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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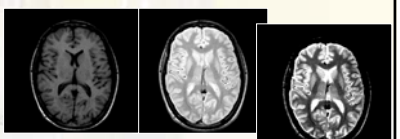
Outline

- 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?

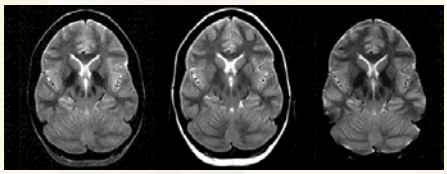
- What contrast is available on CT
- What contrast is available on MRI
  - –T1
  - –T2
  - –PD


Axial CT


T1 PD

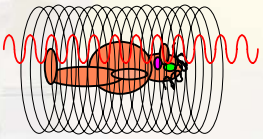
How are images acquired in MR?

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

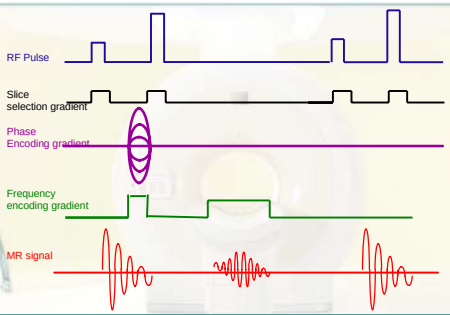

T2 CSE 12 minute scan | T2 TSE (FSE) 3 minute scan | T2* EPI 30 second scan

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

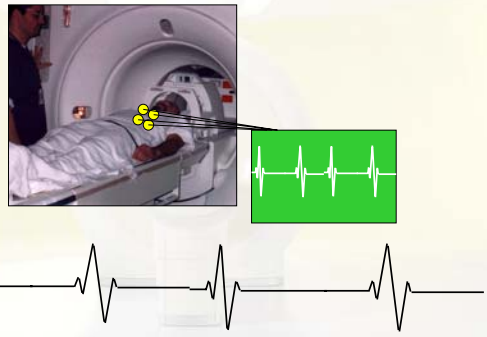


Timing Diagram



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

ECG



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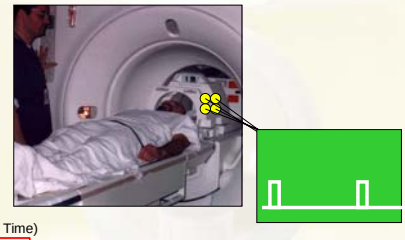
What is this?



TR (Repetition Time)

90^0 90^0

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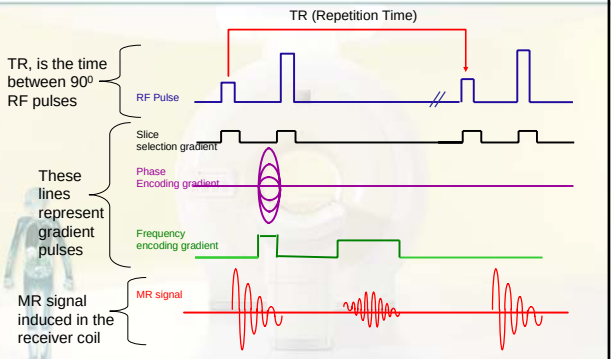
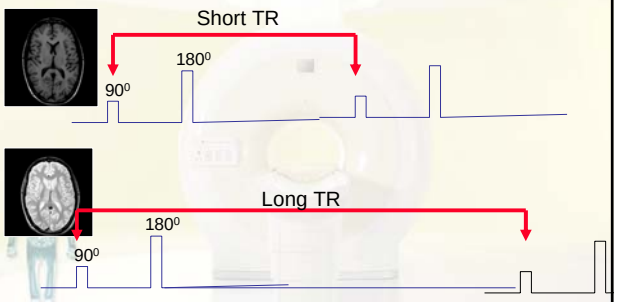
Timing Diagram



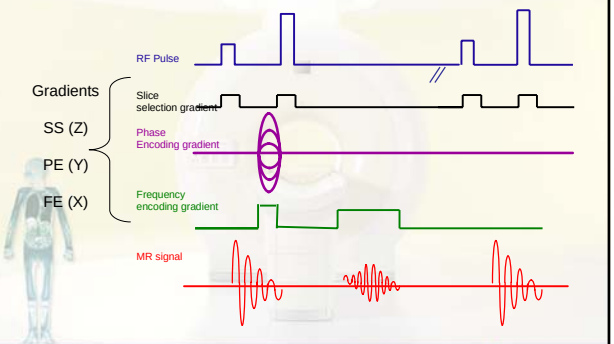
Slide # 9

Short TR & Long TR Imaging



Slide # 10

Timing Diagrams - Gradients



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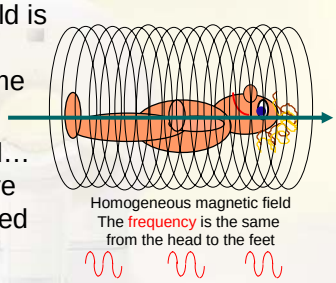
Slice Selection

