MRI of the cruciate ligaments

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MRI of the cruciate ligaments

• Normal anatomy of the ACL / PCL

• Mechanisms of injuries and associated injuries of the ACL/PCL
• Classification of injuries of the ACL/PCL

• MRI features of the ACL
  • Ruptures (complete / partial)
  • ACL reconstruction

• MRI features of the PCL
  • Ruptures (complete / partial)

• MRI of the chronic ruptured ACL/PCL

• MRI of the degenerative ACL/PCL

• Take home messages
ACL

- **Origin**: posterior medial surface of the lateral femoral condyle

- **Insertion**: anterior medial portion of the area intercondylaris of the tibia

- Runs parallel to the roof of the intercondylar notch, approx. parallel to the Blumensaat`s line

- 2 bundles: small anteromedial and larger (tight) posterolateral bundle

- Fan-shaped spreading at the tibial insertion

from Sectional Anatomy, Thieme
**ACL**

- Intracapsular, extrasynovial
- Width 11 mm, length: 31 to 38 mm
- Most important function: prevention of anterior tibial translation, prevention of hyperextension of the knee, protection of excessive tibial rotation, secondary restraint to valgus/varus stresses

**MRI**

- Striated appearance, fat between fascicles (hyperintense on T2w/T1w)
- Higher signal than the throughout hypointense PCL
PCL

- Intracapsular, extrasynovial
- Stronger, thicker and more tear-resistant than the ACL: width 13 mm, length 38 mm
- **Origin**: lateral aspect of the medial femoral condyle
- **Insertion**: posterior aspect of the proximal tibia
- The cross-sectional area of the PCL decreases from proximal to distal

from Sectional Anatomy, Thieme
PCL

- Composed of an anterolateral and posteromedial band
- Function: stabilizes the joint against excessive varus or valgus angulation and resists internal rotation of the tibia on the femur
# Forces and supporting structures responsible for resistance

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<thead>
<tr>
<th>Force</th>
<th>Primary resistance</th>
<th>Secondary resistance</th>
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<tr>
<td>Anterior translation</td>
<td>ACL</td>
<td>MCL, LCL</td>
</tr>
<tr>
<td>Posterior translation</td>
<td>PCL</td>
<td>none</td>
</tr>
<tr>
<td>Varus (medial to lateral)</td>
<td>LCL</td>
<td>ACL, PCL</td>
</tr>
<tr>
<td>Valgus (lateral to medial)</td>
<td>MCL</td>
<td>ACL, PCL</td>
</tr>
<tr>
<td>Internal rotation of tibia (femur fixed)</td>
<td>LCL</td>
<td>ACL, capsule</td>
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<tr>
<td>External rotation of tibia (femur fixed)</td>
<td>MCL</td>
<td>PCL, capsule</td>
</tr>
<tr>
<td>Hyperextension</td>
<td>PCL</td>
<td>ACL, posterior capsule</td>
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# Typical injury configurations of the knee

<table>
<thead>
<tr>
<th>Mechanism of Injury</th>
<th>Bone Bruise / Osteochondral Lesion</th>
<th>Ligamentous Injury</th>
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<tr>
<td><strong>Pivot shift</strong>: valgus stress, flexed knee, internal rotation of femur</td>
<td>posterolateral tibial plateau, middle aspect of lateral femoral condyle</td>
<td>ACL</td>
</tr>
<tr>
<td>Valgus stress</td>
<td>direct impact: lateral femoral condyle</td>
<td>MCL and menisci</td>
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<tr>
<td>Varus stress in flexed knee and with internal rotation of the tibia (potentially Segond fracture)</td>
<td>tibia inferior to the joint: avulsion of the lateral capsule</td>
<td>ACL</td>
</tr>
<tr>
<td><strong>Dashboard</strong>: direct impact from anterior, knee flexed</td>
<td>anterior aspect of tibia, rarely posterior aspect of patella</td>
<td>PCL</td>
</tr>
<tr>
<td>Hyperextension</td>
<td>„kissing contusion“: anterior aspect of tibia, potentially anterior aspect of femoral condyles</td>
<td>PCL or/and ACL</td>
</tr>
<tr>
<td>Severe abduction/adduction forces + rotational forces</td>
<td>at the sites of impaction</td>
<td>MCL, LCL ACL, PCL, menisci</td>
</tr>
<tr>
<td>Lateral (sub-)luxation of the patella</td>
<td>lateral aspect of the trochlea femoris, medial inferior aspect of patella</td>
<td>Tear/strain of the medial retinaculum of the patella</td>
</tr>
</tbody>
</table>
Classification of ACL/PCL injury

Grad I - intraligamenous injury without a change in ligament length

Grade II - partial tear (incomplete tear with a small increase in laxity)

