Reducing Magnetic Susceptibility: Technical Strategies and Clinical Utility
Clinical Protocol Challenges in MSK
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Magnetic Susceptibility
◆ Quantitative measure of material’s tendency to become magnetized by B0: proportional to strength of B0 and susceptibility constant (1.5T ONLY!)
◆ When exposed to B0, materials become magnetized to different extents (depending on chemical composition)
◆ Create own magnetic field, distort B0 and creating frequency shift
◆ Adjacent tissues with different susceptibilities distort field and results in mis-mapping of spins

MRI of Metal Components
• Single Point Imaging (Ramos-Cabrer et al., MRI 2004)
  – Acquires a single k-space location of the free induction decay (FID) immediately following excitation
  – Very long scan time
• Prepolarized MRI (Venook et al., MRM 2006)
  – Requires specialized electromagnets to generate low Bo fields (0.4-1.0T and 20-180 mT)
• View Angle Tilt (VAT, Cho et al., Med Phys 1988)
  – View Angle Tilt (Kim Butts, PhD): re-apply slice-select gradient during the read out period; results in re-registration of in-plane and slice distortions
  – Uses slice selection gradient during readout to reduce in plane distortion
  – Blurred output images
  – Distortion in slice-selection direction

Reduction of Susceptibility: Current Capabilities
◆ Frequency shift misregistration causes signal hyperintensity and void
◆ Distortion in slice and readout ∝ 1/strength of Gz and Gx
  ◆ Increase Gx strength, decrease misregistration
  ◆ Wide receiver bandwidth (GE 100-125kHz over frequency range; Philips/Siemens 350-500Hz/pixel)
  ◆ Issues of gradient performance and linearity; performance off of isocenter
  ◆ High resolution frequency direction: decrease voxel size, increase spatial resolution and definition of metal-induced distortion
◆ Signal loss secondary to diffusion on SE; partially corrected by FSE
  ◆ Increase NEX, increase SNR
◆ Avoid frequency-selective fat suppression and GRE techniques
◆ SEMAC (slice encoding for metal artifact correction; Lu et al MRM 2009)
  ◆ Additional phase encoding in the slice direction

Imaging of Osteolysis
• Loosening at bone-metal or bone-cement interface
  – Risk: 10-15% of patients over 20 year period
  – Wear-induced synovitis and bone loss: #1 FACTOR THAT LIMITS THE LONGEVITY OF JOINT REPLACEMENT
  – Starts at synovial level; activates osteoclasts
  – How do we monitor this process?
• Conventional radiographs underestimate the extent
  – Inaccurate; poor reliability

Imaging of Osteolysis

- Oblique views impart greater sensitivity, especially at the posterior column/wall (Southwell et al; JBJS 1999; 81B: 289-295)

**Imaging of Osteolysis**

- Helical CT with optimized protocol to reduce artifact reduction helpful (Puri et al; JBJS 2002; 84A: 609-614)
- Multidetector helical CT
  - Allows for higher mAs technique and facilitates reformations
- Increase effective energy
  - HSS THA: 140 kVp, 300 mAs
  - Uses ionizing radiation; radiation burden for serial examinations an issue
  - Inferior soft tissue contrast

**Imaging of Osteolysis**

  - Superior soft tissue contrast (process starts at a synovial/soft tissue level)
  - Direct multiplanar capabilities
  - No ionizing radiation
  - BUT: issues of artifact generated by the components
  - Validation of MRI necessary: revision surgery imperfect standard

**Accuracy of MRI in detecting periacetabular osteolysis**

- **MRI Sensitivity = 95%**
  - 83 of 87 locations with lesions were correctly identified
  - Radiographs (current standard with oblique views) = 52%
  - CT (optimized) = 75%
  - For radiographs and CT, lesion detection was dependent on lesion location
  - MRI had consistently good sensitivity in all lesion locations
- **MRI Specificity = 98%**
  - 48 of 49 locations having no lesions were correctly identified
  - X-Ray 96%; CT 100%

**MRI Assessment of Wear-induced Synovitis**

Closed Hip Society 2010

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**Purpose**

To prospectively review MRI patterns of synovitis in an ongoing study of symptomatic individuals scheduled for revision surgery and to compare to a cohort of asymptomatic controls revised for instability, using a blinded histologic analysis as the standard.

**Hypothesis**

Distinct qualitative synovial patterns on MRI exist for infection, MOM, metal on poly and ALVAL reactions that would be concordant with histological findings at revision surgery.