- 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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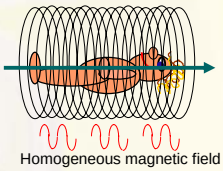
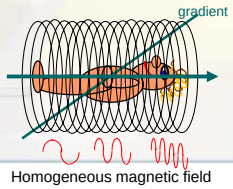
Selective Excitation

- 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



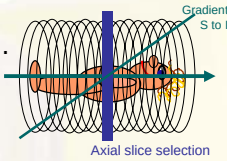
Homogeneous magnetic field



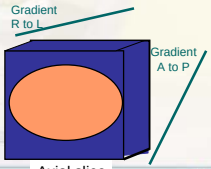
Homogeneous magnetic field
With a linear gradient field applied

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

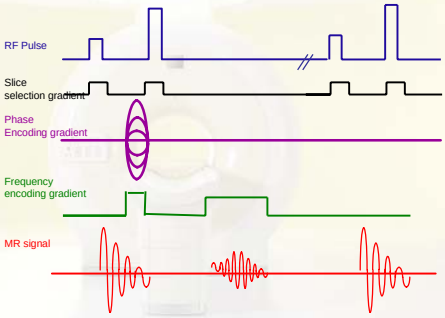


Axial slice selection

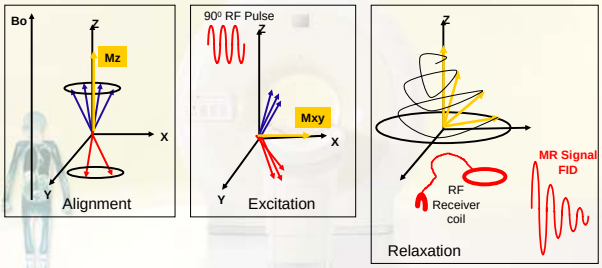


Axial slice

Timing Diagram- Signal



MR Excitation Relaxation



Timing Diagram - TE

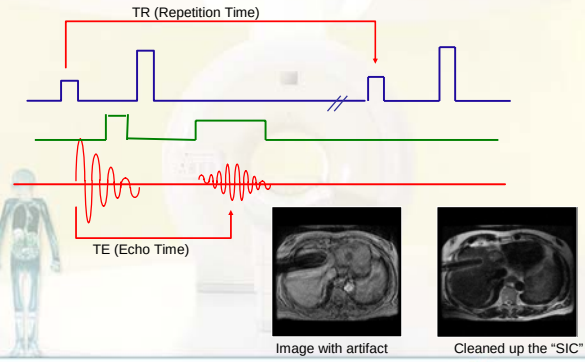
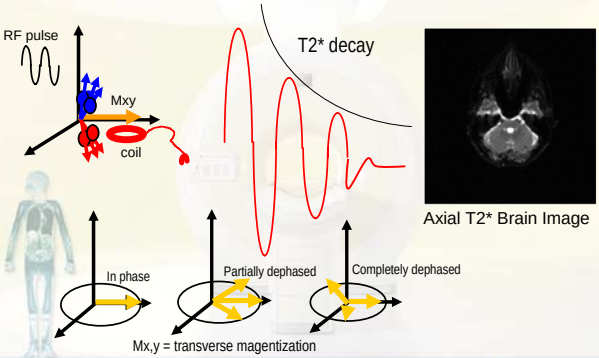


Image with artifact

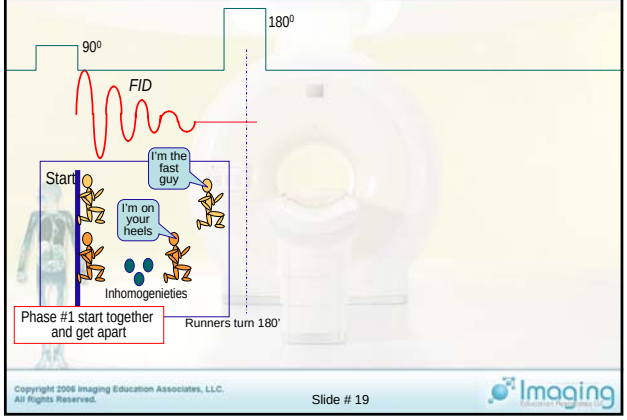
Cleaned up the "SIC"

T2* Decay



Axial T2* Brain Image

Runners on the Race



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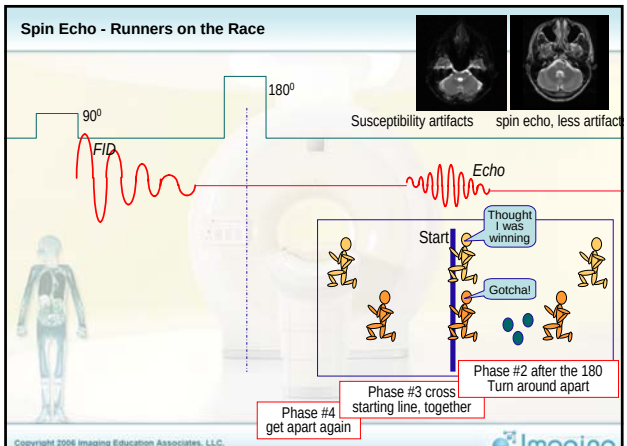
Spin Echo - Runners on the Race



