MENISCAL GRADING SYSTEM
- Grade I: focal or globular intrasubstance signal
- Grade II: horizontal intrasubstance increased signal not extending to an articular surface
  - Not predictive of development of meniscal tear
- Grade III signal: meniscal tear
  - Signal extending to at least one meniscal surface
  - Tear may only be visualized on one 3mm slice

POSTOPERATIVE EVALUATION OF MENSICI
NORMAL POSTOPERATIVE APPEARANCE
- Traditional short TE meniscal “windows” of limited value
- Need fluid sensitive techniques with moderately high spatial resolution
- Residual grade III signal may persist, without fluid imbibition into meniscal remnant
- Blunted tip with no fragmentation

POSTOPERATIVE EVALUATION
PRIMARY MENISCAL REPAIR
- Grade III signal persists in areas of fibrovascular healing
- Conventional spin echo pulse sequences are unsuitable for evaluation of healing
- Abnormal signal may persist for up to 27 months postoperatively
- Fat suppression and water sensitive techniques, particularly when performed with a higher resolution matrix accentuate fluid imbibition into repair site and are predictive of healing

Imaging as a Primary Outcome Measure
Morphologic Analysis: Meniscal repair
- MRI vs. arthrography
  - Sensitivity 97%, specificity 100%
  - Positive predictive value 100%
  - Negative predictive value 88%
- MRI vs. arthrography: partial vs complete healing
  - Sensitivity 83%, specificity 100%
  - Positive predictive value 100%; negative predictive value 89%
- Standard established for further research
CANDIDATES FOR MENISCAL TRANSPLANTATION

- Arthroscopic/MR evidence of meniscal deficiency
- Relative preservation of joint space on standing radiographs
- Grade 0-2 or focal grade 3 (modified Outerbridge) cartilage grading on MR
- Normal joint architecture on coronal MR: lack of proliferative change and condylar squaring
- Ligament stability (native or ACLR)
- Normal subchondral signal: edema, sclerosis, condensation of trabeculae

A Clinical and Objective Evaluation of Meniscus Allograft Transplantation at Minimum Two-Year Follow-Up
Scott A. Rodeo MD, Hollis G. Potter MD, Mario Berkowitz MD, Peter Sultan MD, Thomas L. Wickiewicz MD, and Russell F. Warren MD

- 36 pts with 42 fresh-frozen, non-irradiated meniscal transplants
- 24 males, 12 female; ave. age 33.3 yrs (17-51)
- Ave. interval to transplant: 10.8 yrs (4 mo-30 yrs)
- 24 with bone plugs or block; 16 with sutures; 2 OCA with hemiplateau
- Evaluated with PE, MRI and clinical outcome measures of symptoms, function and pain (Lysholm II knee scale, IKDC and visual analog scale)

“Meniscus Score”: 0-15

Objective MRI Scoring Of Meniscal Transplantation
- Position (0-3): degree of extrusion judged independently in sagittal and coronal planes by 1/3’s
- Signal intensity of fibrocartilage (0-3)
- Size (0,1): normal, reduced by 1/3 or more
- Capsular healing (0-2): completely healed, partially detached, completely detached
- Morphology of transplant (0,1,3): normal, tear, displaced tear

Objective Scoring Of Meniscal Transplantation
36 Patients; 42 XP; mean F/U 56 mo.

<table>
<thead>
<tr>
<th># of Transplants</th>
<th># of Patients</th>
<th>Average MR Grading*</th>
<th>Femoral Condylar Squaring**</th>
<th>Noyes Cartilage Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>17</td>
<td>2.4</td>
<td>1.4</td>
<td>59%</td>
</tr>
<tr>
<td>Fair</td>
<td>18</td>
<td>5.4</td>
<td>2.4</td>
<td>52%</td>
</tr>
<tr>
<td>Poor</td>
<td>6</td>
<td>5.3</td>
<td>2.3</td>
<td>49%</td>
</tr>
<tr>
<td>Failure</td>
<td>4</td>
<td>10.2</td>
<td>2.7</td>
<td>25%</td>
</tr>
</tbody>
</table>

*Meniscus graded by position, signal, size, healing to capsule and morphology (0-15)

**Flattening graded by 0-3 (none to >66%)

- MR grade correlates with femoral condylar flattening (r²=0.51, p<.01)
- MR grade correlates with cartilage score (r²=0.30, p=.03)
- Significant improvement for menisci transplanted as OCA or with common slot

