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Review

Importance of Preoperative Magnetic Resonance Imaging Evaluation of the Anterior Cruciate Ligament Injuries

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Patients with a clinically suspected tear of the anterior cruciate ligament (ACL) are generally diagnosed using magnetic resonance imaging (MRI). It is accepted that MR is the most effective radiological modality for diagnosing ACL injuries. Formerly, the essential aim of MRI was to detect whether the ACL tear was partial or total. Recently, however, there has been an increasing interest in the region of rupture. In addition, it is highly important to focus on the tissue quality of the remaining ligament. These findings will help the orthopedic surgeon to choose the right surgical treatment technique. In this review, the classical MRI findings of the ACL injuries, as well as the location of the injured region and the quality of the remaining tissue, are addressed.

Keywords: Knee, magnetic resonance imaging, anterior cruciate ligament

INTRODUCTION

Every year, there is a statistically growing number of knee ligament injuries due to an increase in sports activities. The anterior cruciate ligament (ACL) tear or sprain is considered to be one of the most common sports injuries. The incidence of ACL rupture is 35 per 100,000 (1). An ACL injury may lead to pain, recurrent instability, progressive meniscus injury and cartilage damage, decrease in the quality of life, and finally osteoarthritis of the knees (2). The first surgical interventions for the ACL rupture were performed in the 1970s as open repair (3, 4). This treatment was abandoned after it was realized that the mid-term outcome was not satisfying. Arthroscopic ACL reconstruction is nowadays a standard treatment option following ACL rupture in active patients. The success rate of the arthroscopic ACL reconstruction has been reported as ranging between 70% and 90% (5, 6). In this standard treatment, the location of the tear and the quality of the remnant tissue was not important, so ruptured ACL debridement was the standard surgical procedure.

The ACL is composed of two functional bundles. These bundles are the anteromedial bundle (AM) and posterolateral bundle (PL), according to their insertion to tibia (7). An isolated PL or AM bundle reconstruction can be performed in the presence of clinical and magnetic resonance imaging (MRI) findings due to the inability of one bundle to function and the other to be inadequate (8, 9). With a selective bundle reconstruction in partial ACL tear, at least a full ACL reconstruction or even better results can be obtained. In addition, the advantages of preserving the proprioceptive functions of the ligament and having surgery with less morbidity are endured.

Despite anatomical and selective reconstruction techniques, the quest for ideal treatment in ACL surgery continues. Preservation of the injured ACL tissue can provide the maintenance of the proprioceptive and natural knee kinematics and is thought to accelerate healing by reducing surgical morbidity. More recently, arthroscopic primary repair of ACL tears is becoming popular again. DiFelice et al. (10) reported very successful results of the arthroscopic primary repair in patients with proximal tears, which are called type I, and good remnant tissue quality. Some authors agree with these findings (11, 12). This review emphasizes that the proximal ACL tear and good remnant tissue quality are critical for a successful outcome of the arthroscopic primary ACL repair.

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The assessment of soft tissue injuries in the knee joint with MRI has also established itself as the next diagnostic tool, following physical examination and x-ray. It is accepted that MRI is the most effective radiological method with 90% to 95% sensitivity and 95% to 100% specificity when assessing ACL injuries. In addition, if the MR images are not optimized, the technique can be less reliable in partial or chronic ruptures (13, 14). When direct and indirect findings in MRI of knee are evaluated together, much information can be obtained about the affected bundle, rupture site, and the residual tissue quality of the ACL tear.

The aim of this review is to emphasize the importance of the affected bundle, the location of the injury and the structure of the remnant ACL tissue, as well as to discuss the classical findings of MRI with the ACL injury. These findings may guide the orthopedic surgeon to choose the right surgical treatment technique.