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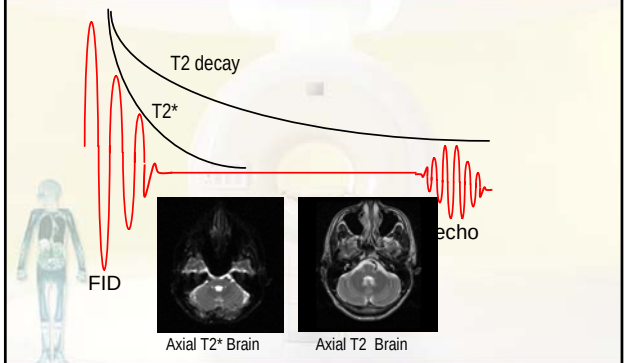
T2* and T2 Decay



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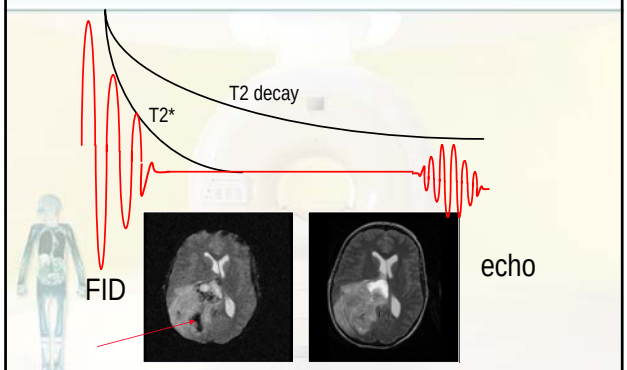
Is Susceptibility artifact always a bad thing?



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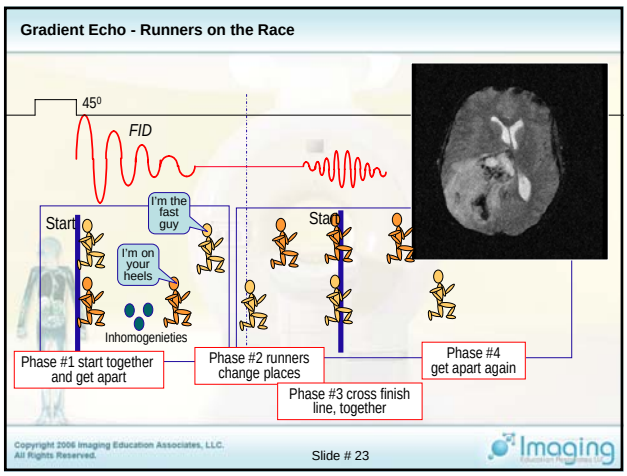
Gradient Echo - Runners on the Race



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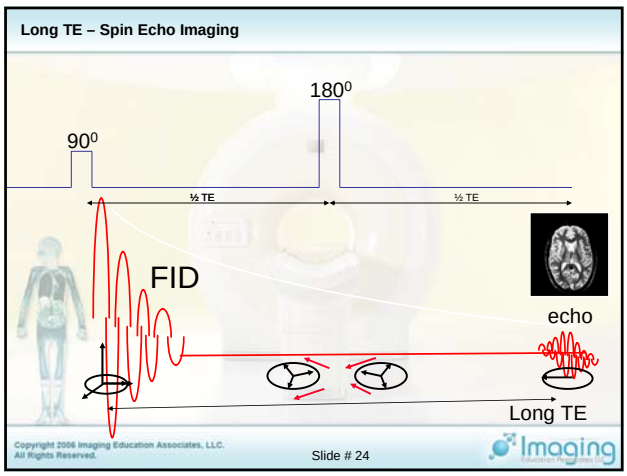
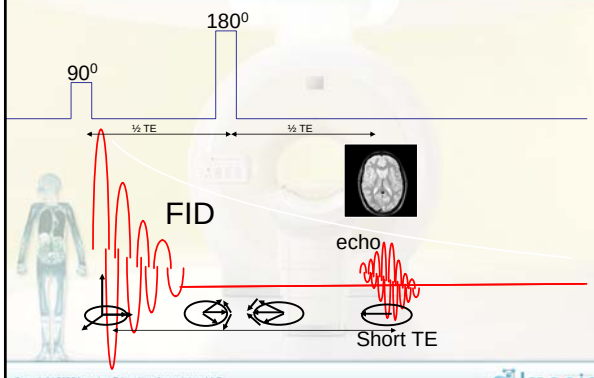
Long TE – Spin Echo Imaging



Slide # 24

Short TE – Spin Echo Imaging



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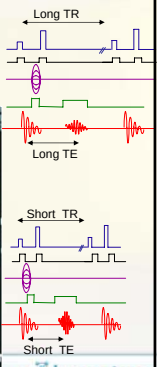
A Few Fun Facts about T1 & T2

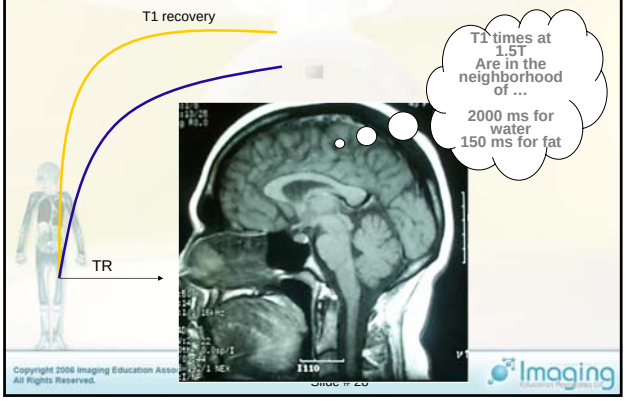
We cannot change…. T1 recovery T2 decay unless we change Field strength Temperature or Add contrast agents!

