ACL Update

IMAGING MODALITIES FOR ASSESSING THE ANTERIOR CRUCIATE LIGAMENT DEFICIENT KNEE

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Imaging of the anterior cruciate ligament (ACL) deficient knee, while difficult in the past, is, with technological advances, becoming increasingly accurate and more valuable in its role of providing information upon which diagnosis and treatment can be based. Magnetic resonance imaging (MRI), noninvasive and nonionizing, has been the most significant contribution in this area and, in many situations, the imaging method of choice. Routine radiography remains the most important fundamental technique in the initial evaluation of the injured knee, while the roles of arthrography, computerized tomography, and bone scan, despite their documented value, are declining.

RADIOGRAPHS

In the patient with a suspected disruption of the ACL ligament, plain radiographs should be obtained. One must eliminate the possibility of associated fracture in the patient population with an acute hemorrhosis. Although the majority of adult patients will have a "mop-end" tear of the ACL, some adults and many younger patients will demonstrate an avulsion of the tibial eminence. This finding is often visible on plain radiographs (Fig 1).

Close examination of the plain anteroposterior or oblique film may reveal evidence of a lateral capsular avulsion fragment. This fragment, known as the "Segond" fracture, is considered by some to be a pathognomonic sign of anterior cruciate injury (Fig 2). This fragment, also called the lateral capsular sign, is an avulsion fracture of the articular edge of the lateral tibial plateau by the middle third of the lateral meniscotibial ligament. Day undertook a study to determine the significance of the Segond fracture in knee ligament injuries. Of 1854 radiographs reviewed, 22 showed a Segond fracture. Of these 22, 19 patients were found at surgery to have disruption of the ACL. The three non-surgical patients had clinical anterior cruciate laxity. Two fractures were explored and were found to represent avulsions of the iliotibial tract.

Radiological assessment of ACL deficiency has been attempted by many authors. Some have tried the use of "goniometers" to stress the knee before obtaining the radiograph (Fig 3). Problems with these methods, due to equipment size, logistics, and expense, have restricted their use. Hooper described a technique to document sagittal laxity in the knee joint. The laxity was recorded as the average displacement of the medial and lateral femoral condyles. There was a significant difference between the ACL deficient and normal populations. With this method, the sagittal displacement correlated positively with the pivot shift test. Franklin et al published a quadriceps contraction technique to assess instability of the knee due to rupture of the ACL. Their technique involved a standard cross-table lateral radiograph. The beam is centered on the joint, the

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knee is supported on a 30° wedge (knee bolster), and a 15 lb weight is suspended from the ankle. The patient is instructed to straighten the knee as much as possible until the exposure. This technique was reported to be as accurate as the KT-1000 arthrometer in the diagnosis of unilateral rupture of the ACL.

Radiographic signs of ACL deficiency 6 to 12 months after injury include peaking of the intercondylar tubercles, spurring and hypertro-
Fig 3: The use of stress radiographs. Template B is superimposed on Template A and anterior instability is determined as the difference in the distance between the two vertical lines as measured on radiographs made with the knee stressed and unstressed.

Fig 4: Early peaking of the intercondylar eminence.

Fig 5: Conventional (A) and 30° flexion views (B) of the same patient.

Fig 5A.

Fig 5B.

Fig 5.

phy of the intercondylar eminence, osteophyto-
sis of the inferior facet of the patella, stenosis of
the intercondylar notch, narrowing of the carti-
lage space, and buttressing osteophyrosis. Figure 4 demonstrates early peaking of the tibial
tubercles in an ACL deficient knee. Cartilage
space narrowing, a later sign of arthrosis, is
detected earlier if the standing anteroposterior
view is taken with the knee flexed \(^6\,^7\) (Fig 5).

It has been suggested that variability of shape
and width of the intercondylar notch may pre-
dispose a patient to disruption of the ACL. 
Houseworth et al\(^8\) designed a computer graphics
study to calculate anterior and posterior outlet
areas. They found that the ratio of posterior to
total area was significant and concluded that a
narrow posterior arch may predispose a knee to
ACL tears.

**ARTHROGRAPHS**

Various authors have reported on the use of
arthrographic techniques for the evaluation of
the suspected ACL deficient knee \(^9\,^11\). Although
the double-contrast arthrographic method of
examining the ACL has been reported in the
radiologic literature as an accurate method for
diagnosing both meniscal and cruciate injuries,
the examination is generally considered better
Fig 6A: Lateral bone scintigraphy: focal lesion in the subchondral bone in the weight-bearing region of the lateral femoral condyle (arrow). This is the only planar image that demonstrates the focal femoral lesion.

Fig 6B: Anterior bone scintigraphy demonstrates an additional lesion in the left medial tibial plateau (curved arrow). There is diffuse peri-articular increased uptake about the knee, but no definite lateral femoral condyle lesion is identified in the anterior projection.

