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Examination through familiarity with basics and a systematic approach

Managing ACL tears: Evaluation and diagnosis

*ABSTRACT: Anterior cruciate ligament (ACL) tears are common in young sports participants; women are at greater risk than men. The ACL provides stability during normal knee motion in jumping, cutting, deceleration, and direction-changing activities. Typically, injury occurs as a result of an awkward landing or a pivot with twisting of the knee. A large hemarthrosis stretches the joint capsule and results in pain. In the examination, the injured knee must be compared with the uninjured knee. The Lachman test is an excellent test for ACL laxity. The pivot shift test is the most specific test for a complete ACL tear. Plain x-ray films are used to find ligament injury and identify associated fractures. MRI helps in evaluation of associated injuries. (*J Musculoskel Med. *2004;21:381G-390)*

An estimated 100,000 new anterior cruciate ligament (ACL) injuries occur each year.[1] Isolated ACL injuries account for half of all knee ligament injuries; about 1 of every 3000 persons in the general population injures an ACL in a given year.[2] ACL tears are common in young, active persons; 70% of injuries occur during sports participation. Within the high-risk population of recreational skiers, the rate of injury increases to about 1 of every 2000 adult skier visits.[3]

Women are at greater risk for tearing their ACL than men. The incidence of ACL tears in female high school basketball players[4] and female volleyball players of all ages[5] is 4 times higher than in age- and sport-matched males. The incidence of ACL tears in female indoor soccer players is 6 times greater than in male indoor soccer players of all ages.[6]

A patient who has an ACL tear requires careful assessment to detect the associated injuries that are common in incidents involving high-energy mechanisms. Primary care physicians, athletic trainers, and physical therapists are often first to evaluate injured patients. A familiarity with proper evaluation of ACL tears and the associated complex injury patterns helps ensure proper diagnosis. Accurate diagnosis of an ACL tear and associated injuries leads to proper nonoperative treatment or appropriate, timely referral to a sports medicine specialist.

In this 2-part article, we describe the overall evaluation and management of ACL tears. This first part reviews the normal anatomy of the ACL; its biomechanics and function; the common injury patterns; and proper evaluation, including tests and imaging, leading to diagnosis. In the second part, to appear in a later issue of this journal, we will describe nonoperative management of ACL tears, the indications for referral to a sports medicine specialist, preoperative management, the various techniques used for ACL reconstruction surgery, and the components of postoperative care.

EPIDEMIOLOGY

Differences in anatomy, neuromuscular physiology, and flexibility and the presence of a menstrual cycle in women seem to account for the gender differences in ACL injury rates. Women have a wider pelvis than men, increased valgus alignment of the knee, and increased external tibial torsion; the latter places the ACL at an inherent mechanical disadvantage, par-

