Musculoskeletal MRI: Practical Protocols

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Learning Objectives

• Discuss general considerations in designing clinical MRI protocols
• Understand the role of contrast resolution in the context of imaging connective tissues
• Present clinical MRI protocols for MSK MRI at 3.0 T

What is a “Practical” MRI Protocol

• A practical protocol is not a perfect protocol
• The final product must satisfy many different customers with competing interests
• For every protocol there is a colleague with a better protocol

Organizational Guidelines

• Use detailed MRI requests and patient questionnaires to extract sufficient history
  – Mark site of tenderness/mass with fiducial marker
• Use targeted MRI protocols
  – Primary objective
  – Secondary objective
• Limit patient examination times to 45 minutes or less
• Always perform the most important sequence first
• Invest in education for technologists

General Approach for Designing Clinical MRI Protocols

1. Obtain sufficient signal to noise (SNR) to get the job done
2. Optimize contrast for the tissue that you are evaluating
3. Select image plane and resolution based on the anatomy that you are evaluating
4. Adjust acquisition parameters to minimize artifact
**Principle 1:** *Musculoskeletal MR imaging protocols are optimized for contrast resolution at the expense of imaging speed*

Commonly used sequences for MSK MR imaging
- Conventional spin echo
- Fast (Turbo) spin echo
- Gradient echo
Conventional Spin Echo

- Advantages
  - Excellent contrast
  - Experience
  - Validation studies
- Disadvantages
  - Long imaging times

3.0 T Proton density weighted spin echo

Fast (Turbo) Spin Echo

- Advantages
  - Efficient signal acquisition
  - Fast imaging times
  - Higher spatial resolution
  - Excellent contrast
- Disadvantages
  - Image blurring
  - Magnetization transfer
  - High SAR

1.5 T Turbo Spin Echo PD-weighted

Gradient Echo

- Advantages
  - Fast imaging times
  - 3D acquisitions are feasible
- Disadvantages
  - Moderate image contrast
  - Prone to artifact
    - Metal artifact

1.5 T Water Excited T1-weighted GRE
**Principle 2:** First optimize contrast based on tissue type, then adjust resolution based on anatomy

**Effect of collagen on tissue contrast**
- Efficient spin-spin (T2) relaxation
  - Tissue T2 is inversely related to collagen concentration
  - Tissue T1 is less dependent on collagen concentration
  - Anisotropic arrangement of collagen fibrils produces an orientation dependence of T2 (Magic angle effect)
- Magnetization transfer
  - Collagen is the dominant macromolecular component for magnetization transfer

**Sequence Selection for MSK MRI**

**Soft tissues**
- Muscle/Fat/Bone Marrow
  - T1 FSE
  - T2 FSE with fat suppression
  - STIR

**Connective Tissues**
- Menisci/Ligaments/Tendons
  - T1 SE
  - T1 or PD FSE
  - PD FSE with fat suppression
- Articular Cartilage
  - PD FSE with or without fat suppression
  - Fat suppressed T1 spoiled gradient echo

**MRI Contrast in MSK Imaging**

**Field Dependence of Relaxation Times**

**Principle 3:** In evaluation of connective tissue pathology tissue contrast will primarily be determined by:

*Pulse Sequence*

* Echo Time
How do tissue properties influence MRI contrast?

Effect of collagen on cartilage T2

T2 weighted MRI (7T) Cartilage T2 Map

Freeze Fracture

Inverse Correlation of Cartilage T2 and Polarized Light Microscopy

Polarized Light Microscopy

Cartilage T2 Mapping

T2: 10 100 ms

0 (min)

1 (max)

Polarized Light Microscopy

Orientation with B0

The Magic Angle Effect in evaluation of connective tissue

Orientation Dependence of T2

Collagen Fiber Orientation

B0 = m/r3 • (3cosθ-1)


Dependence of Cartilage T2 on Collagen Fibril Orientation

T2-weighted Image

B0

T2

54.7°

54.5°

Magic Angle

Magic Angle Effect: Tendons
Tailoring the MRI protocol for evaluation of connective tissues

- Most clinical MSK MRI requests are for evaluation of connective tissue pathology
- Primary indications
  - Shoulder: rotator cuff tear
  - Knee: meniscal tear
  - Ankle: tendon or ligament tear

MSK MRI protocol must be designed to accurately characterize connective tissue pathology, with the critical factor being identification of a surgical lesion (i.e. tear).

