Original Article

MRI and arthroscopic findings in acute and chronic ACL injuries. A pictorial essay

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Abstract

Objectives: The purpose of this paper is to present the various forms that an ACL injury may acquire on MRI and knee arthroscopy. **Methods:** The MR imaging studies and arthroscopy files of 192 patients with an acute or chronic ACL injury were reviewed by an independent musculoskeletal radiologist and the imaging finding were confirmed or disapproved during knee arthroscopy. **Results:** MR imaging findings in regard to ACL tears were confirmed in 186 cases (96.87%), in meniscal injuries in 106/122 (86.88%) cases and in full thickness articular cartilage defect in 33/36 (91.6%) cases. The main source of error was an inadequately performed MRI from a technical point of view. **Conclusion:** High resolution 3T MRI is very reliable in detecting ACL, meniscus and articular cartilage lesions in acute and chronic injuries. **Level of evidence:** Level IV, Case series.

Keywords: ACL, Arthroscopy, Cartilage, Knee, Meniscus, MRI

Introduction

Knee injuries involving the Anterior cruciate ligament (ACL) are common sports injuries with over two million cases occurring every year. The number of ACL injuries has increased over the years due to increasing participation of young adults in sporting activities¹. ACL is commonly injured in athletic activities involving rapid deceleration, change of direction, pivoting and jumping.

Most ACL tears (approximately 80%) are complete, occurring around the middle one-third of the ACL (90%) or less frequently close to the femoral (7%) or tibial (3%) attachments. Less frequently, (approximately 20%), ACL tears are incomplete with partial disruption of the ACL fibers². The majority of ACL injuries can be diagnosed on the basis of history of injury and clinical examination. However, the accuracy of clinical examination is not adequately high thus it has to be complemented with MR imaging (MRI) evaluation. Currently, MRI and arthroscopy are the reference standards for diagnosing an ACL injury^{3,4}.

The purpose of this study is to present a wide spectrum of MRI appearances with arthroscopic correlation in a series of patients with an acute or chronic ACL injury.

Materials and Methods

The 3T MRI studies of the knee, performed on 1.5 or 3T, along with arthroscopy files of 192 patients with an acute or chronic ACL injury were collected and reviewed by an independent experienced musculoskeletal radiologist (OP), who was blind to the results of arthroscopies. There were 89 patients with an acute ACL tear and 103 patients with chronic (later than 6 months post-injury) tears.

All arthroscopies were performed by a single orthopedic surgeon with years of experience, who had kept notes of the intraoperative findings. All arthroscopies were reviewed by another independent reviewer blind to the MR imaging reports. The percentage agreement between MRI and arthroscopic findings was assessed.

The authors have no conflict of interest.

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Results

MRI findings, as regards the ACL were confirmed in 186 cases (96.87%), in 106/122 (86.88%) cases with a meniscus injury and 33/36 (91.6%) cases with a full thickness articular cartilage defect. There was no significant difference between acute and chronic tears. The main source of error was an inadequately performed MRI from a technical point of view. A second source of error was the lack of sufficient number or quality of MRI sequences to especially evaluate cartilage or meniscus defects.

MRI findings in acute and chronic ACL tears

The MRI findings in acute and chronic ACL tear cases are presented in Figures 1-18.

Arthroscopic findings in acute and chronic ACL tears

The arthroscopic findings in acute and chronic ACL tear cases are presented in Figures 19-25.

Discussion

Knee injuries involving the Anterior cruciate ligament (ACL) are common sports injuries with over two million cases occurring every year. The number of ACL injuries has increased over the years with increasing participation of young adults in sporting activities¹.

ACL is commonly injured in athletic activities involving rapid deceleration, change of direction, pivoting and jumping. ACL injuries are frequently accompanied with injuries to secondary stabilizing anatomical knee structures. Knowledge of the presence and/or the extent and severity of those injuries helps profoundly contemplating the surgical procedure. MRI is the imaging technique of choice to evaluate ligamentous injuries of the knee⁵. Currently, MRI and arthroscopy are the reference standards for diagnosing an ACL injury^{3,4}.

Injury of the anterior cruciate ligament (ACL) leads to loss of stability of the knee and probably significant dysfunction. The ACL resists anterior tibial translation during extension and provides rotational stability^{6,7}.