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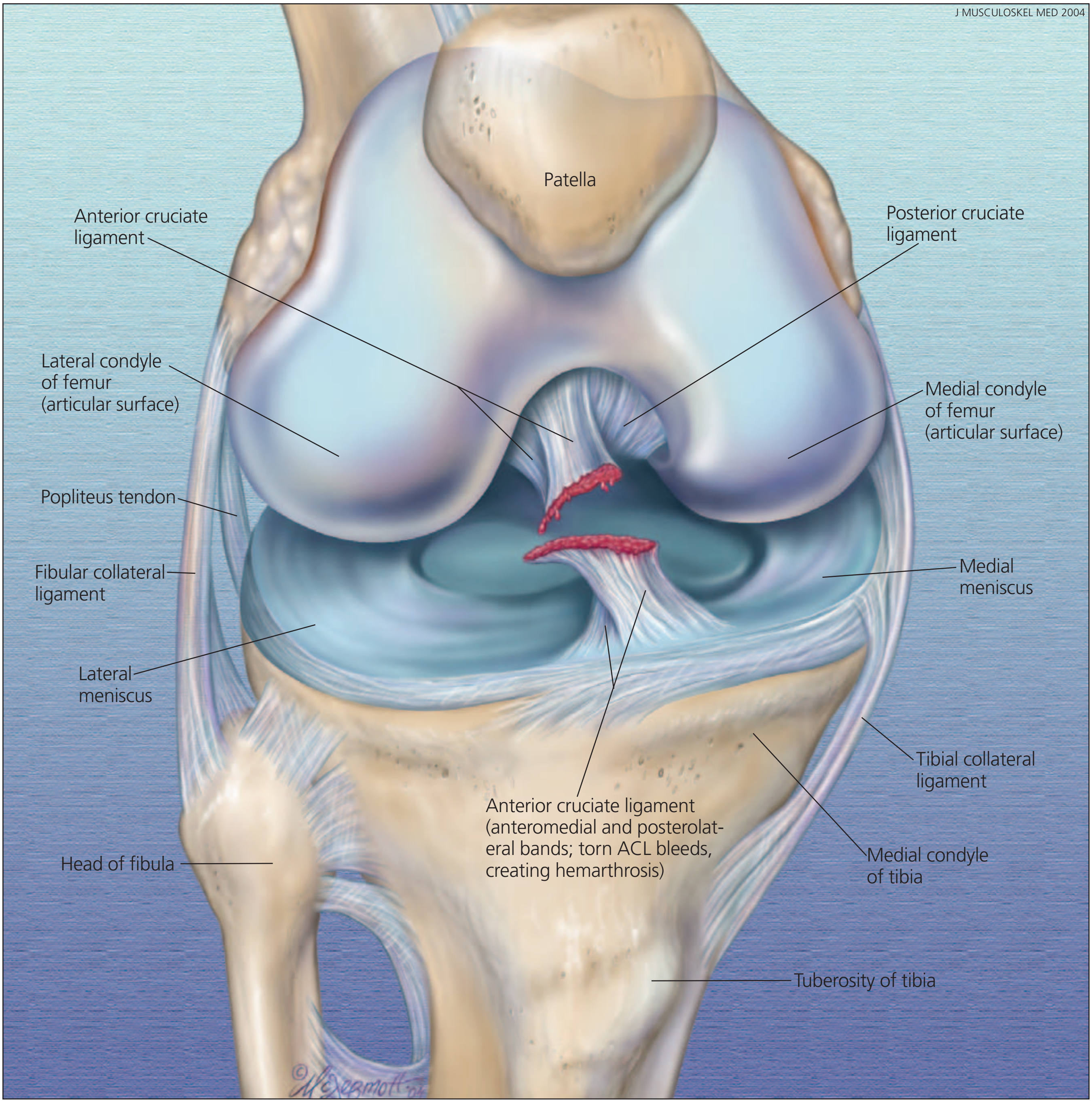


Figure 1 – *A familiarity with basic knee anatomy helps in proper evaluation of anterior cruciate ligament (ACL) tears and associated complex injury patterns. The ACL is 1 of 4 ligaments that stabilize the knee joint. It stabilizes the femur on the tibia and serves to prevent the tibia from rotating and sliding forward during agility, jumping, and deceleration activities. The knee ligaments are prone to injury with contact to the knee or with the force of a hard muscle contraction (as in a quick change of direction during running) because the knee joint is well exposed and its bone anatomy provides little support to its stability.*

ticularly during jumping activities.[7] Neuromuscular gender differences include less total muscle mass in women, delayed muscle activation and slower force generation,[8] and decreased ability to generate muscle force, even when there is correction for differences in size.[9]

In addition, women athletes have an altered muscle recruitment pattern, including a tendency to recruit quadriceps muscles rather than hamstrings or gastrocnemius muscles[10]; this places their ACLs at additional risk. Women have greater general laxity in ligaments throughout their body, including the ACL, than men of the same age. Estrogen and progesterone receptors have been demonstrated within the ACL[11]; women athletes are at greater risk for ACL injury during the ovulatory phase of their menstrual cycle.[12]

The pediatric equivalent of an ACL tear is an avulsion of the tibial eminence, which has a similar mechanism. Although these avulsion fractures are considered childhood injuries and have been shown to occur more often in children, they also occur in adults.[13] Recent data suggest that tibial avulsion fractures occur primarily in boys but may occur at any age in women.[14] The specific reason for this gender-age interaction is unclear.

