How to Get Rid of Fat – Comparison of Fat Suppression Techniques in Clinical MRI

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Declaration of Conflict of Interest or Relationship

Research support from Siemens Healthcare

18 YO male with low back pain - Fibrous dysplasia

Courtesy of Dr. Boaz Karmazyn
15 yo w/ hip pain and decreased ROM

Normal bone marrow
Leukemia

Courtesy of Dr. Boaz Karmazyn

Fat Saturation

T1w
T1w + FS

Chemical Shift Artifact

rBW = 125Hz
rBW = 490Hz
Artifacts in EPI

- N/2 Ghosting
- Chemical shift
- Distortion (Expansion)

More severe at higher field strength 😊

Fat Suppression Options

- Based on chemical shift difference (Freq. Selective)
  - Conventional FatSat (FS) or ChemSat (CS)
  - Composite RF pulse (ProSat, WE, SpSp, CHESS, etc.)
  - In-phase / Op-phase and DIXON/IDEAL
- Based on T1 relaxation difference
  - STIR
- Hybrid
  - SPIR and SPAIR
- Based on spatial distribution (Spatial sat. band)
- Subtraction (For dynamic imaging)

MRI Properties of Fat

- Chemical Shift:
  
<table>
<thead>
<tr>
<th>Field Strength</th>
<th>F/W Separation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5T</td>
<td>220 Hz</td>
</tr>
<tr>
<td>3.0T</td>
<td>440 Hz</td>
</tr>
</tbody>
</table>

- T1 and T2 relaxation time:
  
<table>
<thead>
<tr>
<th>Field Strength</th>
<th>T1 Relaxation Time</th>
<th>T2 Relaxation Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5T</td>
<td>220 ms</td>
<td>80 ms</td>
</tr>
<tr>
<td>3.0T</td>
<td>260 ms</td>
<td>120 ms</td>
</tr>
</tbody>
</table>

- J-coupling
Chemical Shift Selective Saturation

- **Spectrally selective excitation** (Narrow BW excitation with no gradient applied) + spoiling.
- Suppress signal within certain **resonance frequency range**, i.e. fat.

Shoulder w/o & w. Fat Suppression

- PD
- PD + Fat Sat

Strong versus Weak FatSat for Ortho

- Optimized Flip Angle
- Fixed Flip Angle
Quick FatSat for Breast Imaging

- Interleaved, 1/40 k-space lines.
- Use Quick FatSat to maintain temporal resolution.

Inhomogeneous B₀ field

Better Shim Capability

Gradient shim

High order shim
Adjust Shim Volume

3D T2 SPACE w. FatSat @ 3T

Optimizing Center Frequency

Multiple scan of 20 sec each

100 Hz 150 Hz 200 Hz 250 Hz

Full Scan with Offset of 200 Hz
Adjust/Confirm Center Frequency

Composite RF Pulse
- Concatenation of sub pulses to improve performance (i.e. insensitive to $B_0$ and $B_1$ inhomogeneity)
- Composite ChemSat Pulses:
  - CHEmical Shift Selective (CHESS)
  - Binomial Pulse (ProSat, WE)
  - Spectral Spatial Pulse (SpSp)
  - Band Selective Inversion with Gradient dephasing (BASING)
  - MEGA, MELV

ProSet
- Principle of Selective excitation technique
- A train of RF pulses with pre-defined amplitude ratios and spacing
- Produce water-only or fat-only excitation
1-1 Binomial for Water Only

\[ \Delta t = \frac{1}{2} \Delta f \]

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1-1 Binomial for Fat Only

\[ \Delta t = \frac{1}{2} \Delta f \]

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ProSet Examples

- Limited slice thickness
- Lengthy pulse

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WE versus FatSat for Foot

Water Excitation

Conventional Fat Sat

Spectral Spatial (SpSp) pulse

Excitation Profile of SpSp

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Zur Y., MRM, 43, 410, 2000
SpSp Considerations

- Less spatially selective with short sub-pulses.
- More sensitive to $B_0$ inhomogeneity with fewer sub-pulses.
- Require accurate alignment of RF and gradient waveforms.

