MRI Applications in Spine

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Who is this for?

I assume that you know the basics of MRI physics, but **do not know much about MRI clinical applications**.

Caveat:
This is mostly generic advice.
Consult vendor Apps for vendor-specific options.
Learning Objectives

1. To be able to list and discuss basic features of several common indications for spine MRI;
2. To be able to list and discuss the most common clinical MRI techniques used for the spine;
3. To be able to list and discuss the key image quality and MR safety issues for MRI of the spine
References

• Good place to get started with MRI clinical applications basics: https://www.acr.org/Clinical-Resources/Practice-Parameters-and-Technical-Standards/Practice-Parameters-by-Modality
Spine Anatomy

Typical # of vertebrae

- Cervical (C-spine): 7
- Thoracic (T-spine): 12
- Lumbar (L-spine): 5

- Spinal cord at C-spine & T-spine
- Below the conus are nerve roots, the Cauda Equina (Latin for “horse’s tail”)

Figure courtesy cancer.gov.
Indications for Spine MRI

MRI is the only modality for evaluation of internal structure of the cord*

- Congenital spine and spinal cord malformations
- Inflammatory/autoimmune disorders (e.g. MS, lupus, muscular dystrophies)
- Infectious conditions
- Vascular disorders (vascular malformations, cord infarctions)
- Degenerative conditions (disc degeneration, disc herniation, spinal stenosis)
- Trauma
- Neoplastic abnormalities
- Miscellaneous (CSF leak, amyloid deposition)

*From ACR-ASNR-SCBT-MR-SSR Practice Parameter for the Performance of Magnetic Resonance Imaging (MRI) of the Adult Spine
Spine Coils

• CTL (older)

• Cervical

• Thoracic and Lumbar
Spine Coils Within the Bed

Newer spine coils for thoracic and lumbar, are embedded within the bed:

This removes need for swapping coils but may increase distance to patient (thus decreasing SNR).
Spine Coil Elements and Parallel Imaging

Note: # of coil elements in R/L and F/H direction:
- Establishes limits on parallel imaging acceleration factors (i.e. SENSE/iPAT)
- No SENSE/iPAT acceleration in A/P direction
Other Acceleration Methods

Other caveats:

• Simultaneous Multi-Slice (SMS)
  • Best used for axial stacks with a lot of slices

• Compressed Sensing
  • Vendor may have pulse sequence limitation (e.g. only 3D TSE)
Pulse Sequences for MRI

• Mainly turbo spin echo (TSE) scans
  • AKA fast spin echo
  • Relatively fast and resistant to susceptibility artifacts, BUT
  • Higher SAR (and patient heating, esp. for T1W)
MRI Sequences (at WashU)

CERVICAL SPINE
- Scout (TSE)
- Sag T1 TSE
- Sag T2 TSE
- Sag T2 TSE FS – (possibly STIR)
  - for marrow replacement processes (mets), facet inflammation, cord signal abnormalities
- Ax T2 MEDIC (near metal: TSE)
  CONTRAST injection - for myelopathic symptoms or Hx of malignancy

PRE

POST
- SAG T1 TSE DIXON
- AX T1 VIBE FS
THORACIC and LUMBAR SPINE

- Scout (TSE)
- Sag T1 TSE
- Sag T2 TSE
- Sag T2 TSE FS – (possibly STIR)
  - for marrow replacement processes (mets), facet inflammation, cord signal abnormalities
- Ax T2 TSE

CONTRAST injection - for myelopathic symptoms or Hx of malignancy

PRE

POST

- SAG T1 TSE DIXON
- AX T1 VIBE FS
Scan Planning for Spine MRI

• Sagittal Coverage
  • Scoliosis may require more slices and increased scan duration

• Axial Orientation
  • Cord pathology: axials perpendicular to cord
  • Disc pathology: axials parallel to each disc
  So, multiple stacks may be needed.

• Single-Stack (e.g. tumor) vs. Multi-Stack (e.g. disc disease, curved spine)

• Selective axials to save time
MERGE / MEDIC / mFFE

- Axial 2D multi-echo gradient echo
- Used for cord pathology in C-spine
- Healthy cord has “butterfly” appearance; great contrast
- Later echoes may be degraded by motion, susceptibility, or low SNR
  - Consider dropping them from the echo averaging

3-5 echoes are used
We use 3 at WashU.
Spine Diffusion

- Traditional DW-EPI will produce “sawtooth” geometric distortion
- Read-out segmented EPI (RESOLVE) can reduce this:

For spine DTI:
RF Shading Artifacts

- Common in torso/abdomen at 3T
- RF wavelength ~1/10 that in air
- Standing waves cause shading
- In spine: worst near T/L Junction