ANATOMY AND BIOMECHANICS

The ACL is intracapsular but extrasynovial. It receives the majority of its blood supply from the middle geniculate artery, which arises from the popliteal artery and pierces the posterior capsule. The femoral origin of the ACL is on the lateral wall of the intercondylar notch at its most posterior edge, originating from the 11 o'clock location in right knees (Figure 1) and the 1 o'clock location in left knees. The fibers of the tibial attachment are parallel to the anteroposterior (AP) axis of the tibial plateau at the level of the posterior edge of the anterior horn of the lateral meniscus.

The ACL is composed of 2 bands of fascicles; the smaller anteromedial band is tighter in flexion, and the larger posterolateral band is tighter in extension. This differential allows the ACL to remain taut in the full range of knee motion and produces a rotation of the ACL fibers as the knee moves from extension to flexion. The ACL fibers receive their innervation from the tibial nerve, which infiltrates the capsule posteriorly, investing Golgi receptors and nerves; the nerves transmit pain and the Golgi receptors are proprioception mechanoreceptors that sense ACL stretch.[15]

The importance of ACL function has been emphasized in active persons who require knee stability in various activities.

A normal ACL provides knee stability in the AP plane and, secondarily, rotational stability in extension. It also allows for proper articulation of the tibia on the femoral condyles. The importance of ACL function has been emphasized in active persons who require knee stability in various activities, such as jumping, cutting, deceleration, and changing direction. In the normal ACL, the proprioceptive sensory function provides positional feedback to central motor control in the cerebellum to protect the knee during use.[15]

The ACL is a viscoelastic structure that can undergo time-dependent stretch and return to its resting length without structural damage. It is composed of multiple bands that control multiaxial movement and guide the tibiofemoral articulation through a complex helicoid motion involving both rotational and translational vectors. The exact location of its broad insertion sites and the angle at which it traverses the knee provide both rotational and translational stability during normal knee motion in jumping, cutting, deceleration, and abrupt direction-changing activities.

The ACL is the primary restraint against anterior tibial displacement, providing nearly 90% of anterior translational stability of the tibia—especially at 30° of flexion, when the effect of secondary stabilizers is minimized—allowing for a more direct evaluation of ACL function. Secondary restraint against AP motion of the knee is provided by a combination of the static restraint from the menisci, capsular ligaments, and tibiofemoral articulation and the dynamic restraint from muscles crossing the knee. Because of these secondary restraints, when there is a complete tear of the ACL, a knee may feel stable to the examiner if the knee is examined in full extension or at 90° of flexion. The anatomy of the ACL allows it to serve as a secondary restraint against tibial rotation while the knee is in full extension.

CLINICAL SIGNS AND SYMPTOMS

History

Typically, injury of the ACL occurs as a result of an awkward landing or a pivot with twisting of the knee while an athlete is changing direction or landing from a jump. Noncontact ACL tears are most common and frequently are related to this mechanism of deceleration or change of direction. The patient usually reports hearing a "pop" or feeling a tearing sensation and collapses to the ground as a result of the ACL tearing and the knee giving way.

Approximately 80% of patients notice a rapid onset of swelling within 3 hours of injury; however, more gradual swelling over 24 hours does not rule out an ACL tear. The swelling results from a hemarthrosis of the ACL, which bleeds when it is torn. In a high-energy mechanism, hemarthrosis may occur as a result of an intra-articular fracture. Patients who have an ACL injury report that immediately following the injury, they were unable to continue playing or skiing because of instability and had difficulty in bearing weight.

Physical examination

To perform an accurate and reliable ligament examination, make sure that the patient is comfortable and relaxed. Pain or apprehension in even the most compliant patient causes involuntary muscle contracture across the injured knee; this invalidates examination findings.

Figure 2 – *The Lachman test is performed to evaluate the knee for laxity of the anterior cruciate ligament. The knee is placed in a position of 20° to 30° of flexion and is slightly externally rotated to relax the pull of the quadriceps and iliotibial band. The femur is firmly stabilized with the examiner's outer hand; an anteriorly directed force is applied to the proximal calf. The examiner estimates displacement in millimeters (in comparison with the contralateral limb) and assesses the presence or absence of an end point.*

A large hemarthrosis stretches the joint capsule and results in pain. If a patient is experiencing severe pain with a tense effusion, we aspirate the knee from the suprapatellar pouch using sterile technique.