Knee MRI

All examinations were performed with a 3.0T MRI machine (Siemens, Magnetom, Skyra, Erlangen, Germany) and a 16-channel knee-dedicated tx rx in our clinic. We used our standardized protocol, which has three sequences in the sag-

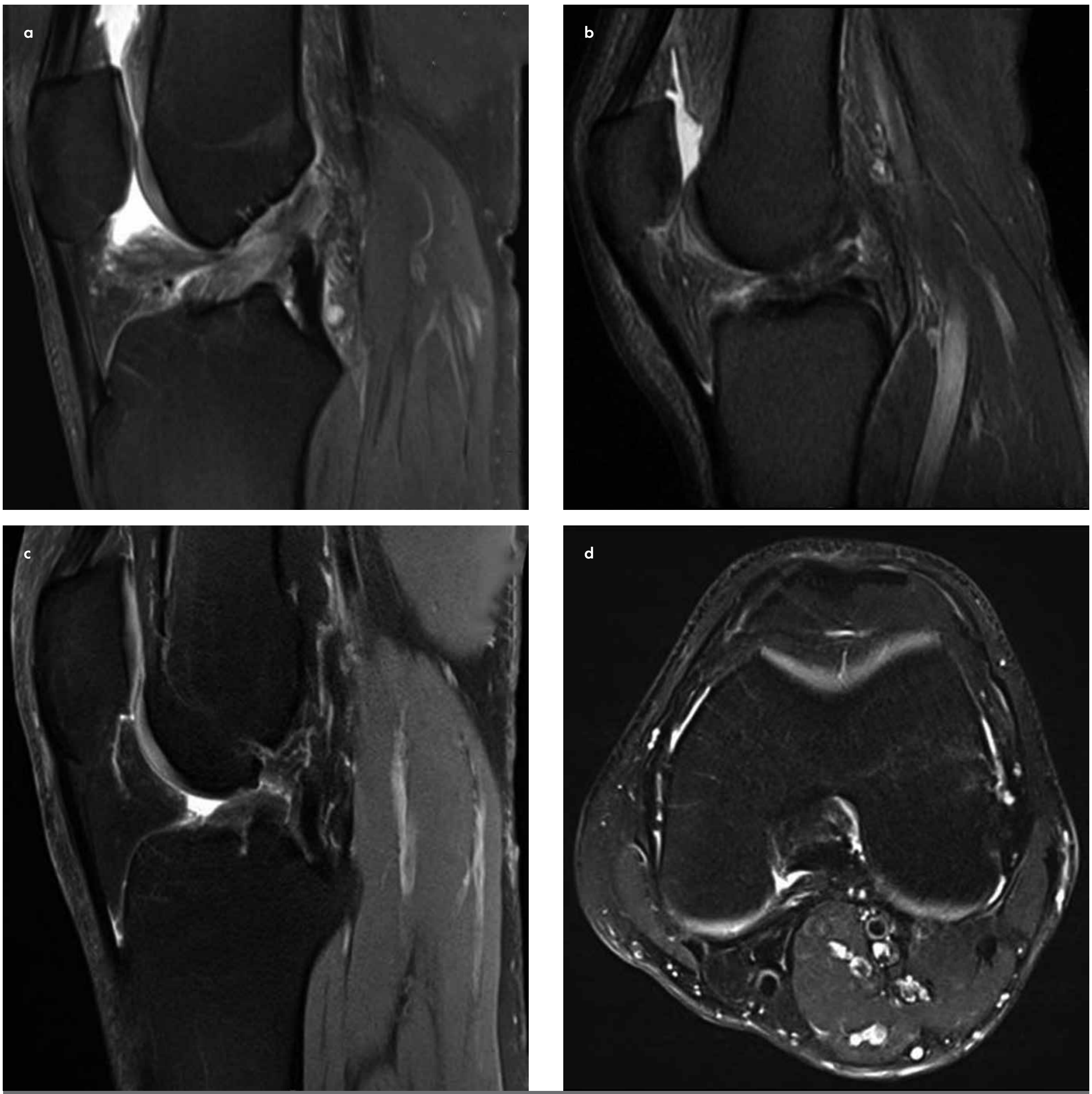

FIGURE 1. a-d. Three separate sagittal proton-density MRI images of the knees depict the anterior cruciate ligament disruption. Acute injury (a) subacute injury (b) chronic injury (c). Axial proton-density MRI images of the knee depicting a chronic anterior cruciate ligament disruption and "empty notch sign" (d).

FIGURE 2. a-b. Sagittal proton-density MRI image of the knee: The asterisk marks the hemarthrosis. (a) Axial proton-density MRI image of the knee: The asterisk marks the hemarthrosis (b).

