Class Business

- **Tuesday (3/7) from 6-9pm**
  - 6:00-7:30pm Groups
    - Avanto
      - Sara Said, Yara Azar, April Pan
    - Skyra
      - Timothy Marcum, Diana Lopez, Shenzhen Zhang
    - Prisma
      - Dehong Zheng, Jiqian You, Fang-Chu Lin, AnMy Vuong
  - 7:30-9:00pm Groups
    - Avanto
      - Binru Chen, Junjie Chen, Yuhua Chen
    - Skyra
      - Jie Fu, Qihui Lyu, Cass Wong
    - Prisma
      - Nyasha Matasia, Tadi Ali, Vahid Ghodrat

Class Business

- **HW #1**
  - $13.3\pm3.2\ [15.75, 6.5]$
- **HW #2**
  - $11.7\pm2.6\ [15, 6]$
- **HW #3**
  - $13.7\pm1.4\ [15, 9.5]$
- **Class Average**
  - $38.7\pm6.5\ [46, 22.4]$
Lecture #14 - Learning Objectives

- Describe the origin and correction for several artifacts.
- Understand the impact of spatial resolution and scan time on signal-to-noise ratio.
- Explain the importance of readout bandwidth and the +/- of high (or low) readout bandwidth.
- Define the origin, artifact, and possible correction for chemical shift artifacts.
- Appreciate why motion causes image artifacts in MRI.
- Be able to identify several artifacts in an MR image.

Lecture #15 - Learning Objectives

- Distinguish Type-1 and Type-2 chemical shift artifacts, their origin, and mitigation.
- Describe advantages and disadvantages of two partial fourier acquisition methods.
- Explain the advantages and disadvantages of multi-slice imaging.
- Explain the advantages and disadvantages of multi-echo imaging.
- Identify ways to improve imaging protocols.
**GRE & Fat/Water Frequency**

**Water Spins in a Uniform Field**

**GRE & Fat/Water Frequency**

**Water Spins in a Gradient Field**

**GRE & Fat/Water Frequency**

**Water & Fat Spins in a Gradient Field**
GRE & Fat/Water Frequency

- High Bandwidth
  - Less chemical shift
  - Lower SNR
  - Short TE/TR
- Low Bandwidth
  - More chemical shift
  - Higher SNR
  - Longer TE/TR

Type-1 Chemical SNR Artifact (spatial mis-registration).

GRE and Fat/Water Phase

- Pixels are frequently a mixture of fat and water
- Pixel intensity is the vector sum of fat and water

Fat: In-Phase $\rightarrow + \rightarrow > 0$
Water: Opposed-Phase $\leftarrow + \rightarrow = 0$

The TE controls the phase between fat and water.
GRE and Fat/Water Phase

- Pixels are frequently a mixture of fat and water
- Pixel intensity is the vector sum of fat and water

\[ T = \frac{1}{f} + \pi - \pi \]

The TE controls the phase between fat and water.

In-Phase
Opposed-Phase

Type-2 Chemical Shift Artifact (aka India Ink artifact)

Which image is the in-phase image?

A.  
B.  

Images Courtesy of Scott Reeder
Which image is the in-phase image?

A. In-Phase
B. Opposed-Phase

Images Courtesy of Scott Reeder

---

Gradient Echoes & Fat Suppression

- Why is fat suppression/separation important?
  - Fat is bright on most pulse sequences.
  - But so are many other things...
    - CSF & edema
    - Flowing blood
    - Contrast enhanced tissues
- Fat obscures underlying pathology
  - Edema, neoplasm, inflammation
- How can fat be eliminated in GRE images?
  - Fat saturation pulses
  - Multi-echo acquisitions
    - Dixon/IDEAL

---

Fat Suppression

A frequency-selective radiofrequency pulse is applied to the volume of interest to create a new vector of magnetization that points in a direction at right angles to the main magnetic field. This creates a new field of view for imaging. The frequency-selective pulse is followed by a second pulse that dephases the spins in the new field of view, and these dephased spins are then imaged. This process allows for the selective suppression of fat signals, as fat signals are phase sensitive and are therefore suppressed in the new field of view. This allows for the selective visualization of other tissues, such as water or fluid, which are not phase sensitive and therefore are not suppressed.
Fat Suppression

Fat-Sat Image

Fat-Sat Can Be Spatially Non-Uniform

GRE & Fat/Water Separation - How?

RF
Slice Select
Phase Encode
Freq. Encode
TR

TE₁

TE₂

TE₃

Fat/Water Reconstruction
Gradient Echoes & Fat/Water Separation

Water Image  Fat Image

Images Courtesy of Scott Reeder

Gradient Echoes & Fat/Water Separation

Imperfect Fat Sat  Water Image  Fat Image

In-Phase  Opposed-Phase

Images Courtesy of Dr. Scott Reeder

Partial Fourier Imaging
Partial Fourier Imaging

How do you acquire each dataset?
What is an advantage/disadvantage to each approach?

