Radiographic Evidence of Anterior Cruciate Ligament Insufficiency

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Abstract: Anterior cruciate ligament (ACL) tears are commonly seen injuries. Initially, these injuries are routinely evaluated with radiographs, followed by magnetic resonance imaging (MRI). The altered kinematics at the time of injury or for the duration of a chronic tear can create indirect findings on radiographs and MRI. These signs may help establish a diagnosis of an ACL tear or the chronicity of the injury. This article discusses these signs. [Orthopedics. 2014; 37(11):759-762.]

A knee injury is a common reason an individual will present to a physician for evaluation. It is the joint most commonly associated with sports-related injuries. However, the same mechanisms that cause knee injuries during sports can cause knee injuries at home or work. A tear of the anterior cruciate ligament (ACL) is the most common knee ligamentous injury. It is estimated that there are nearly 250,000 ACL injuries annually in the United States.¹ An ACL-deficient knee has biomechanics that are different from those of a normal knee. A biomechanics study showed that an ACL-deficient knee had altered kinematics in 3 of the 6 degrees of freedom.² The altered forces in the knee create reproducible changes that can be seen on radiographic and magnetic resonance imaging. This article reviews the acute and chronic signs of ACL-deficient knees seen on imaging.

Anterior Cruciate Ligament Kinematics

The indirect signs of ACL tears are a response to or result of abnormal forces on the knee. In the sagittal plane, ACL-deficient knees have an increase in anterior translation from 0° to 15° of flexion when compared with ACL-intact knees. There is minimal difference after 15°.² Likewise, the ACL-deficient knee has an increased internal rotation from 0° to 15° of flexion.² In the coronal plane, there is a medial shift of the tibia at various measurements of flexion up to 90°.² These shifts explain some of the changes seen on knee imaging after an ACL tear. If not corrected, these altered forces applied to the knee can cause the knee to create its own adaptive responses to produce stabilization.

Segond Fracture

One of the classic signs in ACL injuries is the Segond fracture, also known as the “lateral capsular sign” (Figure 1). The French surgeon Paul Segond described what would later be known as a Segond fracture in 1879. This was prior to the use of radiographs. Dr Segond described a constant avulsion fracture at the anterolateral tibia that occurred after a forced internal rotation was applied to a knee. Despite occurring in only approximately 1 of 10 ACL tears, it is a strong indicator of ACL injury. The fracture has traditionally been described as an avulsion of the lateral capsule. However, recent literature has implicated the recently described anterolateral ligament.³ The anterolateral ligament originates on the lateral femoral epicondyle and inserts on the anterolateral tibia with attachments to the lateral meniscus. It has the presumed role of controlling internal rotation of the tibia. Claes et al³ showed that this structure is the anatomic culprit in Segond fractures. Claes et al³ reported that 95% of the Segond fractures in their series had an associated ACL.
tend. This is consistent with previous literature indicating a strong correlation between the two.

The Segond fracture should not be confused with the arcuate sign. The arcuate sign, an avulsion fracture at the proximal fibula at the insertion of the arcuate ligament complex, is pathognomonic of posterolateral corner injuries of the knee. However, the majority of patients (~90%) with injuries of the posterolateral corner have injuries to the cruciate ligaments. Therefore, physicians must have a high degree of suspicion for ACL tear when the arcuate sign is present (Figure 1).

**Deep Lateral Femoral Notch Sign**

The same forces that create the Segond fracture can create another indirect sign of an acute ACL tear: the deep lateral femoral notch sign (Figure 2). When first described, the deep lateral femoral notch sign was correlated with chronic ACL insufficiency. However, recent literature has demonstrated its presence in the acute setting. One study even reported predominance in the acute ACL tear as compared with the chronic ACL tear.

The terminal sulcus or lateral notch is a normal depression on the lateral femoral condyle. It indicates the transition point of the patellar articular surface from the tibial articular surface. Visualized on lateral radiographs, it is located 0 to 10 mm posterior to Blumensaat’s line and is less than 1.5 mm deep. At depths greater than 1.5 mm or locations greater than 10 mm posterior to Blumensaat’s line, it is known as the deep lateral femoral notch sign. It is seen in approximately 7.5% to 26.4% of acute ACL tears. If present, it is associated with an ACL tear 70% to 100% of the time. This defect is caused by the abnormal anterior translation and internal rotation of the tibia. The posterior aspect of the lateral tibial plateau forcefully impacts the lateral femoral condyle.

