Clinical Musculoskeletal MRI and Protocol Essentials

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Indiana University
Clarian Health Partners

Objective

To demonstrate how various MRI techniques can be optimized and combined to provide high quality images and yield clinically relevant diagnostic information.
Agenda

• List imaging goals for musculoskeletal MRI.
• Discuss the value of different pulse sequences.
• Review common problems and solutions in musculoskeletal MRI.
• Illustrate advanced imaging techniques.

Imaging Goals
Imaging goals for MSK (1)

• Document extent of disease
• Answer the clinical question
• Provide images to direct treatment

Imaging goals for MSK (2)

• Anatomic detail
  – Meniscus tear
• Bone marrow assessment
  – Metastatic disease
• Signal abnormalities
  – Cartilage damage
• Contrast enhancement
  – Abscess
Imaging goals for MSK (3)

• Magnet accreditation
  – American College Radiology (ACR) guidelines
    • FOV/slice thickness/sequence
    • Typically 2 sequences x 3 planes
      – Anatomy sequence
        » e.g. T1
      – Pathology sequence
        » e.g. STIR

Imaging Considerations

• Signal to noise
• Coils
• Chemical shift
• Bandwidth (receiver)
Signal to Noise Ratio

- SNR affects ability to perceive low contrast objects
- Structures can be obscured when images have low SNR
- More signal is better

How much signal is enough?

- SNR demonstration, next 4 slides
  - Low contrast text (“the signal”) present on ALL images
  - Identical spatial resolution for each image
  - Differing SNRs
    - 100% added noise
    - 40% added noise
    - 20% added noise
    - 0% noise
- We must exceed an SNR threshold to see the signal (text).
- Challenge: when can you read the text?
Journey to Preeminence

20% noise

0% noise
Signal to Noise Ratio

• SNR affects ability to perceive objects
• Size of the object plays a role
• Differing SNRs, images with different sized objects
  – 100% added noise
  – 40% added noise
  – 20% added noise
  – 0% noise

100% noise
What do we learn from this demonstration?

• Noise (SNR) affects our ability to perceive low contrast structures.
• High spatial resolution does not guarantee visibility.
• An SNR threshold must be reached to see the signal.
• The size of the object affects the ability to see the object at a given SNR.
SNR is a tradeoff...

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Coil Selection

- **signal \( \propto r^3 \)**
  - head (30 cm d)
  - knee (18 cm d)
Coil Positioning

inverse square law

\[
\frac{1}{d^2}
\]

Chemical Shift

- water and fat resonate at slightly different frequencies
- water:fat boundaries
  - water plus fat (white stripe)
  - water minus fat (black stripe)
Addressing Chemical Shift

- Swap phase and frequency encoding directions
- Get rid of the fat signal!
  - chemical saturation (fatsat)
  - STIR
- Increase receiver bandwidth

Bandwidth and Chemical Shift

<table>
<thead>
<tr>
<th>Tesla Larmour (mHz)</th>
<th>GE BW (+/- kHz)</th>
<th>Siemens BW [Hz/pixel]</th>
<th>Chemical Shift (Hz)</th>
<th>Chemical Shift (pixels, 256 resolution)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>13</td>
<td>45</td>
<td>1.15</td>
<td>0.57</td>
</tr>
<tr>
<td>0.7</td>
<td>30</td>
<td>105</td>
<td>2.68</td>
<td>1.34</td>
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<tr>
<td>1.5</td>
<td>64</td>
<td>224</td>
<td>5.73</td>
<td>2.87</td>
</tr>
<tr>
<td>3</td>
<td>128</td>
<td>448</td>
<td>11.47</td>
<td>5.73</td>
</tr>
</tbody>
</table>
What is the Receiver Bandwidth?

Importance of Bandwidth

*Narrow Setting*

- Better SNR,
  - $\text{SNR} \propto 1/\sqrt{\text{BW}}$
- Increased chemical shift artifact
  - Applicable to non fatsat images
  - Less chemical shift at lower fields
    - Chemical shift $\propto$ Tesla
      - $\sim$ twice chemical shift at 1.5T than 0.7T, 4X at 3.0T
    - Can use $\sim$ half BW setting at 0.7T than 1.5T
- Caveat: longer time to sample MR signal (echo)
  - Increased inter echo spacing
    - More blurring with FSE/TSE
Importance of Bandwidth

COR PD Fatsat, 1.5T
BW=780 Hz/pixel

COR PD Fatsat, 1.5T
BW=80 Hz/pixel

Protocol Considerations

• Adequate signal
  – SNR impacts our ability to differentiate similar relaxation tissues
  – SNR impacts our ability to see small, low contrast structures
• Reliability
• Speed
• Anatomic visualization
  – Spatial resolution
    • FOV, matrix, thickness
• Pathologic visualization
  – Fluid sensitive sequence (non contrast)
  – IV gado (fatsat T1 or subtraction T1 series)
### Sequence Use

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<th>Use</th>
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<td>Bone marrow, tumor staging</td>
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<tr>
<td>T1 fatsat</td>
<td>Post contrast imaging</td>
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<tr>
<td>PD</td>
<td>Anatomy</td>
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<td>PD fatsat</td>
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<td>T2 / T2 fatsat</td>
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T1 versus PD

• T1 SE shows bone marrow best
  – Most specific sequence for marrow imaging
    • Critical for osteomyelitis, stress fracture, tumor
  – Bone marrow may be isointense with marrow fat on PD, obscures pathology
• T1 shows anatomy well
  – But menisci and labral tissue may be artificially bright due to magic angle effect
  – PD is better than T1 for meniscus and tendon tissue