A Few Fun Facts about TR & TE



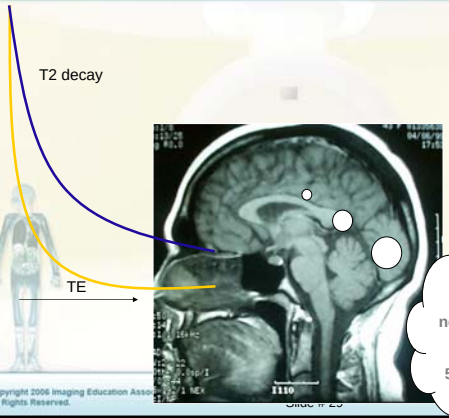
We can change TR & TE And… TR goes with T1 TE goes with T2

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

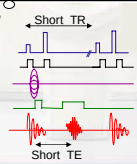
T2 times at 1.5T Are in the neighborhood of … 200 ms for water 50 ms for fat

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

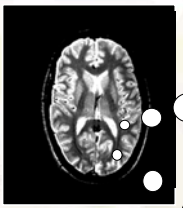
T2 times at 1.5T Are in the neighborhood of … 200 ms for water 50 ms for fat

Slide # 31
Imaging

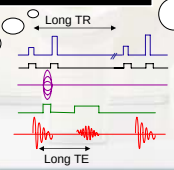
Let's make a T2 image

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

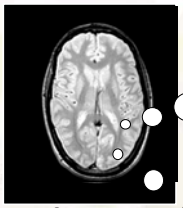
T2 times at 1.5T Are in the neighborhood of … 200 ms for water 50 ms for fat

Slide # 32
Imaging

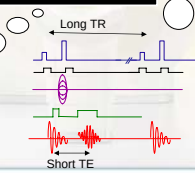
Let's make a PD image

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



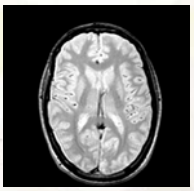
We can change TR & TE And… TR goes with T1 TE goes with T2

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

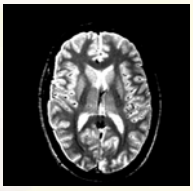
Slide # 33
Imaging

Image Contrast Parameters

T1WI
Short TR
Short TE
Bright fat, short T1 time



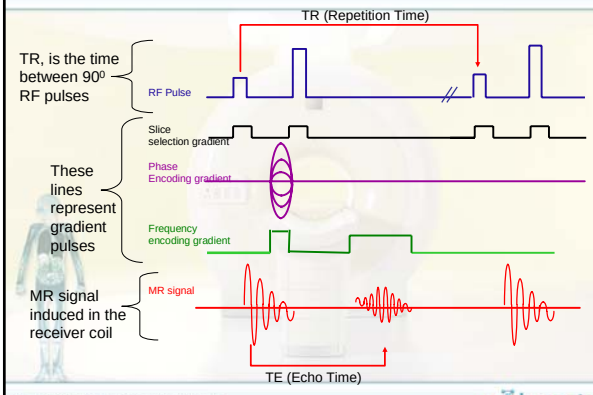
PDWI
Long TR
Short TE
Bright fat & water



T2WI
Long TR
Long TE
Bright water, long T2 time

Slide # 34
Imaging

Timing Diagram – RF and Gradient Pulses



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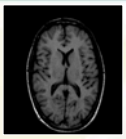
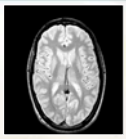
Imaging

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

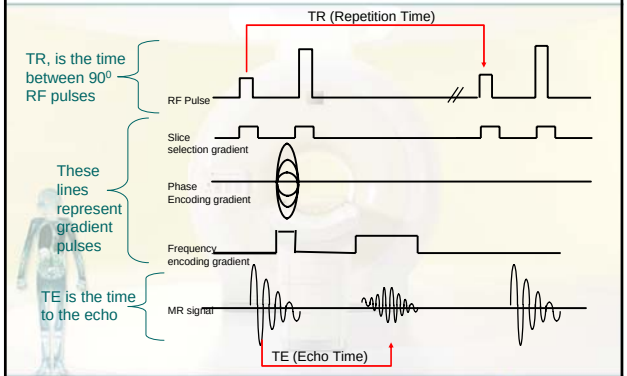
Gradient echo family

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

Slide # 36
Imaging

Timing Diagram – Spin Echo



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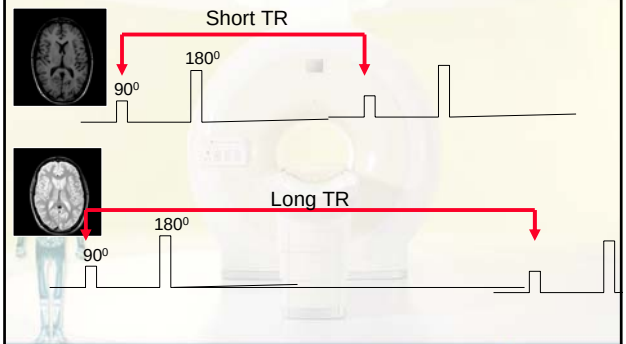
Short TR & Long TR Imaging