Fig 6C: Posterior bone scintigraphy has been mirror-imaged to facilitate comparison. Note the medial tibial plateau lesion (curved arrow) with diffuse increased peri-articular uptake. The focal lateral femoral condyle lesion is not appreciated.

Fig 6D: Coronal SPECT demonstrates left lateral femoral condyle lesion on cut #1 (arrow) and medial tibial plateau lesion on cuts 2 and 3 (curved arrow). For evaluation of the menisci, Pavlov et al.\textsuperscript{12} reporting on the accuracy of double-contrast arthographic evaluation of the ACL, found that this method of evaluation was 95% accurate in confirming the ligament to be either intact or abnormal. Demonstration of the cruciate ligaments with computed tomography, in combination with single\textsuperscript{13} or double-contrast arthrography, has been reported. This has not been generally accepted because of time constraints and invasive risks. These techniques have now been replaced in most centers by MRI.

**Bone Scintigraphy**

Bone scintigraphy is commonly used to detect fractures in patients with negative radiographs. Bone scintigraphy is generally regarded as sensitive but not specific. Focal bone repair can occur in a variety of conditions that can be seen in association with knee trauma. Bone scintigraphy has been used extensively to assess chronic knee pathology.\textsuperscript{14,15} Focal increased bone repair has been demonstrated at the site of chronic torn menisci presumably from local synovitis.\textsuperscript{16}

At the authors' center bone scintigraphy has been used to confirm osseous lesions demonstrated on MRI in the acute ACL population. Multi-view planar views as well as SPECT (single photon emission computed tomography) sequences have been utilized. All the bone infractions demonstrated intense focal increase on SPECT. Avulsions of ligamentous insertions, such as the medial collateral ligament (MCL) also demonstrated focal increased bone repair on scintigraphy.\textsuperscript{17} Examples of such
lesions are presented with their scans. Figure 6 is of a 22-year-old man who sustained an isolated ACL tear in his left knee while playing hockey. Figure 7 demonstrates the bone of a 22-year-old man who sustained ACL and MCL tears to his left knee while playing football. The arrowhead points to an area of faint but definite focal uptake, which is an avulsion of the femoral insertion of the MCL. The large lesion on the left lateral tibial plateau was confirmed on MRI. The less intense lesion in the lateral femoral condyle was not seen on MRI. Bone scintigraphy can detect radiographically-silent, MRI-demonstrated, subchondral bone infarctions, as well as avulsions of ligaments.

**MRI**

MRI is a non-invasive imaging modality showing an ever-increasing application for evaluation of musculoskeletal disorders. It has been particularly successful in the assessment of the disrupted ACL. MRI is also able to detect concomitant soft tissue and osseous pathology in the acutely injured knee. Vellet et al. demonstrated the superiority of T2-weighted non-orthogonal sagittal over conventional orthogonal sagittal MRI in the evaluation of ACL injury. In T2-weighted images water appears as an area of high signal intensity, demonstrated as white, and cortical bone, ligaments, and menisci, of low signal intensity, are demonstrated as black. In a prospective, controlled study of acutely injured knees with MRI and surgical confirmation Vellet et al. demonstrated 100% sensitivity, specificity, accuracy, and negative and positive predictive value with the completely disrupted ACL. The nonorthogonal imaging plane is graphically defined through a bony landmark anteromedial to the base of the intercondylar eminence and runs tangential to the medial intercondylar surface of the lateral femoral condyle to the site of the ACL insertion at approximately 20° to 30° to the vertical sagittal plane (Fig 8).

The ACL can best be examined using sagittal and sagittal oblique planes. These are obtained with the knee extended and the leg externally rotated 15° to 20°. With nonorthogonal sagittal MRI the normal ACL (Fig 9) is shown as a linear, bipartite, low signal intensity structure. The differentiation between anteromedial (AMC) and the posterolateral components (PLC) is rarely discrete but often identified at a point of...
apparent divarication inferiorly. At their femoral attachments, the PLC is inseparable from the AMC and, at this point, their signal characteristics are similar.

The AMC is a compact, sharply margined, linear, homogeneously hypointense, 1.5 mm to 3 mm structure. It is demarcated anteriorly by synovial fluid bathing the surface of the investing synovium. T2-weighted images better demonstrate this latter relationship. The somewhat flared tibial origin represents the only consistent site at which discrete AMC fascicles are identifiable.

The PLC arises from a broader base than the AMC. It is a less compact, tapering triangular structure with an intermediate signal intensity, allowing identification of individual ligamentous fascicles in some images.