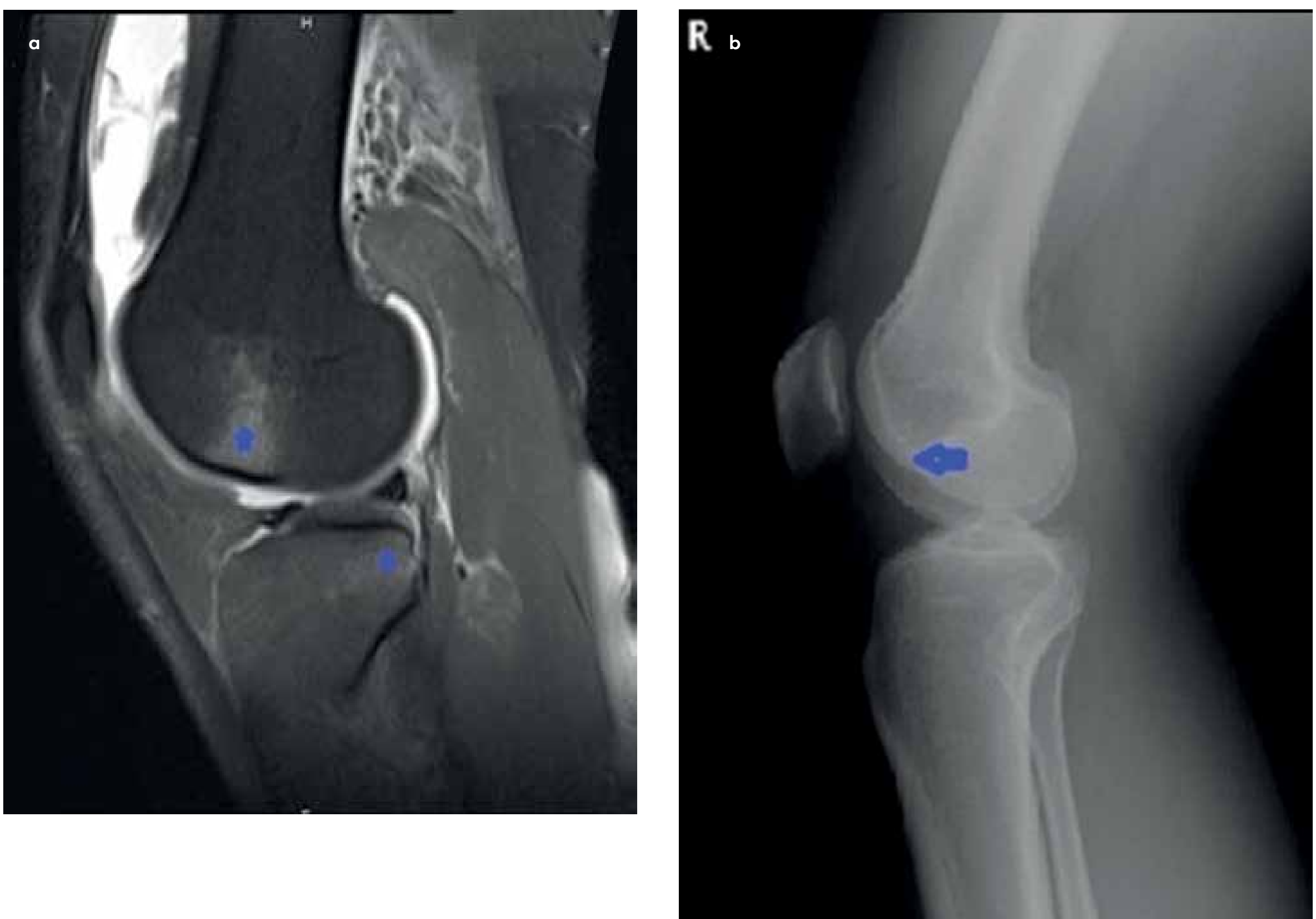

FIGURE 3. a, b. Sagittal T2 proton-density of knee: The asterisk marks the central third of the lateral femoral condyle and posterior third of the lateral tibial plateau bone bruise (a) Lateral knee direct graphy: The arrow marks deep sulcus (terminalis) sign (b).

ittal orientation [1- fat-suppressed proton-density weighted turbo spin-echo (FS PD TSE) sequence 2; T1-weighted turbo spin-echo sequence 3; T2 with water excitation (T2 DE3D WE) sequence]; two sequences in the coronal orientation [1- fat-suppressed proton-density weighted turbo spin-echo (FS PD TSE) sequence 2; T2 turbo inversion recovery magnitude short tau inversion recovery (T2_TIRM_COR(STIR) sequence], and one sequence in the axial orientation [1- fat-suppressed proton-density weighted turbo spin-echo (PD_TSE_FS_TRA) sequence]. The parameters used for image acquisition were a 320X256 matrix and 3.0 mm slice thickness with 0.3 mm inter-slice gap.