Grade III - complete rupture

Partial tears are more difficult to diagnose and grade on MRI

- ACL ruptures more frequently than the PCL (3:1)
- Most ACL injuries are complete tears, whereas most PCL injuries are incomplete tears.
- Tears of < 25% are associated with a more favourable clinical outcome.
ACL rupture

Mechanisms of injury

1. Pivot shift injury (most frequent)
   - valgus load on a flexed knee, external rotation of tibia or internal rotation of femur

2. Hyperextension injury
   - direct injury, e.g. secondary, to a car bumper impacting on the anterior tibia of a pedestrian
   - depending on the amount of force: also PCL and meniscal injury

3. Internal rotation of the tibia with a flexed knee and varus stress
   - potential avulsion of the lateral tibial plateau (Segond fracture) and tear of the LCL
ACL rupture

Pivot shift injury

Sanders; Radiographics 2000
ACL / PCL rupture

Hyperextension injury
ACL rupture

Varus stress

+ internal rotation of the tibia in a flexed knee: injury of ACL, LCL, iliotibial tract, potentially avulsion of the lateral tibial plateau (Segond fracture)
ACL rupture

Bone contusion dependent on the mechanism of injury

**Mechanisms of injury**

**Pivot shift**
- Valgus load
- Flexed knee
- Internal rotation of tibia

**Hyperextension injury**
- Direct force applied to the anterior tibia

**Varus stress**
- Flexed knee
- Internal rotation of tibia
  (potentially Segond fracture)
Direct (primary) signs of a complete ACL rupture

• Discontinuity of, i.e. tear of fibers (75% middle, 20% proximal, 5% distal portion)
• Atypical or undulated course or focal angulation of fibers
• Diffuse hyperintensity on all types of MR-sequences
• Blurred and broadened delineation of the ligament

MRI sensitivity and specificity: about 90%
ACL rupture

Indirect (secondary) signs of a complete ACL rupture

- Anterior subluxation of the tibia relative to the femur
- Dorsal subluxation of the posterior horn of the lateral meniscus
- Increased angulation of the PCL ("sea horse sign")
- Bone edema: e.g. at the posterolateral tibial plateau and at the middle to anterior aspects of the lateral femoral condyle
- (Deep) lateral femoral notch sign: depression on the lat. femoral condyle
- Trauma of the proximal tibiofibular joint
- Posterolateral corner injury (LCL, popliteus muscle and tendon, arcuate complex (arcuate, fabello-fibular, popliteal-fibular ligaments)
ACL rupture

Associated injuries of a complete ACL rupture

• Shear injury of the Hoffa`s fat pad

• Osseous avulsion, e.g. Segond-fracture = tear of the lateral capsule at the tibia with avulsion of the lateral tibial plateau (internal rotation of the tibia, flexed knee and varus stress) high association with ACL rupture (75-100%) with menisceal tears (60-706%)

• Meniscal tears and lesions of the collateral ligaments

Subluxation of the tibia / femur, subluxation of the posterior horn of the lat. meniscus / tibia and changes in configuration of the PCL are features of instability after ACL rupture.
ACL rupture

Indirect (secondary) signs of a complete ACL rupture

- Bone edema at the postero-lateral tibial plateau and lateral femoral condyle; **specificity about 95%**
- (deep) lateral femoral notch sign > 1.5 mm pathological
- Increased angulation of the PCL
ACL rupture

Indirect (secondary) signs of a complete ACL rupture

- Anterior subluxation of the tibia (> 5mm pathologic)
- Posterolateral corner injury
- Trauma of the proximal tibiofibular joint

MRI sensitivity and specificity: about 94% (direct and indirect signs)
ACL rupture

Associated injuries of a complete ACL rupture

- Impression fracture of the lateral tibial plateau
- Horizontal tear of the posterior horn of the medial meniscus
- Osseous avulsion at the distal tibial insertion

MRI features: ACL

PDw FS

T1w

PDw FS
ACL: Recent partial rupture

More difficult to diagnose, MRI sensitivity definitely lower than for complete ruptures

Possible signs of a recent partial rupture
- Discontinuity of single fiber portions
- Abnormal orientation of fiber portions
- Focal signal alterations (esp. hyperintensities on T2w)
- Thickening of the ligament (typically spindle-shaped)
- Lamellar deposition of fluid

Most reliable signs for the distinction between a complete and an incomplete ACL rupture:
- Bone edema at typical locations
- Dorsal subluxation of the posterior horn of the lat. meniscus
ACL partial rupture

46 y/o male
pivot shift injury

44 y/o female
motorcycle accident
ACL reconstruction

- The natural history of an ACL injury without surgical intervention varies from patient to patient and depends on the patient's activity level, degree of injury and instability symptoms.
- Prognosis of a partially torn ACL is often favourable, whereas complete ACL ruptures have a much less favourable outcome.
- Graft tissues include the patellar, hamstrings, quadriceps, Achilles, semitendinosus, gracilis or posterior tibialis tendons.
- Some increased signal of the graft in T2w is normal and may persist for many years.
- The position of the bone tunnel in the distal femur and proximal tibia are crucial for a proper function of the ACL graft.
ACL reconstruction
PCL rupture

• Injures less frequently than the ACL but: avulsion fractures of the tibia more common than with ACL injuries

• PCL tears tend to be partial tears with the potential to heal on their own.