Hermitian Symmetry

• If \( f(x) \) is real valued, then its frequency representation \( S(k) \) is redundant.
• If \( S(k) \) is known for \( k \geq 0 \), then \( S(k) \) for \( k < 0 \) can be generated according to:
  \[
  S(-k) = S^*(k)
  \]
• k-space is Hermitian (conjugate) symmetric.

\[
S(-k_x, -k_y, -k_z) = S^*(k_x, k_y, k_z)
\]
Hermitian Symmetry

\[ S(k_x, k_y, k_z) = A e^{i\phi} \]

- Every point in \( k \)-space has a magnitude and a phase
- The phase of the signal at \((k_x, k_y, k_z)\), however, may not be the same as the phase of the signal acquired at \((-k_x, -k_y, -k_z)\)
  - Noise
  - Motion
  - Resonance frequency offsets
  - Hardware group delays
  - Eddy currents
  - Coil phases (Receive B1 inhomogeneity)

Partial Fourier Imaging - Advantages

- Readout Direction
  - Reduced Echo Time (TE)
    - Improved SNR; Less T2* decay
  - Reduced gradient moments
    - Reduced flow artifacts
- Phase Encode Direction
  - Reduced Scan Time

Partial Fourier Imaging - Disadvantages

- Lower SNR (faster scanning…)
- Simple reconstruction (zero-filling)
  - Blurring
- Complex reconstruction (Homodyne or POCS)
  - Increased recon time (trivial…)
  - Residual artifacts
2D Slice Interleaving

Spin Echo

Wasted Time

Slice 1 Slice 2 Slice 3
Slice Interleaving

Sequential 2D Imaging

Imaging Time = TR * Nky * Nslices

Slice Interleaved 2D Imaging

Imaging Time = TR * Nky * Nslices / Ninterleaves

2D Slice Interleaving

- **Advantages**
  - Accelerate imaging by Ninterleaves

- **Disadvantages**
  - Acceleration limited by Ninterleaves = TR/TE
  - SAR
  - Difficult to acquire immediately adjacent slices
    - Hard to get good 180° slice-profile to match 90° slice-profile for multi-slice imaging

- **Applications**
  - T2 imaging
    - TR must be long (Why?)
  - DWI
    - TR should be long

Multi-Echo Spin Echo Imaging
How do we calculate scan time?

\[ T_{\text{Scan}} = TR \cdot PE \cdot N_{\text{avg}} \]

- \( T_{\text{Scan}} = 1000 \text{ms} \cdot 256 \cdot 1 = 4:16 \) [mm:ss]
- Assumes one echo per TR.

Spin Echo

![Spin Echo Diagram]

Wasted Time
**Fast Spin Echo**

- RF
- $G_{\text{Slice}}$
- $G_{\text{Phase}}$
- $G_{\text{Readout}}$
- Signal

Echo-1, Echo-2, Echo-3

**T$_2$ Weighting (FSE vs. SE)**

**FSE**
- TR = 2500
- TE = 116
- ETL = 16
- NEX = 2
- 24 slices
- Time = 2:51

**SE**
- TR = 2500
- TE = 112
- ETL = N/A
- NEX = 1
- 24 slices
- Time = 22:21

Images Courtesy of Frank Korosec
**T₁ Weighting (FSE)**

- ETL=4
- ETL=16
- ETL=24

Higher ETL reduces scan time, but introduces blurring.

---

**Fast Spin Echo**

- **Advantages**
  - Turbo factor accelerates imaging
  - Can be used with 2D slice interleaving
  - Allows T₂ weighted imaging in a breath hold

- **Disadvantages**
  - High turbo factors (ETL>4):
    - Blur images
    - Alter image contrast
  - Fat & Water are both bright on T₂-weighted
    - Water/CSF T₂ is long (~180ms)
    - Fat T₂ is shorter (~85ms)
    - Repeated 180° reduces spin-echo interaction
    - This "lengthens" the moderate T₂ of fat
  - SAR can be high

---

**Spin Echo EPI**
Spin Echo EPI

• Advantages
  – Can acquire data in a “single shot”
  – Can be used with 2D slice interleaving
  – Allows T2* weighted imaging in a breath hold

• Disadvantages
  – Single Shot EPI
    • Ghosting
    • Blur images
    • Image distortion
    • Alter image contrast
  – Multi-shot EPI
    • Slower than single shot
      Faster than SE

• Applications
  – DWI, Perfusion, fMRI

Protocol Optimization for Fast Scanning
The Infeasible Protocol

- T₁-weighted GRE (FLASH)
  - TR/TE/flip 162ms/4ms/30°
  - Matrix Size 256 (read) x 256 (phase)
  - FOV 480mm (read) x 480mm (phase)
  - Resolution 1.9mm x 1.9mm x 8mm
  - Acq. Time 43s (scanner reported)
  - rSNR 3.41
- Artifact - Breathing motion
- Advantage - Abundant SNR
- Disadvantage - Scan time too long
  - Low Resolution