STIR, and compare with FLAIR

STIR/TRIM: Short Tau Inversion Recovery,
FLAIR: FLuid Attenuated Inversion Recovery, "Dark Fluid"

Interleave of Inversion & Acquisition
Dependence on Flip Angle and TR

As the inversion flip angle or TR decreases:
- T1 decreases
- Suppression less selective

Multifocal MRSA Osteomyelitis

Courtesy of Dr. Boaz Karmazyn of IUSM

STIR versus FATSAT in the Presence of Field Inhomogeneity
More about STIR

- In-sensitive to $B_0$ inhomogeneity
  - More reliable than FATSAT for large FOV and off-center (shoulder)
  - Works at lower field strengths
- High visibility for fluid
  - Long T1 bright on STIR
  - Long T2 bright on STIR, given long enough TE
- Lower SNR
  - Improved with shorter TE (17-48 msec)
- Bad idea with Gd
  - Shorter post-contrast tumor T1
- Red marrow signal can obscure subtle edema
  - Use TE=45-48+ to suppress marrow

Modified STIR for MSK

- TE=50-100; TI=110-120 @ 1.5T
- Improved SNR and maintain fluid sensitivity

Water Saturation plus STIR

- Water
- Fat
- Silicone (220Hz, 320Hz)
- Silicone Breast Implants
**SPIR**

- **S**pectral selective **I**nversion **R**ecovery
- Frequency selective inversion pulse (100° – 110°) to invert fat only.
- SNR of water is preserved.

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**B₁ Non-uniformity**

- Inherent in the scanner
  - Design and tuning of body coil
- Caused by patient
  - RF shielding and dielectric effect
  - Often seen in Torso and Pelvis
  - More prominent at high field such as 3.0T

Consequence:
- Receiving -> variation of signal intensity
- Transmitting -> variation of flip angle

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**In-homogeneous B₁ field**
• **SPAIR, ASPIR**
  - Spectral Attenuated Inversion Recovery
  - Spectral-selective Adiabatic Inversion Recovery
  - Adiabatic Spectral-selective Inversion Recovery
  - Uses an adiabatic frequency selective inversion pulse.

**Conventional vs Adiabatic Inversion**

**B1 Sensitivity**
Abdominal Applications

- DW SS-EPI @ b=50 w. SPAIR
- HASTE w. SPAIR

SPAIR, ASPIR

- STIR ‘like’ contrast, but for fat only.
- Insensitivity to $B_1$ inhomogeneity (better for 3.0T).
- Takes longer time than FatSat and SPIR (compensate by applying less frequently).
- SPAIR delay time can be set on Phillips.

In/Op Phases and DIXON, IDEAL

- TE: 0 ms
- 2.25 ms
- 4.5 ms
- @ 1.5T

Water
Fat

$S_{w} = \frac{S_{x}(TE_{in}) + S_{x}(TE_{out})}{2} ; S_{f} = \frac{S_{x}(TE_{in}) - S_{x}(TE_{out})}{2}$
17 yo boy with Hodgkin's disease, treated for right knee metastasis

Two and Three Point DIXON

Two-point DIXON Example

TE = 2.4ms

TE = 4.8ms
3PT DIXON Example

TE = 2.4ms  TE = 4.8ms  TE = 9.5ms

Water-only  Fat-only  T2*

Breast Fat Suppression @ 3.0T

Cor T1 of Pelvis with TSE DIXON
TSE DIXON of Ankle with Metal

Water + Lipid Suppression in MRS

Very Selective Saturation (VSS) Pulse
Shaping the PRESS box with VSS bands

- 6 default ROI-edge bands controlled by UserCV
- 4 - 6 additional GRx bands
- Progressive flip angles

Benefit of VSS Sat. Band

- Lipids
- Cit
- Cho/Cr
- 3 cm thick
Summary

• There are MANY options to perform fat suppression in MRI.
• Each has its own pros and cons.
• Need to understand their potentials and pitfalls when selecting the best fat suppression options according to the application.

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Thank You!

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