MRI of the Meniscus, ACL, MCL, and PCL
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Outline: MRI Meniscus
- Anatomy
- MRI parameters and accuracy
- Tear criteria on MRI
- Tear classification and examples
- Miscellaneous topics
- Pitfalls

Meniscus: anatomy
- Medial meniscus
  - Posterior horn larger
- Lateral meniscus
- Anterior horn, body, posterior horn
- Attached to tibia: 4 meniscal roots
- Meniscofemoral ligaments:
  - Humphrey and Wrisberg
- Intermeniscal ligaments

Meniscus: microanatomy
- Fibrocartilage
- Circumferential Type 1 collagen bundles (yellow)
- Intervenous radial “be” fibers (blue)
- Peripheral vascular “red zone”
  - 10 – 30% medial meniscus
  - 10 – 25% lateral meniscus
- Inner avascular “white zone”

Outline: MRI Meniscus Parameters
- Spin echo or fast spin echo
  - No difference in tear detection rate
- Proton density: favored over T2w (except root tears)
- Slice thickness (3 – 4 mm), FOV (16 cm or less), matrix (at least 192 x 256)
- Tesla: any
  - No difference in detection rates
  - Higher T: higher spacer resolution / faster
  - Improved reader confidence

Nguyen JC et al. Radiographics 2014; 34:981
Meniscal tear: diagnostic accuracy

- No significant difference between 1.5 and 3 Tesla

<table>
<thead>
<tr>
<th></th>
<th>1.5 T</th>
<th>3 T</th>
<th>1.5 T</th>
<th>3 T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>93%</td>
<td>96%</td>
<td>77%</td>
<td>82%</td>
</tr>
<tr>
<td>Specificity</td>
<td>90%</td>
<td>88%</td>
<td>99%</td>
<td>98%</td>
</tr>
</tbody>
</table>

Van Dyck P et al. JBJS 2013; 95:916

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Meniscus Tear: MRI criteria

- Abnormal morphology
  - Truncation, absence
- Abnormal signal
  - "Two-slice-touch rule"
  - Extends to articular surface (unequivocally)
  - Two consecutive or orthogonal images

Meniscus Tear: indirect signs

- Meniscal extrusion: relative to tibia
  - May also occur without meniscal tear
  - Cartilage damage, malalignment
- Abnormal superior popliteomeniscal fascicle
  - Abnormal in 29/30 with lateral meniscal tear
  - Normal in 29/29 with no lateral meniscal tear
- Parameniscal cyst
  - 90 – 100% association (except AHLM: 64%)

Nguyen JC et al. Radiographics 2014; 34:981

Meniscus: internal signal

- Not in contact with articular surface
- Vascularity (periphery): children
- Radial tie fibers (periphery)
- Contusion: globular, ill-defined
- Degenerative signal
  - If linear in medial meniscus: progress to tear
  - If middle aged without osteoarthritis

2. Cothran RJ et al. AJR 2001; 177:1189
5. De Smet AA et al. AJR 2001; 176:63
6. De Smet AA et al. RJ 2012; 199:481
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Meniscal Tear: classification ISAKOS

- International Society of Arthroscopy, Knee Surgery, and Orthopaedic Sports Medicine

<table>
<thead>
<tr>
<th></th>
<th>Tear depth</th>
<th>Location / rim width</th>
<th>Radial location</th>
<th>Central to popliteal hiatus</th>
<th>Tear pattern</th>
<th>Quality of meniscal tissue</th>
<th>Tear length</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Partial or complete</td>
<td>Zone 1, 2, or 3</td>
<td>Anterior, middle, posterior</td>
<td>Yes or no</td>
<td>Horizontal, radial, longitudinal, flap, complex</td>
<td>Degenerative, nondegenerative, undetermined</td>
<td>Millimeters</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Meniscus Tear: MRI Classification

- Vertical
  - Longitudinal
  - Radial
  - Oblique

- Horizontal
  - Parameniscal cyst
  - Flap

- Complex

Meniscal Tear: vertical

- Longitudinal: non-displaced
  - Usually peripheral
  - Often traumatic
  - Associated with ACL tears
    - 90% of medial tears
    - 83% of lateral tears
  - >1 cm in length: unstable
  - Pitfall: meniscofemoral ligament of Wrisberg

Meniscal Tear: vertical

- Longitudinal: displaced
  - Bucket-handle
  - Medial > lateral
  - Double-PCL (medial)
  - Intact meniscal ring
  - Pitfall: oblique meniscocapsular ligament

Nguyen JC et al. Radiographics 2014; 34:981
Meniscal Tear: vertical
- Longitudinal: displaced
  - Flipped fragment
  - Connected at one end
  - Free fragment

