Meniscal repair & replacement

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Target audience: Radiologists and imaging scientists interested in techniques to define meniscal structural integrity, suitabilty for repair, as well as imaging indications for meniscal transplantation

Outcome/Objectives:

1. To become familiar with criteria of suitability for meniscal repair
2. To become familiar with the use of parametric mapping to assess meniscal structural integrity, as well as the integrity of the articular cartilage with regards to suitability of the candidate for meniscal transplantation

Purpose:

- Meniscal deficiency is one of the most common orthopaedic conditions, resulting in osteoarthritis.
- Meniscal functions are multifold, including aiding in forced transmission by increasing the contact area and thereby decreasing contact stresses, shock absorption, joint lubrication, proprioception, chondrocyte nutrition, and joint stability in the ACL deficient knee (*AJSM 2006;34(8):1334-44.*; *AJSM 2010; 38(8):1591-7*; *J Bone Joint Surg Am. 1982;64(6):883-8.*; *J Orthop Res.2000;18(1):109-15.).*
- The ability of combined morphologic and parametric MR assessment of meniscal fibrocartilage will enable determination of suitability of tissue for repair, and in the setting of irreparable tissue and meniscal deficiency, suitability of the candidate for meniscal transplantation or scaffold placement. This will hopefully delay the progression of osteoarthritis and joint failure.

Assess suitability of tissue for repair:

- Horizontal versus vertical tear
- Zone of cleavage relative to meniscal vascular zones
- Rim size *(Tenuta &Arciero AJSM 1994)*
    - Better healing closer to vascular periphery
    - Healed: 2.17mm versus 3.30mm in unhealed (p=.004)
    - No healing if greater than 4 mm
- Quality of remaining tissue
- Status of articular cartilage
- Associated injuries (ligaments)
- “classic repairable tears”: peripheral longitudinal, bucket, radial split extending to the capsule in YOUNG patients
- Tissue augmentation: fibrin clot, stem cells, etc.

Assessment of meniscal repair:

- Grade 3 signal persists in areas of fibrovascular healing using conventional sequences
- Both indirect and direct MR arthrography has been used to assess meniscal repair but are invasive
- Fat suppression techniques using high resolution scanning has been successfully compared to conventional arthrography and arthroscopy (*Arthroscopy 1998; 14(1):2-8.*)
- Parametric mapping: UTE and T2* (*Osteoarthritis Cartilage 2013, 21:1083-91)*
    - Ovine model of meniscal repair: UTE and FSE compared to multiphoton microscopy

    - Morphologic grading correlated well to T_2*; however, T_2* was more predictive of healing based on histology as standard
    - T_2* values are predictive of meniscal healing and show potential as a biomarker for meniscal integrity
- Regional differences indicating collagen disruption are detectable: T2* is a biomarker of repaired meniscus

Greater than 10-year results of red-white longitudinal meniscal repairs in patients 20 years of age or younger (*Am J Sports Med 2011;39(5):1008-17***)**

- Long-term outcome of meniscal repairs extending into avascular region
- N=29 Simultaneous ACLR in 18 Age 20 or younger
- Mean follow-up 16.8 years (range, 10.1-21.9 years)
- Evaluation: validated knee rating systems, MRI with T2 mapping, radiographs, follow-up arthroscopy
- 62% (18/29) had normal or nearly normal characteristics in all of the parameters assessed (healed)
- 38% (11/29) failures
- No significant difference in articular cartilage T2 scores between the involved and contralateral tibiofemoral compartments in healed menisci
- Conclusion: A chondroprotective joint effect was demonstrated in the healed meniscal repairs

Meniscal allograft transplantation: candidates

- MR evidence of meniscal deficiency
- Normal joint architecture on morphologic imaging (lack of condylar squaring and subchondral bony flattening)
- Ligament stability (native or reconstructed)
- Grade 0-2 or focal grade 3 (modified cartilage grading on MR)
- Use of parametric mapping as a marker for early osteoarthritis in the meniscal deficient knee
- Use of MRI to assess load in meniscal deficient patients (ISMRM 2015 #3389)
    - Feasibility of using a MRI compatible displacement-controlled loading device to apply consistent axial load, while maintaining a controlled femoral-tibial positioning

      Demonstrate the feasibility of using an MRI compatible displacement-controlled loading device to apply a consistent axial load, while maintaining controlled femoral-tibial positioning when acquiring MR images on four volunteers. The repeatability test showed repeatable knee position across different scans, to within 1 mm of translation and 2 degrees of rotation. Cartilage thickness decreased in response to the applied load, indicating stress relaxation of the tissue. The greater reproducibility of thickness measurements found when the cartilage was loaded for 12 minutes prior to scanning suggests that the articular cartilage may have approached steady-state of deformation at this time point

      Conclusion: An MR compatible positioning device is capable of repeatable tibiofemoral joint positioning; reproducible measurements of cartilage deformation under loading are obtained by pre-loading the lower limb for at least 12 minutes.
    - Same conditions will apply at the time of transplantation

Assessment of transplants

- 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
- Cartilage status
- Presence/extent of synovitis

Objective Scoring Of Meniscal Transplantation
36 Patients; 42 XP; mean F/U 56 mo *(Am J Sports Med. 2001;29(2):246-61.)*

	# of Transplants	# of Patients	Average MR Grading*	Femoral Condylar Squaring**	Noyes Cartilage Score
Good	17	7	2.4	1.4	59%
Fair	18	16	5.4	2.4	52%
Poor	6	4	5.3	2.3	49%
Failure	4	4	10.2	2.7	25%

*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 (r^2=0.51, p<.01)**
- **MR grade correlates with cartilage score (r^2=0.30, p=.03)**
- **Significant improvement for menisci transplanted as OCA or with common slot**

- Objective assessment of transplants correlates statistically to the degree of condylar remodelling and the extent of articular cartilage degeneration
- High prevalence of arthrosis at the time of transplantation is likely predictive of transplant failure
- Preoperative assessment will evaluate those patients who are likely to fail

Current status of meniscal transplantation: How do we improve it?

- Meniscus transplantation can reliably improve symptoms
- However, less data to suggest that we can truly restore meniscus function
- Currently no evidence that meniscus transplantation can prevent further cartilage degeneration
- Tissue availability and sizing
- Tissue material properties – high loads posterior horn
- Fundamental problem is lack of cells that can repair microscopic matrix damage:
- Incomplete cellular repopulation of acellular transplants
- Transplanted cells in viable tissue are replaced by host cells
- Cell migration into meniscus during graft incorporation is associated with matrix remodeling which compromises material properties
- May be ideal to *prevent* cellular repopulation with host cells, since repopulation requires matrix remodeling

- Preservation of transplanted viable cells by preventing or controlling immune response and inflammatory reaction post transplantation
- **Goal: transplant viable tissue**, allow transplanted cells to survive transplantation, and synthesize matrix molecules/repair microscopic matrix damage

Evaluation of a Porous Polyurethane Scaffold in a Partial Meniscal Defect Ovine Model
Maher, Rodeo, Potter et al, Arthroscopy 2010

- Sheep model-partial lateral meniscectomy N=42:
  - Degradable polyurethane scaffold N=23
  - Defect left unfilled N=19
- Examined at 3, 6, 12 months with MRI and T2 and T1ρ mapping

- Supports new tissue formation
- No damage to underlying cartilage early but MRI demonstrated prolongation of T2 at 12 months over the central weight-bearing area of the LTP with disruption of collagen orientation on histology
- No significant differences were found in the T2 or T1 values for any zone between the scaffold-implanted and non–scaffold-implanted groups ($P > .1$)

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