5.1 Pulse Sequences & Image Contrast for MRI

Timing Diagrams for Spin Echo
pulse sequences including: spin echo, fast spin echo, inversion recovery, gradient echo and echo planar imaging

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Slide # 2

Outline

• Timing diagrams
• What is a pulse sequence?
• What is a spin echo?
• Review Spin Echo & Fast spin echo
• Inversion Recovery & Fast IR
• Gradient Echo

Slide # 3

What contrast characteristics in MR?

• What contrast is available on CT
• What contrast is available on MRI
  – T1
  – T2
  – PD

Axial CT

T1  PD

Slide # 4

How are images acquired in MR?

• Pulse Sequences
  – SE
  – FSE
  – IR
  – Fast IR
  – GE
  – EPI

T2 CSE 12 minute scan
T2 TSE (FSE) 3 minute scan
T2* EPI 30 second scan

Slide # 5

To create MR images

• The patient is placed in the magnetic field
  – to align the spins
• The RF pulse is applied
  – to excite the spins
  – at the Larmor Frequency

Slide # 6

Timing Diagram

• A pulse sequence is… a sequence of pulses
• A timing diagram is the order and timing of pulses
**Slide # 7**

ECG

**Slide # 8**

What is this?

TR (Repetition Time)

**Slide # 9**

Timing Diagram

TR, is the time between 90° RF pulses

These lines represent gradient pulses

MR signal induced in the receiver coil

RF Pulse

Slice selection gradient

Phase Encoding gradient

Frequency encoding gradient

**Slide # 10**

Short TR & Long TR Imaging

Short TR

Long TR

**Slide # 11**

Timing Diagrams - Gradients

Gradients

SS (Z)

PE (Y)

RE (X)

**Slide # 12**

Slice Selection

- If the magnetic field is homogeneous, the frequency is the same... head to feet
- If the RF is applied... in this case the entire body would be excited

Homogeneous magnetic field

The frequency is the same from the head to the feet
Selective Excitation

- To excite a location within the imager, within the body.
- A magnetic field gradient is applied.
- The RF pulse is applied that matches a location.

Phase & Frequency Encoding

- Once the slice is selected...
- Encoding along the other axes,
  - With gradients: R to L, A to P
  - For encoding: Phase encoding, Frequency encoding

Timing Diagram - Signal

- RF Pulse
- Slice selection gradient
- Phase Encoding gradient
- Frequency encoding gradient
- MR signal

Timing Diagram - TE

- TR (Repetition Time)
- TE (Echo Time)
- Image with artifact
- Cleaned up the "SIC"

T2* Decay

- RF pulse
- Mxy
- T2* decay
- Axial T2* Brain Image
- In phase
- Partially dephased
- Completely dephased
- Mx, y = transverse magnetization

MR Excitation Relaxation

- Alignment
- Excitation
- Relaxation
- MR Signal
Runners on the Race

- Phase #1: Start together and get apart
- Phase #2: Runner turn 180° and get apart
- Phase #3: Runners change places
- Phase #4: Runner turn 180° and get apart again

Spin Echo - Runners on the Race

- FID
- Phase #1: Start together and get apart
- Phase #2: Runner turn 180° and get apart
- Phase #3: Runners change places
- Phase #4: Runner turn 180° and get apart again

T2* and T2 Decay

- T2 decay
- T2* decay
- Axial T2* Brain
- Axial T2 Brain

Is Susceptibility artifact always a bad thing?

- FID
- Axial T2* Brain
- Axial T2 Brain

Gradient Echo - Runners on the Race

- FID
- Phase #1: Start together and get apart
- Phase #2: Runner turn 180° and get apart
- Phase #3: Runners change places
- Phase #4: Runner turn 180° and get apart again

Long TE - Spin Echo Imaging

- FID
- Long TE
Short TE – Spin Echo Imaging

A Few Fun Facts about T1 & T2

We cannot change....
T1 recovery
T2 decay
unless we change
Field strength
Temperature or Add contrast agents!

A Few Fun Facts about TR & TE

We can change
TR & TE
And...
TR goes with T1
TE goes with T2

A Few Fun Facts about T1 recovery

T1 times at 1.5T
Are in the neighborhood of...
2000 ms for water
150 ms for fat

A Few Fun Facts about T2 Decay

T2 times at 1.5T
Are in the neighborhood of...
2000 ms for water
50 ms for fat

A Few Fun Facts about Image Contrast

T1 times at 1.5T
Are in the neighborhood of...
2000 ms for water
150 ms for fat

We cannot change....
T1 recovery
T2 decay
unless we change
Field strength
Temperature or Add contrast agents!