STIR

• More robust than “fatsat”
• Works reliably at all field strengths

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<th>Field Strength (T)</th>
<th>TI (msec)</th>
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<tr>
<td>1.5</td>
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<td>1.0</td>
<td>130</td>
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<td>110</td>
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<td>0.3</td>
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81 y/o f, right hip prosthesis

87 y/o m with shoulder pain
87 y/o m with shoulder pain

Extended Axial Survey

- For axial fat suppressed sequences (T2 or post-contrast T1), split the stack of slices into 2 sets and scan each separately
  - Some MR scanners will center the imaging volume in the isocenter of the magnet
  - Ensures more uniform fat suppression
- IR/STIR is more reliable for large FOV and off center FOV imaging
Homogeneous portion of field ~ 35 cms

Patient position for scan 1

Patient position for scan 2
Magnetic Susceptibility

• Dephasing (loss of signal) secondary to local magnetic field inhomogeneity
• Worst with gradient echo sequences
  – “blooming”
  – black trabecular bone
  – increased with longer TE times
  – increased with higher field strengths

Or, turn lemons into lemonade ....
Magnetic Susceptibility

Post-surgical change "blooming" artifact

Dark trabecular bone on gradient echo imaging

56 y/o F with left shoulder pain and lung cancer
56 y/o F with left shoulder pain and lung cancer

Black trabeculae, dephasing secondary to susceptibility.

Metastatic focus, destroyed trabeculae, increased specificity.
40 y/o man with right hip pain

coronal T1, 3.0T

coronal STIR, 3.0T

40 y/o man with right hip pain

coronal FLASH, 3.0T

axial T1, 3.0T

axial STIR, 3.0T
40 y/o man with right hip pain

PVNS

Hip Fracture, Question Pathologic

GRE 450/18/20
FSE IR 3050/42/150

susceptibility scan
Common problems

• Coverage
• Coil selection/positioning
• FOV
• Wrap
• Patient positioning
• Frequency and phase directions
Coverage

Os acromiale versus unfused acromial apophysis; cut off @ 22 years

Coil Positioning

Torso coil centered over pelvis
Coil Positioning

Flex coil centered over hip

Coil Positioning

ideal

actual
Good position of coil

13 yo with knee pain
13 yo with knee pain

Correct knee orientation
Correct knee orientation

MEDIAL OR LATERAL???
Positioning

54 year old man with shoulder pain

Positioning

54 year old man with shoulder pain
11/26/2009

Positioning

EXTERNAL ROTATION

INTERNAL ROTATION

But, the axials never lie...

Looks like a right shoulder...

60 year old man with painful range of motion
ABER positioned view
slices placed off coronal locator

Diagram for left side

humerus
glenoid
Scan plane

Encoding Axis Orientation

frequency, 256 points
Phase, 176 points
Frequency Axis Orientation

27 y/o asymptomatic female; TR/TE = 900/25,
16 FOV, 4 mm thick slice, 140 phase steps, 4 NEX

Advanced imaging
Blade (Siemens)  
Propeller (GE)

- Radial k-space sampling  
- Central portion of k-space is greatly oversampled  
  - Motion is averaged

23 year old man with shoulder pain

BLADE
23 year old man with shoulder pain

BLADE

CONVENTIONAL  RADIAL

ORTHOPEDIC HARDWARE
Why does metal cause artifacts at MRI?

• Metal alters the susceptibility of the local magnetic field
  – Susceptibility is the “magnetizability” of a tissue or material
• Metal distorts the local magnetic field

Why does metal cause artifacts at MRI?

• Eddy currents
  – Induced by the switching gradient fields and the RF
  – Result in the creation of a magnetic field within and around the metal
    • Causes additional distortion of the local magnetic field
Artifact Depends on Hardware Composition

**susceptibility of metals**

**Bad Metals**
- Stainless steel
  - Large artifacts
  - Plates, screws
- Cobalt chrome
  - Moderate artifacts
  - Older hips
  - Bipolar hips
  - Knees

**Good Metals**
- Titanium
  - Minimal artifacts
  - Newer hips
  - IM nails
- Oxidized Zirconium
  - Oxinium
  - Modest artifacts
  - Knees

**Metal and MRI Sequences**

**Bad Sequences**
- Gradient echo
- Fatsat anything
- (spin echo)

**Good Sequences**
- Fast spin echo (FSE)
- STIR (FSE IR)
Optimal Scanning

• Metal friendly pulse sequence
  – FSE and FSE IR
  – Longer echo train
    • 19-21

• Wide bandwidth
  – Siemens: 700-800 Hz/pixel
    • nominally 150-200
  – GE: 64-128 kHz
    • nominally 16-20

Optimal Scanning

• High matrix
  – f512 x p320
  – f320 x p256
• Frequency encode axis away from the ROI
• (Thinner slices)
Wide Bandwidth

- *Receiver* bandwidth
- Decreases the size of magnetic susceptibility artifacts
  - Each pixel contains more frequencies
    - Compresses the appearance of the artifact into fewer pixels
- Decreases the time to read out the echo 😊
  - Decreases the interecho spacing for FSE
- Reduces the SNR 😞

Effect of Bandwidth on Metal Artifact, SE T1
Porcine hindquarter, Cobalt-Chrome Prosthesis
Pooley RA, et al

Which is better?

80 Hz/pixel

150 Hz/pixel

300 Hz/pixel
51 y/o woman with synovial osteochondromatosis of the hip and subsequent total hip replacement

1/2006

51 y/o woman with synovial osteochondromatosis of the hip and subsequent total hip replacement

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51 y/o woman with synovial osteochondromatosis of the hip and subsequent total hip replacement.
What did we learn?

• Reviewed imaging goals for MSK MRI.
• Understand value of different pulse sequences.
• Elevate awareness of common MSK imaging problems.
• Detailed imaging parameters for patients with hardware.
END