In acute complete ACL disruption, MRI shows loss of continuity of the AMC, PLC, and respective fascicles (Fig 10). There is also expansion and retraction of the disrupted ends, with loss of definition of the ACL's bipartite structure and the component signal differentiation. In addition to disruption of the AMC, there is loss of the integrity of the anterior synovial reflection, with variable irregularity of the anterior marginal fascicles of the AMC. This signals inhomogeneity of the respective components and reflects the presence of synovial fluid and/or blood within the interstices of the ligament.

Nonorthogonal MRI characteristics of the partial ACL rupture may include a number of findings (Fig 10): redundancy and loss of continuity of the individual components, which is best appreciated in the less compact posterolateral component; retraction of individual fascicles, as in complete ACL tears that are less evident in partial ACL tears and also more difficult to appreciate in the presence of residual intact ligament; and, contour irregularity of the cortical margins of the ACL. One can often visualize signal intensity changes, which are found in acutely disrupted ACLs, due to the presence of edema, hemorrhage, and exudation of synovial fluid. Again, T2-weighted images best demonstrate these changes.18,20

According to Vellet et al18 a number of MRI features may make diagnosis difficult:

1. Partial avulsive tears at the tibial origin of the ACL are difficult to differentiate because of the normal prominence of the individual fascicles in the AMC and PLC at their tibial attachments.
2. Partial avulsions from the femur may be difficult to identify, since little retraction may be evident at the site of injury.
3. Partial or complete tears with fascicles in continuity may be difficult to identify because the synovial reflection is intact.
4. Particularly in the presence of medial rotational injury related to collateral ligament injury, the ACL may be deviated in a bow-string fashion as it crosses over the PCL. This distortion may be interpreted as an acute disruption.

Marks et al21 reported on MRI-detected bone lesions in ACL-injured knees. MRI scans of 53
Fig 11: Acute, partial ACL disruption. Top left: Some loss of definition of the components of the bipartite structure and thickening of the ACL at the individual fascicles appear to be intact, although slightly redundant. Top right: Oblique discontinuity in the AMC (long arrow) and localized loss of definition of the anterior synovial reflection consistent with disruption of the AMC. Lower left: Continuity of the intact, lateral part of the AMC with definition of the intact synovial reflection and some residual irregularity of the proximal part of the anterior margin of the AMC. Lower right: Intact femoral insertion of the AMC.

Fig 12A: Reticular lesion of the lateral femoral condyle.

Fig 12B: Focal impaction of the lateral femoral surface.

patients were evaluated prospectively after acute injury. Osseous lesions were classified relative to their architectural appearance and relationship to cortical bone. Twenty-one percent of this patient population revealed such lesions. Twelve patients had 1 lesion, 16 had 2 lesions, and 16 had 3 lesions. Sixty-seven percent of these lesions were reticular, indicating hemorrhage and edema in medullary bone (Fig 12A). Twenty-five percent were geographic lesions, that is, those associated with the cortical margin. Impaction fractures—those demonstrating variable degrees of anterior cortical osteochondral surface depression—occurred in 7% (Fig 12B). Osteochondral fractures were present in 1%. No infarctions were seen on plain radiographs, nor were there evident at arthroscopy. The lateral compartment was involved 84% of the time. Repeat MRI was performed on 21 patients. No reticular infarctions showed sequela at follow up. Sequela at the site of geographic lesions was seen in 14 of 21 patients (66%). These included overt cartilage loss, cortical impaction, osteochondral defects, subcortical osteosclerosis, and cartilage thinning. These underlying “bone bruises” provide an explanation for progression to subsequent arthritic change.

The natural history studies of ACL-injured knees reveal articular degeneration at follow up in a significant number of patients. Mankin concluded in his review of articular cartilage response to injury that “impactive injuries to the cartilaginous surface that exceed a critical threshold cause injury not only to the chondrocytes but also to the underlying bone and, in experimental studies at least, such injuries progress rapidly to osteoarthritic lesions.” The conventional view of posttraumatic arthritis of the knee proposes that instability leads to cartilage wear and arthritic change. The MRI suggests that the subcortical bone infraction is a variable important to include in the equation. With subsequent stability there may be a slow evolution of meniscocartilaginous pathology; with instability the progression may be more swift. The MRI, then, may provide the missing piece of the puzzle, linking the laboratory to the clinic. The subcortical infraction detected on
MRI may play an important role in the pathogenesis of posttraumatic osteoarthrosis of the knee.

CONCLUSION

There are many imaging modalities that can be utilized in the patient with an ACL injured knee. These include plain radiographs, stress radiographs, arthrography, computed tomography, bone scintigraphy, and MRI. Their use can be applied to the acutely injured knee or in the patient with chronic insufficiency of the ACL. The decision to utilize one modality over another is based on cost, availability, information required, and observer interpretation. Recent advances in MRI technology promise to provide a noninvasive means to image the ACL deficient knee, both in terms of the ligaments themselves and other soft tissue and osseous structures.

REFERENCES