Lancs V et al. Skeletal Radiol 2015; 44:375

Meniscal Tear: vertical
- Radial
- Incomplete or complete
- Free edge tear
- Disrupted bow tie appearance of meniscus

Nguyen JC et al. Radiographics 2014; 34:981

Meniscal Tear: vertical
- Radial
- Root tear
- “Ghost meniscus”
  - Absent on one slice
- Possible meniscal extrusion (relative to tibia)

Choi JY et al. AJR 2014; 203:1286

Meniscal Tear: vertical
- Oblique vertical
  - Parrot beak
  - Vertical flap tear

Lecas LK et al. AJR 2000; 174:161
Engstrom SK et al. Skeletal Radiol 2012; 41:933

Meniscal Tear: horizontal
- Often to or near apex
- Parameniscal cyst
  - Multilocular
  - Axial plane around meniscus
  - Medial: away from meniscus
- Pitfall: AHLM ganglion cyst

Nguyen JC et al. Radiographics 2014; 34:981

Meniscal Tear: horizontal
- Horizontal flap tear
- Flap: deep to MCL
  - May not be low signal
- Superior 6x > inferior
- Key: truncated meniscus
- Also: hemi-bucket handle

Lecas LK et al. AJR 2000; 174:161
Meniscal Tear: complex
- Does not fit into one specific tear pattern
- Often degenerative and macerated

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Miscellaneous
- Healed tear
- Discoid meniscus
- Meniscal flounce
- Meniscal ossicle

Healed Tear
- Meniscocapsular junction
- Width < 2 mm
- Only visualized on intermediate-weighted signal sequences
- Intermediate or bright T2 signal with bridging low signal strands

From: Kijowski R et al. AJR 2014; 202:585

Discoid Meniscus
- 1 – 5% of knees
- Lateral 10-20x than medial
- 3 variants:
  - Complete: block shape, tear
  - Incomplete: 80% or less tibial coverage
  - Wrisberg variant
- 15 mm on coronal image
- 3 or more bow ties on sagittal image (4 mm thick)

Nguyen JC et al. Radiographics 2014; 34:981

Wrisberg Variant
- Discoid meniscus variant
- Incidence: <1 %
- PHLM
  - Only attachment is via Wrisberg ligament
  - Sagittal plane: vertical orientation
  - Possibly thickened
- Hypermobile

Singh K et al. AJR 2006; 187:394
Meniscal Flounce
- Transient physiologic distortion
- Rippled appearance
- 0.2 – 0.3% asymptomatic knees
- Secondary to knee flexion
- Does not indicate tear

From: Park JS et al. AJR 2006; 187:364

Meniscal Ossicle
- Fat containing ossicle
- Posterior horn medial meniscus: 88%
- Incidence: 0.15%
- Traumatic: associated with meniscal or root tear
- Vestigial: Bengal tigers and some rodents
- Simulate tear or intra-articular body

Mohankumar R et al. AJR 2014; 302:1040

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Pitfalls
- Lateral meniscus “rip tear”
- Oblique meniscomeniscal ligament
- Meniscocapsular separation
- Parameniscal cyst: AHLM

Oblique Meniscomeniscal Ligament
- Normal variant: 1 – 4%
- Crosses from medial to lateral meniscus
- Either direction
- Simulates bucket handle tear

Sanders TG et al. Radiology 1996; 213:213
Meniscocapsular Separation

- MRI inaccurate
- Positive predictive values:
  - 9% medial and 13% lateral

<table>
<thead>
<tr>
<th>MRI Finding</th>
<th>Positive Predictive Value (Medial)</th>
<th>Positive Predictive Value (Lateral)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meniscal displacement &gt; 5 mm</td>
<td>0%</td>
<td>4%</td>
</tr>
<tr>
<td>Meniscal corner tear</td>
<td>0%</td>
<td>50%</td>
</tr>
<tr>
<td>Fluid signal at meniscocapsular border</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Abnormal meniscal fascicle</td>
<td>---</td>
<td>8%</td>
</tr>
</tbody>
</table>

Rubin DA et al. Radiology 1996; 201:829

*Ramp Lesion*

- PHMM tear:
  - Longitudinal
  - Peripheral attachment
  - < 2.5 cm in length
- Associated with ACL tear
  - Seen in 17% of ACL tears
- Difficult to see at arthroscopy
- Form of meniscocapsular separation?

