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**

Carolyn Kaut Roth, RT (R)(MR)(CT)(M)(CV) FSMRT
CEO Imaging Education Associates
www.imaginged.com candi@imaginged.com



## Outline

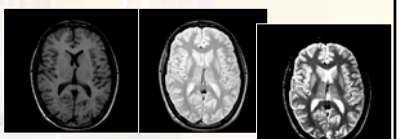
- Timing diagrams
- What is a pulse sequence?
- What is a spin echo?
- Review Spin Echo & Fast spin echo
- Inversion Recovery & Fast IR
- Gradient Echo




## What contrast characteristics in MR?

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

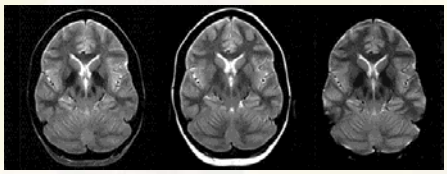

Axial CT


T1 PD




## How are images acquired in MR?

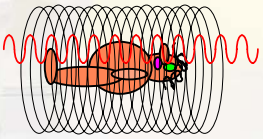
- Pulse Sequences
  - –SE
  - –FSE
  - –IR
  - –Fast IR
  - –GE
  - –EPI


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



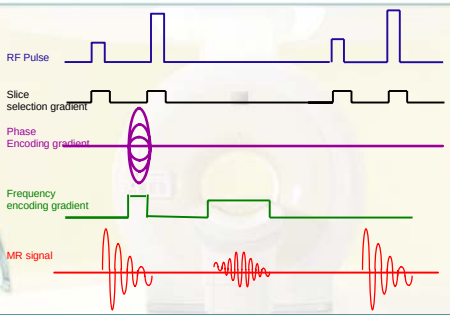

## To create MR images

- 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



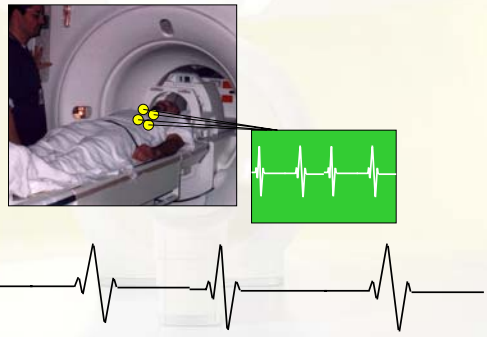



## Timing Diagram




- A pulse sequence is… a sequence of pulses
- A timing diagram is the order and timing of pulses

## ECG





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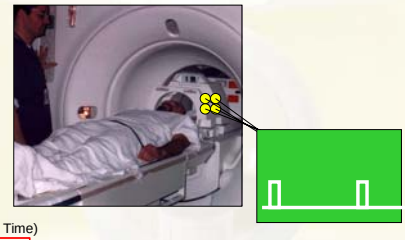
## What is this?



TR (Repetition Time)

$90^0$ $90^0$



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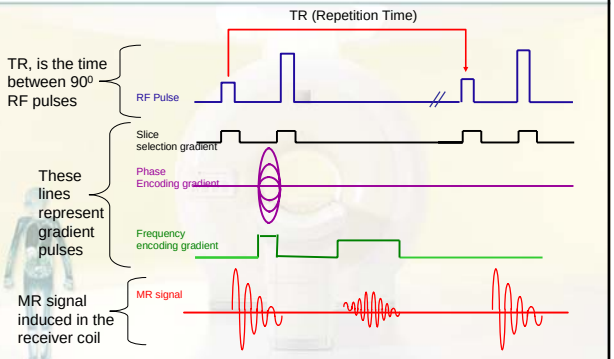
## Timing Diagram



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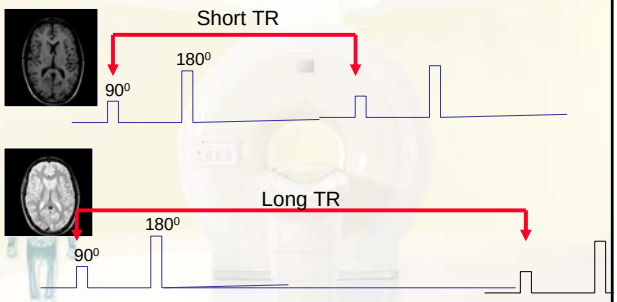
## Short TR & Long TR Imaging



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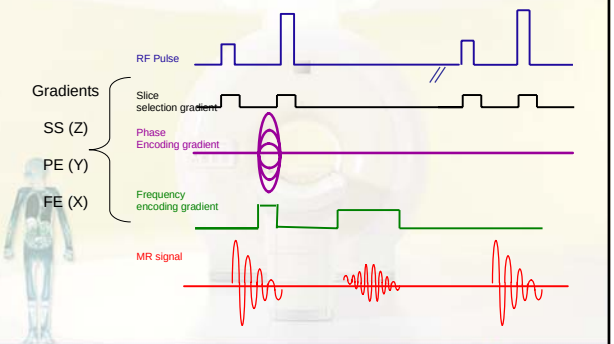
## Timing Diagrams - Gradients



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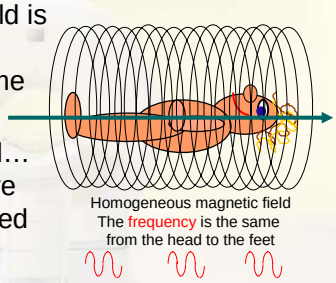
## Slice Selection

- 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



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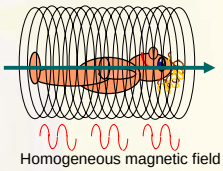
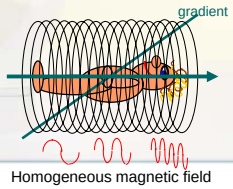
## Selective Excitation