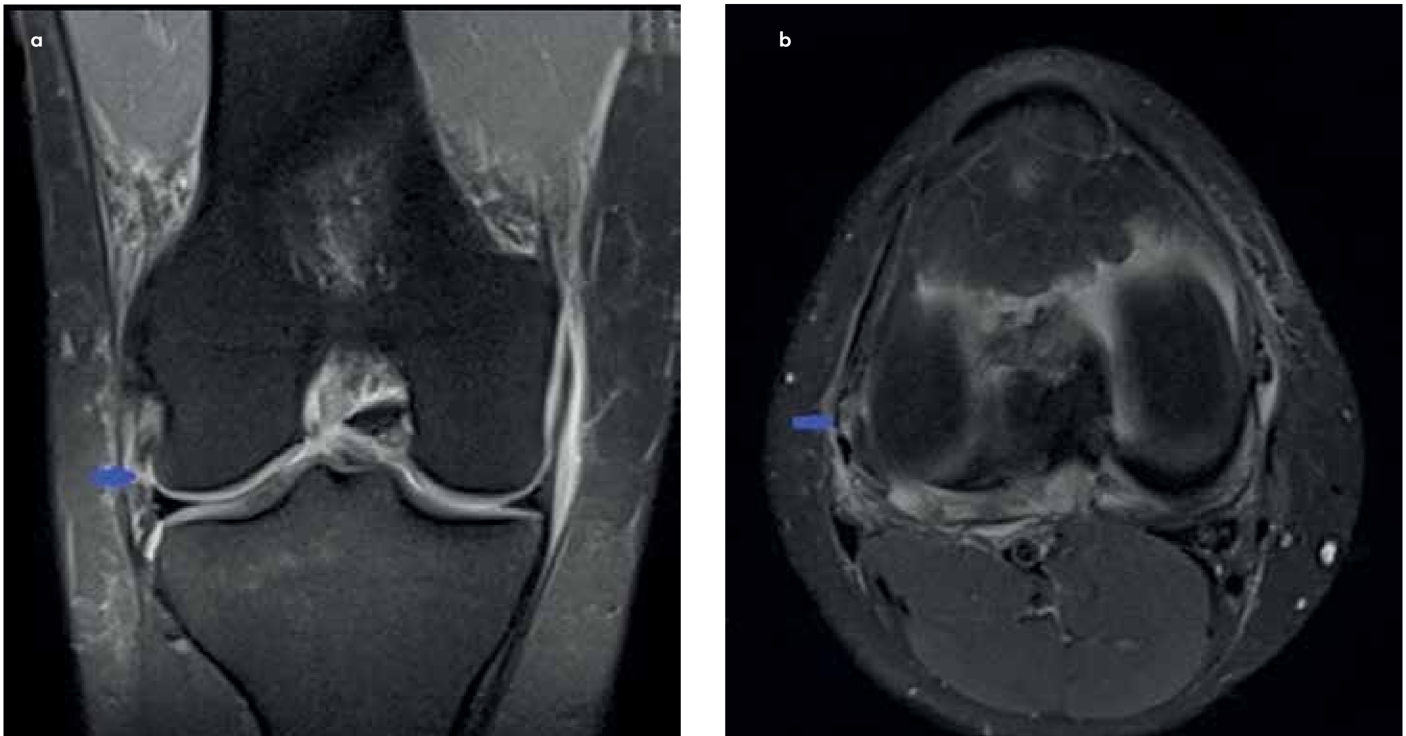

FIGURE 4. a, b. Coronal proton-density MRI image of the knee: The arrow marks disruption of the femoral part of the anterolateral ligament (a) Axial proton-density MRI image of knee: The arrow marks anterolateral ligament (b).

