MRI Techniques for Neuro and MSK Imaging

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Declaration of Conflict of Interest or Relationship

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Typical Neuro Protocols

**Routine Brain**
- LOC 3PL
- SAG T1 SE
- SAG T2 FLAIR
- AX T2 FLAIR
- AX T1 SE
- AX T2 TSE FS +C
- AX DW EPI +C
- AX T1 3D IRSPGR +C
- COR T1 SE FS +C
- SAG T1 SE +C OPT
- AX T1 SE +C OPT

**Routine Spine**
- LOC 3PL
- SAG COR LOC
- SAG T1 TSE
- SAG STIR
- AX T1 TSE
- SAG T2 TSE +C (3D)
- Sag T1 TSE FS +C
- AX T1 TSE +C
Typical Ortho Protocols

**Routine Knee**
- AX LOC
- SAG COR LOC
- AX T2 TSE FS
- AX GRE
- SAG PD TSE
- SAG T2 TSE
- COR PD TSE
- COR STIR
- OCOR T2 ACL
- OSAG T2 ACL

**Routine Shoulder**
- AX LOC
- SAG COR LOC
- AX PD TSE FS
- AX GRE
- COR PD TSE
- SAG PD TSE
- COR MOD IR
- SAG T2 TSE FS
- SAG T2 TSE
- COR T2 TSE

Outlines

- Conventional Spin Echo (CSE)
- Fast Spin Echo (FSE / TSE)
  - 2D and 3D Fast Spin Echo (SPACE, CUBE)
  - Single Shot Fast Spin echo (SSFSE, HASTE)
- Multi Contrast Spin Echo (T2 Mapping)
- Inversion Recovery (IR)
  - FLAIR
  - T1-FLAIR
  - IR-FSE
  - IR-SPGR / MP-RAGE
  - Phase Sensitive Recon

The Structure of MR Pulse Sequences

- **Magnetization Preparation Section**
  - Chemical Shift Selective Saturation / Excitation
  - Spatial Selective Saturation
  - Magnetisation Transfer (MT), CHESS water suppression
  - Inversion Recovery (IR)

- **Data Acquisition Section**
  - Slice/Slab Selective Excitation
  - Phase Encodings(s)
  - Signal Generation
    - Spin Echo (SE), Fast SE (FSE/TSE), Single-shot FSE (SSFSE/HASTE)
    - Gradient Recalled Echo (GRE), Single-shot GRE (EPI)
    - Diffusion Weighting (DWI/DTI) and Gradient Moment Nulling (GMN)
  - Frequency Encoding
  - Filling of K-space

- **Magnetization Recovery Section**
  - Spoiling
  - Driven Equilibrium
**Conventional Spin Echo**

- **Excitation**
- **Refocusing**
- **Phase Encoding**
- **Frequency Encoding**
- **TE/2**
- **TR**
- **Next Excitation**

**Criteria**
- rBW
- Min. FOV
- Chem. Shift
- Distortion
- SNR

**Signal and Contrast of CSE**

- Long TE / Greater T2 contrast
- Max. signal when:
  - Excitation = 90°
  - Refocusing = 180°

- When TR>>TE:
  \[ S = M_x (1 - e^{-TR}) e^{-TE/T2} \]

**More Efficient Use of MR Signal**

- **B_1** / \( M_y \)
- **TE** = 10 – 200 ms
- **TR** = 400 – 4000 ms
Fast Spin Echo and CPMG Condition

1. Refocusing RF pulses are 90 deg out of phase with respect to excitation RF pulse.
2. Identical spacing between refocusing RF pulses.
3. Identical phase accumulation between refocusing RF pulses.

Fast/Turbo Spin Echo Train

Available TE_{eff} in FSE/TSE

Echo Train Length = ? & Echo Spacing = ?
RARE, FSE/TSE Sequence

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FSE/TSE Artifact

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T2 Blurring and Edge Ringing

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FSE/TSE versus CSE

MT Effect  Bright Fat  Contrast Difference

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PD  T2

CSE  FSE  CSE  FSE

T1 SE vs TSE of Hip Joint

rBW = 485Hz/pix, ETL=1  rBW = 485Hz/pix, ETL=5

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Bright Fat with due to J-coupling

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CSE and TSE of Knee

Driven Equilibrium (Fast Recovery, Restore)

- Add $180^\circ_y + 90^\circ_x$ RF pulses to refocus and flip the $M_y$ back to Z axis.
- Allow shorter TR (~2000ms) while maintaining T2w or PDw.