- 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



Homogeneous magnetic field



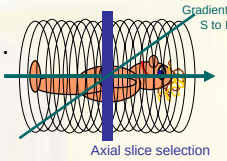

Homogeneous magnetic field
With a linear gradient field applied



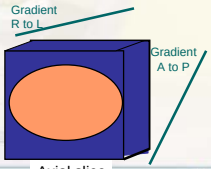


## Phase & Frequency Encoding

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




Axial slice selection

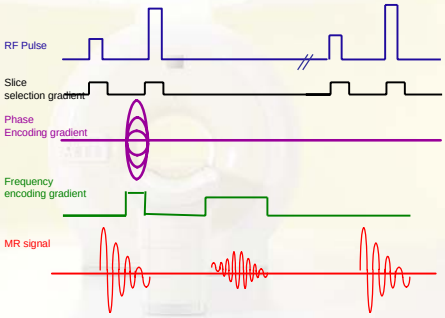



Axial slice





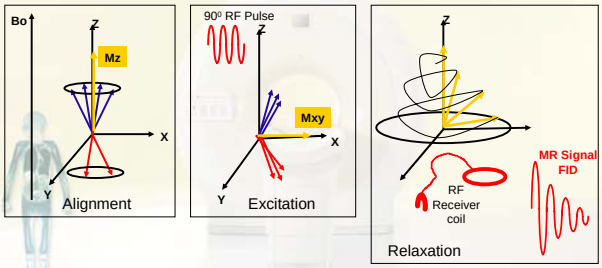
## Timing Diagram- Signal








## MR Excitation Relaxation








## Timing Diagram - TE

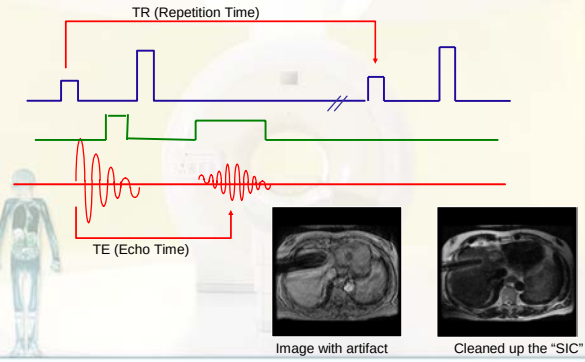


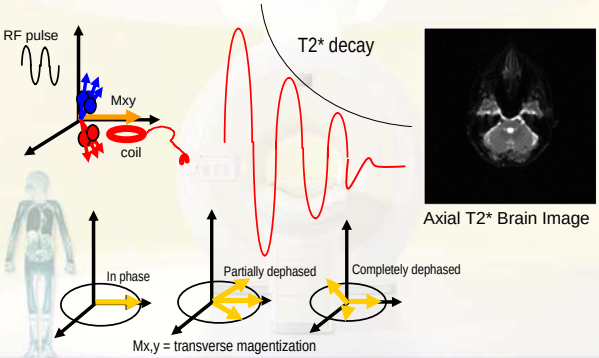

Image with artifact

Cleaned up the "SIC"



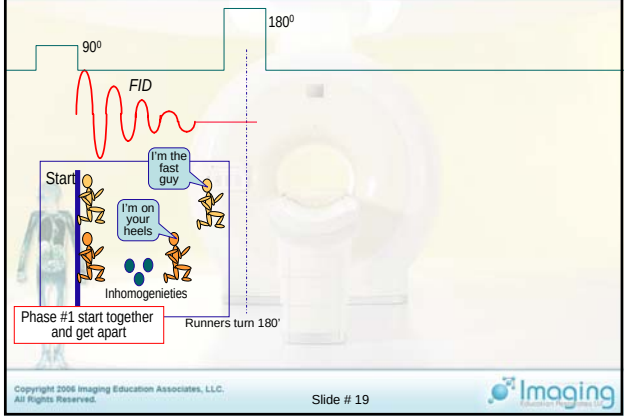


## T2* Decay




Axial T2* Brain Image

## Runners on the Race





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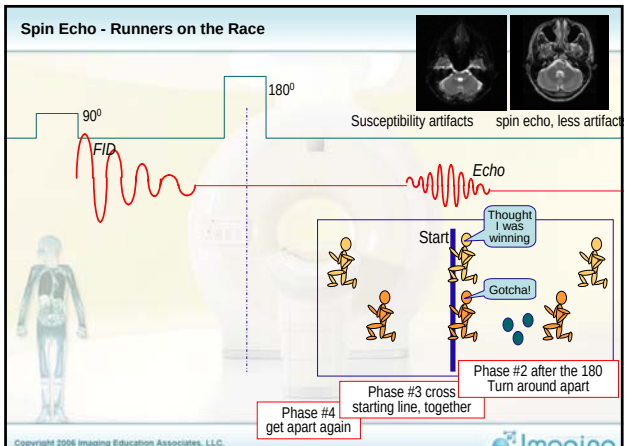
## Spin Echo - Runners on the Race





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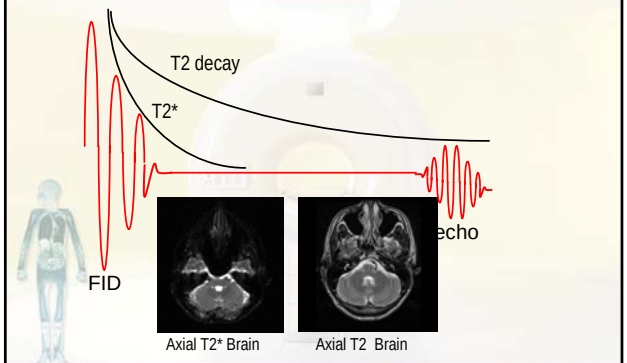
## T2* and T2 Decay





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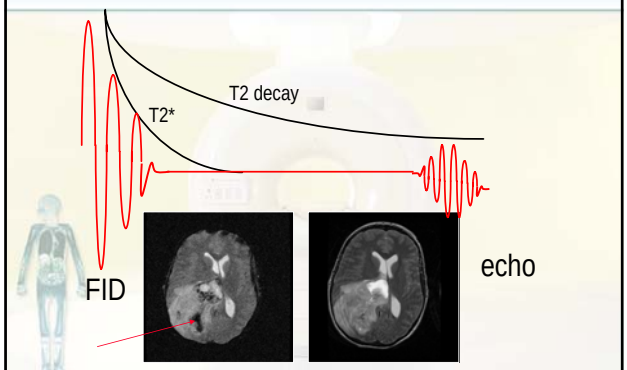
## Is Susceptibility artifact always a bad thing?





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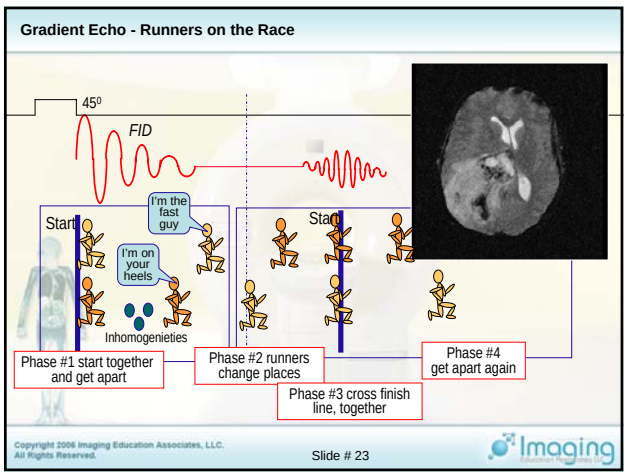
## Gradient Echo - Runners on the Race





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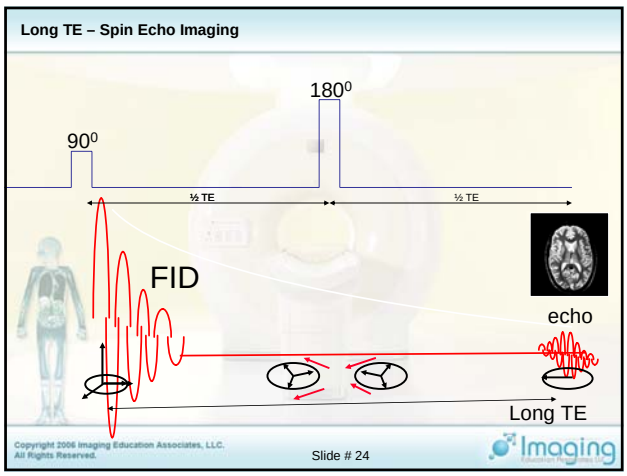
## Long TE – Spin Echo Imaging