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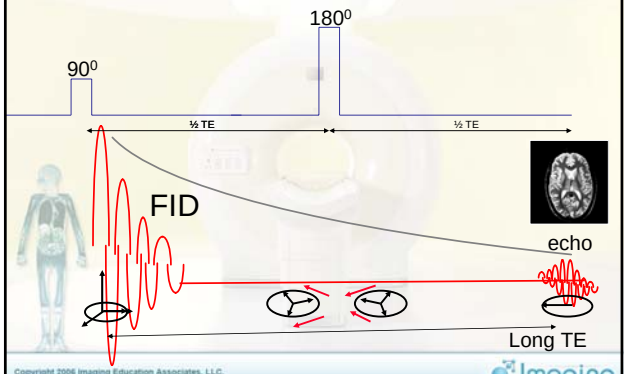
Long TE – Spin Echo Imaging



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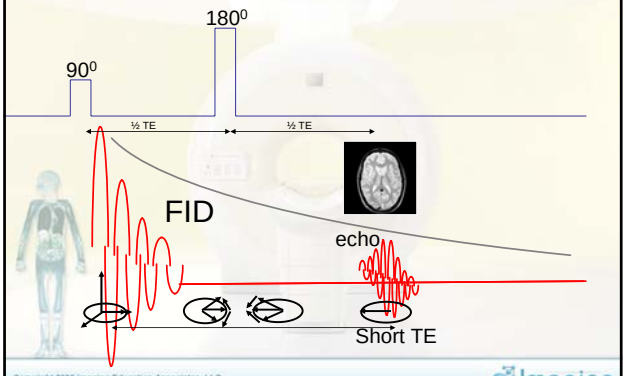
Short TE – Spin Echo Imaging



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Dual Echo Imaging (2 for 1)

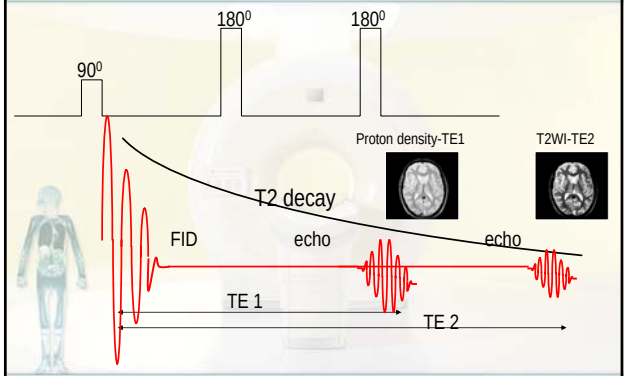

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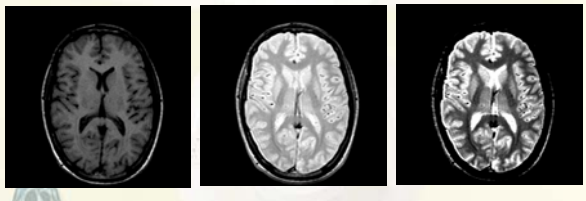
Image Contrast Parameters



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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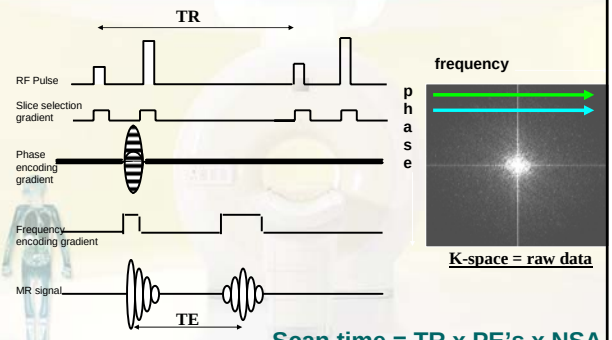
Outline