The differential diagnosis of a hemarthrosis in the knee with a history of recent trauma includes ACL tear, avulsion fracture of the tibial eminence, intra-articular fracture of the tibial plateau or femoral condyle, patellar dislocation or fracture or both, and meniscal peripheral avulsion. Therefore, the aspirate is inspected for blood and the presence of fat droplets, which indicates an intra-articular fracture. A local anesthetic may be injected into the knee to provide comfort and aid in the physical examination.

In all aspects of the examination, the injured knee must be compared with the contralateral uninjured knee. In the acute setting, possible associated injuries must be evaluated. Deformities, focal swelling or ecchymosis, and specific areas of point tenderness must be evaluated for associated fractures, meniscal tears, or injuries of the collateral ligaments or posterior cruciate ligament (PCL); such injuries may indicate a complex multi-ligament injury pattern or knee dislocation.

Focal joint line tenderness to palpation and discomfort with rotation-compression maneuvers may indicate an associated meniscal tear. Classically, the "unhappy triad" described by O'Donoghue[16] was identified as an ACL–medial collateral ligament (MCL) injury associated with a medial meniscal tear. More recently, it has been determined that lateral meniscal tears are more common with acute ACL injuries and medial meniscal tears are more common in chronic ACL-deficient knees, but if medial tears occur in the setting of an acute ACL injury, they are more likely to be repairable.[17]

Collateral ligaments and posterolateral corner structures must be evaluated for concomitant injury. Range of motion may be limited by a hemarthrosis, muscle spasm, associated meniscal tears or fractures, or impingement of the ACL stump in the anterior knee. ACL stump impingement may also result in crepitus felt by the examiner's thumb on the anterolateral joint line.

Figure 3 – *When a knee with a suspected acute anterior cruciate ligament (ACL) injury is evaluated, plain radiography should be the first imaging study that is ordered. In this lateral x-ray view of an ACL-deficient knee, an anterior subluxed tibia is demonstrated. An anteroposterior standing x-ray view can be used to evaluate any joint-space narrowing and the presence of malalignment.*

Testing

Lachman test. In the office setting, this is an excellent test for ACL laxity because the patient usually is able to relax enough to allow for a reliable examination and it provides both a quantitative evaluation of millimeters of tibial translation and an appreciation of the quality of the "end point." In the Lachman test, the knee is placed in a position of 20° to 30° of flexion and slightly externally rotated to relax the pull of the quadriceps and iliotibial band (Figure 2). The femur is firmly stabilized with the examiner's outer hand (eg, left hand for right knee), and an anteriorly directed force is applied to the proximal calf with the examiner's other hand on the tibia. The examiner may place his or her own flexed knee under the patient's knee to provide slight flexion and help stabilize the femur.

The examiner should estimate the displacement (in millimeters) and assess the presence or absence of an end point and, if present, the firmness of the end point (graded as firm [normal], marginal, or soft). The laxity is measured not as an absolute amount but as a comparison with the contralateral limb; the side-to-side differences are graded. Grade I laxity is a 1- to 5-mm difference, grade II is a 6- to 10-mm difference, and grade III is a greater than 10-mm difference.

Lateral meniscal tears are more common with acute ACL injuries, and medial meniscal tears are more common in ACL-deficient knees.

Pivot shift test. In this test, the patient is in a supine position and relaxed or, preferably, given general anesthesia. While the limb is held in external rotation and the knee in full extension, the lateral tibia is subluxed anteriorly in relation to the femur. While external rotation of the limb is maintained, the hip is brought into abduction to relax the iliotibial band, and an axial and valgus load is applied to the knee as it is slowly flexed. This test simultaneously evaluates both rotation and translation of the tibial plateau relative to the femoral condyle.

All variations of the pivot test (including the classic, Losee, side-lying, and flexion-rotation drawer tests) are based on anterior subluxation of both the lateral and medial plateaus of the tibia in extension and very early flexion (the lateral side subluxing more than the medial). With further flexion (at 20° to 40°), the posterior pull of the iliotibial tract reduces the lateral tibia. Usually, the clinician grades the relocation event subjectively (absent pivot, 0; a pivot with a smooth glide, 1+; a pivot with an abrupt shift, or jump, 2+; or momentary locking in a subluxed position before reduction, 3+).[18]

The pivot shift test is the most specific test for a complete ACL tear, but in patients who are awake, it is often confounded by patient guarding and apprehension. In an examination under anesthesia, the presence of an asymmetric pivot is pathognomonic of a complete ACL tear; a negative pivot test result in the setting of increased anterior translation determined by the Lachman test or instrumented laxity testing is suggestive of a partial ACL tear.