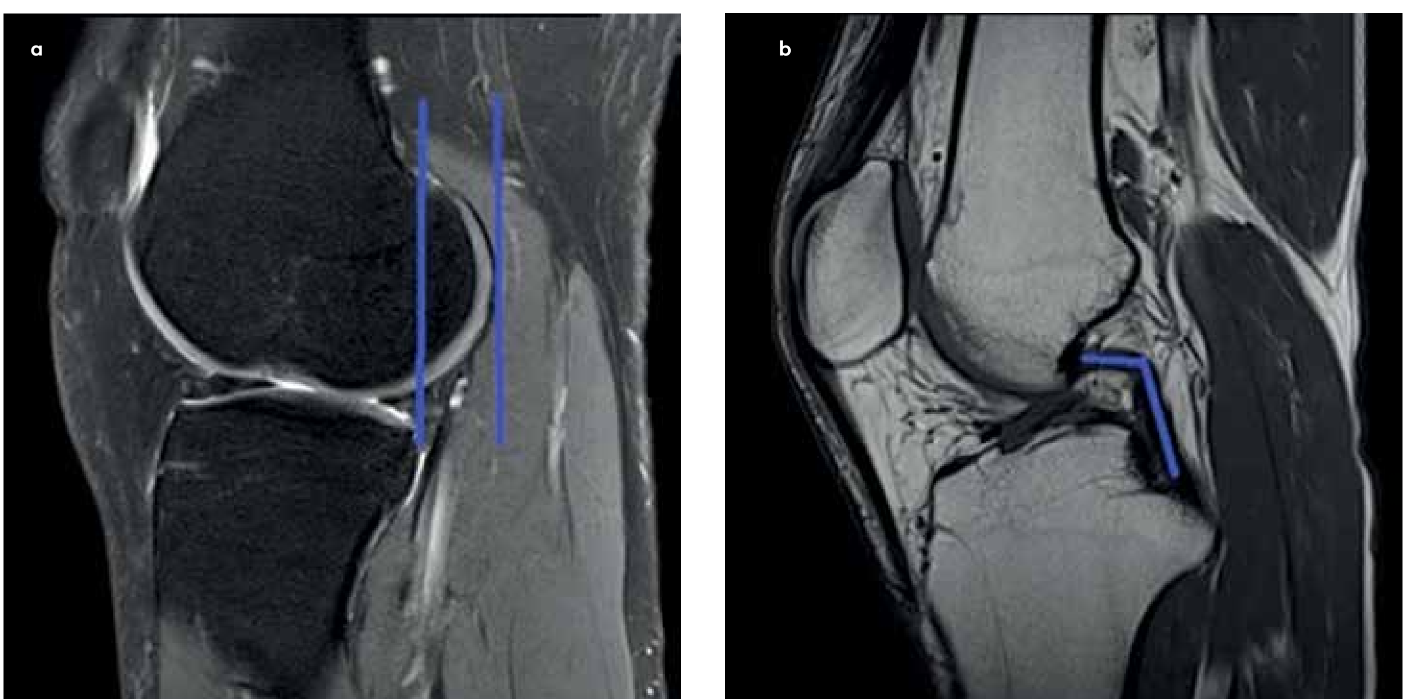

FIGURE 5. a, b. Sagittal proton-density MRI image of the knee: The amount between two longitudinal lines shows the anterior tibial translocation. (a) Sagittal T1 MRI image of the knee: The angle between the two blue lines shows the PCL buckling (b).