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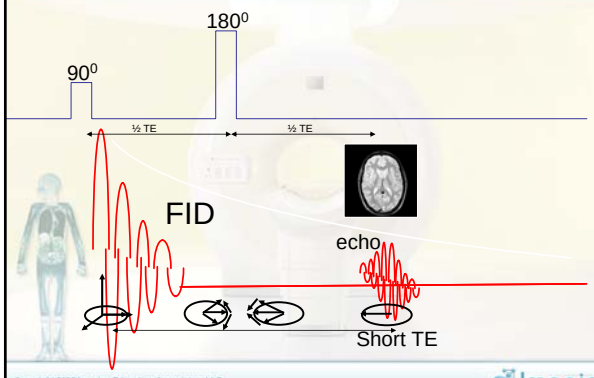
## Short TE – Spin Echo Imaging



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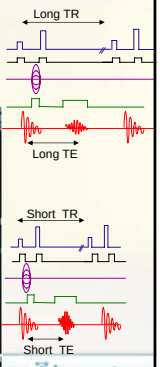
## A Few Fun Facts about T1 & T2

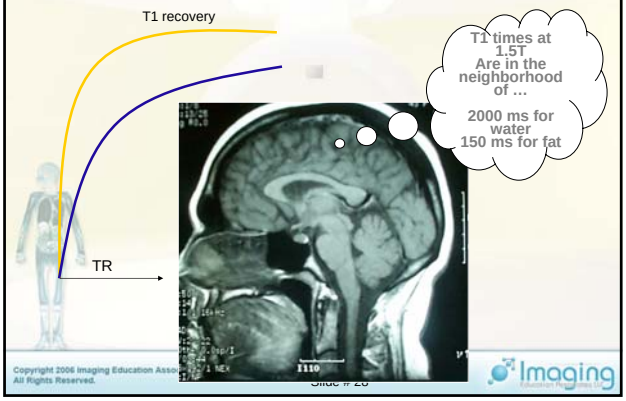
We cannot change…. T1 recovery T2 decay unless we change Field strength Temperature or Add contrast agents!

## A Few Fun Facts about TR & TE



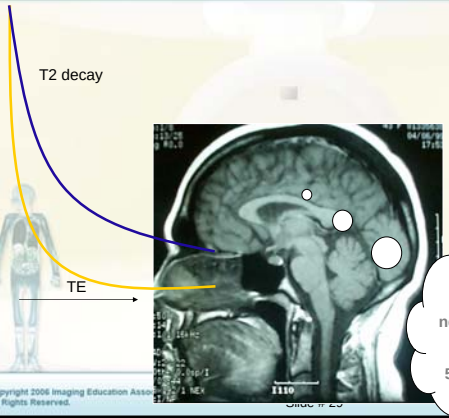

We can change TR & TE And… TR goes with T1 TE goes with T2

## 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 … 200 ms for water 50 ms for fat

## A Few Fun Facts about Image Contrast

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

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

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

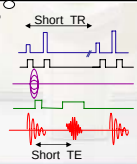
T2 times at 1.5T Are in the neighborhood of … 200 ms for water 50 ms for fat

## Let's make a T1 image

T1WI

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

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




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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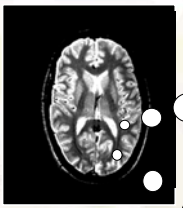
Imaging

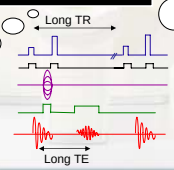
## Let's make a T2 image

T2WI

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



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




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

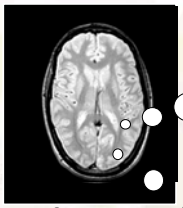
T2 times at 1.5T Are in the neighborhood of … 200 ms for water 50 ms for fat


Slide # 32
Imaging

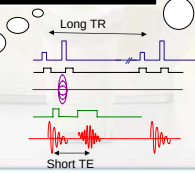
## Let's make a PD image

PDWI

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



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




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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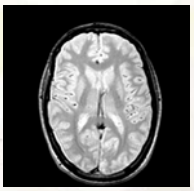
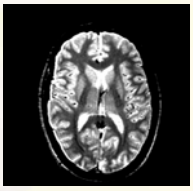
Imaging

## 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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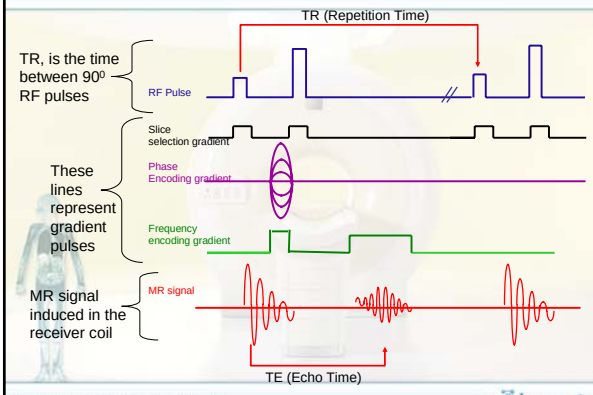
Imaging

## Timing Diagram – RF and Gradient Pulses





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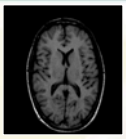
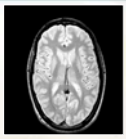
Imaging

## What is a Pulse Sequence?





Spin echo family

Longer Scan times Better quality

| T1Weighted Image | PD Weighted Image | T2 Weighted Image |
|---|---|---|
| SE | SE | SE |
| (TSE) FSE | (TSE) FSE | FSE |
| IR | FLAIR | STIR |
| Fast IR | Fast FLAIR Looks like PD | Fast STIR Looks like T2 |

Gradient echo family

Faster Scan times lower quality

| (T1 FFE) GrE spoiled | (PD FFE) GrE | T2* Weighted Image |
|---|---|---|
| TOF MRA | EPI Flair | (T2* FFE) GrE |
| Enhanced MRA | | PC MRA |
| | | EPI |
| | | Perfusion |
| | | Diffusion |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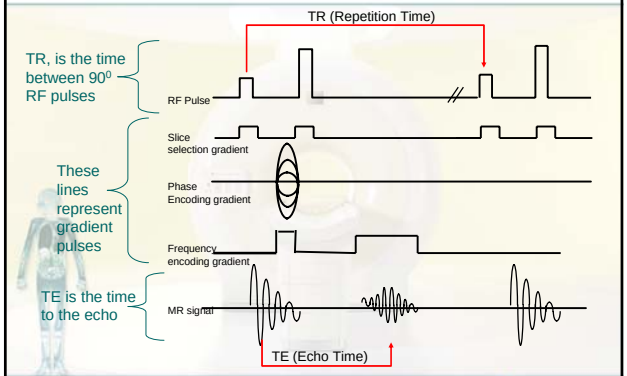
Imaging