Anterior drawer test. The anterior drawer test is performed with the knee at 90° of flexion. Although commonly cited as part of the ACL evaluation, hamstring tone and the secondary restraints of the knee are not eliminated; therefore, the ACL is not reliably directly tested in this position. Many normal knees have significant translation in this position, and an ACL-deficient knee may be restrained in this position. For these reasons, the anterior drawer test is the least reliable test and is not routinely relied on for diagnosis of an ACL tear.

Instrumented ligament testing. Devices have been used to provide an objective measurement of AP displacement of the tibia on the femur. Test reliability may be influenced by the tester's experience and proficiency. In addition to diagnosing ACL injuries, instrumented ligament testing is a valuable tool for monitoring graft integrity after reconstruction.

Imaging

Plain radiography should be the first imaging study ordered when any knee with a suspected acute ACL injury is evaluated. Ligament injury may be found and associated fractures may be identified.

An avulsion of the insertion of the ACL within the intercondylar eminence may be seen on a lateral or tunnel view. A Segond fracture results from an avulsion of the lateral capsule from the tibia at a location posterior to the Gerdy tubercle and superior and anterior to the fibular head. Often, such a fracture is associated with an ACL injury; if present, it represents an ACL tear until proved otherwise.

Figure 4 – *This anteroposterior x-ray film of a chronic anterior cruciate ligament–deficient knee shows a "lateral notch sign" (an exaggeration of the normal indentation of the sulcus terminalis on the lateral femoral condyle), blunting of the intercondylar eminence, periarticular osteophyte formation, intercondylar notch stenosis, and flattening of the femoral condyles.*

On a lateral x-ray film of a knee with a torn ACL, the tibia is occasionally subluxed anteriorly on the femur (Figure 3). An AP standing x-ray view can be used to evaluate any joint-space narrowing and the presence of malalignment. A weight-bearing 45° flexed posteroanterior x-ray view (the "skier's" view) is needed to carefully examine the articulation of the posterior femoral condyles with the tibial plateau. X-ray films of a chronic ACL-deficient knee may demonstrate a "lateral notch sign," which is an exaggeration of the normal indentation of the sulcus terminalis on the lateral femoral condyle (Figure 4).

Other radiographic findings noted in chronically ACL-deficient knees include intercondylar eminence blunting, periarticular osteophyte formation, and intercondylar notch stenosis. Because chronically ACL-deficient knees are likely to have associated meniscal tears, Fairbanks changes of a meniscectomized knee may be noted in association with chronic ACL tears. Fairbanks changes include flattening of the femoral condyles on AP x-ray films, joint-space narrowing on a 45° flexion weight-bearing view, and marginal osteophytes along the ridge of the femoral condyle.[19]

Although the diagnosis of an ACL tear usually can be made on the basis of the history,

Figure 5 – *MRI helps in evaluation of associated meniscal tears, bone bruises, occult fractures, chondral injuries, and complex ligament injury patterns. In this MRI scan of an anterior cruciate ligament (ACL) tear, loss of continuity of ACL fibers and increased signal within the substance of the ACL are shown.*