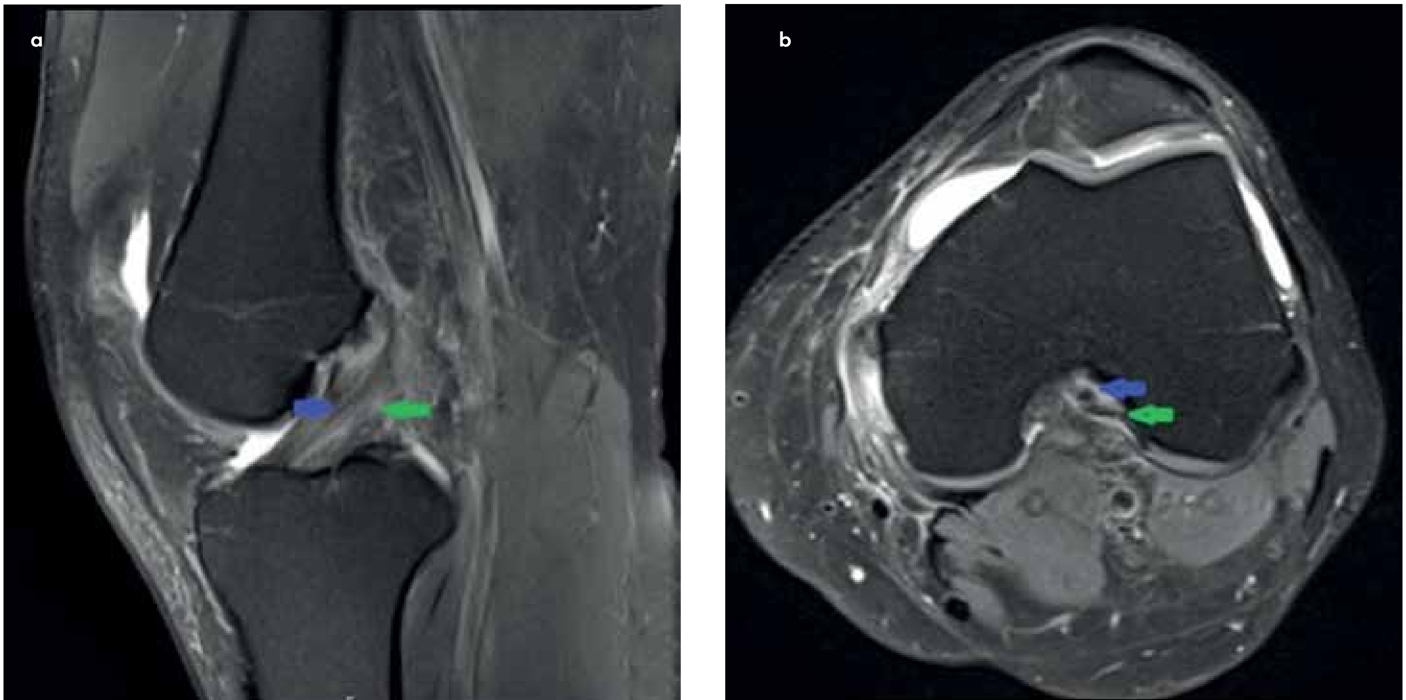

FIGURE 6. a, b. Sagittal proton-density MRI image of the knee: The blue arrow shows intact anteromedial bundle; the green arrow shows disrupted posteromedial bundle. (a) Axial proton-density MRI image of the knee: The blue arrow shows disrupted posterolateral bundle femoral attachment; the green arrow shows intact anteromedial bundle femoral attachment (b).

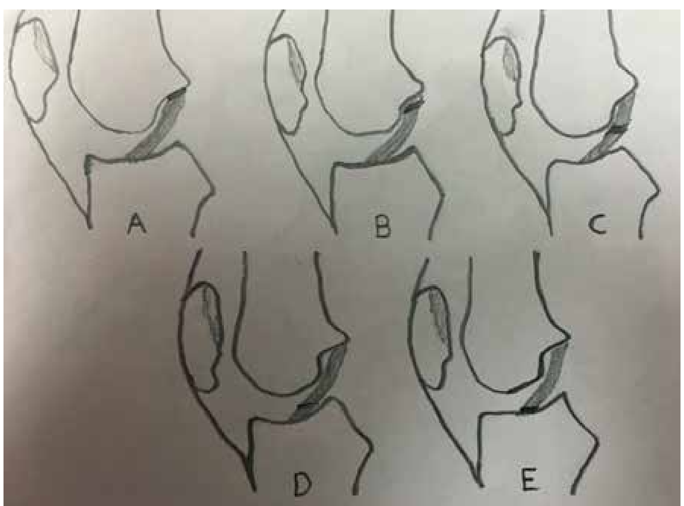

FIGURE 7. a-e. Tear type classification (Drawings by B. Polat). Type I proximal avulsion tear (a). Type II proximal tear (b). Type III midsubstance tear (c). Type IV distal tear (d). Type V distal avulsion tear (e).

A normal ACL is characterized by continuous, homogeneous low-signal intensity fibers, extending from the intercondylar notch of the tibial plateau to the medial aspect of the lateral femoral condyle. The ACL is best visualized with a turbo spin echo (TSE) sagittal intermediate weighted sequence and axial intermediate weighted with fat-suppression sequence. In addition, tibial attachments of the AM and PL bundles can be seen with coronal images.

Knee MRI scans were evaluated for the presence or absence of the following direct and indirect signs. These signs are discussed below.