Tears of the ACL may be partial or complete. Partial tears can range from a minor tear involving just a few fibers to a more extensive involvement of the ACL fibers. A partial tear may involve both or only one single bundle. Sometimes plastic deformity of the ACL without fiber discontinuity can result in ACL insufficiency.

The mechanism of the ACL injury includes internal rotation of the tibia relative to the femur. This commonly occurs during falls while skiing, as well as in contact sports such as football. With valgus stress, the medial femorotibial joint compartment is distracted producing medial collateral injury and medial meniscal injury (O'Donoghue's triad). Another mechanism of ACL injury is hyperextension such as during jumping or high kick maneuvers, that leads to bone

contusion on the anterior tibia and femoral condyle². ACL tears resulting from hyperextension frequently occur without concomitant collateral ligament or meniscal injury. The third mechanism is external rotation of the tibia relative to the femur with varus stress which leads to impaction and bone edema at the medial compartment and distraction laterally resulting in avulsion of the lateral tibial rim (Segond fracture) and tear of the lateral collateral ligament².

Associated injuries such as meniscal tears or cartilage injuries may hinder a complete clinical examination. As a result, MRI is valuable in the assessment of suspected ACL injury, particularly in multiligamentous knee injuries. MRI is a radiation free modality with high soft tissue resolution⁸. MRI is highly accurate in diagnosing ligamentous knee injuries and bears a sensitivity of 80% to 100%⁹. The purpose of our study is to present a spectrum of ACL injuries and concomitant findings as assessed with MRI and arthroscopy.

ACL tears on MRI can be evaluated using primary, pertaining to the ACL ligament itself and secondary or indirect signs, pertaining to other anatomical structures or involving the general knee alignment.

Primary ACL tear signs on MRI include the presence of ACL swelling, in acute tears, increased signal on T2 and PD-weighted images, fiber discontinuity and abnormal ligament positioning, especial absence of the normal attachment at the medial posterior surface of the lateral femoral condyle (empty notch sign). In chronic ACL injuries frequent findings include attachment of the ACL stump to the PCL, flattening or projection of the distal stump into the anterior recess or projection of the stump or no visualization of the ACL.

Secondary MRI signs of ACL tear include the presence of bone marrow edema on the lateral femoral and the posteromedial tibial condyle, anterior tibial subluxation, buckling of the PCL, posterior displacement of the posterior horn of the lateral meniscus¹⁰, vertically oriented LCL¹¹ and, less frequently, the presence of a Segond avulsion fracture in the lateral aspect of the tibial plateau. The presence of the lateral femoral notch sign, a depression on the lateral femoral condyle at the site of the terminal sulcus, is also an indirect sign of ACL injury. Bone marrow contusion of the medial tibial plateau along with meniscocapsular separation of the posterior horn of the medial meniscus (ramp lesions) have recently received attention in medical literature.

Although meniscal, articular cartilage and collateral ligament tears, especially involving the medial collateral ligament, are frequent findings their presence does not indicate the presence of an ACL tear as well. Evaluation of the ACL morphology is necessary to be performed in at least two planes, coronal and sagittal. No significant difference between 1.5T and 3T magnets has been established in terms of accuracy in the detection of ACL tears. MR Imaging of the knee at 55° of flexion and less at 30° of flexion allow an improved diagnosis of injuries to the anterior cruciate ligament as compared to MRI examinations at extension. The diagnosis of meniscal injuries, however, was not superior at

either flexion positions compared to commonly performed examinations at knee extension²².

MRI has compromised accuracy in detecting partial ACL tears. Partial ACL tears should be differentiated from mucoid degeneration of ACL or of a normal ACL¹². This also applies when high resolution 3T MRI is used¹³. Arthroscopy is necessary in partial ACL tears to establish the final diagnosis¹⁴.

MRI is helpful in diagnosing meniscal and cruciate ligament injuries but arthroscopy still remains the gold standard for definitive diagnosis¹⁵.

Due to its high sensitivity and specificity and almost high accuracy for ACL injuries of knee joint in comparison to arthroscopy, MRI is an appropriate screening tool for therapeutic arthroscopy, making diagnostic arthroscopy unnecessary in most patients. It can be used as a first line investigation in patients with soft tissue trauma to knee¹⁶.

