**Imaging of Articular Cartilage**

Prof. Dr. K. Verstraete
Ghent University

**Clinical Imaging of Articular Cartilage**

- **Introduction : Articular Cartilage**
- **Histology and biochemical composition**
- **Review of Imaging Procedures**
  - Plain Radiography
  - Arthrography and CT-arthrography
  - MR imaging
    - SE sequences, GE sequences, MR-arthrography
- **Imaging of Specific Cartilage Lesions**
  - Focal chondral lesions (traumatic and osteochondritis dissecans)
  - Diffuse chondral lesions = Osteoarthritis

**Articular Cartilage Damage: Grading**

**Arthroscopic Cartilage Lesion Classification System** described by Outerbridge
- **Grade 0** = normal cartilage
- **Grade 1** = thickening and softening
  - Deep disruption of the collagen framework allowing the proteoglycans to increase the hydration of cartilage, leading to cartilage thickening and softening
- **Grade 2** = Superficial fissuring
- **Grade 3** = Deep partial-thickness defect
- **Grade 4** = Full-thickness cartilage defect
- Grades 2, 3 and 4 can be visualized with imaging
- These grades can be used by radiologists (Yulish et al.)
Clinical Imaging of Articular Cartilage

• Introduction: Articular Cartilage
• Histology and biochemical composition
• Review of Imaging Procedures
• Plain Radiography
• Arthrography and CT-arthrography
• MR imaging
  • SE sequences, GE sequences, MR-arthrography
• Imaging of Specific Cartilage Lesions
  • Focal chondral lesions (traumatic and osteochondritis dissecans)
  • Diffuse chondral lesions = Osteoarthritis

Imaging Articular Cartilage

1. Plain Radiography:
   • Acute traumatic cartilage injury:
     • Focal chondral lesion: invisible
     • Osteochondral avulsion:
       • only displaced osseous fragment is visible
   • Chronic cartilage degeneration = Osteoarthritis:
     • Narrowing of joint space
     • Subchondral bone:
       • Sclerosis
       • Geode formation (subchondral cysts)
     • Osteophyte formation

2. Arthrography and CT-arthrography
   • Direct visualization of
     • Articular cartilage
     • Surface lesions (grade 2, 3 and 4)
   • Can be applied in
     • Acute traumatic chondral injury
     • Chronic chondral degeneration
   • Multiplanar imaging possible with MDCT

3. MR imaging
   • Non-invasive imaging method
   • Multiplanar imaging capability
   • Excellent soft tissue contrast
     • Direct visualization of cartilage
     • Direct visualization of joint fluid + subchondral bone
     • Rarely need for contrast agent
   • Grade 3 and 4 lesions easily detected
   • Grade 2 lesions moderately well displayed
   • Other structures (menisci, ligaments) can also be evaluated

3. MR imaging
   • Fast-SE-sequences
     • 2D and 3D
   • GE-sequences
     • 3D
   • MR-arthrography

Fast (turbo) Spin Echo Sequence

• Provides high resolution images
  • (384 x 512 or 256 x 512)
  • In relatively short imaging time (4-5 min)
• Adequately displays cartilage and cartilage defects
  • Grade 3 and 4 lesions easily detected
  • Grade 2 lesions moderately well displayed
  • Accuracy for detection of chondral lesions:
    • Sensitivity of 73% – 87%
    • Specificity of 79% – 94%
Fast/Turbo Spin Echo Sequences (FSE/TSE)
- PD/T2-weighted or intermediate weighted (TE = 33-50 ms)
- With fat suppression
- Sensitive for surface defects and intrinsic cartilage lesions
- Combination of sagittal and coronal imaging planes
  - Allow for evaluation of all joint structures

Grade 2 : Superficial Fraying

Fatsat PD FSE
Fatsat T2 FSE

2D TSE with Driven Equilibrium Pulse
DRIVE, RESTORE, DEFT-FSE

- long TE sequences: T2 enhancement, signal enhancement
- short TE sequences: Increased signal of free water with otherwise unchanged signal intensities
  → "arthrographic" effect


Imaging Articular Cartilage

3. MR imaging:
- Fast-SE-sequences
- 3D and 3D
- GE-sequences
- \( ^{3}P \)
- MR-arthrography

3D Fast Spin-Echo - SPACE
3D PDw SPACE
proton-density-weighted sagittal image with fat suppression
2 mm or less in-plane resolution

SPACE = Sampling Perfection with Application optimized Contrast
Using different flip angle Evolutions

"Cartilage-Specific" 3D – GE-Sequences
3D GRE acquisitions with spectral fat saturation or water excitation