**Methods: patient cohorts**

- **Cohort I: Control**
  - capsule tissue from control pts. undergoing exchange to constrained liner for instability

- **Cohort II:**
  - **IIA: Polyethylene +/- PMMA**
  - **IIB: Metal and Polyethylene +/- PMMA**
  - osteolysis tissue in pts. undergoing revision THA (metal on poly +/- PMMA)
• Cohort III: Metal on metal  
  – synovial tissue from pts. with symptomatic MOM articulations

**Methods: MRI scan parameters**
- Scanning performed on 1.5 Tesla clinical scanner
- Scan parameters for morphologic evaluation (*Potter et al, JBJS 2004*)
  - TE = 26 ms (eff)
  - TR = 4000-6000 ms
  - ETL = 18-24
  - Receiver bandwidth = ±100-125 kHz
  - NEX = 4-5
  - FOV = 22 cm x 22 cm
  - Acquisition Matrix = 512 x 352 (In plane: 420 μm x 625 μm)
  - Slice Thick = 3.5-4 mm/0 gap

*All scan parameters optimized for minimizing susceptibility artifact*

**Methods: MRI assessment of synovium**
Blinded analysis by one musculoskeletal radiologist
- Group 1: low SI pseudocapsule with no discernible debris
- Group 2:
  - 2A: inhomogeneous intermediate signal debris interpreted on MRI as polymeric debris (polyethylene +/- PMMA)
  - 2B: mixed low to intermediate signal debris interpreted as both metallic and polymeric debris
- Group 3: homogeneous high signal fluid interspersed with fine intermediate signal (ALVAL/ALTR)
- Group 4: laminar appearance of synovium with surrounding high signal (infection)

Correlated to blinded assessment by pathologist using H & E and polarized light

**Results**
- 24 patients, 113 samples
  - 10 samples: excluded fibrin only
  - 6 samples excluded: osteolysis in Gruen zone III, V, VI (not covered by coil)
- Total 103 histological samples
- MRI Group 1 – no debris
  - 4 samples
- MRI Group 2A – intermediate debris (poly)
  - 58 samples
- MRI Group 2B – intermediate/low intermediate debris (metal + poly)
  - 24 samples
- MRI Group 3 – homogenous fine debris (metal)
  - 17 samples
- MRI Group 4
  - None detected on MRI or at histology

**Results – Group 1**
- Low SI pseudocapsule with no discernible debris
- 4 samples from capsule
- 100% concordance with histology (no particles)

**Results – Group 2A**
- Inhomogeneous intermediate signal debris interpreted on MRI as polymeric debris (polyethylene +/- PMMA)
  - 58 samples
    - 1 = no particles
Results – Group 2B
• Mixed low to intermediate signal debris interpreted as both metallic and polymeric (poly +/- PMMA) debris
• 24 samples
  – 2 = no particles
  – 3 = poly only
  – 18 = poly + metal (75% concordance)
  – 1 = metal only

Results – Group 3
• Homogeneous high signal fluid interspersed with fine intermediate signal (ALVAL/ALTR)
• 17 samples
  – 15 = no particles (88% concordance)
  – 2 = metal only

Discussion: MRI of wear-induced synovitis
• MRI can distinguish between tissue containing particulate (polymer +/- metal) and normal periprosthetic tissue without debris
• Pathology confirmed the absence of infection in all cases
• While sensitive for polymer debris, smaller amounts of metallic debris may go undetected by MRI
• Quantitative analysis of the relative amounts of polymer vs. metal is necessary
• Histology limited on current study by sampling error
• ALVAL/ALTR appears to elicit a specific synovial pattern on MRI
• Current study is ongoing and further evaluation is warranted

MRI of MOM surface replacement: Prospective Evaluation
AAOS 2010

Purpose
• To review patterns of osteolysis and synovitis in symptomatic individuals with MOM resurfacing implants and compare to a cohort of asymptomatic controls
• To compare established MRI protocol to prototype pulse sequence

Hypotheses
• Abnormal synovial patterns are present in both symptomatic and asymptomatic individuals and are detectable by MRI
• There will be a marked reduction in artifact with the prototype pulse sequence

Methods
• Patients referred to MRI due to non-specific pain unexplained by radiographs
• Scanning performed on 1.5 Tesla clinical scanner
• Body and surface coils used for imaging
• Scan parameters for morphologic evaluation (Potter et al, JBJS 2004)
  – TE = 26 ms
  – TR = 4033 ms
  – ETL = 18
  – Receiver bandwidth = ±100 kHz
  – NEX = 4-5
FOV = 22 cm x 22 cm
Acquisition Matrix = 512 x 352 (In plane: 420 μm x 625 μm)
Slice Thick = 4 mm/0 gap

