CT and MR Imaging Around Metal Implants

Garry E. Gold, MD FASCBTMR
Professor of Radiology, Bioengineering and Orthopaedic Surgery
Stanford University
Financial relationships:
Research Support: GE Healthcare
Consultant: Olea Medical, Cotera Inc.
Outline

• Metallic Implants
• CT Imaging
• Conventional MRI Methods
• Advanced MRI Methods
• Clinical Examples
Take-Home Points

- Modifications in 2D FSE parameters can help routine imaging around metal
- IDEAL is useful for advanced imaging around metal
- MAVRIC SL enables imaging of total joint replacements
Outline

• Metallic Implants
• CT Imaging
• Conventional MRI Methods
• Advanced MRI Methods
• Clinical Examples
Metallic implants increasingly used in medicine

- Stents
- Fracture fixation
- Spinal fusion
- Joint reconstruction

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
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)
Outline

- Metallic Implants
- CT Imaging
- Conventional MRI Methods
- Advanced MRI Methods
- Clinical Examples
Metal Artifacts

- Amount of metal
- Orientation in gantry
- CT settings - kVp, mAs, kernel
- Alloy type
  - aluminum - titanium - steel - cobalt chrome increasing artifacts
Metal Artifacts - Tips

- Scan short-axis to hardware
- Use 140 kVp and high mAs
- Use thin sections and reformat
- Use standard or soft recon kernel
- Use extended dynamic range if available
Titanium Osteotomy Plate

0.5 - 1 mm sections, 140 kVp
MDCT of Total Joint Replacement

- Bone Stock Loss
- Loosening
- Particle Disease
- Infection
MDCT for THR Evaluation

- 2 - 3 mm slices at 1 mm intervals
- Pitch < 1
- 140 kVp
- Large focal spot
- Soft tissue filter
- 2 - 3 mm MPR’s
- mAs of up to 900

Scan and acquire data sets for both hips
Bilateral Hip Prostheses

Maximum mAs, 140 kVp
Femoral Nail - ? New Fracture

Maximum mAs, 140 kVp, 1.25 mm sections
Evaluate Osteotomy
5th MT Stress Fracture

Sagittal Reformation at Diagnosis
Scan 1: Foot flat

Scan 2: Toes up

...Re-fracture
CT may complement MRI

MR Arthrogram  CT Arthrogram
Outline

• Metallic Implants
• CT Imaging
• Conventional MRI Methods
• Advanced MRI Methods
• Clinical Examples
Metal in MRI

Displacement artifacts:
- Bulk Distortion
- Signal Loss (in slice)
- Signal Pile-up (through slice)
MRI of hardware: Factors influencing visualization

- Hardware
  - Alloy type (worst: cobalt chrome, stainless steel)
  - Susceptibility
- Geometry
  - Image matrix
  - Slice width
- Scan technique
  - Pulse sequence selection
  - Receiver bandwidth
Technique: 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).

- Lower magnetic field strength may have some advantages over higher field
Imaging around metal: IDEAL

Fat-Sat FSE  
IDEAL FSE

Conventional MRI Technique: Summary

- **Metal friendly pulse sequence**
  - FSE, FSE IR, IDEAL
    - Avoid Chemical Fat Suppression
  - Longer echo train: 19-21

- **Wide bandwidth**
  - Siemens: 700-800 Hz/pixel
  - GE: 64-128 kHz

- **High frequency matrix (512)**

- **Thinner slices**

- **Increase averages for SNR**
Outline

• Metallic Implants
• CT Imaging
• Conventional MRI Methods
• Advanced MRI Methods
• Clinical Examples
Multispectral MRI

Metal in the field causes extreme frequency shifts. Mutlispectral MRI attempts to correct by collecting data in the frequency direction as well as spatial directions.