Mitigation:
- Avoid 3T
- Use “multi-transmit RF shimming”
Motion Artifacts

• Motion artifacts due to cardiac motion, swallowing, respiration

• “Sat Bands”
  • Suppresses tissue signal anterior to vertebrae, BUT
  • Often not needed and adds significantly to SAR

• Consider other options
  • Motion resistant scans (e.g. Propeller)
  • Reduced echo spacing
Flow Artifacts

• CSF flow along spine
  • Younger patients have faster flow
  • T2W: flow voids
  • Use flow compensation
    • May need to specify direction (slice or readout)
  • Vendor-specific approaches
    • PSS (Pseudo-Steady State) scans reduce this

• Post-Gad
  • Consider 3D T1W (e.g. VIBE)
**Metal Artifacts**

Reduce metal artifacts by:

- **Use large bandwidth**
  - commonly >1000Hz/pixel

- **Use strong imaging gradients**
  - Some vendors lump this into a “MARS” mode
  - Otherwise try thin slices and large matrix w/ same FOV

- **Use View Angle Tilting (VAT) w/ SEMAC or MAVRIC**

- **For Fat Sat:** STIR (most robust, but only for pre-Gd) or Dixon

![Comparison of MR images with different techniques](image)

<table>
<thead>
<tr>
<th>Technique</th>
<th>Time</th>
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<tbody>
<tr>
<td>Traditional</td>
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<tr>
<td>MARS + VAT</td>
<td>3.37 min</td>
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<tr>
<td>SEMAC + VAT</td>
<td>5.48 min</td>
</tr>
</tbody>
</table>

*Courtesy: Hennepin County Medical Center*
3D Turbo Spin Echo

- Good for disc pathology
- Poor cord contrast

2D T2W TSE

3D T2W TSE
Spinal Cord Stimulators

Scan requirements vary by vendor.

Generally:
- Put external remote in MR Safe Mode
- Check scanning requirements including:
  - Static Magnetic Field
  - SAR or $B_{1+}^{\text{rms}}$

Example:
- Abbott spinal cord stimulator w/ Penta leads:
  - 1.5T only
  - whole body SAR no more than 0.1 W/kg (!)
Low SAR Spine Protocols

- **How to reduce SAR or B1+rms:**
  - Use low SAR pulses
  - Reduce flip angle for refocusing pulses
  - Get rid of sat bands
  - Increase TR (but not too much for T1W scans)
  - Increase # of concatenations (Siemens) or stacks (Philips)

- Abbott document has low SAR brain and spine (Siemens) protocols
  - Contact melissa.ham@abbott.com for a copy
### Table 3: Comparison of Scan Parameters for Cervical Spine Protocols (Male, 72 kg/159 lb)

<table>
<thead>
<tr>
<th>Scan Parameters</th>
<th>Localizer</th>
<th>T2 Weighted Turbo Spin Echo (TSE) - Sagittal</th>
<th>T2 Weighted TSE with Short Tau Inversion Recovery (STIR) - Sagittal</th>
<th>T2 Weighted TSE - Transverse</th>
<th>T2 Multi-Echo 2-D Transverse</th>
<th>T1 Weighted TSE - Sagittal</th>
<th>TI Weighted TSE with Dark Fluid Technique - Sagittal</th>
<th>3-D T2 Weighted CISS - Transverse</th>
<th>WB-SAR ≤ 0.8 W/kg</th>
<th>WB-SAR ≤ 1.0 W/kg</th>
<th>WB-SAR ≤ 1.0 W/kg</th>
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<td>Low RF</td>
<td>Normal</td>
<td>Normal</td>
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<td>0.33</td>
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<td>0.33</td>
<td>0.33</td>
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</tbody>
</table>

*Note: Values may vary based on scanner and factors not listed in this table.