- T1w - "dark fluid"
- T2*w - "bright fluid"
- DESS-3D-WE
- SPGR
- FLASH-3D- T1-WE
- FFE T1
- WATSc

Disadvantages
- Relatively long acquisition times
- High extrinsic but low intrinsic cartilage contrast
- Insensitive to bone marrow pathology
- Less valuable in evaluation of structures other than cartilage
- Prone to susceptibility effects (postoperative knee)

Fat Suppressed T1 w 3D-Spoiled GRE
- 3D sequence with high spatial resolution (1mm)
- Selective fat suppression (fs 3D-SPGR; T1 FFE SPIR)
- Or selective water excitation (FLASH-3D-we; DESS-3D-we)
- Provides excellent contrast between
  - Cartilage (high SI)
  - Joint fluid (low SI)
  - Subchondral bone and bone marrow (dark)
  - Fat, muscle and synovium (grey)

Fat Suppressed T1 w 3D-Spoiled GRE
- Allows 2D reconstructions

3D-fsGRE shows deep cartilage layers better than T1 FSE
3D-FSGRE Thickness Map

DESS 3D-sequence

- Double-echo Steady State
- Mixed T1- & T2-weighted 3D-GE sequence
- Without fat suppression or water excitation
- Cartilage: intermediate signal intensity
- Joint fluid: very high signal intensity

DESS 3D Sequence

- Very high contrast between
  - Joint fluid (very high SI = bright white)
  - Cartilage (intermediate SI = grey)

DESS 3D Sequence:

- Adequately displays cartilage and cartilage defects
- Grade 3 and 4 lesions easily detected
- Grade 2 lesions moderately well displayed
- Presence of joint fluid is necessary for grade 3 lesions
- Other structures are readily visible
  - Menisci and ligaments (black, unless lesion)
  - Subchondral bone (high SI – T1 effect of fat BM)

DESS 3D Sequence: Disadvantage

- Sensitive to susceptibility artifacts (micrometallic parts)
- Occur rarely after arthroscopy
- Occur frequently after some cartilage repair procedures

3 mm axial (2 min) +2 mm cor (5 min)
Cartilage Imaging: Sensitivity

- **Grade 3/4:**
  - 3D-GE (SPGR FS, DESS WE) at least 2 imaging planes: 85% - 100%
  - TSE PD/T2 (FS): 80% - 95%
  - MR and CT Arthrography: 50% - 100%

  Woertler et al. (1996) AJR 166:679-683

- **Grade 1/2:**
  - All Pulse Sequences: < 70% resp. < 50%

  Gagliardi et al. (1994) AJR 162:629-636

Limitations in MRI of Articular Cartilage Degradation

- **Underestimation of lesion:**
  - Size
  - Depth (Grade)

- **Difficult detection of lesions in critical locations:**
  - Knee: lateral Tibia (< 60%), Trochlea

- **Limited spatial resolution (standard pulse sequences):**
  - Fissures
  - Joints with relatively thin cartilage

- **Less accurate in postoperative knee**

Murphy et al. (2001) Skeletal Radiol 30:305-311

Imaging Articular Cartilage

3. MR imaging
   - Fast-SE-sequences
   - GE-sequences
   - 3D-GE-sequences
   - MR-arthrography

MR Arthrography

- Intraarticular injection of a Gd chelate solution (e.g. 20 mL - 2.5 mmol/L)
- Cor-Sag-Tra T1-w imagesand at least one PD/T2-w sequence
- Accurate depiction of articular cartilage lesions

CT Arthrography

- Single contrast arthrography
- Intraarticular injection of a iodinated CM diluted with saline
  - e.g. 20 mL - 300mg/mL (0.5-1:1)
- Most accurate technique for imaging of surface defects
- Insensitive to intrinsic cartilage pathology

Clinical Imaging of Articular Cartilage

- Introduction: Articular Cartilage
- Histology and biochemical composition
- Review of Imaging Procedures:
  - Plain Radiography
  - Arthrography and CT-arthrography
  - MR imaging:
    - SE sequences, GE sequences, MR-arthrography
- Imaging of Specific Cartilage Lesions:
  - Focal chondral lesions (traumatic and osteochondritis dissecans)
  - Diffuse chondral lesions = Osteoarthritis
Imaging of Abnormal Cartilage

- Isolated, focal chondral lesions:
  - Found in 25% - 66% of arthroscopies
  - Difficult to detect clinically (may masquerade as meniscal tears)
  - Imaging:
    - CT-arthrography
    - Cartilage specific MR sequences

- More diffuse abnormal cartilage
  - Osteoarthritis and inflammatory arthritis
  - Late stages: can be detected with plain radiography
  - Early stages: CT-arthrography or MRI

Traumatic Chondral Injury

- Often solitary
- Can be small or large
- Acutely angled margins
- Can be purely chondral or osteochondral
- Often accompanied by underlying subchondral bone marrow edema = microtrabecular fractures
- If BME → look for cartilage lesion!