All scan parameters optimized for minimizing susceptibility artifact

Results
- 43 hips in 39 patients enrolled to date
  - 21 men, 18 women
  - Age: 52 ± 10 y.
  - BMI: 26.1 ± 4.9 kg/m2 (20.8-36.7)
  - 31 symptomatic / 12 asymptomatic hips
- Time between arthroplasty & MRI: 2.1 ± 1.8 yr (0.1-9.0 y.)
- Osteolysis present in 5/31 symptomatic hips (16%)
  - Range: 0.2 – 54.9 cm3 (mean 2.3+/− 10.1cm3)
  - Gruen Zones: 1-3, 5, 6-9, 13, 14
  - All patients were symptomatic

Results
- Synovial expansion present in 28/43 hips (65%)
  - Mean: 22.91 ± 55.05 cm3
  - Range: 0–223.1 cm3
  - 20 symptomatic / 8 asymptomatic
- Subset of hips evaluated with HHS hip score had poor correlation with synovitis measurements (p=0.03)
- Synovitis did not correlate to BMI
- In symptomatic pts, synovitis did weakly correlate to blood Co (r=0.6, p=0.03) but not blood Ch

Discussion: MRI of MOM surface replacements
- MRI allows for imaging of metal-on-metal hip resurfacing implants using optimized scanning protocol
- Osteolysis and synovitis may be evaluated and tracked quantitatively using optimized scanning protocol
  - About half of those pts with synovitis had normal standard radiographic measurements (total anteversion with CT not assessed)
  - Osteolysis and femoral neck erosion occurred only in symptomatic individuals
- Synovial expansion (“pseudotumors”) occur with BOTH MOM and MOP constructs
- Newly developed MRI techniques further suppress metal artifact for MOM scans
- Further questions:
  - Does the preferential anterior neck erosion create a stress riser for fatigue fracture?
  - Lack of correlation between HHS hip score and presence of synovitis:
    • Later time points and larger recruitment may establish relationship
    • Clinically silent synovitis noted in control subjects

Early Reactive Synovitis and Osteolysis Following Total Hip Arthroplasty CORR 2010; 468(12):3278-85
- To use MRI to assess asymptomatic patients after total primary hip arthroplasty (OA)
  - Detect early wear induced synovitis
  - Understand its natural history
  - To compare in vivo rates of synovitis among different bearing surfaces

- Study group of 31 patients (33 hips) was subdivided based on type of bearing surface:
  - Metal on cross-linked polyethylene N=7
  - Ceramic on ceramic (Alumina) N=12
  - Ceramic on cross-linked polyethylene N=14

- Outcomes:
  - Subjective pain and function scores: Visual Analog Pain Scale (VAS); Patient Assessment Questionnaire (PAQ); WOMAC Index
  - MRI using a standardized technique at min. 12 month F/U (mean, 23 mo; range 12-37 mo)
Results

- Synovial expansion present in 13/33 (39%) of hips
  - Mean: 22.91 ± 55.05 cm³
  - Range: 0 – 223.1 cm³
  - Metal on poly had lower % (2/7; 29%) but higher mean volume of synovitis (1038 mm³)
  - Ceramic on poly had higher percentage (7/14; 50%) but lower mean volume (691 mm³)
  - Ceramic on ceramic: 4/12; 33%; mean volume 805 mm³

- Osteolysis in 1/33 (3%)
- Synovitis did not correlate to pain, activity level, patient satisfaction or clinical outcome scales
- Findings indicate that synovitis occurs in asymptomatic, highly functioning patients in all types of bearing surfaces

MRI in Total Knee Arthroplasty

- Component loosening and polyethylene wear
- Extensor mechanism
- Unstable arthroplasty: MCL, LCL, popliteus tendon
- Patellofemoral instability
- Fulminant infection: sinus tracks and soft tissue abscesses
- Juxta-articular soft tissue masses


(MR) Imaging of Arthroplasty

- MOST ACCURATE TEST TO DETECT WEAR INDUCED SYNOVITIS AND BONE LOSS
  - Serial evaluation of painful AND asymptomatic arthroplasty
  - MRI allows for detection of joint lining at the origin of adverse biologic reaction
  - Quantitative assessment of intracapsular synovial load and osteolysis
  - Qualitative assessment of patterns of bone loss
  - Detect compression of adjacent nerves and vessels
- Synovial expansion (“pseudotumors”) occur with BOTH MOM and MOP constructs
- NOT ALL SOFT TISSUE MASSES SURROUNDING ARTHROPLASTIES ARE WEAR-RELATED
- Caution to implicate wear-induced disease in the absence of expansion of the pseudocapsule
- MRI protocols available through potterh@hss.edu

References