## Timing Diagram – Spin Echo



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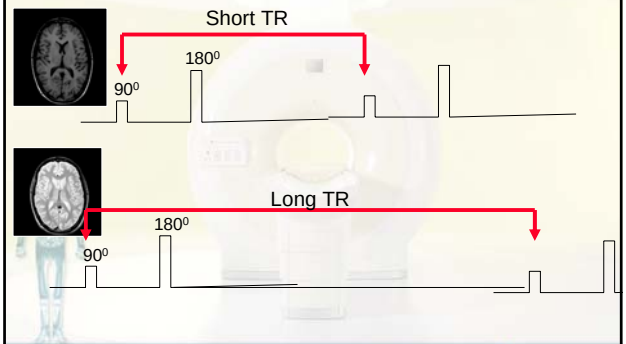
## Short TR & Long TR Imaging



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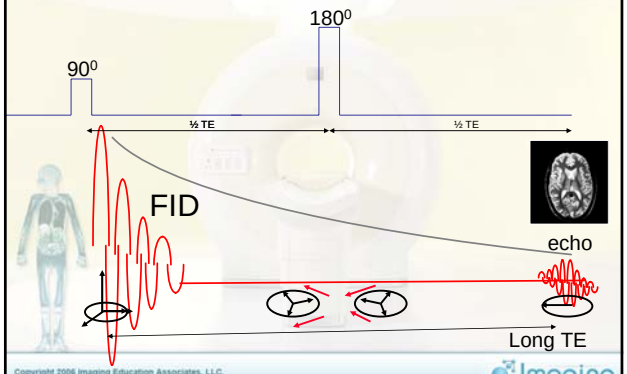
## Long TE – Spin Echo Imaging



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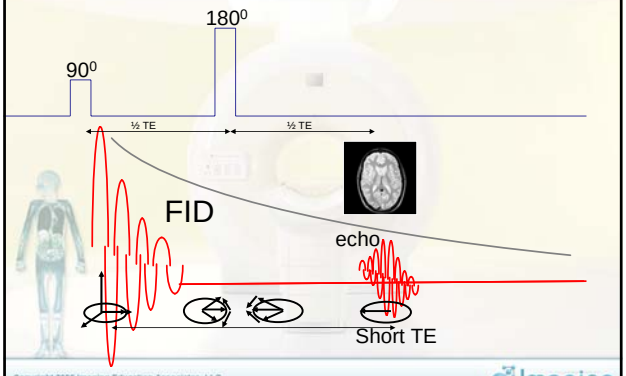
## Short TE – Spin Echo Imaging



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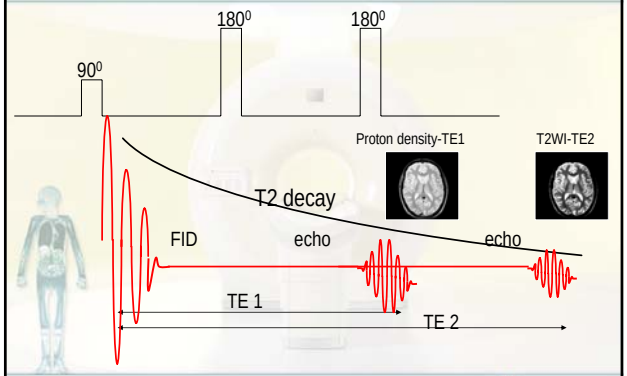
## Dual Echo Imaging (2 for 1)



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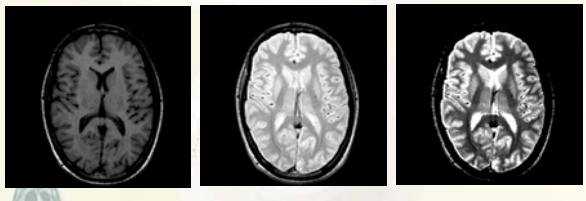
## Image Contrast Parameters



| T1WI | PDWI | T2WI |
|---|---|---|
| @ 1.5T | @ 1.5T | @ 1.5T |
| Short TR (500 ms) | Long TR (4000 ms = 4 seconds) | Long TR (4000 ms = 4 seconds) |
| Short TE (20 ms or less) | Short TE (20 ms or less) | Long TE (100 ms) |
| Bright fat | Bright fat & water | Bright water |
| Scan time about 2 minutes | Scan time about 17 minutes | Scan time about 17 minutes |
| *With 2 signal averages* | *With 2 signal averages* | *With 2 signal averages* |

Scan time for SE = TR * #PE's * NSA



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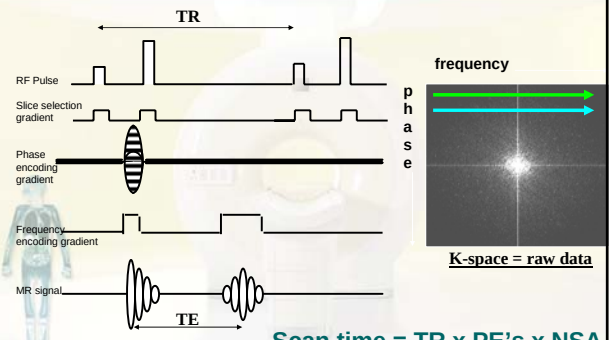
## Outline

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




## Spin Echo Timing Diagram & K-space

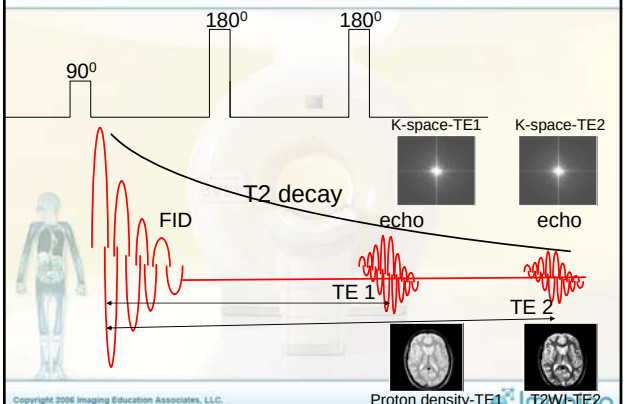



K-space = raw data

**Scan time = TR x PE's x NSA**



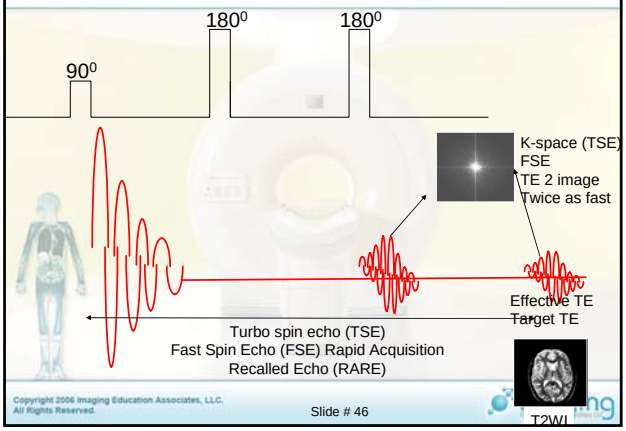

## Dual Echo Imaging & K-space







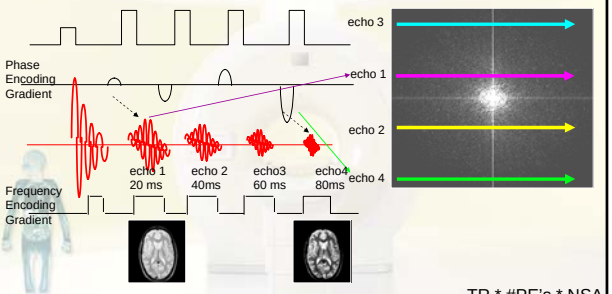
## Fast Spin Echo Imaging & K-space (1 in ½ the time)