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

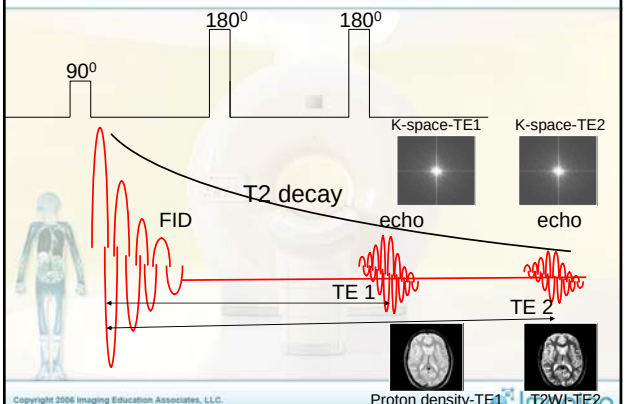
Spin Echo Timing Diagram & K-space



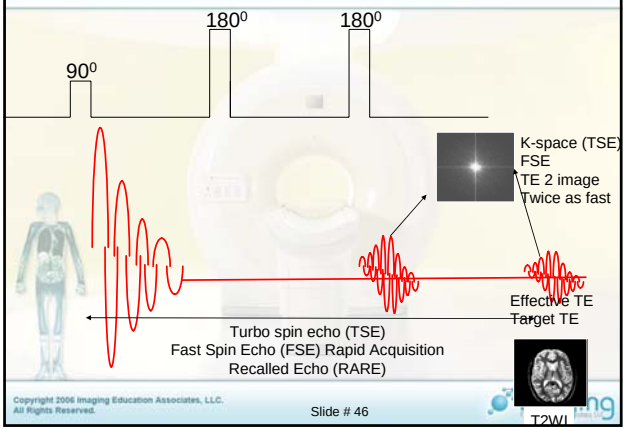
K-space = raw data

Scan time = TR x PE's x NSA

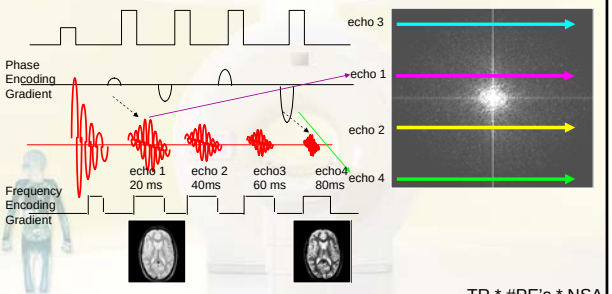
Dual Echo Imaging & K-space



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

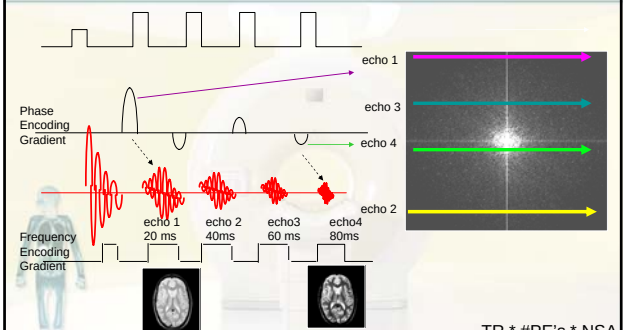


Fast Spin Echo Imaging for PDWI



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)

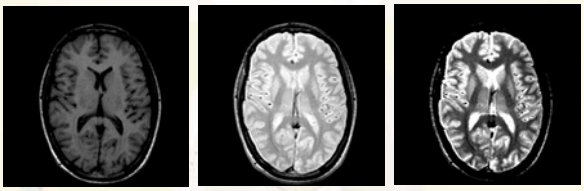
Abnormalities seen on Ultrasound

FDA OK for pregnancy if… benefit outweighs the risk

If mommy fits

Fetal MRI

Image Contrast Parameters - fast spin echo



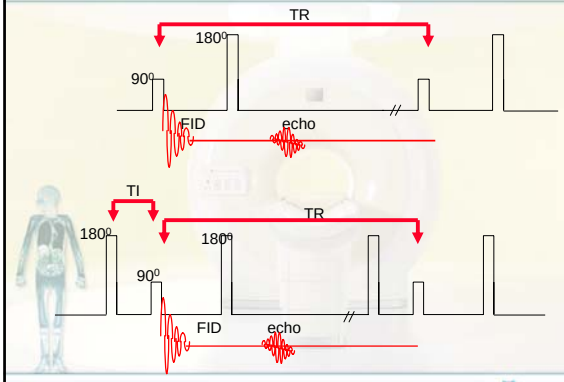
T1WI	PDWI	T2WI
@ 1.5T	@ 1.5T	@ 1.5T
Short TR (500 ms)	Long TR (4000 ms = 4 seconds)	Long TR (4000 ms = 4 seconds)
Short TE (20 ms or less)	Short TE (20 ms or less)	Long TE (100 ms)
Bright fat	Bright fat & water	Bright water
Scan time about 1 minute	Scan time about 8.5 minutes	Scan time about 8.5 minutes
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

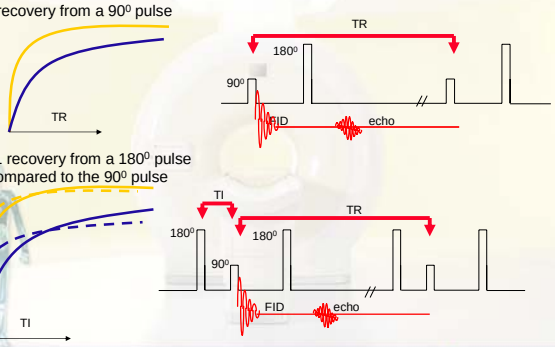
- Timing diagrams
- What is a pulse sequence?
- What is a spin echo?
- Review Spin Echo & Fast spin echo
- Inversion Recovery & Fast IR
- Gradient Echo