ANTERIOR CRUCIATE LIGAMENT

Normal Appearance
- Increased signal within ACL may reflect signal average from adjacent fat
- Two components
  - Anteromedial band
  - Posterolateral bulk (tears in hyperextension; primary restraint for internal rotation)
POSTEROLATERAL CORNER
- Popliteus tendon
- Fabellofibular ligament
- Fibular collateral ligament
- Biceps femoris tendon
- Arcuate ligament
  - Y shaped thickening of posterolateral corner from femur to fibula
- Popliteofibular ligament

NORMAL SIGNAL PROPERTIES:
ACL GRAFT
- Expect homogenously hypointense signal on moderate to long TE sequences
- Graft may show variable signal hyperintensity on short TE sequence
  - Periligamentous vascularity and impingement
  - Animal model of “ligamentization”: necrosis, repopulation, revascularization, cellular proliferation and collagen remodelling
- Allograft vs autograft: slower rate of biologic incorporation in first 6 months may account for signal inhomogeneity

HAMSTRING/PATELLAR TENDON ACLR
Normal Position (traditional endoscopic technique)
- Graft should parallel roof of the intercondylar notch
- Femoral tunnel: at intersection of Blumensaat’s line and posterior femoral cortex
- Tibial tunnel: posterior half of native ACL footprint **

GRAFT INCORPORATION
- Assess signal of graft within femoral and tibial tunnel
- Fully incorporated graft: uniformly hypointense with no ganglion formation
- MR affords accurate measurement of the size of tunnels
  - Clinical significance of tunnel widening unclear
- Failure to incorporate graft with tunnel widening on MR may not reflect functional instability

ABNORMAL ACL GRAFT POSITION ON MRI
- If femoral tunnel is too anterior/inferior: vertical graft → impingement against notch
- If tibial tunnel is too anterior: impingement against roof or kinking
- Central placement within femur → vertical orientation of graft on coronal images

CAUSES OF GRAFT FAILURE
- Reinjury due to provocative trauma
- Malposition of graft
- Overlooked posterolateral corner instability
- Failure at bone/plug interference screw
- “Lax” appearance on MRI:
  - Partial tear, structural elongation, plastic deformation

GRAFT IMPINGEMENT
MR Findings
- Increased signal intensity on short TE sequences
  - Typically in distal two thirds
  - More common against anterior synovial reflection
- May obscure intact graft fibers

MRI OF ACL RECONSTRUCTION
- Attention to technique is crucial to limit artifact from instrumentation and metallic debris
- Synovitis may reflect infection or mode of fixation (biopolymers)
- ALWAYS correlate MRI findings with clinical function of the graft and symptoms
ARTICULAR CARTILAGE

- Viscoelastic substance with strong imaging and biomechanical anisotropy
- Signal properties dependent on:
  - Cellular composition of collagen, proteoglycans and water
  - MR pulse sequence utilized
    - Moderate TE FSE more sensitive to partial thickness lesions
    - Fat suppressed 3D GRE or 3D FSE with isotropic voxels more amenable to semiautomatic segmentation and volume quantification methods
- Orientation of collagen in different laminae of cartilage

Cartilage Repair: Methods of Repair

- Articular cartilage has little to no capacity to undergo spontaneous repair
  - avascular; unable to regenerate across a physical gap
- Debridement
- Marrow stimulation (microfracture)
- Osteochondral transfer
  - autologous (mosaicplasty; OATS)
  - allograft (fresh cadaveric tissue)
- Tissue Engineered Cartilage (three requirements)
  - matrix scaffold
    - carbohydrate based polymers (polylactic acid)
    - protein based polymers (collagen, fibrin)
  - cells
    - chondrocytes
    - chondroprogenitor cell pools (cambial layer of periosteum and perichondrium)
    - mesenchymal stem cells from the bone marrow or synovial membrane
  - signaling molecules (growth factors or genes)
- Synthetic acellular techniques (scaffold)
  - polylactide-co-glycolide copolymer and calcium sulfate (porous)

Imaging as a Primary Outcome Measure

Morphologic Analysis: Cartilage repair

- Signal intensity of tissue (ROI analysis)
- Integrity/hypertrophy of periosteal flap (ACI)
- Morphology; presence/absence of displacement (ACI/ OCA)
- Interface with native cartilage
- Volume of repair “fill”
- Appearance/morphology of subchondral bone
- Assess adjacent and opposite articular cartilage
- Presence/absence of inflammatory synovitis

*Corr 2004;422: 214-223*

MR observation of cartilage repair tissue (MOCART)

