القيمة النازل 6.5 درجة و111.5 درجة على التوالي لتشخيص رباط صليبي طبيعي كمحاولة للحد من تظاهر النازل الذي لا لزوم له.