DIRECT SIGNS

The direct signs of acute ACL tears consist of a structural integrity at any plane (axial, coronal, or sagittal) in the morphology of ACL, abnormal ligament contour, and abnormal MRI signal characteristics of the ligament itself. MRI studies performed in the acute period may show hyperintense appearance in the sagittal T2 sequences and are indicative of the loss of integrity and edema (Figure 1a). In the subacute period, the edematous appearance gives place to the fragmented appearance of lower intensity (Figure 1b). In the chronic period, the ACL may appear to be completely absent or undulated in the T2-weighted sagittal and axial sequence (Figure 1c, d) which can be named "empty notch sign" (15).

INDIRECT SIGNS

Hemarthrosis

Anterior cruciate ligament injury is the most common reason of traumatic knee hemarthrosis. The reason for acute hemarthrosis is injury to the branches of the middle geniculate artery. Bomberg et al. (16) reported that acute traumatic hemarthrosis in 71% of patients is caused by an ACL tear. Other most common causes of traumatic knee hemarthrosis are patellar dislocation and meniscal tear. Hemarthrosis is not considered a specific finding indicative of ACL injuries. It can be seen in the overall joint, particularly in the suprapatellar pouch, presenting as hyperintense in T1 and intermediate to hyperintense in T2 sequence (Figure 2a, b).

Bone Bruise and Deep Sulcus Sign

When the ACL is torn, anterior translation of the tibia leads to abnormal contact of the lateral femoral condyle and lateral tibial plateau. This abnormal contact leads to microtrabecular fractures, edema, and hemorrhage on the subchondral bone. This condition is called bone marrow edema or bone bruise on

MRI. Generally, it is accepted that most common bone bruise locations in case of an acute ACL tear is the central third of the lateral femoral condyle and posterior third of the lateral tibial plateau (Figure 3a). This bone bruise pattern is sometimes seen in the medial compartment during severe injuries. Dunn et al. (17) reported that 418 of 525 (80%) patients with ACL tear had bone bruise imaging findings. Osteochondral depression of lateral femoral condyle in sulcus terminalis where a junction between the weight bearing tibial articular surface and the articular patellar surface of the femoral condyle, can be called "deep sulcus terminalis sign" (18). An average of 2 mm of collapse on the lateral femoral sulcus can be seen on direct graphy, as well as on MRI (Figure 3b). In a MR review study, bone contusions or bruise in the lateral compartment of the knee increased the specificity and positive predictive value in the ACL injury (19).

Segond Fracture or Anterolateral Ligament (ALL) Rupture

The abnormal varus stress and internal rotation of the tibia during the ACL injury causes the avulsion fracture of the lateral tibial condyle, which is called the Segond fracture. The Segond fracture is actually a bony avulsion of the ALL (20). This lesion, which is better seen on a direct graph, may also be detected on MRI.

Anterolateral ligament originates from the lateral femoral epicondyle, and it has a diagonal course and inserts at the anterolateral part of the tibial plateau, which is posterior to Gerdy's tubercle (21). Based on previous anatomic studies, the ALL has been divided into three segments: femoral (from the origin to the bifurcation point); meniscal (from the meniscal insertion to the bifurcation point); and tibial (from the tibial insertion to the bifurcation) parts (21, 22). Fat-saturated T2 weighted, proton-density weighted coronal and axial images of magnetic resonance generally show ALL precisely. With the coronal view, the meniscal part, the femoral part and the tibial part of the anterolateral ligament are easily observed (Figure 4a). With the axial view, ALL can be seen just in front of the lateral collateral ligament (Figure 4b) (23). Helito et al. (24) found that 32.6% of patients with a torn ACL had ALL injuries.

Anterior Tibial Translocation

Magnetic resonance studies of the sagittal section of the lateral femoral condyle were described as an indirect finding if there was a 7 mm or greater anterior translocation of the tibia relative to the femur (25). The amount of anterior tibial translocation is measured by calculating the distance between the posterior edges of lateral femoral condyle and the posterior edges of the tibia by drawing tangential vertical lines. The measurement should be made in the middle of the lateral femoral condyle of the sagittal plane images (Figure 5a). The mean anterior translocation amount in chronic ACL tears is 8.7 mm on average, while in acute ACL tears, it is 5.4 mm on average. The anterior tibial translocation has been shown to increase with time (26). This finding is considered equivalent to the physical examination of the anterior drawer test. According to Vahey et al. (25), the tibial anterior translocation was a specific finding for the ACL tear. It is accepted that subluxation of at least 5 mm has 58% sensitivity and 93% specificity for an ACL tear.