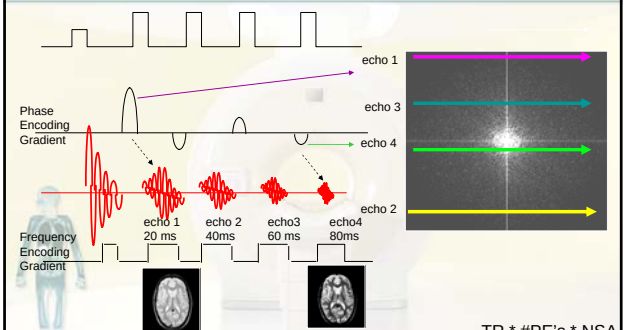
## Fast Spin Echo Imaging for PDWI




Scan time (FSE) = $\frac{\text{TR} * \#\text{PE's} * \text{NSA}}{\text{ETL}}$




## Fast Spin Echo Imaging for T2WI




Scan time (FSE) = $\frac{\text{TR} * \#\text{PE's} * \text{NSA}}{\text{ETL}}$

## Single Shot Fast Spin Echo Imaging for T2WI (SSFSE)

Abnormalities seen on Ultrasound

FDA OK for pregnancy if… benefit outweighs the risk

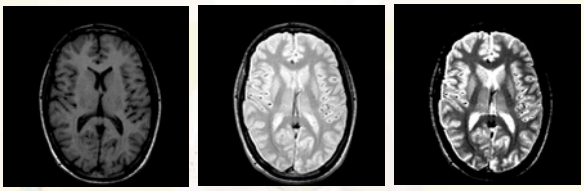
If mommy fits

**Fetal MRI**





## Image Contrast Parameters - fast spin echo



| T1WI | PDWI | T2WI |
|---|---|---|
| @ 1.5T | @ 1.5T | @ 1.5T |
| Short TR (500 ms) | Long TR (4000 ms = 4 seconds) | Long TR (4000 ms = 4 seconds) |
| Short TE (20 ms or less) | Short TE (20 ms or less) | Long TE (100 ms) |
| Bright fat | Bright fat & water | Bright water |
| Scan time about 1 minute | Scan time about 8.5 minutes | Scan time about 8.5 minutes |
| *With 2 signal averages* | *With 2 signal averages* | *With 2 signal averages* |
| *ETL of 2* | *ETL of 2* | *ETL of 2* |

$$\text{Scan time for SE} = \frac{\text{TR} * \#\text{PE's} * \text{NSA}}{\text{ETL}}$$



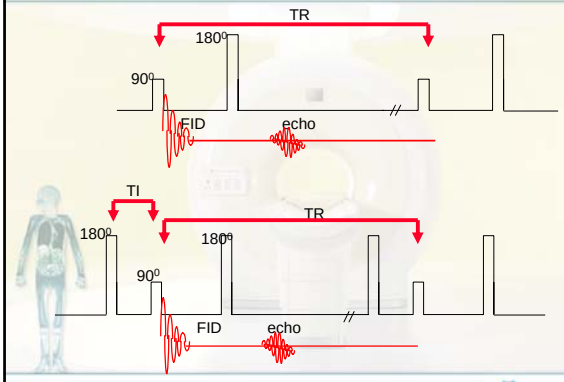
## Outline

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





## Spin Echo vs Inversion Recovery

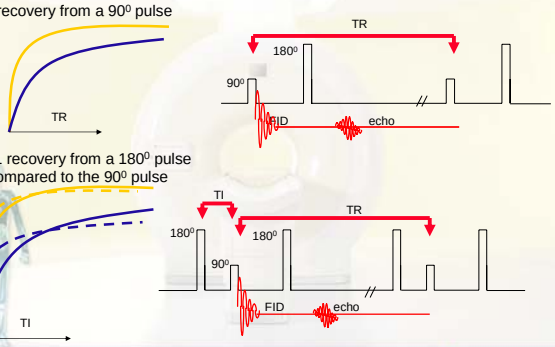







## Why an initializing 180⁰ pulse

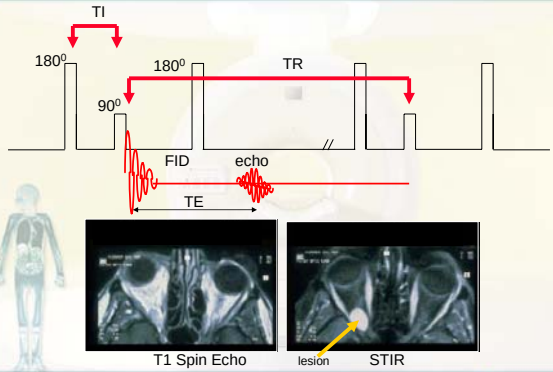
T1 recovery from a 90⁰ pulse





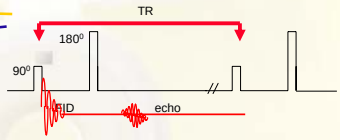



## Inversion Recovery – STIR (Short Tau Inversion Recovery)

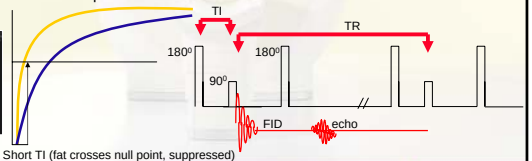


**Why an initializing 180⁰ pulse**

T1 recovery from a 90⁰ pulse




T1 recovery from a 180⁰ pulse
Compared to the 90⁰ pulse




Bone contusion

Short TI (fat crosses null point, suppressed)



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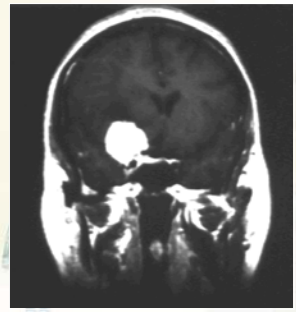
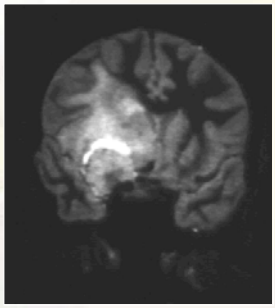
Imaging