• Isolated ruptures are infrequent. People who have injured just their PCL are usually able to return to sports without knee stability problems.

• 50 % middle portion > proximal portion > distal portion
PCL rupture

1. **Dashboard injury (most common)**: Direct blow to the proximal anterior tibia in a flexed knee, forcefully displacing the tibia posteriorly. Bone contusions at the site of impact (ant. tibial plateau).

2. **Hyperextension**
   - with continued extension and tibial translation the ACL may rupture as well if additional varus or valgus force - collateral ligament disruption may occur
   - Bone contusions: anterior portion of the tibial articular surface and anterior aspects of the femoral condyles

3. **Hyperflexion** (usually no other ligaments are damaged)

4. **Severe abduction or adduction forces, when associated with rotational forces**, may rupture the cruciate ligaments after the collateral ligaments fail
   - Bone contusions at sites of impaction; in valgus or internal rotation injuries- e.g. at the posterolateral tibia and articular surface of the medial femoral condyle

5. **“Reversed Segond fracture“ (rarely)**, external tibial rotation and valgus stress avulsion fracture of the tibial deep component of the MCL, may be associated with PCL rupture + peripheral medial meniscal tear
PCL rupture

Dashboard injury

posterior tibial translation

Sanders; Radiographics 2000
PCL rupture

Hyperflexion injury

torn PCL
Direct (primary) signs of a complete PCL rupture

- Discontinuity of, i.e. tear of fibers
- Atypical course or focal angulation of the ligament
- Diffuse hyperintensity (on all sequences)
- Blurred and widened delineation of the ligament
PCL rupture

Indirect (secondary) signs of a complete PCL rupture

- Bone edema dependent on the mechanism of injury
- Meniscal tears and lesions of other ligaments
- Osseous avulsion
- Posterior tibial translation
PCL rupture

Indirect (secondary) signs of a complete PCL rupture

43 y/o m, motorcycle accident

Bone contusion, e.g. in the anterior aspect of the tibia

+ ACL rupture

22 y/o m, MVA

+ LCL rupture
+ bucket handle tear of the medial meniscus

MRI sensitivity and specificity (both direct and indirect signs): >> 90%
PCL rupture

Indirect (secondary) signs of a complete PCL rupture

Avulsion fracture of the PCL

33 y/o male, force onto the anterior aspect of the knee

- Uncommon
- Usually dashboard injury

From Ogawa et al.; J of Orthopaedic Surgery and Research 2010

MRI sensitivity and specificity (both direct and indirect signs): >> 90%
PCL partial rupture

- Discontinuity of single fiber portions
- Abnormal orientation of fiber portions with continuous fibers partially intact
- Variable thickening of the ligament
- Focal hyperintensities on T2w/PDw images

Partial tear in the middle third of the PCL

25yo male, posterolateral corner injury
Chronic ACL/PCL tears

- Heterogeneous signal within the lig.; DD acute tears, degenerative changes
- A) Atrophy, B) thickening with focal or diffuse inhomogeneities representing scar tissue, C) healing
- Presence of small cysts at the origins or insertion of the ligament
- Focal angulation
- Lack of edema, h/o trauma in the past
Degeneration of the ACL/PCL

68 y/o female with osteoarthritis of the knee

- Common cause of increased signal within the lig.; DD acute/chronic partial tears
- Secondary signs of acute ACL/PCL injury (e.g. bone bruise, ant. tibial subluxation) are absent.
- No history of recent trauma, symptoms, but knee pain or restricted movement
- MRI: thickened, ill-defined ligament, increased signal on all sequences (intact fibers best seen on T2w), surface of the ligament often intact.
Take home messages

• ACL injuries are more likely complete tears and will more likely require surgery.

• PCL injuries are more likely incomplete tears, and the majority heal by their own.

• Partial tears are more difficult to diagnose due to the unspecific features on MRI.

• Task of the radiologist is to recognize a complete rupture and its location, as well as to find/report concomitant injuries which may influence treatment management.

• Knowledge of the mechanism of injury allows a better understanding and confirmability of the found combinations of injuries on MRI.

• The location of the bone contusion as well as the identification of the primary, secondary, and associated injuries in cases of ACL/PCL ruptures play a crucial role for a more straightforward diagnostic assessment with MRI.