Schurz et al recommend using the MRI as a diagnostic tool, especially in the diagnosis of lateral meniscal tears. Nevertheless, clinical symptoms are the main indication for an operative intervention and MRI should only be a tool to verify the clinical diagnosis¹⁷.

In a study of 148 patients diagnosis of meniscal tears using MRI was found to show 92% sensitivity and 87% specificity rendering MRI a reliable diagnostic tool for displaced meniscal tears¹⁸. MRI in the presence of ACL tears has lower sensitivity for detecting meniscal tears¹⁹. Sensitivity and specificity of 74 and 66%, respectively, for medial and 50 and 84% for lateral meniscus has been reported²⁰. MRI cannot completely replace arthroscopy in the diagnosis of acute knee injuries. On the other hand, Puri et al, in a series of 30 patients, concluded that carefully performed clinical examination can give equal or better diagnosis of menisci and ACL injuries in comparison to MRI scan. When clinical signs and symptoms are inconclusive, performing an MRI scan is likely to be more beneficial in avoiding unnecessary arthroscopic surgery²¹.

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Figure 1 A-C. Acute ACL tear in an 18-year old football player. Sagittal fat-suppressed T2-weighted image showing hyperintensity and discontinuity of the ACL at its middle portion (arrow, A). The subsequent sagittal image (B) demonstrates some torn fibers projecting within the anterior recess and assuming an hypointense tongue-like appearance (arrow) that represents folding of the free edge on itself. A more lateral image (C) shows the typical bone bruise pattern (Lateral femoral condyle and posterior aspect of the lateral tibial plateau- asterisks) along with a peripheral longitudinal tear of the posterior horn of lateral meniscus (arrow).

Figure 2 A, B. Posttraumatic ACL reconstruction failure using a hamstring tendon autograft in a football player 1 year postoperatively with correct placement of the tibial and femoral tunnels. There is discrete discontinuity of the ACL graft which is shown as an amorphous cloud-like hyperintense mass on a sagittal intermediate-weighted image (A) and on a sagittal 3D T2 GRE image (B). Some hypointense foci (arrows) in the graft on the 3D T2 GRE image (B) are due to metallic debris.

Figure 3 A, B. Subsequent more lateral sagittal images (A, B) show diffuse arthrofibrosis which occupies the posterior aspect of Hoffa's fat pad. Arthrofibrosis has signal intensity similar to muscles on the intermediate-weighted and on 3D T2-weighted GRE images, respectively. Note the presence of anterior tibial subluxation.

Figure 4. On a more sagittal image, there is mild depression of the lateral femoral notch with thinning of the overlying cartilage, along with the typical bone bruise pattern that accompanies ACL rupture, that is bone bruise at the weight bearing surface of the lateral femoral condyle and at the posterior aspect of the lateral tibial plateau.

Figure 5 A-C. Acute ACL tear in a 23-year old female basketball player. A coronal T1-weighted image (A) and a coronal fat-suppressed intermediate-weighted image (B) show the presence of a bulky and edematous femoral ACL insertion (arrows), which is hypointense on T1-weighted (A) and hyperintense on intermediate-weighted (B) images. A sagittal intermediate-weighted image (C) demonstrates an hyperintense ACL with non-discrete fibers at its proximal portion.

Figure 6. On a more medial sagittal image to Figure 5C there is also a partial longitudinal tear at the white/red zone of the medial meniscus (arrow) along with high signal and irregularity at the capsular margin of the posterior horn of the lateral meniscus (a so-called "ramp" lesion- arrowhead). Note mild concomitant bone bruise at the adjacent posteromedial tibial plateau and moderate amount of fluid in the knee joint.

Figure 7 A, B. Acute ACL tear in a 28-year old skier. On a sagittal STIR image (A), there is disruption of the middle portion of ACL (arrow) with flattening of the distal stump. On a more lateral section (B), bone bruise pattern (asterisks) consistent with ACL injury is seen (Lateral femoral condyle and posterolateral tibial plateau) along with deepening of the lateral femoral notch (arrow). There is also mild edema at the musculotendinous junction of the popliteus. Meniscal injuries cannot be evaluated on this sequence.