The deep lateral femoral notch sign has been shown to be more prevalent among younger individuals and males. This is thought to be due to higher-energy injuries in these cohorts. Occasionally, the force is strong enough to cause joint incongruity or a displaced osteochondral fracture. Some advocate open elevation and bone grafting for a depression greater than 6 mm to avoid posttraumatic degeneration.

A recent study also showed a statistically significant correlation between this sign and lateral meniscus tears. Of 132 patients with the deep lateral femoral notch sign, approximately 40% had a lateral meniscus tear. The anterior horn of the lateral meniscus is directly below the terminal sulcus. However, with the pivot shift mechanism, the posterior tibial plateau impacts the femoral condyle. As a result, the posterior horn of the lateral meniscus is more likely to be involved than the anterior horn.

**Cupola Sign**

Changes seen on radiographs after chronic ACL insufficiency include the cupola sign, femoral notch narrow-
ing, and tibial spine peaking. The cupola sign is an adaptive response to anterior translation. It is an osteophyte on the posteromedial corner of the tibia that is best seen on lateral radiographs (Figure 3). In normal knees, the med- 
dial meniscus acts as a sec-
donary stabilizer to sagittal translation of the tibia as op-
posed to the lateral meniscus, which has more influence in axial rotation. The posterior horn of the medial meniscus thickens as a result of a tran-
sected ACL. Over time, an osteophyte develops, providing a buttress against anterior translation. Mullis et al \textsuperscript{11} retrospec-
tively examined 102 knees that underwent a total knee arthroplasty. Forty-three knees had a posteromedial osteophyte. All knees with a posteromedial osteophyte had ACL compromise.

**Narrowed Notch and Peaking of Tibial Spine**

In addition to the cupola sign, other osteophytes occur as a result of chronic ACL insufficiency. Increased medial shift of the tibia combined with the pivot shift mecha-
nism of the knee causes osteophyte formation in the femoral notch and on the tib-
al spine. Peaking of the tibial eminences can occur as early as 6 months after an ACL tear. Lateral tibial peaking is more evident than medial peaking. The primary function of the tibial spine is to act as medial to lateral stabilizers.\textsuperscript{12} They project toward the inner as-
psects of the femoral condyles. With increased cartilage con-
tact stress on the medial femoral condyle, both the tibial spine and the intercondylar notch hypertrophy. This oc-
urs predominately at the me-
dial condyle adjacent to the medi-
tal tibial spine.

Femoral notch narrowing from osteophyte formation is different from the debate in the literature regarding the proposed pre-injury cor-
relation of the femoral notch width and ACL tears. The suggestion that a narrowed notch places the ACL at an increased risk has existed since 1939. Many studies have tried to determine if a narrowed notch predisposes an individual to an ACL tear. It seems the debate is not enti-
tirely settled. A recent study examining notch morphology and notch index showed that a Type A femoral notch (as compared with Type U or W) increased the risk for ACL inj-
ury, but notch index did not.\textsuperscript{13} This is in contrast to the find-
ings of another recent study measuring 4 notch widths on magnetic resonance imaging. Notch width was an indepen-
dent risk factor for ACL tears in both males and females.\textsuperscript{14}

**Magnetic Resonance Imaging Findings**

Magnetic resonance imaging is the most accurate nonin-
vasive technique for determin-
ing the integrity of the ACL. Several primary and sec-
donary signs can be used to deter-
mine ACL integrity (Table). Both primary and secondary magnetic resonance imaging signs have value in diagnosing an ACL tear.\textsuperscript{15} The most com-
mmonly seen secondary sign is the characteristic bone bruise pattern. Bone bruises are seen in up to 80\% of ACL tears.\textsuperscript{16} They are produced by the pivot shift mechanism creat-
ing an increased signal on T2-
weighted images on the lateral femoral condyle and the poste-
rior lateral tibial plateau (Fig-
ure 4). A patella dislocation will produce a characteristic bone bruise pattern as well (Figure 5) and can mislead the diagnosis. The bone bruise pattern of the patella disloca-
tion will be without the tibial component and the femoral contusion will be more an-
terior than the ACL femoral contusion.

**CONCLUSION**

When evaluating for ACL insufficiency, physicians must be able to recognize primary and secondary signs on imaging to make a diagnosis. These signs provide clues to the mechanism of injury and are helpful in determining the suc-
cess of primary repairs.

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