Acute, Traumatic Chondral Injury Flap Tear

CT-Arthrography for Traumatic Chondral Injury

Invasive: X-rays; Contrast medium; Injection into joint
Acute, Traumatic Chondral Injury
Focal defect - Fissure

Acute, Traumatic Chondral Injury without BME
Fibrillation and Flap Tear

Acute, Traumatic Chondral Injury
Delamination

Traumatic Chondral Injury
Fibrillation - Focal defect + BME

Acute, Traumatic Chondral Injury with BME
Fissure

Acute, Traumatic Chondral Injury with BME
Osteochondral Contusion
Acute, Traumatic Chondral Injury with BME
ACL Tear with Osteochondral Impaction

Old, Traumatic Chondral Injury without BME
Focal Subchondral Sclerosis = “Scar”

Clinical Imaging of Articular Cartilage

- Introduction: Articular Cartilage
- Histology and biochemical composition
- Review of Imaging Procedures
  - Plain Radiography
  - Arthrography and CT-arthrography
  - MR imaging
    - SE sequences, GE sequences, MR-arthrography
- Imaging of Specific Cartilage Lesions
  - Focal chondral lesions (traumatic and osteochondritis dissecans)
  - Diffuse chondral lesions = Osteoarthritis
Clinical Imaging of Articular Cartilage

- Introduction: Articular Cartilage
- Histology and biochemical composition
- Review of Imaging Procedures
  - Plain Radiography
  - Arthrography and CT-arthrography
  - MR imaging
    - SE sequences, GE sequences, MR-arthrography
- Imaging of Specific Cartilage Lesions
  - Focal chondral lesions (traumatic and osteochondritis dissecans)
  - Diffuse chondral lesions = Osteoarthritis

Imaging of Osteoarthritis

- Typical Findings:
  - Diffuse chondral thinning
  - No acutely angled, but obtuse margin of defects
  - Multiple chondral defects of varying size and depth
- Plain Radiography
  - For late stages
  - Study alignment (varus/valgus)
- CT-scan: CT-Arthrography
- MR imaging

Cartilage Fissure and Early Osteoarthritis

Retropatellar Osteoarthritis:
Partial Thickness Chondral Defects

Future Directions – Research Applications

- Current FSE, GRE and DESS sequences can detect gross morphologic changes (grade 2, 3 and 4 chondral defects)
- New pharmacological therapies require earlier detection of biochemical and structural change in cartilage
- New imaging techniques for cartilage are being developed

T2 Relaxation Rate Measurement

- 42 y: Anterior knee pain
- Focally increased T2
- Radial zone
- Reflects damage to collagen network
- Disadvantage:
  - Susceptible to artifacts due to orientation of collagen fibers relative to magnetic field

Courtesy: T. Mosher Milton S. Hershey Medical Center, Hershey, PA, USA
Anionic Contrast Agent Imaging

- **dGEMRIC**: delayed Gd-DTPA²⁻ enhanced MRI of Cartilage
- Imaging 2 hours after i.v. injection of Gd-DTPA²⁻
- Color maps display diffusion of Gd into cartilage

\[ [\text{Gd}] \text{ high in areas with low } [\text{GAG}] \]
\[ [\text{Gd}] \text{ low in areas with high } [\text{GAG}] \]

--

**dGEMRIC Detects Early Cartilage Lesions Without Morphologic Change**

- Increased uptake of Gd-DTPA²⁻ in degenerative cartilage
- **Chondromalacia grade 1**
  - Softening, swelling without superficial fraying

Courtesy of D. Burnstein MRM 2001; 45:36-41

--

**Summary: Clinical Imaging of Cartilage**

- **Conventional MR Imaging**
  - Fast-SE sequences with fat suppression in 3 imaging planes
  - "Cartilage-specific" 3D-GE sequences < 2mm – time consuming
  - Sufficient for routine diagnosis in most cases
- **CT Arthrography**
  - Alternative technique if MR not available or contra-indicated
  - At present best modality to depict surface lesions
- **MR Arthrography**
  - Reserved for unclear cases
  - Surgical planning