Spin Echo vs Inversion Recovery

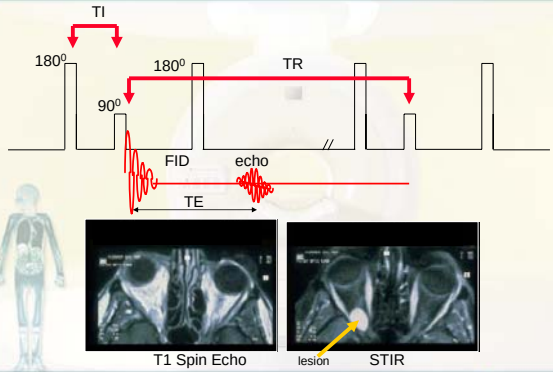


Why an initializing 180⁰ pulse

T1 recovery from a 90⁰ pulse

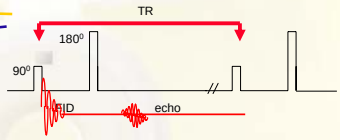


Inversion Recovery – STIR (Short Tau Inversion Recovery)

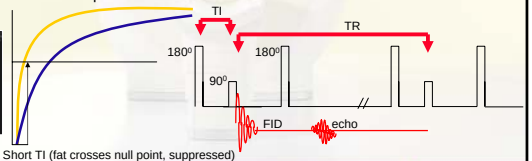


Why an initializing 180⁰ pulse

T1 recovery from a 90⁰ pulse



T1 recovery from a 180⁰ pulse
Compared to the 90⁰ pulse



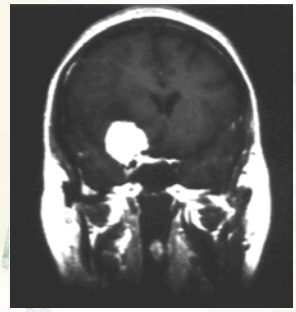
Bone contusion

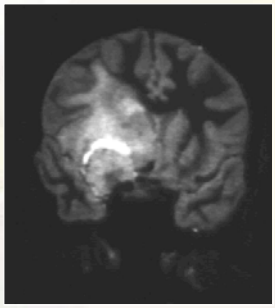
Short TI (fat crosses null point, suppressed)

Slide # 55

Imaging

STIR is NOT fatsat





STIR will suppress gadolinium enhancing lesions

Slide # 56

Imaging

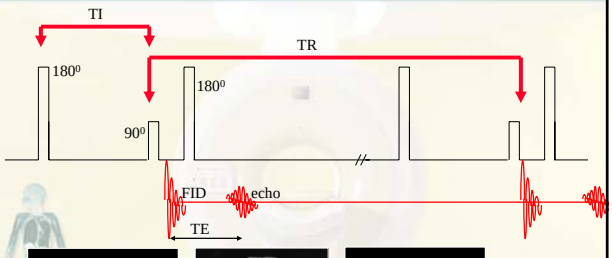
FATSAT FSE vs STIR

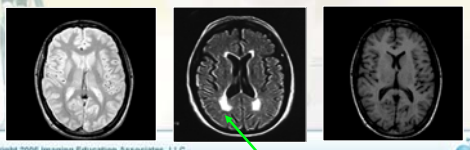
FSE *STIR*

Slide # 57

Imaging

Inversion Recovery – FLAIR (Fluid Attenuated Inversion Recovery)





PD *FLAIR* *T1*

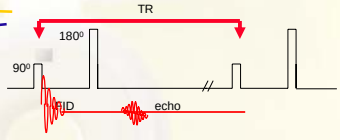
Slide # 58

Imaging

Why an initializing 180⁰ pulse

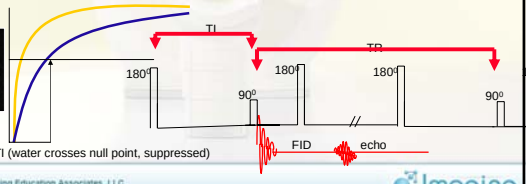
T1 recovery from a 90⁰ pulse

T1SE



T1 recovery from a 180⁰ pulse
Compared to the 90⁰ pulse

FLAIR



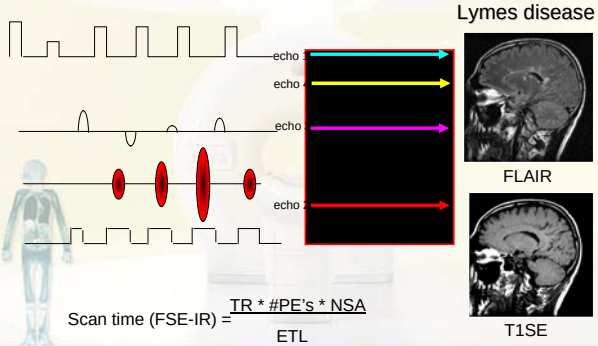
Long TI (water crosses null point, suppressed)

