A Biomechanical Approach to Interpreting Magnetic Resonance Imaging of Knee Injuries

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KEYWORDS

• Knee • Injury • Biomechanics • Mechanism • Instability • MR imaging • Imaging

KEY POINTS

- An understanding of the functional anatomy of the knee aids in recognizing common injury mechanisms of knee trauma at magnetic resonance (MR) imaging and resulting clinical instability.
- The presence of specific osseous and soft-tissue injuries can help elucidate the mechanism of injury and provide a targeted approach to MR imaging evaluation of the knee following trauma.
- Injuries of the knee can be categorized as occurring in hyperextension, in physiologic extension, and in flexion with varying degrees of angulation and rotation, and result in characteristic osteochondral, ligamentous, meniscal, and musculotendinous lesions.
- Recognition by the radiologist of these key injury patterns and clinical instability may aid in the detection of occult and subtle injuries that may require early surgical treatment to prevent subsequent treatment failure.

INTRODUCTION

Magnetic resonance (MR) imaging of knee injuries enables identification of soft-tissue and radiographically occult bone injuries, and facilitates analysis and reporting of injury constellations in the context of functional knee instability. Previous works have described the stabilizing structures of the knee, common destabilizing injury patterns, and the MR imaging appearance of common knee injuries. The purpose of this review is to discuss the normal functional anatomy of key soft-tissue stabilizers of the knee, summarize the currently known etiology and types of posttraumatic knee instability, present the most common resultant MR imaging injury patterns, and synthesize a unified model for use as a targeted reporting checklist during MR image interpretation. By illustrating the biomechanical mechanism and clinical relevance of potentially destabilizing injuries, an improved understanding will allow the radiologist to better identify significant, subtle, and potentially occult injuries, and thus provide more clinically relevant interpretations.

NORMAL FUNCTIONAL ANATOMY

Normal knee motion involves flexion and extension in the sagittal plane, translation in 3 planes (anterior-posterior, medial-lateral, and proximal-distal),

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and both internal and external rotation of the femur relative to the tibia.[1] In full extension, the femur is slightly internally rotated, with the lateral femoral condylar rotation locking the knee in place. As a result there is minimal abduction, adduction, or rotational laxity to the fully extended knee. With flexion, the femur rotates externally and unlocks the knee. Moderate passive rotation and mild laxity in lateral motion are normally demonstrated with the knee in 90° of flexion.[2] Destabilizing knee injuries commonly produce clinically detectable increases in rotational or lateral knee laxity than would otherwise be expected for a given state of knee flexion.

Knee instability has been classified according to the Committee on Research and Education of the American Orthopedic Society for Sports Medicine as: (1) 1-plane or straight, (2) rotatory, or (3) combined instability.[2] The osseous structures of the knee provide minimal inherent stability. Rather, the soft-tissue structures that span the joint provide the dynamic stabilizing action. The cruciate and collateral ligaments, the joint capsule, and the musculotendinous units play a crucial role in providing knee stability (**Fig. 1**). The cruciate ligaments are intra-articular but extrasynovial structures that primarily resist anteroposterior displacement of the tibia relative to the femur to stabilize the knee joint. The vertical axis of flexion and rotation of the knee, termed the central pivot, normally lies close to the attachment sites of the posterior cruciate ligament (PCL).[3–5] Destabilizing knee injuries result in the shift of this central pivot away from the injured structures (**Fig. 2**).

The cruciate and collateral ligaments serve complementary roles in stabilizing the knee during rotation. During tibial internal rotation the cruciate ligaments coil and effectively shorten about the central pivot. In particular, the PCL becomes increasingly taut, thus providing proportionally greater stabilization than the anterior cruciate ligament (ACL), with a concomitant increase with knee flexion.[2,6] However, the collateral ligaments straighten during internal rotation, become relatively lax, and provide less stability. Conversely, during tibial external rotation the collateral ligaments shorten, assume more static tension, and provide increased stability. The cruciate ligaments uncoil and effectively lengthen during external rotation, thus diminishing their stabilizing function. With neutral rotation, the cruciate and collateral ligaments are not under any specific tension and provide less overall resistance to motion (**Fig. 3**).[2]

The ACL comprises 2 distinct bundles. The anteromedial bundle primarily resists anterior tibial translation with the knee in flexion, and the posterolateral bundle resists anterior tibial translation and rotation with the knee in extension.[7] The ACL is the primary constraint against anterior tibial translation; straight anterior instability implies complete disruption of the ACL, often accompanied by medial and lateral capsular ligament injury (see later discussion).[2,8,9] The presence of a concomitant complete PCL disruption further exacerbates this instability.[2,3]

The PCL is the primary stabilizer against posterior translation of the tibia, although the posterior

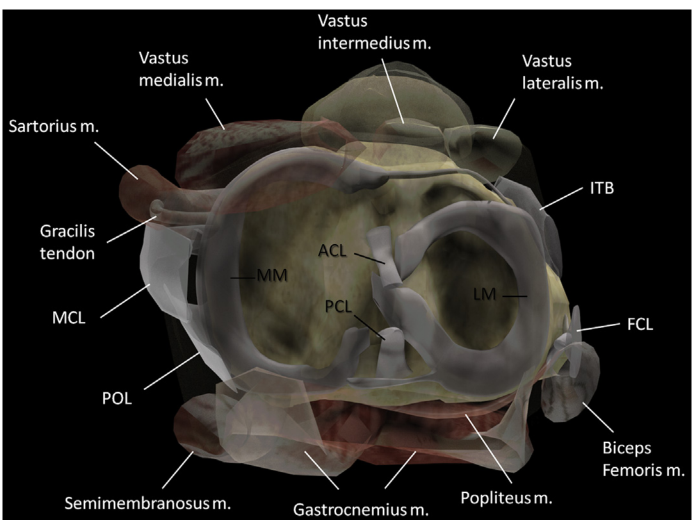

Fig. 1. Computer-generated image showing key anatomic structures of the knee. The tibial articular surface is viewed en face from a superior perspective, and the femoral condyles are transparent. ACL, anterior cruciate ligament; FCL, fibular collateral ligament; ITB, iliotibial band; LM, lateral meniscus; MCL, medial collateral ligament; MM, medial meniscus; PCL, posterior cruciate ligament; POL, posterior oblique ligament.