Buckling of the Posterior Cruciate Ligament

In the sagittal imaging of knee MRI with ACL tears, the sigmoidal orientation develops in the posterior cruciate ligament (PCL) due to the anterior translation of the tibia relative to the femur (27). This sign is called buckling of the PCL, and it can be observed with acute or chronic ACL tears (Figure 5b). In some studies, it has been reported that sigmoidal or curved appearance of PCL is more common in chronic ACL tears than in acute ACL tears (28). Yoo et al. (29) found that the reason for PCL buckling is the anterior subluxation of the tibia with ACL tears, and they also noted that hyperbuckling disappears after ACL reconstruction. For this reason, the PCL buckling observed after an ACL reconstruction is an indication of ACL laxity.

Tear Location of and the Residual Tissue Quality of ACL

Partial ACL injuries that affect the AM or PL bundle constitute approximately 30% of all ACL injuries (Figures 6a, b) (30). Biomechanical studies have shown that the PL bundle affects the rotational stability (pivot shift test), and the AM bundle affects the antero-posterior translational stability (anterior drawer test) (31). It is easy to diagnose complete ACL tears, compared to partial tears (sensitivity of 62%-81%; specificity of 19%-97%; and accuracy rates of 25%-53%) (32). An oblique axial sequence, thin slice, and the use of 3 Tesla MRI may increase these accuracy rates (33, 34). In contrast to physical examination and MR assistance, a definitive diagnosis of partial ACL tears is determined during arthroscopy. Although a definitive decision of selective reconstruction for partial ACL injury is given during arthroscopy, a well-evaluated MRI will guide to the surgeon before surgery.

Current ACL reconstruction procedures, which are called anatomic or double-bundle reconstruction, have limitations. Approximately, the failure rate of 10% can be found in the ACL reconstruction surgery. Limitation of movement, arthrosis, and recurrent instability are the main reasons of such failure (35). Recent biomechanical studies have suggested that the ACL reconstruction is not always successful with regard to gaining normal knee kinematics and does not totally prevent early osteoarthritis in the knee (36, 37). Arthroscopic ACL repair has many theoretical advantages over reconstruction. These advantages have gradually increased the interest in this surgical technique in recent years. With this technique, a normal knee kinematics is more effectively preserved, and the development of osteoarthritis is prevented as the patient's ACL is preserved (38). Arthroscopic ACL repair does not require graft tissue and bone tunnels, which provides shorter surgical time and recovery with fewer complications than the ACL reconstruction surgery (39). A detailed MRI evaluation is mandatory preoperatively if arthroscopic ACL repair is considered. The success of the surgery is directly affected by the remnant tissue quality and the localization of the tear. The modified Sherman classification system helps to classify the tear localization in five types (Figure 7). In Type I tear, the femoral part of ACL is avulsed, but more than 90% of the distal ACL is intact. In Type 2, there is a proximal tear with 75%-90% of intact distal ACL. In Type 3, there is midsubstance tear between 25% and 75% of the ACL. Types 4 and 5 are the distal tears, with 10%-25% of the distal ACL remaining intact in Type 4, and less than 10% of the distal ACL left intact. Type 5 tears can be divided into two groups, as soft tissue avulsions (type VA) or bony avulsions of tibial insertion (type VB). In the decision of arthroscopic primary ACL repair, this classification is very helpful.

In addition, the tissue quality can be classified as good, fair, and poor. If all fibers are intact in the same direction with a homogeneous signal, it is called a good quality tissue. If some fibers are in the same direction with a mildly heterogeneous signal, it is called a fair quality tissue, and if most fibers are in different directions with heterogeneous signal, it is called a poor quality tissue. Tears with good tissue quality must be preferred for an arthroscopic ACL repair.

CONCLUSION

Patients with a suspected ACL tear are diagnosed with an MRI scan. It is accepted that MRI is the most effective radiological modality, with 90%-95% sensitivity and 95%-100% specificity for detecting ACL injuries. Historically, MRI is mainly used to determine the ACL injury and to discern whether the tear is partial or complete. However, recently the MRI targeting has been expanded. Nowadays, the MRI classification of the remnant tissue quality and the localization of the ACL tear are the most important findings for primary arthroscopic ACL repair. As a result, choosing the right surgical technique for the ACL tear treatment is easier with these findings and the MRI help.

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