*Marlovits et al; Eur J Radiol 2006; 57:16-23*

- MACT assessed in 13 pts at 24 month postop (9 points in grading scale)
  - Degree of fill
  - Integration and structure (homogeneous, clefts)
  - Surface integrity
  - Signal intensity (SI)
  - Subchondral lamina and bone
  - Adhesions and effusion
- Correlated to KOOS and VAS; significant correlation for fill, structure, subchondral bone and SI
- ICC (3 independent readers); \( \kappa \) ranged between 0.765-1.00
Imaging of Microfracture

Prospective study of 48 patients treated with microfracture evaluated by validated clinical outcome instruments and cartilage sensitive MRI

- bony overgrowth was noted in 25% of patients, but did not have a negative effect on clinical outcome scores
- adverse functional scores after 24 months did correlate with poor percentage fill

*J Bone Joint Surg 2005; 87(9):1911-1920*

Imaging of Cartilage Structure

- Water proton pools:
  - Free water (accounts for bulk of MRI signal)
  - Bound to PG by electrostatic charge (assess fixed charge density)
    - Sodium MRI
    - Gd-DTPA-2 techniques (dGEMRIC)
      - Correlated to static (compressive) mechanical properties at 9.4T*
    - T1 rho imaging
  - Associated with collagen fibrils and macrostructure
    - Quantitative T2 mapping: internuclear dephasing of unbalanced dipole interactions
    - Assess alterations in collagen orientation
      - Correlated to dynamic mechanical properties at 1.5T and 9.4T*

*Cartilage Structure: Collagen*

- Deep radial zone (40-60%): collagen oriented perpendicular to subchondral zone—strong angular dependence: vertical striations evident and short T2 values
- Transitional zone (20-30%): more random collagen orientation—less angular dependence and longer T2s
- Superficial zone (<10%): parallel to surface (beyond resolution of clinical MRI)

*Xia et al; Osteoarthritis and Cart 2001: 9:393-406*

Welsch et al (Radiology 2008; 247:154-161) studied 20 pts following MFX or MACT with mean F/U 28.6 vs 27.4 mo

- MFX tissue showed reduced mean T2 whereas MACT showed mean T2 similar to control tissue (56.4msec); MFX showed no stratification while MACT did from deep to superficial areas
Imaging of Osteochondral Allografts

- Prospective, longitudinal study of cartilage defects treated with hypothermically stored fresh osteochondral allografts using validated clinical outcome instruments and MRI
- Allografts remain intact without displacement
  - fissures noted at the graft/host interspace in 14/18 (78%) grafts
  - poor incorporation was noted in 4/18 (22%) grafts, 1 had intense bone marrow edema pattern and 3 had frank subchondral marrow fibrosis (low signal on all pulse sequences)
  - collapse of the subchondral bone in the graft was correlated to lack of bony integration based on signal characteristics
- Sirlin et al. correlated MRI of shell osteochondral allografts to the results of antihuman leukocyte antigen antibody screening (Radiology 2001;219:35-43)
  - Pts. who expressed positive humoral immune responses were associated with decreased incorporation, greater marrow edema pattern and a higher proportion of surface collapse of their graft

Quantitative MR Assessment of Articular Cartilage

Biochemistry: Clinical Utility

- Osteoarthritis: Breakdown of matrix
  - Swelling of PG, increase cartilage permeability
  - Disruption of collagen → increased mobility of water → prolongation of T2 and loss of stratification
    - Assess “disease modifying” abilities of pharmaceutical therapy (viscosupplementation)
    - Optimize timing of meniscal transplantation/realignment/osteotomy
- Cartilage Repair
  - Assess components of matrix in repair tissue
  - Assess response of adjacent hyaline cartilage to surgical repair
  - Imaging to serve as an outcome variable for the FDA?
  - Obviate the need for second look arthroscopy/biopsy

MRI of Articular Cartilage

- Standardized, validated sequences available for all joints
- Sequences should not be limited by instrumentation
- Provide noninvasive detection of traumatic injuries
- Monitor progression of cartilage degeneration in OA and disease status in RA
- Provide objective outcome assessment for cartilage repair techniques
- Future development: detect early changes in matrix prior to morphologic alteration
  - noninvasive tissue characterization of repair tissue
  - optimize timing of meniscal transplantation/PF realignment/osteotomy

References
6. Kelly BL, Shapiro GS, DiGiovanni CW, Buly RL, MD, Potter HG, Hannafin JA. Vascularity of the hip