We can change
TR & TE
And...
TR goes with T1
TE goes with T2
Let’s make a T1 image

**T1WI**

Short TR (500 ms)  
Short TE (20 ms)  
Bright fat

We can change TR & TE  
And...  
TR goes with T1  
TE goes with T2

T1 times at 1.5T  
Are in the neighborhood of...  
2000 ms for water  
150 ms for fat

Let’s make a T2 image

**T2WI**

Long TR (4000 ms)  
Long TE (100 ms)  
Bright water

We can change TR & TE  
And...  
TR goes with T1  
TE goes with T2

T2 times at 1.5T  
Are in the neighborhood of...  
200 ms for water  
50 ms for fat

Let’s make a PD image

**PDWI**

Long TR (4000 ms)  
Short TE (20 ms)  
Bright fat & water

We can change TR & TE  
And...  
TR goes with T1  
TE goes with T2

Timing Diagram – RF and Gradient Pulses

TR, is the time between 90° RF pulses

Phase

These lines represent gradient pulses

MR signal induced in the receiver coil

TE (Echo Time)

Image Contrast Parameters

**T1WI**  
Short TR  
Short TE  
Bright fat, short T1 time

**PDWI**  
Long TR  
Short TE  
Bright fat & water

**T2WI**  
Long TR  
Long TE  
Bright water, long T2 time

What is a Pulse Sequence?

Spin echo family  
Longer scan times  
Better quality

Gradient echo family  
Faster scan times  
Lower quality

T1 Weighted Image

SE (T2*)  
FSE  
IR  
Fast IR

PD Weighted Image

SE  
FSE  
FLAIR  
Fast FLAIR  
Looks like PD

T2 Weighted Image

SE  
FSE  
STIR  
Fast STIR  
Looks like T2

EPI

Perfusion

Diffusion

T2* Weighted Image

(T2* FSE)  
GrE spoiled  
TOP MRA  
Enhanced MRA

(PD FSE)  
GE  
EPI Pair

(T2 FSE)  
GE  
PCE MRA  
EPI  
Diffusion
Timing Diagram – Spin Echo

TR, is the time between 90\(^\circ\) RF pulses

These lines represent gradient pulses

TE is the time to the echo

TR (Repetition Time)

Frequency encoding gradient

Phase encoding gradient

MR signal

TE (Echo Time)

Long TE – Spin Echo Imaging

Short TR & Long TR Imaging

Short TR

Long TR

Short TE – Spin Echo Imaging

Long TE – Spin Echo Imaging

FID echo echo

T2 decay

TE 1

TE 2

Proton density-TE1 T2WI-TE2

Dual Echo Imaging (2 for 1)

Image Contrast Parameters

T1WI @ 1.5T
Short TR (500 ms) Bright fat
Scan time about 2 minutes With 2 signal averages

PDWI @ 1.5T
Long TR (4000 ms = 4 seconds) Bright fat & water
Scan time about 17 minutes With 2 signal averages

T2WI @ 1.5T
Long TR (100 ms) Bright water
Scan time about 17 minutes With 2 signal averages

Scan time for SE = TR * #PE's * NSA
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Spin Echo Timing Diagram & K-space

Scan time = TR x PE's x NSA

Dual Echo Imaging & K-space

FID echo echo
T2 decay
TE 1
TE 2
Proton density-TE1 T2WI-TE2
K-space-TE1 K-space-TE2

Fast Spin Echo Imaging & K-space (1 in ½ the time)

K-space (TSE)
FSE
TE 2 image Twice as fast

Fast Spin Echo Imaging for PDWI

Scan time (FSE) = TR * #PE's * NSA ETL

Fast Spin Echo Imaging for T2WI

Scan time (FSE) = TR * #PE's * NSA ETL
Abnormalities seen on Ultrasound
FDA OK for pregnancy if... benefit outweighs the risk
If mommy fits

**Fetal MRI**

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**Image Contrast Parameters - fast spin echo**

**T1WI**
- Short TR (500 ms)
- Bright fat
- Scan time about 1 minute
- With 2 signal averages
- ETL of 2

**PDWI**
- Short TR (4000 ms)
- Bright fat & water
- Scan time about 8.5 minutes
- With 2 signal averages
- ETL of 2

**T2WI**
- Long TR (4000 ms)
- Bright water
- Scan time about 8.5 minutes
- With 2 signal averages
- ETL of 2

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**Spin Echo vs Inversion Recovery**

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**Inversion Recovery – STIR (Short Tau Inversion Recovery)**
Why an initializing 180° pulse

- T1 recovery from a 90° pulse
- T1 recovery from a 180° pulse
- Compared to the 90° pulse

Short TI (fat crosses null point, suppressed)

T1 recovery from a 90° pulse
T1 recovery from a 180° pulse
Compared to the 90° pulse

Long TI (water crosses null point, suppressed)

FLAIR

STIR is NOT fatsat

STIR will suppress gadolinium enhancing lesions

STIR will suppress gadolinium enhancing lesions

STIR is NOT fatsat

Inversion Recovery – FLAIR (Fluid Attenuated Inversion Recovery)