**Abbott Low SAR C-Spine**
# Table 4: Comparison of Scan Parameters for Thoracic Spine Protocols

| LOCALIZER                | T1 WEIGHTED TSE | T2 WEIGHTED TSE WITH 3.2 T-SPACE | T3 WEIGHTED TSE WITH 3.2 T-SPACE | T4 WEIGHTED TSE WITH 3.2 T-SPACE | T5 WEIGHTED TSE | T6 WEIGHTED TSE WITH 3.2 T-SPACE | T7 WEIGHTED TSE | T8 WEIGHTED TSE WITH 3.2 T-SPACE | T9 WEIGHTED TSE | T10 WEIGHTED TSE WITH 3.2 T-SPACE | T11 WEIGHTED TSE | T12 WEIGHTED TSE WITH 3.2 T-SPACE | T13 WEIGHTED TSE | T14 WEIGHTED TSE WITH 3.2 T-SPACE | T15 WEIGHTED TSE | T16 WEIGHTED TSE WITH 3.2 T-SPACE | T17 WEIGHTED TSE | T18 WEIGHTED TSE WITH 3.2 T-SPACE | T19 WEIGHTED TSE | T20 WEIGHTED TSE WITH 3.2 T-SPACE |
|--------------------------|-----------------|----------------------------------|-----------------------------------|-----------------------------------|-----------------|-----------------------------------|----------------|-----------------------------------|----------------|-----------------------------------|----------------|-----------------------------------|----------------|-----------------------------------|----------------|-----------------------------------|----------------|-----------------------------------|----------------|-----------------------------------|----------------|-----------------------------------|
| Scan Parameters          | LOCALIZER       | T1 WEIGHTED TSE | T2 WEIGHTED TSE | T3 WEIGHTED TSE | T4 WEIGHTED TSE | T5 WEIGHTED TSE | T6 WEIGHTED TSE | T7 WEIGHTED TSE | T8 WEIGHTED TSE | T9 WEIGHTED TSE | T10 WEIGHTED TSE | T11 WEIGHTED TSE | T12 WEIGHTED TSE | T13 WEIGHTED TSE | T14 WEIGHTED TSE | T15 WEIGHTED TSE | T16 WEIGHTED TSE | T17 WEIGHTED TSE | T18 WEIGHTED TSE | T19 WEIGHTED TSE | T20 WEIGHTED TSE |
|                          | T1               | T2                 | T3                 | T4                 | T5                 | T6                 | T7                 | T8                 | T9                 | T10                | T11                | T12                | T13                | T14                | T15                | T16                | T17                | T18                | T19                | T20                |
| **X, y, z, cm**          |                  |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |
|                          |                  |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |
| **Slice Number**         |                  |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |
|                          |                  |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |
| **Slice Thickness**      |                  |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |
|                          |                  |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |
| **Number of Average**    | 1                | 2                  | 2                  | 2                  | 2                  | 2                  | 2                  | 2                  | 2                  | 2                  | 2                  | 2                  | 2                  | 2                  | 2                  | 2                  | 2                  | 2                  | 2                  | 2                  | 2                  | 2                  | 2                  | 2                  | 2                  |
| **Acquisition Time**     |                  |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |
| **Scanning Time**        |                  |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |
| **Note**                 |                  |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |

5: Acquisition time may vary based on scan parameters and factors not listed in this table.

Note: All scan parameter names are standard and universally accepted.

Abbott Low SAR T-Spine
### Table 5. Comparison of Scan Parameters for Lumbar Spine Protocols (Male, 81 kg/179 lb)

<table>
<thead>
<tr>
<th>Scan Parameters</th>
<th>{(R_{\text{RMS,IR}})}</th>
<th>Slices</th>
<th>Flip Angle, degree</th>
<th>TE, ms</th>
<th>TR, ms</th>
<th>Number of Averages</th>
<th>Concatenations</th>
<th>S/N no.</th>
<th>GRAPPA</th>
<th>PFT</th>
<th>Factor PE</th>
<th>Turbofactor NA</th>
<th>RF power</th>
<th>Acquire in Two Parts</th>
<th>Acquisitions Time, min</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>T2 Weighted TSE</strong></td>
<td><strong>SAGITAL</strong></td>
<td><strong>TRANSVERSE</strong></td>
<td><strong>SAGITAL</strong></td>
<td><strong>TRANSVERSE</strong></td>
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<td><strong>TRANSVERSE</strong></td>
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<td><strong>SAGITAL</strong></td>
<td><strong>TRANSVERSE</strong></td>
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<td><strong>LOCALIZER</strong></td>
<td>STANDARD PROTOCOL</td>
<td>WBSAR ≤ 0.6 W/kg</td>
<td>WBSAR ≤ 0.1 W/kg</td>
<td>STANDARD PROTOCOL</td>
<td>WBSAR ≤ 0.6 W/kg</td>
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<td>STANDARD PROTOCOL</td>
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<td><strong>R_{\text{RMS,IR}}</strong> (µT)</td>
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<td>2.8</td>
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<td>0.9</td>
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<td>2.0</td>
<td>1.0</td>
<td>3.0</td>
<td>2.2</td>
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<td><strong>Slices</strong></td>
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<td>15</td>
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<td>18</td>
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<td>8</td>
<td>20</td>
<td>20</td>
<td>10</td>
<td>6/8 in, 6/9 slice groups</td>
<td>6/3 in 9 slice groups</td>
<td>2/3, 1 in 3 slice groups</td>
<td>3/3 in 3 slice groups</td>
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* - Acquisition time may vary based on scan parameters and factors not listed in this table.

Note: Estimation of scanner-reported SAR values requires accurate patient weight and scan parameters. The SAR values may vary from patient to patient and further modifications may be needed to reduce SAR.
Acknowledgements

Dave Hitt, RT
Joyce Spilker, RT
Allen Elster, MD

Thank You!
Multiple Stack Artifact

**Cause:** Slice overlap from different stacks

**How to avoid:** Scanning each stack sequentially rather than interleaved