Figure 8 A, B. Postoperative arthrofibrosis in the patient presented in Figure 7. A coronal T1-weighted (A) and a sagittal intermediate-weighted sequence (B) show correct positioning and signal intensity of the graft. Low signal intensity biabsorbable cross pins are seen, which do not produce metallic (blooming) artifact.

Figure 9 A, B. A: A sagittal T2-weighted image shows a cyclops lesion, presenting as a mildly hypointense nodule at the outlet of the intercondylar notch (arrow, A) along with an adjacent hypointense band at the inferior/posterior aspect of Hoffa's fat pad. The posterior horn of the lateral meniscus is distorted due to previous partial meniscectomy (B).

Figure 10 A, B. A coronal fat-suppressed intermediate-weighted image shows partial rupture of the proximal and deep insertion of MCL whereas bone bruise pattern for ACL injury is seen on (A) and the subsequent posterior section (B). Note small quantity of fluid within the tibial tunnel.

Figure 11 A-D. Acute ACL tear in a 17-year old football player. Sagittal fat-suppressed intermediate-weighted images show avulsion of the distal insertion of ACL (arrow, A), partial tear of the PCL which exhibits high signal and tear of the posterior capsule (arrow, B), peripheral longitudinal tear of the posterior horn of the lateral meniscus (C) and thickening and hyperintensity of the posteromedial corner of the knee (D). The irregularity of the capsular margin of posterior horn of the medial meniscus indicates the presence of a ramp lesion.

Figure 12 A-C. Acute ACL tear in a 17-year old football player. Coronal fat-suppressed intermediate-weighted images demonstrate avulsion of the distal insertion of MCL (arrow, A) along with a depression fracture of the lateral tibial plateau (arrowhead) and avulsion of the lateral capsular ligament (Second fracture, arrow, B) with bone marrow edema in the adjacent bone. On an axial intermediate-weighted image (C) there is also partial tear of the lateral patellar retinaculum.

Figure 13 A, B, C. Chronic rupture of the ACL with presence of osteoarthritis. An axial fat-suppressed intermediate-weighted image (A) and a sagittal 3D T2-weighted GRE image (B) show a small fluid collection at the medial surface the lateral femoral condyle (arrow), where the anatomic insertion site of the ACL is located, with no discernible fibers in any sequence and imaging plane. The distal part of ACL is flattened (arrow, C) and attached to the PCL with hypointense fibrotic tissue (asterisk) on an intermediate-weighted image. The absence of the typical pattern of bone bruise indicated the chronicity of the ACL rupture (not shown).

Figure 14 A, B. Chronic rupture of the ACL with presence of osteoarthritis. Extensive OA changes, apparent on a coronal T1-weighted (A) and a coronal fat-suppressed intermediate weighted image (B). Large areas of denuded cartilage with sclerosis and flattening of the subchondral bone at the medial and lateral compartment of the knee are noted and large osteophytes project into the intercondylar notch abutting against the PCL. The posterior horn (arrow) and body of the medial meniscus are truncated.

Figure 15 A, B. ACL hamstring graft failure in 32-year athlete 4 years postoperatively. A sagittal intermediate-weighted image shows a cloud-like amorphous area at the anatomic site of ACL and anterior translation of the tibia and anterior placement of the tunnel (A). A coronal T1-weighted image (B) shows fat within the tunnels, the empty notch sign and small size of the posterior horn of the medial meniscus due to previous meniscectomy.

Figure 16 A, B. ACL hamstring graft failure in 32-year athlete 4 years postoperatively. A coronal fat-suppressed intermediate-weighted image (A) shows cartilage irregularities on both medial and lateral compartments along with a foci of bone marrow edema of the underlying subchondral bone at the lateral tibial plateau. A sagittal intermediate-weighted sequence (B) shows irregularity of the capsule at the attachment of the posterior horn of the medial meniscus with some separation. A metallic artifact is noted due to the presence of staple used to stabilize the hamstring graft at the exit of the tibial tunnel.

Figure 17 A, B, C. ACL graft failure due to tunnel malpositioning. Anterior placement of the tibial tunnel with graft impingement against the roof of the intercondylar notch, leading eventually to graft failure (A). Excision of the posterior horns of the medial and lateral menisci (B). Anterior subluxation of the tibia (C) with imaging signs of osteoarthritis presence: cartilage defects or thinning at the medial femoral condyle, with foci of subchondral bone marrow edema, presence of central and marginal osteophytes without bone marrow edema pattern consistent with acute ACL rupture.