**STIR is NOT fatsat**





STIR will suppress gadolinium enhancing lesions



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Imaging

**FATSAT FSE vs STIR**

*FSE* *STIR*



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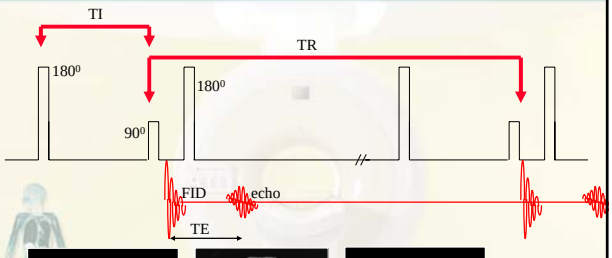
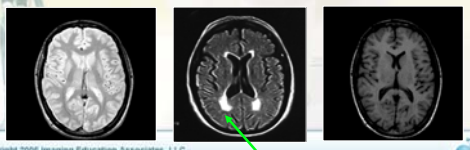
Imaging

**Inversion Recovery – FLAIR (Fluid Attenuated Inversion Recovery)**



*PD* *FLAIR* *T1*



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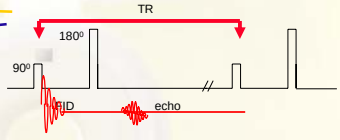
Imaging

**Why an initializing 180⁰ pulse**

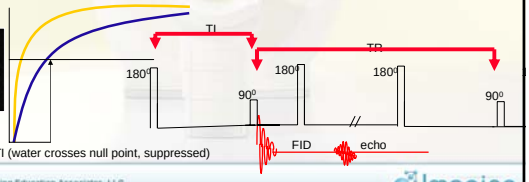
T1 recovery from a 90⁰ pulse

T1SE




T1 recovery from a 180⁰ pulse
Compared to the 90⁰ pulse

FLAIR




Long TI (water crosses null point, suppressed)



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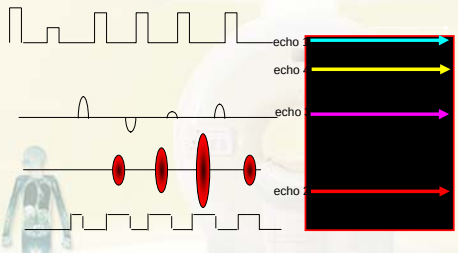
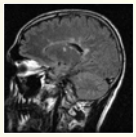
Imaging

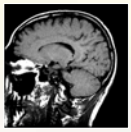
**Fast Inversion Recovery – scan time**




Lymes disease



FLAIR



T1SE

Scan time (FSE-IR) = $\frac{TR * \#PE's * NSA}{ETL}$



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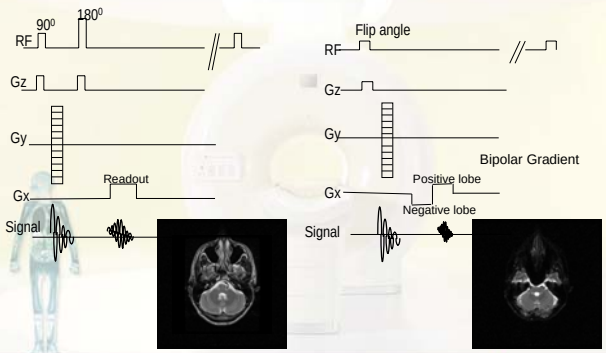
Imaging

## 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



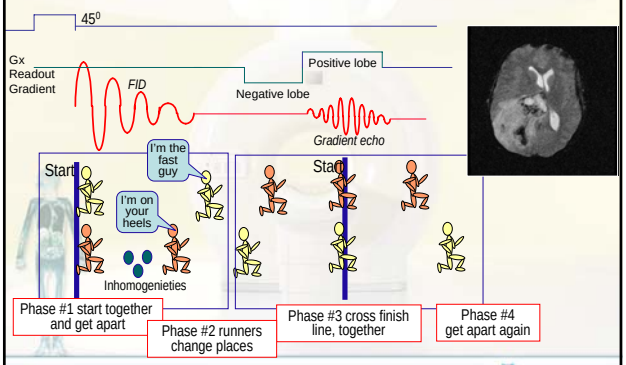

## Spin Echo vs Gradient Echo







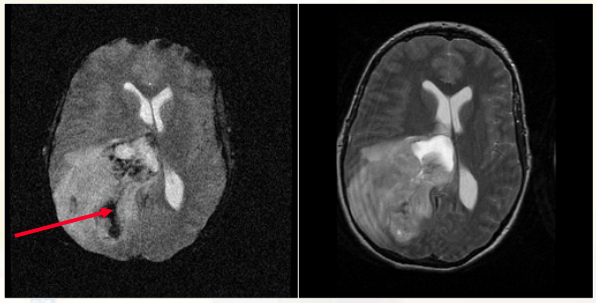
## Gradient Echo – runners on the race







## Susceptibility Artifacts on Gradient Echo



Axial T2* Brain

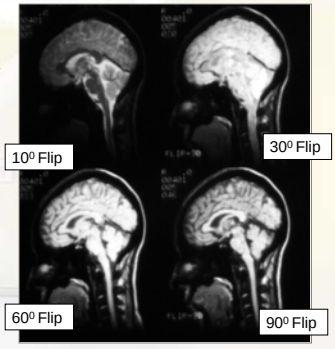
Axial T2 Brain




## Flip Angle and Image Contrast

Flip angle goes with TR
TR goes with T1

Big flip, more T1
Little flip, less T1



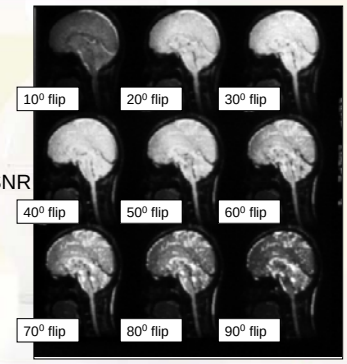




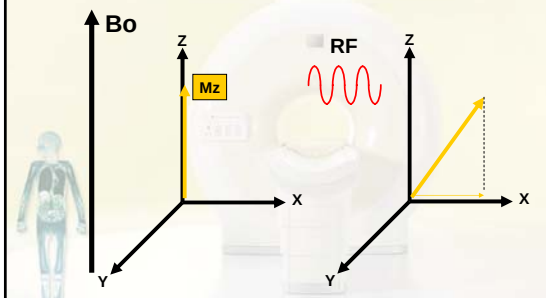
## Flip Angle and Signal Quality (SNR)

As Flip increases
SNR increases
To a point

Ernst Angle
angle for optimum SNR



## Flip angle





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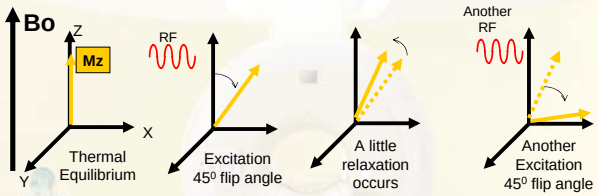
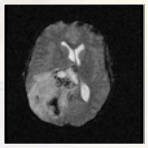
Imaging

