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 $\propto$ 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

- 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

- MRI more sensitive than x-ray *(JBJS 2004: 86A:1947-1954)*
  - 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:
  - 2 A: 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

  - 16 = poly only (28% concordance)
  - 34 = poly + metal
  - 7 = metal only

- 50 of 58 samples had poly debris (sensitive for PE)
- BUT: Metal was present in 41 of 58 samples that was not detected on MRI

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

Clin Orthop Rel Res 2003; 406:129-135

(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**

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