Resolution: 1.9 x 1.9 x 8mm – rSNR=3.41 – Scan Time=43s

The Infeasible Protocol Cont’d

- T₁-weighted GRE (FLASH)
  - TR/TE/flip 162ms/4ms/30°
  - Matrix Size 256 (read) x 256 (phase)
  - FOV 300mm (read) x 300mm (phase)
  - Resolution 1.2mm x 1.2mm x 8mm
  - Acq. Time 43s
  - rSNR 1.33
- Artifact - Breathing motion
- Advantage - High SNR, Focused FOV
- Disadvantage - Scan time too long
The Infeasible Protocol Cont’d

Add Partial Phase FOV

- T₁-weighted GRE (FLASH)
  - TR/TE/flip  162ms/4ms/30°
  - Matrix Size  256 (read) x 192 (phase)
  - FOV  300mm (read) x 225mm (phase)
  - Resolution  1.2mm x 1.2mm x 8mm
  - Acq. Time  33s
  - rSNR  1.15
- Artifact  - Wrap, Breathing
- Advantage  - Reduced Scan Time
- Disadvantage - Reduced SNR
  - Scan time too long
Add 3/4 Partial Fourier

- T₁-weighted GRE (FLASH)
  - TR/TE/flip: 162ms/4ms/30°
  - Matrix Size: 256 (read) x 144 (phase)
  - FOV: 300mm (read) x 225mm (phase)
  - Resolution: 1.2mm x 1.2mm x 8mm
  - Acq. Time: 23s
  - rSNR: 1.00
- Artifact: Subtle blurring
- Advantage: Breath hold-able
- Disadvantage: Decreased SNR


Add Partial Fourier

Resolution: 1.2 x 1.2 x 8mm – rSNR=1.0 – Scan Time=23s

Now what? Still 23-seconds!

- Can’t decrease FOV more.
- Can’t increase partial Fourier fraction.
- Could decrease TR
  - Lower SNR
  - Altered T₁ contrast
- Could increase bandwidth
  - This shortens the TE/TR slightly
  - Decreases SNR significantly
- Could decrease spatial resolution.
  - Blurs the images
Asymmetric Voxels

- T₁-weighted GRE (FLASH)
  - TR/TE/flip: $162\text{ms}/4\text{ms}/30°$
  - Matrix Size: $256$ (read) x $108$ (phase)
  - FOV: $300\text{mm}$ (read) x $225\text{mm}$ (phase)
  - Resolution: $1.2\text{mm}$ x $1.6\text{mm}$ x $8\text{mm}$
  - Acq. Time: $19s$
  - rSNR: $1.33$

- Artifact: Partial voluming
- Advantage: Decreased scan time
- Disadvantage: Low spatial resolution

Resolution: $1.2 \times 1.6 \times 8\text{mm}$ – rSNR=1.33 – Scan Time=19s

More Asymmetric Voxels

- T₁-weighted GRE (FLASH)
  - TR/TE/flip: $162\text{ms}/4\text{ms}/30°$
  - Matrix Size: $256$ (read) x $72$ (phase)
  - FOV: $300\text{mm}$ (read) x $225\text{mm}$ (phase)
  - Resolution: $1.2\text{mm}$ x $2.3\text{mm}$ x $8\text{mm}$
  - Acq. Time: $12s$
  - rSNR: $1.33$

- Artifact: Partial voluming & blurring
- Advantage: Decrease scan time
  - Ample SNR
- Disadvantage: Very low spatial resolution
More Asymmetric Voxels

Resolution: 1.2 x 2.3 x 8mm – rSNR=2.00 – Scan Time=12s

Previously...

Resolution: 1.2 x 1.2 x 8mm
rSNR=1.0 – Scan Time=23s

Comparison

Isotropic Resolution

Resolution: 1.2 x 1.2 x 8mm
rSNR=3.41; Scan Time=43s

Partial Fourier

Resolution: 1.2 x 1.2 x 8mm
rSNR=1.15; Scan Time=33s

Infeasible

Partial Phase FOV + Partial Fourier

Resolution: 1.2 x 2.3 x 8mm
rSNR=2.00; Scan Time=12s

Low Resolution

Resolution: 1.2 x 2.3 x 8mm
rSNR=2.00; Scan Time=12s
Conclusion

• Minimum k-space acquisition only...
  – Decreases scan time from 42s to 21s
  – Decreases rSNR by 3.41x
    • BUT this is still sufficient...
  – Additional changes may compromise
    • Image contrast
    • Spatial Resolution
    • Signal-to-noise
• These approaches still benefit from multi-echo and/or multi-slice acquisitions.

Thanks

DANIEL B. ENNIS, PH.D.
ENNIS@UCLA.EDU
310.206.0713 (OFFICE)
HTTP://ENNIS.BOL.UCLA.EDU
PETER V. UEBSRROTH
BLOG.
SUITE 1417, ROOM C
10945 LE CONTE AVENUE