## Steady State




**Steady State is the condition whereby Everything that relaxes is flipped again**

**Transverse magnetization**
**SS images demonstrate T2* effects**
**Bright fluid**

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Imaging

## Steady State Imaging

**FIESTA – IAC's**
*Fast Imaging Employing a steady STAte*

*Steady State images* *Shaded Surface Display* *3D reformats*


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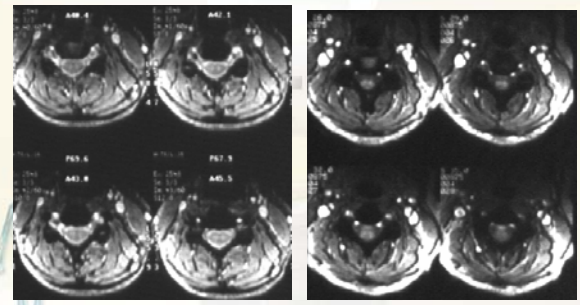
Courtesy of: Mumtaz Pasha
Imaging

## Steady State VS Spoiled Gradient Echoes



Steady State
T2* FFE
Coherent Gradient Echo

"Spoiled" (spoil away transverse)
T1 FFE
Incoherent Gradient Echo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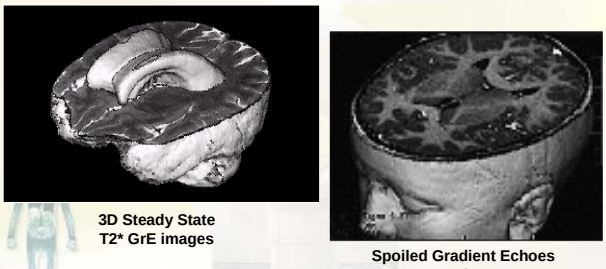
Imaging

## 3D Steady State vs 3D Spoiled Gradient Echoes



**3D Steady State**
**T2* GrE images**



**Spoiled Gradient Echoes**
**T1 GrE images**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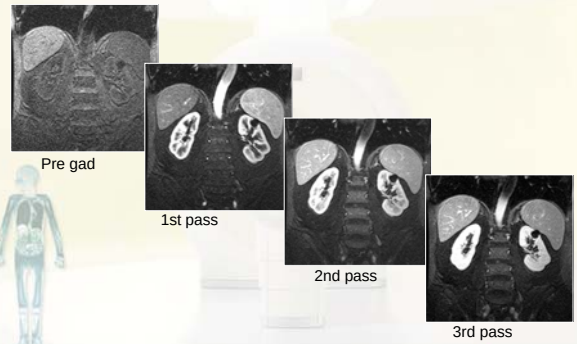
Imaging

## Dynamic Enhanced (T1) Spoiled Gradient Echoes



Pre gad
1st pass
2nd pass
3rd pass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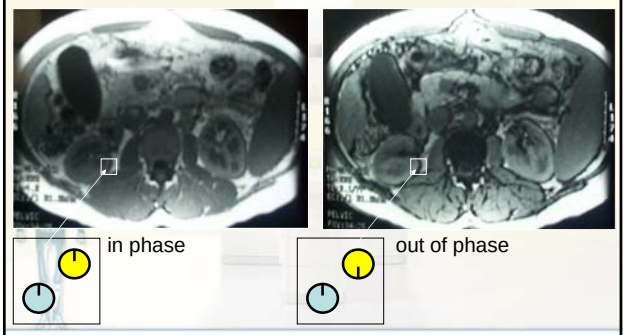
Imaging

## Chemical Shift Artifact on Gradient Echoes



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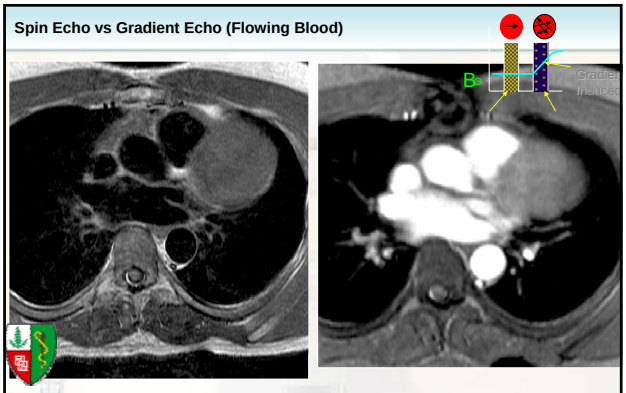
## Spin Echo vs Gradient Echo (Flowing Blood)





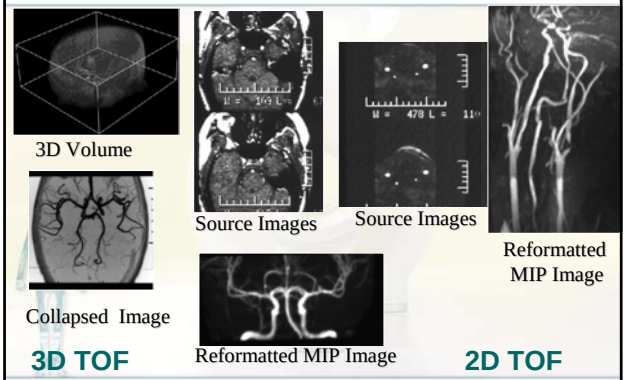

Slide # 74

## Cardiac Perfusion




Slide # 75

## Time of Flight (TOF) MR Angiography (MRA) – T1 Gradient Echo



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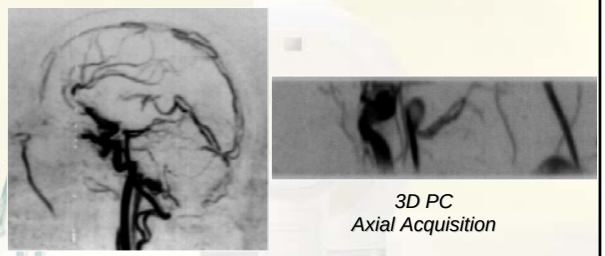
## Phase Contrast (PC) MR Angiography (MRA) – T2 Gradient Echo



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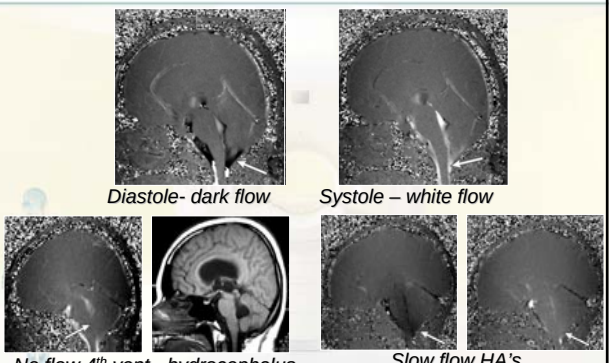
## Phase Contrast (PC) MR Angiography (MRA) – CSF Flow



