Imaging around metallic implants using MRI

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Metallic implants increasingly used in medicine

- Stents
- Fracture fixation
- Spinal fusion
- Joint reconstruction after tumor resection

Spinal Fusion Implant
Metallic implants increasingly used in medicine

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Spinal Fusion Implant
Total Knee Replacements

- Total knee replacements (TKRs) increasing in prevalence
  - In 2006: >540,000 primary TKRs and 39,000 revision TKRs
  - 2005 to 2030: Primary and revision total knee arthroplasty expected to grow 673%

Complications

- Infection
- Periprosthetic osteolysis
- Aseptic/mechanical loosening
- Wear of articular bearing surface
- Periprosthetic fracture

X-ray of osteolysis
Motivation

- MRI is the method of choice for examination of joints
- Evaluation of metallic implants is now limited to x-ray or CT scan with artifacts
- MRI is extremely limited around metal implants due to artifacts (signal loss and distortion)
- **Goal:** Enable the routine use of MRI around metal
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Displacement artifacts near metal. During excitation, a selection gradient causes a frequency variation (black arrows) but frequency shifts cause highlighted spins to be excited in the wrong slice. During imaging readout, the gradient induces a frequency variation, and the off-resonant spin appears to be at the wrong location. The displacements lead to bulk distortion, signal loss and pile-up effects.

Brian Hargreaves, Ph.D.
MR imaging of patients with hardware: Factors influencing visualization
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- Hardware
  - Alloy type
  - Susceptibility
MR imaging of patients with hardware: Factors influencing visualization

- Hardware
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- Geometry
  - Image matrix
  - Slice width
MR imaging of patients with hardware: Factors influencing visualization

- Hardware
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- Geometry
  - Image matrix
  - Slice width
- Scan technique
  - Pulse sequence selection
  - Receiver bandwidth
Artifact Depends on Alloy Type
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Bad Metals

- Cobalt chrome
  - Moderate artifacts
  - Older hips
  - Bipolar hips
  - Knees
Artifact Depends on Alloy Type

Bad Metals

- Cobalt chrome
  - Moderate artifacts
  - Older hips
  - Bipolar hips
  - Knees
- Stainless steel/Fe
  - Large artifacts
  - Plates, screws
Susceptibility Depends on Field Strength

Imaging at 0.3T. 52 year old man with history of osteonecrosis, prior core decompression left hip, right bipolar hip (Courtesy of Ken Buckwalter, MD).
Susceptibility Depends on Field Strength

- Lower magnetic field strength may have some advantages over higher field strength imaging
Susceptibility Depends on Field Strength

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• Worst scenario would be 3.0T
Susceptibility Depends on Field Strength

- Lower magnetic field strength may have some advantages over higher field strength imaging
- Worst scenario would be 3.0T
- New techniques may enable 3.0T Imaging around metal
Matrix and Slice
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- Increased resolution (matrix) in frequency direction reduces the pixel size and the conspicuousness of artifacts
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• Increased phase resolution does not affect artifact size
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- BUT...
Matrix and Slice

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- Increased phase resolution does not affect artifact size
- Decreased slice thickness reduces slice distortion
- BUT...
- Decreased slice thickness and increased matrix decrease SNR
Receiver Bandwidth

- Increased bandwidth decreases metal artifact
- Also decreases blurring and chemical shift
- BUT....
- Increased bandwidth results in lower SNR
Technique: MRI Sequences
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- Bad Sequences
  - Gradient echo
  - Chemical Fat Suppression (fat sat)
  - Spin echo
Technique: MRI Sequences

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Technique: MRI Sequences

• Bad Sequences
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  • Chemical Fat Suppression (fat sat)
  • Spin echo

• Good Sequences
  • Fast Spin Echo
  • STIR
  • IDEAL
  • SEMAC or MAVRIC
MRI Techniques - Inversion Recovery (STIR)

- Suppresses fat signal
- Good for metal
- Less SNR than T2 FS
- Useful as backup sequence to T2 FS
- Necessary at lower magnetic fields, e.g. 0.5 T
MRI Techniques - Inversion Recovery (STIR)

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Chemsat vs. IR

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Conventional Scan Technique Summary
Conventional Scan Technique Summary

- Metal friendly pulse sequence
  - FSE and FSE IR
    - Avoid fatsat
  - Longer echo train
    - 19-21
Conventional Scan Technique Summary

- Metal friendly pulse sequence
  - FSE and FSE IR
    - Avoid fatsat
  - Longer echo train
    - 19-21
- Wide bandwidth
  - Siemens: 700-800 Hz/pixel
    - nominally 150-200
  - GE: 64-128 kHz
    - nominally 16-20
Scan Technique Summary
Scan Technique Summary

- High matrix
  - f512 x p320
  - f320 x p256
Scan Technique Summary

- High matrix
- f512 x p320
- f320 x p256
- Thinner slices
Scan Technique Summary

- High matrix
  - f512 x p320
  - f320 x p256
- Thinner slices
- Frequency encode axis away from the ROI
What if you need IV Gd?
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• Fatsat T1 or SPGR will fail near the hardware
What if you need IV Gd?