Effect of Connective Tissue Pathology on T2

<table>
<thead>
<tr>
<th>Normal Tendon</th>
<th>Tendon Degeneration</th>
<th>Tendon Tear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low concentration of mobile protons</td>
<td>Mobile proton pool, with high collagen concentration</td>
<td>Free Fluid</td>
</tr>
<tr>
<td>$T2 \approx 250 \mu s$</td>
<td>$T2 \approx 20 \text{ ms}$</td>
<td>$T2 \approx 100 \text{ ms}$</td>
</tr>
</tbody>
</table>

T2 changes with tendon pathology

Choice of TE in Evaluation of Tendons and Ligaments

Evaluation of the rotator cuff: Short TE Sequence
Principle 4: In evaluation of connective tissues two TE values are often needed:

- Short TE: high sensitivity, low specificity
- Long TE: low sensitivity, high specificity

Magnetization Transfer With FSE Pulse Sequences

Physics of Magnetization Transfer

Clinical Example: Effect of Magnetization Transfer on visualization of cartilage
Clinical Application of 3D T1-GRE Cartilage Imaging

1.5 T 3D Fat Suppressed T1-weighted GRE

1.5 T Water excited 3D T1-weighted GRE

3.0 T Wrist Imaging

3D Water Excited GRE

Fat Suppressed Proton Density TSE

Contrast versus resolution in visualization of superficial fibrillation

Fat-suppressed 3D FLASH
1mm, 512² matrix
0.1 mm³ voxel size

3D DESS
2 mm, 256² matrix
1.0 mm³ voxel size

Improved visualization of superficial cartilage lesion with FSE

Fat sat T1-weighted GRE

Fat sat Proton Density FSE

Tissue Contrast at the Articular Surface

Bulk Cartilage

Fibrillated Cartilage

Synovial Fluid

Surface Collagen

MT improves visualization of the articular surface of cartilage
Grade I: Blistering

MRI Findings: Focal elevation in Cartilage T2 with or without superficial fibrillation

Diagnostic impact of MT depends on tissue type and location

- Articular Cartilage: MT increases contrast
- Synovial Fluid: MT decreases contrast
- Bulk Cartilage: MT decreases contrast
- Meniscus: MT decreases contrast

Gradient Echo versus FSE

$T_1$-weighted GRE $T_1$-weighted FSE

Gradient Echo versus FSE

$T_1$-weighted GRE $T_1$-weighted FSE

Conventional SE versus FSE in evaluation of meniscal tear

- Conventional SE Sequence
  - TR: 2000 ms
  - TE: 20 ms
- TSE Sequence (ETL: 3)
  - TR: 2000 ms
  - TE: 12 ms

Why are meniscal tears less conspicuous on FSE?

- Magnetization Transfer decreases signal intensity of fluid within tear
- Blurring due to $T_2$ modulation of the point spread function
FSE Blurring

Fourier Transform

\[ T^2 \text{ modulation (filter)} \]

Fourier Transform

Tips to minimize FSE blurring

- Reduce the echo train length (< 6)
- Reduce the time interval between echoes (inter-echo spacing)
- Increase spatial resolution
- Less effect on FSE T2 weighted images than on short TE images

Dynamic Range

Use of fat suppression to increase dynamic range of tissue contrast

FSE Sagittal PD
Sagittal PD with fat suppression

28 Year old female with prior ACL repair and knee pain

TR/TE: 2000 ms/15 ms
TR/TE: 2000 ms/30 ms

Fat Suppression

Summary of tissue contrast considerations

- Signal intensity changes in connective tissues are dominated by T2 effects of collagen on water
- Magnetization transfer is a critical mechanism of contrast at tissue interfaces
- Short TE is needed to detect changes in the collagen matrix (tendon degeneration)
- Long TE is needed to characterize free fluid (diagnose tendon tear)
- Rapid T2 decay results in image blurring with fast (turbo) spin echo sequences
- Fat suppression is useful to increase dynamic range
Composing practical MRI MSK protocols

The Shoulder Protocol
- Primary indication: Rotator cuff evaluation
- Secondary indications
  - Instability
  - Labrum
  - Capsule
  - Cartilage
  - Muscles
  - Marrow
  - Periarticular soft tissues