Kevin Koch, Ph.D. Medical College Wisconsin and Brian Hargreaves, Ph.D, Stanford
Magnetic Resonance in Medicine, 2013
MAVRIC-SL

Hybrid of the SEMAC and MAVRIC Techniques that incorporates the best of both sequences

Brian Hargreaves, PhD and Kevin Koch, Ph.D
MAVRIC SL

- Designed for imaging soft tissue and bone near MR Conditional metal implants
- Reduces susceptibility artifacts
- Aids in the evaluation of complications from arthroplasty and other unrelated condition

- Designed to remove slice distortions and limit frequency-encoded distortions
- Several 3D FSE images acquired at multiple spectral offsets
- Spectral images combined to produce a single composite image

Courtesy of Hospital for Special Surgery, New York
Outline

• Metallic Implants
• Conventional MRI Methods
• IV Contrast
• Advanced MRI Methods
• Clinical Examples
Left: 2D FSE (0.7 x 1.0 mm, scan time: 6:08 min) images of a right MOM total hip arthroplasty. Right: MAVRIC SL of the same patient (1.3 x 1.6 mm, scan time: 5:37 min) demonstrates femoral osteolysis (arrow).
Hip Pain - 3.0T

FSE

MAVRIC-SL
Right: MAVRIC SL shows demarcation between necrotic and viable bone (arrow) as well as adverse local tissue reaction (note large fluid collection).

Courtesy of Hospital for Special Surgery, New York
Note asymmetric position of the femoral head seen on the MAVRIC SL image (right, arrow) due to polyethylene wear with extensive osteolysis (blue arrow).

MAVRIC SL in the Hip

Courtesy of Hospital for Special Surgery, New York
Metal on Metal Hip Implants
History of MoM Bearings

First generation MoM
- 1937 Wiles first THR
- 1950’s McKee and Watson-Farrar adopted MoM articulation
- Fell out of favor in mid 1970’s for low friction Metal on Polyethylene (MoP)

Second generation MoM
- Early 1990’s reintroduction of MoM bearings
- Rebirth of hip resurfacing to preserve bone stock
- Transition to larger head size to reduce dislocation risk
- Estimated that from 1996 to 2004 more than 250,000 MoM articulations were implanted worldwide (1)
- Based on review of Medicare data it is estimated there are ~750,000 patients with MoM bearings (Steven Kurtz PhD 2012 FDA Meeting of the Advisory Panel on MoM bearings)

Metal on Metal Hip Bearings

Total Hip Resurfacing

Total Hip Replacement
MoM 5-year revision rate of 8.8% was ~ 2x to 3x higher than alternative bearings

Review of 294,329 hip replacements between September 1999 and Dec, 2010
MoM 5-year revision rate of 6.2% was ~3x higher than alternative bearings
Failure Modes in Metal on Metal THR

• Most common modes
  • Dislocation
  • Aseptic loosening
  • Bursitis
  • Periprosthetic femoral fracture (resurfacing ~ 1-2%)
  • Wound dehiscence

• Novel failure mode: *Soft tissue necrosis*
  • Results vary substantially between implants
    • Zimmer Metasul: range 0 to 5% at 10 year
    • DePuy ASR: 6% to 18%
    • Estimated to be in the range of ~1% - 4% overall
Soft Tissue Necrosis associated with Metal on Metal hip bearings

Metallosis

Pseudotumor

Aseptic Lymphocytic Vasculitis-Associated Lesions (ALVAL)
Pathogenesis

- Particles released from MoM bearings are smaller (~50 nm) at a rate of \(10^{12}\) to \(10^{14}\) particles per year; \(~13,500\)x higher in number than those released from MoP bearings \(^1\)
- Tissue necrosis
  - Direct cytotoxicity of Cr(III), Co due to oxidative stress
  - Cell mediated hypersensitivity reaction (likely rare)

\(^1\) Keegan et al. JBJS Br (2007), 89:567-73
MRI in Metal on Metal Hips

- Primary modality for evaluation of local soft tissue damage
- High sensitivity for detection of soft tissue mass and fluid collection
- Requires modification of acquisition parameters to reduce metal artifact
55 year old female with MoM implant and groin pain

Adverse Reaction to Metallic Debris (ARMD)

Courtesy of Tim Mosher, MD
Adverse Reaction to Metallic Debris (ARMD)

High volume of synovitis
Thick irregular pseudocapsule wall with low signal intensity
Disruption of the pseudocapsule with periarticular fluid collection

Courtesy of Tim Mosher, MD
Metal-on-Metal Hip Implant:

MAVRIC SL demonstrates ALTR with markedly thickened synovial lining (arrow)

Courtesy of Hospital for Special Surgery, New York
Adverse Local Tissue Reaction

Improved visualization of the periacetabular osteolysis (red arrow), and proximal femoral osteolysis (blue arrow). Note the markedly thickened synovial response (yellow arrow), which is obscured on the 2D FSE image.
Hip Resurfacing (MoM) Fluid Collection

Simple fluid collection that communicates with joint. No evidence of substantial metal debris.
Thank You