- Fatsat T1 or SPGR will fail near the hardware
- STIR may suppress enhancement
What if you need IV Gd?

- Fatsat T1 or SPGR will fail near the hardware
- STIR may suppress enhancement
- Subtraction technique
  - Pre contrast T1 SE or FSE, no fatsat
  - Post contrast, same sequence
  - Subtract series
What if you need IV Gd?

- Fatsat T1 or SPGR will fail near the hardware
- STIR may suppress enhancement
- Subtraction technique
  - Pre contrast T1 SE or FSE, no fatsat
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- IDEAL
Dixon Imaging (IDEAL)

- Water and fat precess at different frequencies
- Acquire 3 images at different echo times (TE)
- Iterative Least-Squares Reconstruction*

Calculate Separate:

- Water Image
- Fat Image
- Recombined Image (with or without chemical shift correction giving in- or out of phase)

IDEAL Imaging in the spine

Radiograph

T1W IDEAL FSE
Brachial Plexus Imaging - NF1

Fat-Sat T1W

IDEAL FSE
Imaging around metal: IDEAL

Fat-Sat FSE

IDEAL FSE
Advanced Methods for MR Imaging around Metal
SEMAC: Slice Encoding for Metal Artifact Correction

Lu W, et al. ISMRM 2008, #838
SEMAC: Slice Encoding for Metal Artifact Correction

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3D Correction of Metal Artifacts
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Spin Echo

Stainless Steel screws cause both in-plane and through-plane artifacts
3D Correction of Metal Artifacts

Spin Echo

VAT Spin Echo

Stainless Steel screws cause both in-plane and through-plane artifacts

View-angle tilting (VAT) corrects in-plane artifacts (Cho, 1988)

W. Lu, B. Hargreaves

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3D Correction of Metal Artifacts

Spin Echo

VAT Spin Echo

3D Corrected (SEMAC)

Stainless Steel screws cause both **in-plane** and through-plane artifacts

View-angle tilting (VAT) corrects **in-plane** artifacts (*Cho, 1988*)

Slab Encoding for Metal Artifact Correction (SEMAC) **through-plane** artifacts (*Lu, 2008*)

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MAVRIC

- Collect multiple 3D FSE images at different T/R frequencies\(^1\):
  - *Multi-Acquisition Variable-Resonance Image Combination* (MAVRIC)\(^2\)
- Benefits:
  - No slice distortion
  - Maximum $\Delta B_0$ offset for any sub-image is ½ RF refocusing bandwidth:
    - ~1 pixel max distortion
- Challenge: Acquisition time


-2kHz Off-Res

+2kHz Off-Res

SEMAC and MAVRIC - TKR at 1.5T

FSE  MAVRIC  SEMAC

10 minute acquisition time for SEMAC and MAVRIC

16 cm FOV, 256 by 128, slice thickness = 3mm, gap 0
SEMAC: ETL = 8, TR 4000, TE Min Full, BW 125
MAVRIC ETL = 20, TR 2400, TE 20, BW 125
2X ARC for SEMAC and MAVRIC

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SEMAC vs MAVRIC

MAVRIC

SEMAC

VAT

2D FSE
SEMAC – Flexible Contrast
<table>
<thead>
<tr>
<th>Subject Population (number)</th>
<th>Imaging findings and change in management</th>
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<tbody>
<tr>
<td>Painful total knee (7)</td>
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<td>Cancer follow-up (3)</td>
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<td>Painful total hip (2)</td>
<td>Fluid detected; hip aspiration performed</td>
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<tr>
<td>Painful biceps repair</td>
<td>Failed biceps repair confirmed at surgery</td>
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<td>Pain after c-spine fusion</td>
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Clinical Experience

Subject Population (number)

Imaging findings and change in management

Painful total knee (7)
- Patella tendon tear confirmed at surgery (1);
- Epicondylar axis for alignment (7)

Cancer follow-up (3)
- Tumor on imaging; confirmed at surgery (1);
- Sent to biopsy (1);
- Stable for follow-up (1)

Painful total hip (2)
- Fluid detected; hip aspiration performed

Painful biceps repair
- Failed biceps repair confirmed at surgery

Pain after c-spine fusion
- No recurrent disc pathology
Chondrosarcoma recurrence

Limb-sparing resection performed

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Painful Total Knee Replacement

Patella Tendon Rupture (Surgery proven)
Infection?

Needle Aspiration

Localization of fluid for aspiration
Infection?

Localization of fluid for aspiration

Needle Aspiration
Painful Total Hip Replacement

Fluid collection near total hip aspirated

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Painful Total Hip Replacement

Fluid collection near total hip aspirated

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Imaging of Spinal Fusion

Painful spinal stenosis – surgically treated
Imaging of Spinal Fusion

Painful spinal stenosis – surgically treated

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Imaging of Spinal Fusion

Painful spinal stenosis – surgically treated
Hybrid Technique - 3.0T
Summary

- Orthopedic Hardware is increasingly common
- Several MR techniques exist to minimize metal artifact
  - Increase receiver bandwidth
  - Thin slices
  - FSE
  - IDEAL, SEMAC, MAVRIC
- Advanced MRI techniques for artifact reduction show promise to make imaging around these implants routine