Optimizing TE: The Shoulder MRI Protocol

<table>
<thead>
<tr>
<th>Sequence</th>
<th>TR (ms)</th>
<th>TE(eff) (ms)</th>
<th>ST (mm)</th>
<th>Matrix</th>
<th>FOV (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial FSE PD with FS (ET 6)</td>
<td>4000</td>
<td>30</td>
<td>3</td>
<td>512 x 512</td>
<td>18</td>
</tr>
<tr>
<td>Coronal Oblique FSE T1 (ET 3)</td>
<td>500</td>
<td>15</td>
<td>4</td>
<td>512 x 512</td>
<td>18</td>
</tr>
<tr>
<td>Coronal Oblique FSE T2 (ET 12)</td>
<td>4000</td>
<td>60</td>
<td>4</td>
<td>512 x 512</td>
<td>18</td>
</tr>
<tr>
<td>Sagittal Oblique FSE PD</td>
<td>4000</td>
<td>100</td>
<td>4</td>
<td>512 x 512</td>
<td>18</td>
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43 year old male with abduction weakness

The Knee Protocol
- Primary indication: detection and characterization of meniscal tear
- Secondary indications
  - Ligamentous injury
  - Osteochondral pathology
  - Soft tissue inflammation

3.0T Knee MRI Protocol

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<th>ST (mm)</th>
<th>Matrix</th>
<th>FOV (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat Sat Axial FSE PD with SE (ET 6)</td>
<td>4200</td>
<td>30</td>
<td>3</td>
<td>512 x 512</td>
<td>16</td>
</tr>
<tr>
<td>Sagittal FSE PD (ET 9)</td>
<td>2500</td>
<td>15</td>
<td>4</td>
<td>512 x 512</td>
<td>16</td>
</tr>
<tr>
<td>Sagittal FSE T2 (ET 6)</td>
<td>5500</td>
<td>45</td>
<td>4</td>
<td>512 x 512</td>
<td>16</td>
</tr>
<tr>
<td>Fat Sat Sagittal FSE PD (ET 5)</td>
<td>4200</td>
<td>30</td>
<td>4</td>
<td>512 x 512</td>
<td>18</td>
</tr>
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23 year old with post-traumatic ACL insufficiency

The Hip Protocol

- Primary indication: pain unresponsive to conservative management
  - AVN
  - Labral tear
  - Acetabular femoral impingement
  - Greater trochanteric bursitis

Problem: Need for large region of coverage with high spatial resolution

29 year old professional hockey player with chronic groin pain

3.0T Hip MRI Protocol

<table>
<thead>
<tr>
<th>Sequence</th>
<th>TR (ms)</th>
<th>TE (ms)</th>
<th>ST (mm)</th>
<th>Matrix</th>
<th>FOV (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coronal FSE T1 3</td>
<td>800</td>
<td>12</td>
<td>5</td>
<td>512 x 512</td>
<td>34</td>
</tr>
<tr>
<td>Coronal FSE T2 with FS T1 5</td>
<td>5500</td>
<td>80</td>
<td>5</td>
<td>1024 x 1024</td>
<td>34</td>
</tr>
<tr>
<td>Coronal and sagittal PD T1 5</td>
<td>2000</td>
<td>30</td>
<td>3</td>
<td>512 x 512</td>
<td>16</td>
</tr>
<tr>
<td>Coronal PD with fat sat T2 18</td>
<td>2200</td>
<td>40</td>
<td>3</td>
<td>512 x 512</td>
<td>16</td>
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Phased array body coil both hips  Paired surface coil symptomatic hip

55 year-old female with left hip and buttock pain with exercise, suspect pyriformis syndrome

3.0 T Hip MRI

Coronal PD  Coronal PD with fat suppression
24 year old female soccer player with chronic hip pain

MR Arthrogram requested for suspected labral tear

Take Home Points

- Trade-off of contrast, resolution, and speed
  - MSK protocols optimized for contrast resolution
- Optimize contrast first then adjust anatomy
  - Contrast is tailored for the tissue type
  - Resolution is tailored for the anatomy
- Connective tissue contrast is strongly influenced by collagen
  - Short T2
  - Magnetization transfer
  - Orientation dependence of signal intensity
- Dynamic range is set by fat, use of fat suppression allows shorter TE’s to be used to obtain fluid sensitive sequences