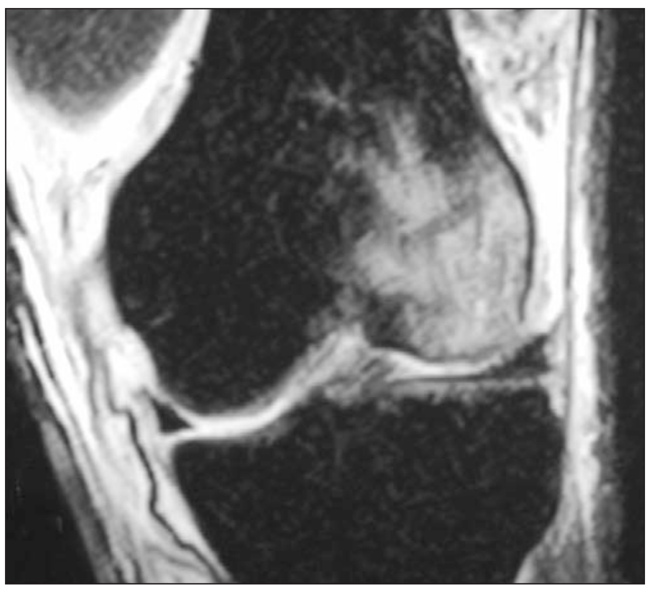
physical examination, and plain radiography, MRI helps in evaluation of associated meniscal tears, bone bruises, occult fractures, chondral injuries, and complex ligament injury patterns. An intact ACL under normal tension is seen on a sagittal view as a straight, low-signal structure that has a smooth contour. A torn ACL shows discontinuity of the ligament in the sagittal plane; loss of tension can create an undulation within the ACL fibers (Figure 5). Edema and hemorrhage are seen as increased signal in the substance of the ACL in an acute injury.

Additional views formatted parallel to the ACL fibers clearly demonstrate the insertion of the ACL fibers on the posterior lateral femoral cortex (Figure 6). Associated MCL injuries are identified on MRI scan; increased signal and, in high-grade injuries, discontinuity in the fibers of the MCL may be demonstrated (Figure 7).

High-signal edema seen in subchondral bone on the posterolateral tibia and anterior lateral femoral condyle represents a bone bruise that resulted from sublux-

Figure 6 – *This MRI scan oriented obliquely through the midsubstance of the anterior cruciate ligament (ACL) demonstrates continuity of the ACL from the tibia to the posterior lateral femoral condyle.*

Figure 7 – *In this MRI scan of a medial collateral ligament (MCL) tear, loss of continuity of the MCL fibers and increased signal within the substance of the MCL are demonstrated. In addition, a bone bruise is seen in the lateral femoral condyle.*



ation of the tibia under the femur at the time of injury; such a bruise is associated with approximately 60% of acute ACL tears.[20] Often these regions of bone marrow edema occur at the site of impaction fractures or focal chondral injuries (Figure 8). MRI also identifies the morphology of associated meniscal tears and alerts sports medicine specialists to tears in the peripheral third in young persons, who benefit from early repair. Whether to obtain an MRI scan should be decided by the treating orthopedist.

True partial ACL tears are extremely unusual. The incidence has been reported at between 10% and 48%[21]; in our opinion, the true number lies at the low end of that spectrum. Partial injuries with a negative pivot shift test result under anesthesia account for fewer than 5% of our patients who have injuries of the ACL.

Figure 8 – *This MRI scan shows a focal chondral lesion (arrow) with subchondral bone loss.*

Commonly, MRI data and even arthroscopic information can be misleading because of the tendency of a torn ACL to scar back to the intercondylar notch or to the PCL; arthroscopically, an ACL that is functionally incompetent and dis-