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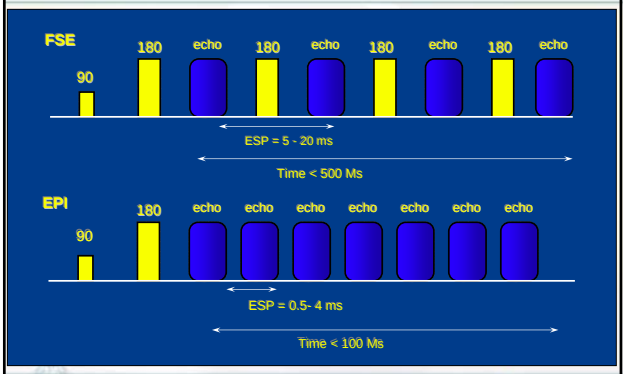
## EPI Speed Compared to FSE





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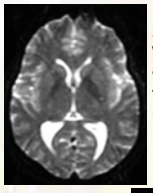
## Single-Shot vs. Multi Shot EPI

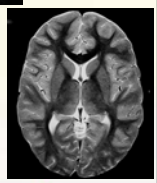
- **Single-Shot** EPI fills all lines of k-space in a single TR period
- Fastest Scan Times
- Most useful for functional imaging techniques



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

- **Multi-Shot** requires multiple passes through k-space to fill all phase lines
- Reduced artifacts
- Allows for higher spatial resolution
- Longer scan times

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 Extracelluar 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


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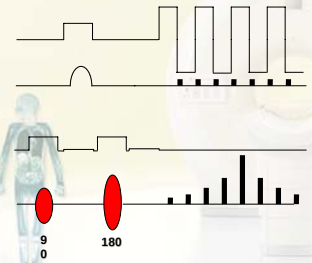
## b-value = 0




T2-weighted Image
(b-value = 0)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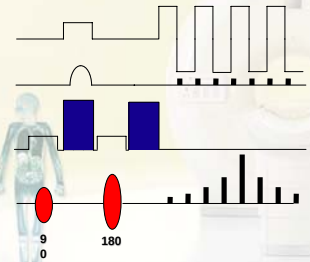
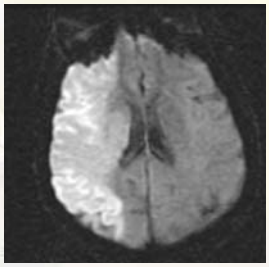
## b-value = 1000



Diffusion-weighted Image
(b-value = 1000)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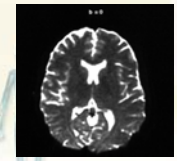
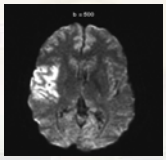
## Diffusion Weighting and b-value

**b-value determines the strength of the diffusion gradients**

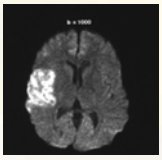
**Increasing the b-value increased diffusion weighting**



b-value = 0



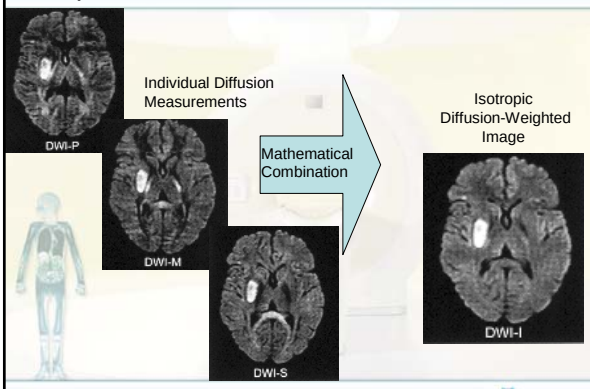
b-value = 500



b-value = 1000


Slide # 84

## Isotropic Diffusion





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Imaging

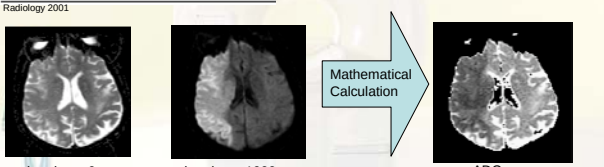
## Apparent Diffusion Coefficient (ADC)

ADC expresses the amount of diffusion

| Tissue | $ADC_1$ ($\mu m^2$/msec) |
|---|---|
| White matter ($n$ = 15) | 1.25 (0.08) |
| Gray matter ($n$ = 15) | 1.71 (0.12) |
| Edema ($n$ = 13) | 1.80 (0.14)* |
| Tumor ($n$ = 14) | 1.75 (0.20) |
| Cyst ($n$ = 5) | 2.75 (0.19) |
| Stroke ($n$ = 1) | 0.84 |

Radiology 2001

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




b-value = 0
T2-weighted

b-value = 1000
Diffusion-weighted + T2

ADC map
Reduced ADC = Reduced Signal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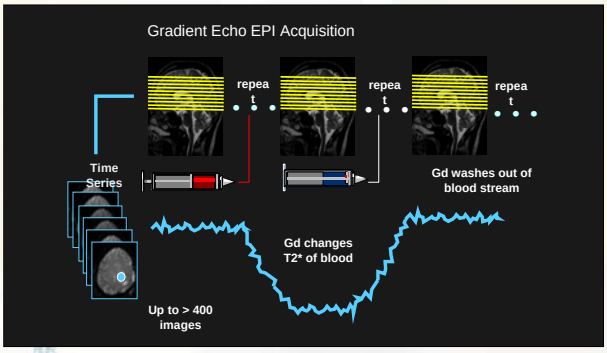
Imaging

## Perfusion Acquisition





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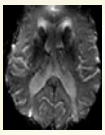
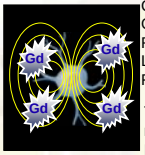
## Perfusion Contrast

Small Magnetic Field Gradient

Brain Cell

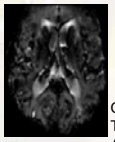


Gradient Echo EPI
TE = 60




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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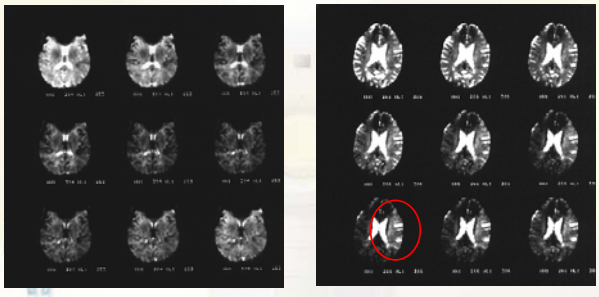
## Perfusion of Stroke



Normal

Abnormal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## BOLD (fMRI)

**B**lood **O**xygen **L**evel **D**ependent

- 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

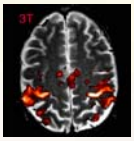


Image courtesy Stanford University


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**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





Imaging

**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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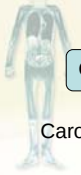

Carolyn Kaut Roth, RT (R)(MR)(CT)(M)(CV) FSMRT
CEO Imaging Education Associates
www.imaginged.com candi@imaginged.com