Restore Example
3D FSE, SPACE, CUBE

Sampling
Perfection with
Application optimized
Contrast using different flip angle
Evolution

3D FSE/TSE w. variable refocusing flip angle schedules:
• Constant: same as 3D TSE
• PD Variant: optimized for short TE
• T2 Variant: optimized for longer TE

Constant Refocusing Flip Angles

T2 Var. Refocusing Flip Angles
Variations of 3D SPACE

T1 SPACE
1 x 1 x 3 mm³

FLAIR SPACE
1 x 1 x 3 mm³

T2 SPACE
1 x 1 x 3 mm³

Isotropic Hires T2 SPC of Brain

3D SPACE, GRAPPA 2, 0.9 x 0.9 x 0.9 mm³; 4:27 min

3D FLAIR SPACE of Brain
3D T2 SPACE of IAC
3D SPACE with 0.3 mm isotropic resolution in 6 min

3D T2 SPACE of Spine

Reducing Susceptibility Artifact w. SPACE
2D TSE T2 MPR of 3D SPACE T2
3D SPACE of Pelvis

AX MPR of 3D Cor PD/T2 of Hip

3D T1 FSE of Brain @ 3T
3D T1 FSE of Pelvis @ 1.5T

TR = 700ms
TR = 553ms

3D SPACE Features

• Offers 3D imaging with isotropic resolution.
• Can be reformatted to other planes or thicker 2D to improve SNR.
• Useful when multiple 2D of same contrast but different orientations are desired.
• Produces better image quality for PD and T2 than T1.
• Reduces SAR @ 3T.
• Helps minimize artifact from susceptibility.

Multi Contrast Spin Echo

\[ M_c(TE) = M_0 \exp(-TE/T_2) \]
Variations of IR Technique

Inversion Options:
- Non-selective
- Slice-selective
- Spectral selective
- Adiabatic
- Flow-induced Adiabatic
- Combination of multiple inversions

Acquisition Options:
- Unlimited (TSE and TFL are common)
- 2D and 3D
- View ordering and correction of k-space modulation can be important.

Applications of IR

- Selectively suppress tissue / background signal based on $T_1$ differences
  - STIR, SPIR, SPAIR
  - FLAIR
- Improve $T_1$ contrast (Phase Sensitive Recon)
  - MP-RAGE, IR-SPGR, IR-TFE
  - T1FLAIR
  - T1IR
- $T_1$ Measurement / $T_1$ Mapping
- Tagging / Labeling
  - Arterial Spin Labeling (ASL)

$T_1$ of Various Tissue Types

<table>
<thead>
<tr>
<th>Tissue</th>
<th>$T_1 @ 1.5T$ (msec)</th>
<th>$T_1 @ 3.0T$ (msec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSF</td>
<td>4400</td>
<td>4500</td>
</tr>
<tr>
<td>WM</td>
<td>780</td>
<td>850</td>
</tr>
<tr>
<td>GM</td>
<td>920</td>
<td>1330</td>
</tr>
<tr>
<td>Blood</td>
<td>1200</td>
<td>1500</td>
</tr>
<tr>
<td>Muscle</td>
<td>870</td>
<td>1160</td>
</tr>
<tr>
<td>Fat</td>
<td>220</td>
<td>260</td>
</tr>
</tbody>
</table>

$T_{1\text{null}} = 0.69 \times T_1$
**STIR, FLAIR, TI and TINull**

**STIR**: Short Tau Inversion Recovery, TRIM

**FLAIR**: FLuid Attenuated Inversion Recovery, “Dark Fluid”

Signal

Fat signal

Fluid signal

Inversion RF Pulse

TI\(_{null}(Fat)\)

TI\(_{null}(Water)\)

**Interleave of Inversion & Acquisition**

**FLAIR Optimization**

TI\(_=2250 \text{ms}\)

TI\(_=2500 \text{ms}\)

TI\(_=2700 \text{ms}\)
From FLAIR to T1FLAIR

- Axial T1 FLAIR @ 3T with TR/TE/TI/ETL = 2100/9.5/900/3
- Improves T1 contrast at 3.0T
- High SAR limits number of slices and coverage

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T1-weighted FLuid-Attenuated Inversion Recovery (T1FLAIR)

- Use shorter TR and TI than FLAIR (Modified FLAIR)
- Suppress CSF and provides good T1 contrast

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T1 FLAIR of Spine
Faster HR → Shorter RR → Less Recovery → Shorter TI

Adjust TI according to TR

Lock TI and TR for Tissue Suppression

Double IR for Brain

Dark Fluid

Dark Fluid & Dark WM
Better Lesion Detection with DIR

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Wattjes MP et al AJNR 2007 28(1):54

MP-RAGE, IR-SPGR

Either with Inversion Recovery or Saturation Recovery

MP-RAGE versus MP-EFGRE @ 3.0T

MP-RAGE 9:14
MP-EFGRE 6:30
T1-weighted Imaging for Brain @ 3.0T

2D SE 60  3D T1 FLAIR  2D FLASH  3D FLASH  3D MPRAGE

IQ=4  IQ=6  IQ=4  IQ=5  IQ=5

IQ: The median perceived overall image quality

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IR with Phase Sensitive (PS) Recon

Signal  Blood  Myocardium

Inversion  Time

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True IR (Real IR) for Brain

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Phase Sensitive Reconstruction

- An image reconstruction option, no additional scan time
- Improve contrast
- May produce artifact.

Ask for both magnitude recon and PS recon images.
Summary

• Main characteristics of spin echo pulse sequence.
• Variations of spin echo pulse sequence and their applications for Neuro and Ortho imaging.
• Key issues for optimizing spin echo based techniques.

Thank You!

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