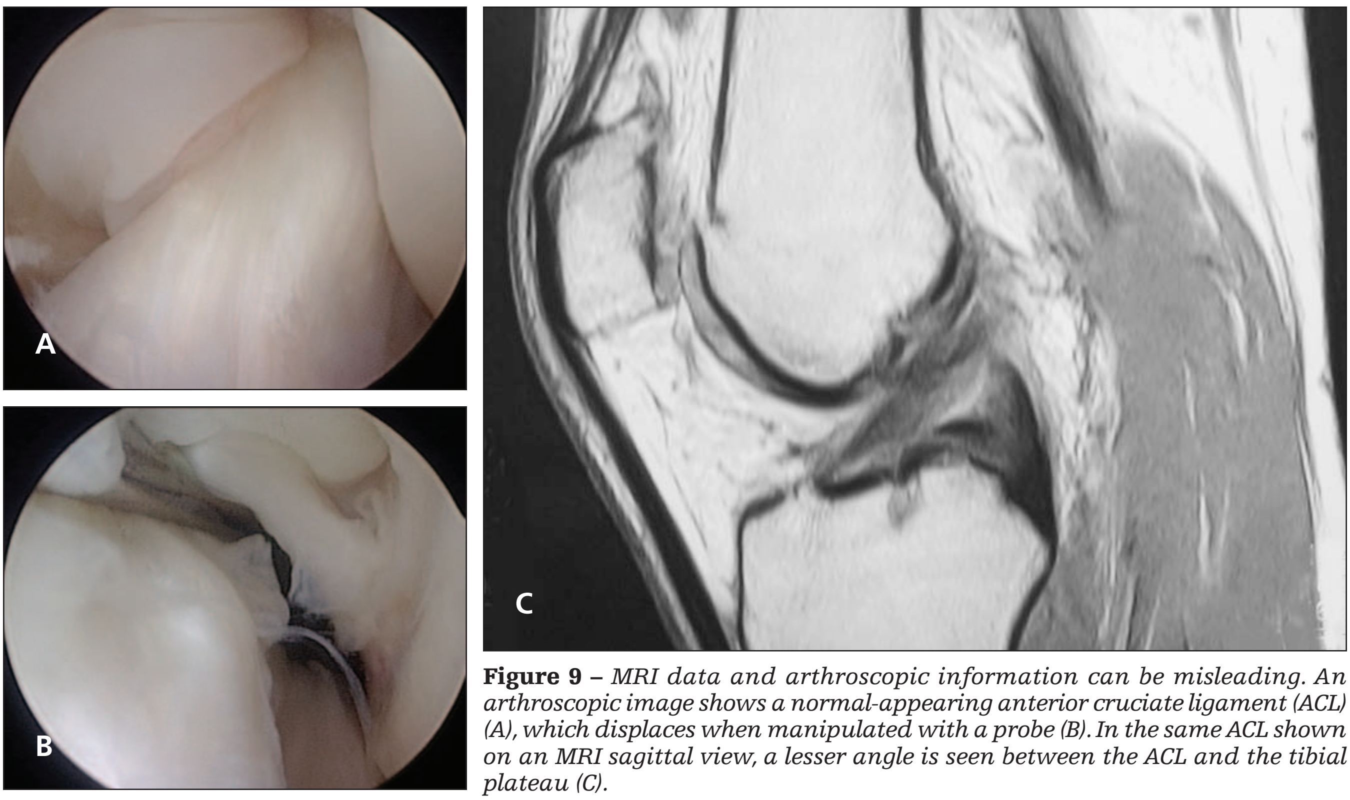


Figure 9 – *MRI data and arthroscopic information can be misleading. An arthroscopic image shows a normal-appearing anterior cruciate ligament (ACL) (A), which displaces when manipulated with a probe (B). In the same ACL shown on an MRI sagittal view, a lesser angle is seen between the ACL and the tibial plateau (C).*

places when manipulated with an arthroscope may appear normal (Figure 9). Findings on MRI that indicate a complete ACL tear include a lesser angle formed between the ACL and the tibial plateau on the sagittal images and loss of the straight-line fiber orientation seen in a healthy ACL under physiologic tension. The best method for differentiating between a partial and a complete ACL tear is the pivot shift examination performed under anesthesia.

Practice Points

- Although most patients with anterior cruciate ligament (ACL) tears notice a rapid onset of swelling within 3 hours of injury, more gradual swelling over 24 hours does not rule out an ACL tear.
- The injured knee must be compared with the contralateral uninjured knee in all aspects of the examination. In the acute setting, possible associated injuries must be evaluated; they may indicate a complex multiligament injury pattern or knee dislocation.
- Plain radiography should be the first imaging study ordered when an acute ACL injury is suspected. MRI helps in evaluation of associated meniscal tears, bone bruises, occult fractures, chondral injuries, and complex ligament injury patterns.

Examination under anesthesia and arthroscopy

When the status of the ACL and menisci remains in doubt, examination under anesthesia with the patient completely relaxed gives a more reliable index of ligamentous laxity. This is followed by arthroscopic inspection of the ACL, menisci, and chondral surfaces. Arthroscopic confirmation of a deficient ACL is usually not necessary in the chronic case when the functional status of the knee is known. Diagnostic arthroscopy is more often used in the acute or subacute setting to clarify an equivocal examination or, potentially, to treat an associated meniscal tear in a patient who does not desire ACL reconstruction. ■

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