Figure 18 A, B. Knee reinjury in a 22-year old basketball player 18 months after hamstring ACL reconstruction. Sagittal fat-suppressed T2-weighted imaging (A) shows the presence of an intact ACL graft with a significant metallic artifact obscuring the tibial tunnel. A coronal fat-suppressed T2-weighted image (B) shows mild bone marrow edema and full thickness lateral femoral condyle defect with subchondral edema. A bucket handle tear of the lateral meniscus is also evident.

Figure 19 A, B. Acute ACL avulsion from the femoral attachment point. Despite looking intact at most of its extent, the ACL is avulsed from the medial surface of the lateral femoral condyle (asterisk).

Figure 20 A, B. Acute midsubstance tear of the ACL in a case of combined ACL-PCL-LCL tear. The arthroscopic probe is inserted in the tear (asterisk). Preservation of the ACL synovium may lead to misjudgment

Figure 21. Acute tear of the ACL at its tibial attachment site (asterisk).

Figure 22 A, B. Chronic ACL tear. The proximal part of the ligament is missing, with only scar tissue remaining. The ACL stump adheres to the intact PCL (asterisk).

Figure 23. The empty wall sign in a patient with a chronic ACL tear. The proximal attachment of the ligament is missing (asterisk).

Figure 24 A, B. Chronic ACL tear with accompanying osteoarthritis. Scar tissue has replaced the ACL (arrows) and the opening of the intercondylar notch is significantly narrowed secondary to the development of osteophytes (asterisk).

Figure 25. Chronic ACL tear with accompanying osteoarthritis. Complete absence of the ACL is noted.

Figure 26 A-C. Non-displaced tear of the posterior horn of the medial meniscus in a patient with acute ACL tear. The anterior part of the meniscus looks intact (A) but, on better inspection, the posterior horn of the meniscus is torn (B). Using the arthroscopic probe the tear is displaced (C). Repair of this type of meniscus tears is absolutely indicated.

Figure 27 A, B. Non-displaced tear of the inferior surface of the posterior horn of the medial meniscus in a patient with acute ACL tear (A, asterisk). Insertion of the arthroscopic probe into the tear (B) reveals its true extent.

Figure 28 A, B. Displaced bucket handle tear of the medial meniscus in a patient with acute ACL tear (A, asterisk). The displaced meniscus tear remains attached to the anterior (B, asterisk) and posterior meniscal horns.

Figure 29 A-C. Acute Medial Femoral Condyle articular cartilage fracture in a patient with an acute ACL tear. The extent of the cartilage injury is appreciated only when the arthroscopic probe is inserted in the cartilage flap.

Figure 30. Acute Medial Femoral Condyle articular cartilage fracture in a patient with an acute ACL tear. There is diffuse cartilage injury indicating the severity of the mechanism of trauma.

Figure 31 A, B. Acute Medial Femoral Condyle articular cartilage fracture in a patient with an acute ACL tear. The partial thickness cartilage defect is covered initially with a blood clot (A), which, when removed reveals the real cartilage injury (B).

Figure 32 A, B. Acute Medial Femoral Condyle articular cartilage defect in a patient with an acute ACL tear (A). The real extent of the lesion is appreciated only when all loose cartilage tissue is removed back to a stable articular cartilage margin (B).

Figure 33. Chronic Lateral Femoral Condyle articular cartilage defect in a patient with chronic ACL tear. The full-thickness cartilage defect shows ragged margins (asterisk). Previous partial lateral meniscectomy is noted (arrow).

Figure 34 A, B. Chronic Medial Femoral Condyle articular cartilage defect in a patient with a chronic ACL tear. The full-thickness cartilage defect is evident (A), and its dimensions and depth are measured with an arthroscopic probe (B).

Figure 35 A, B. Chronic Medial Femoral Condyle articular cartilage defect in a patient with a chronic ACL tear and concomitant osteoarthritis. A diffuse, full-thickness cartilage defect is shown (A) along with degenerative medial meniscus tear which may have caused further attritional cartilage injury (B).