*AHLM Cyst*

- Parameniscal cyst
- Anterior horn lateral meniscus
- Multilocular
- Associated with meniscal tear in only 60% if AHLM
  - If at body and posterior horn lateral meniscus = 100% meniscal tear

De Smet AA et al. AJR 2011; 196:W180

*Meniscus: Take Home Points*

- MRI diagnosis:
  - 2-slice-touch rule
- Basic description:
  - Vertical, horizontal, complex
- Pitfalls:
  - Flap tear: look under MCL
  - Root tear: posterior
  - Meniscocapsular separation

*ACL Anatomy*

- Intra-articular but extrasynovial
- Anteromedial bundle
  - (orange)
  - Thin, taut in flexion
- Posterolateral bundle
  - (blue)
  - Thick, taut in extension
- Attaches to tibial eminence (anterior to tibial spines)

Outline:

- ACL injury
- MCL injury
- PCL injury

*From: Bicer EK, Knee Surg Sport Trauma, Arthros 2009*
**ACL Tear**
- Most common knee ligament injury
- 3x more common in women
- Complete tears > partial tears
- Midsubstance > femoral attachment
- 3 bruise / fracture patterns

**ACL Tear:**
- Abnormal signal
  - T1w, PDw: heterogeneous
  - T2w: fluid signal
- Ligament fiber discontinuity
- Abnormal horizontal orientation
- Accuracy >95% with MRI

Umans, AJR 1995;165:893–897

**ACL: full-thickness tear**

PD-weighted  T2-weighted

**ACL Tear: Fracture pattern #1**
- Lateral femoral condyle impaction
  - MRI: bruise, possible fracture
  - Deep notch sign: >1.5 – 2 mm
- Tibia bruise: posterior
- MCL tear
- PHLM: longitudinal tear

ACL: full-thickness tear

Deep notch
ACL Tear: fracture pattern #2

- Segond fracture
  - Avulsion: lateral tibia
  - Anterolateral ligament attachment
  - Radiography: correlation
  - Indicates ACL tear in 75 – 100%


ACL Tear: fracture pattern #3

- Anterior tibial eminence avulsion
  - ACL intact
  - ACL effectively torn
  - More common in children
Anterior Tibial Eminence Avulsion

ACL Tear:
- Secondary signs:
  - Lateral compartment bone bruise
  - Anterior tibial translation
    - >5 mm
    - Measure from midline of lateral tibial plateau
  - 80% positive predictive value

ACL Tear: secondary signs
- Anterior drawer
- Buckled patellar tendon
- Buckled PCL

ACL Injury
- Associate meniscal tears:
  - PHMM: peripheral, meniscocapsular separation
  - O’Donoghue triad:
    - ACL, MCL, MM tear
    - PHLM: longitudinal tear
**ACL Tear: pitfalls**

- Partial tear: some discontinuity, spared fibers
- Remote full-thickness tear
  - Scarred to PCL, more horizontal
  - No indirect signs (drawer, bruise, effusion)
- Mucoid degeneration
  - Celery stalk, no indirect signs
  - Associated ganglion cysts, no instability


**ACL: partial-thickness tear**

**ACL: remote full-thickness tear**

**ACL: mucoid degeneration + ganglion**

**Outline:**

- ACL injury
- MCL injury
- PCL injury

**MCL Anatomy**

- 2 layers
  - Superficial layer:
    - Tibial collateral ligament
      - 1 femoral attachment
      - 2 tibial attachments
  - Deep layer
    - Meniscofemoral ligament
    - Meniscotibial ligament

MCL Anatomy

- Superficial layer
  - Tibial collateral ligament
  - 9.5 cm in length
  - Strongest layer
  - Courses under pes anserinus tendons


MCL Injury

- Proximal tears more common
- Grading system:
  - Grade 1: surrounding edema
  - Grade 2: internal edema
  - Grade 3: complete discontinuity
- Grading system does not reflect clinical instability and is limited

Schweitzer, Radiology 1995; 194:825

MCL Tear

Grade 1
Grade 2

MCL Tear: Grade 3

T2-weighted
T2-weighted

MCL Tear: Grade ?

Anterior fibers torn, posterior fibers intact

MCL Edema: Osteoarthritis

Outline:

- ACL injury
- MCL injury
- PCL injury

PCL Anatomy:

- 2 bundles
- Anterolateral
- Posteromedial
- Meniscofemoral ligaments
  - Humphrey (anterior)
  - Wrisberg (posterior)

PCL Tear:

- Abnormal increased signal
- Swelling
- Discontinuity
- Posterior tibial avulsion fracture
  - Also: reverse Segond fracture
- Associated posterolateral corner injury: 62%

PCL Tear: MRI

- MRI findings:
  - Increased signal: 97%
  - Indistinct margins: 84%
  - Thickened: 78%
  - *No statistical difference between partial and full-thickness tears
- Discontinuity: more likely full-thickness tear
- Recommend radiographic stress views

Patten, JCAT 1994; 18:793
PCL Avulsion

Posterior Cruciate Ligament Avulsion

Reverse Segond Fracture

Mucoid Degeneration: PCL and ACL

From: Escobedo AJR 2002; 178:979

Syllabus online and other educational material: www.jacobsonmuskus.com
Twitter handle: @jacobson