Fast Inversion Recovery – scan time

Lymes disease

Scan time (FSE-IR) = TR * #PE's * NSA * ETL

FATSAT FSE vs STIR

FSE

STIR

Inversion Recovery – FLAIR (Fluid Attenuated Inversion Recovery)
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Spin Echo vs Gradient Echo

Gradient Echo – runners on the race

Susceptibility Artifacts on Gradient Echo

Flip Angle and Signal Quality (SNR)

As Flip increases
SNR increases
To a point
Ernst Angle
angle for optimum SNR
Steady State Imaging

FIESTA – IAC’s
Fast Imaging Employing a steady STAte

Steady State images
Shaded Surface Display
3D reformats

Steady State VS Spoiled Gradient Echoes

Steady State T2* FFE
Coherent Gradient Echo

“Spoiled” (spoil away transverse)
T1 FFE
Incoherent Gradient Echo

Dynamic Enhanced (T1) Spoiled Gradient Echoes

Pre gad
1st pass
2nd pass
3rd pass

3D Steady State vs 3D Spoiled Gradient Echoes

3D Steady State
T2* GrE images
Spoiled Gradient Echoes
T1 GrE images
**EPI Speed Compared to FSE**

- **FSE**:
  - Time < 500 ms
  - ESP = 5 - 20 ms
- **EPI**:
  - Time < 100 ms
  - ESP = 0.5 - 4 ms

**Single-Shot vs. Multi Shot EPI**

- **Single-Shot**
  - Fills all lines of k-space in a single TR period
  - Fastest Scan Times
  - Most useful for functional imaging techniques
- **Multi-Shot**
  - Requires multiple passes through k-space to fill all phase lines
  - Reduced artifacts
  - Allows for higher spatial resolution
  - Longer scan times

**Single Shot:** Whole brain acquired in 4 seconds, 128 x 128 matrix

**Multi-Shot:** Whole brain acquired in 90 Seconds, 512 x 256 matrix

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**Diffusion-Weighted Imaging**

- **Diffusion Gradients Sensitize the Image**
- **Contrast to the Molecular Motion of Extracellular Water**
- The greater the amount of motion, the darker the resultant MR signal

**Tissue Sample A**
- Normal Diffusion

**Tissue Sample B**
- Restricted Diffusion

Edema results in restricted diffusion

**b-value = 0**

- **T2-weighted Image**
- (b-value = 0)

**b-value = 1000**

- **Diffusion-weighted Image**
- (b-value = 1000)

**Diffusion Weighting and b-value**

- **b-value** determines the strength of the diffusion gradients
- Increasing the b-value increased diffusion weighting
Isotropic Diffusion

Individual Diffusion Measurements → Mathematical Combination → Isotropic Diffusion-Weighted Image

Apparent Diffusion Coefficient (ADC)

ADC expresses the amount of diffusion

<table>
<thead>
<tr>
<th>Tissue</th>
<th>ADC (mm²/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>White matter</td>
<td>1.23 (±0.08)</td>
</tr>
<tr>
<td>Cerebrospinal</td>
<td>1.5 (±0.2)</td>
</tr>
<tr>
<td>Cortex</td>
<td>1.80 (±0.17)</td>
</tr>
<tr>
<td>Thalamus</td>
<td>1.75 (±0.20)</td>
</tr>
<tr>
<td>Medulla</td>
<td>2.75 (±0.19)</td>
</tr>
</tbody>
</table>

Creating an ADC image (or map) results in images where the pixel intensity represents abnormal ADC and eliminates high signal from "T2 shine-through"

Perfusion Acquisition

Gradient Echo EPI Acquisition

Time Series

Up to > 400 images

Gd changes T2* of blood

Gd washes out of blood stream

Perfusion Contrast

Small Magnetic Field Gradient

Concentrated Gadolinium Results in a Larger Magnetic Field Gradient

T2* shortening results in loss of MR signal

Gradient Echo EPI TE = 60

Acquired at Peak Bolus

Perfusion of Stroke

Normal

Abnormal

BOLD (fMRI)

Blood Oxygen Level Dependent

• When neurons fire, blood flow is increased to that area of the brain
• Oxygen level increases
• Local magnetic field changes occur due to the paramagnetic characteristics of oxygenated blood
• Slight change in MR signal
  • 1% - 2% at 1.5 T
  • 4% - 6% at 3.0 T
• Area of signal change indicates area of activity
• Images processed on workstation and data is superimposed over higher resolution anatomic image

Bilateral Finger Tapping
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5.1 Pulse Sequences & Image Contrast for MRI

Timing Diagrams for Spin Echo pulse sequences including: spin echo, fast spin echo, inversion recovery, gradient echo and echo planar imaging

Thank you for your attention!

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