Slide # 59

Imaging

Fast Inversion Recovery – scan time

Lymes disease



FLAIR

T1SE

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

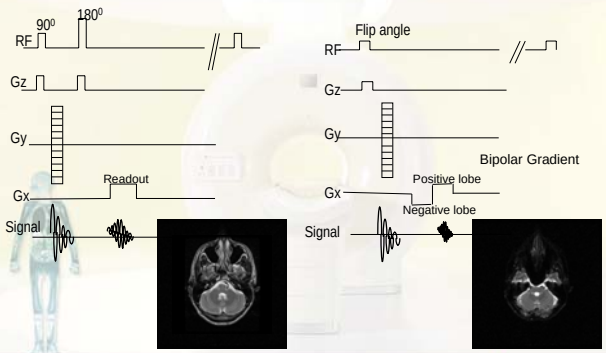
Slide # 60

Imaging

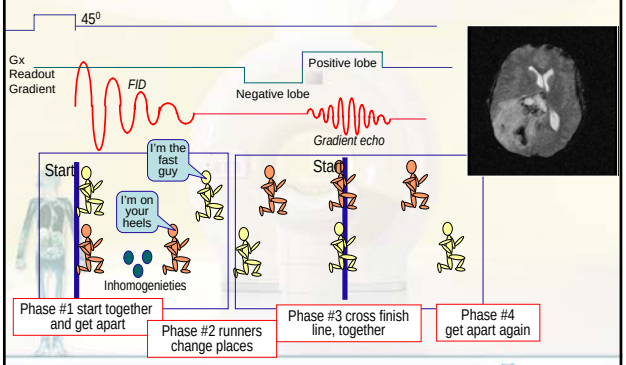
Outline

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

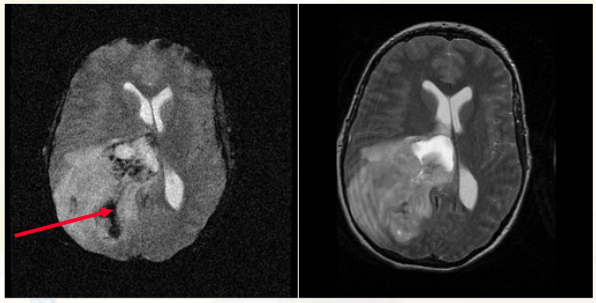
Spin Echo vs Gradient Echo



Gradient Echo – runners on the race



Susceptibility Artifacts on Gradient Echo



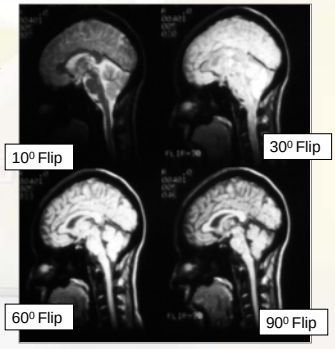
Axial T2* Brain

Axial T2 Brain

Flip Angle and Image Contrast

Flip angle goes with TR
TR goes with T1

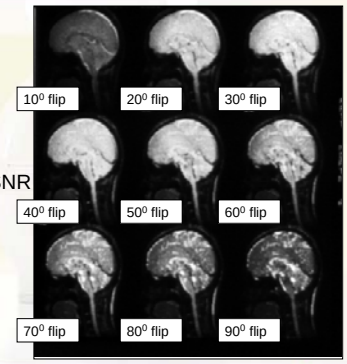
Big flip, more T1
Little flip, less T1



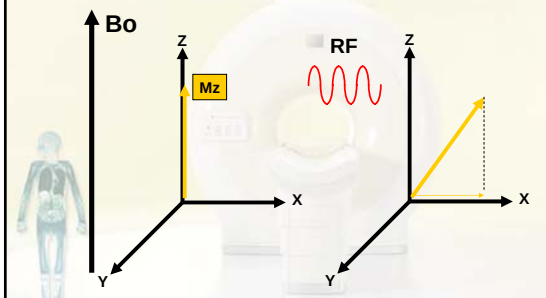
Flip Angle and Signal Quality (SNR)

As Flip increases
SNR increases
To a point

Ernst Angle
angle for optimum SNR

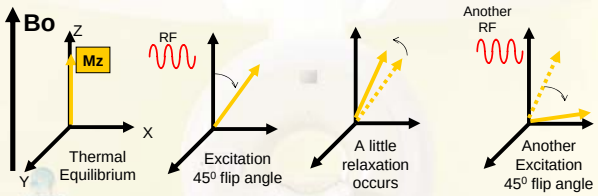


Flip angle



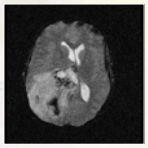
Slide # 67
Imaging

Steady State



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

Transverse magnetization
SS images demonstrate T2* effects
Bright fluid



Slide # 68
Imaging

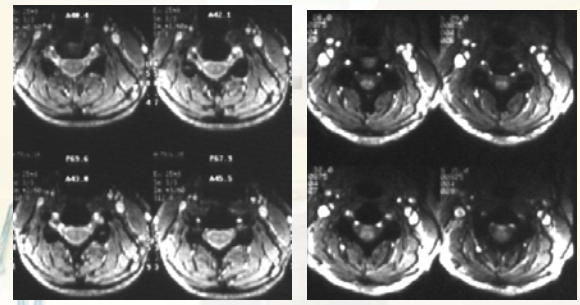
Steady State Imaging

FIESTA – IAC's
Fast Imaging Employing a steady STAte

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

Slide # 69
Courtesy of: Mumtaz Pasha
Imaging

Steady State VS Spoiled Gradient Echoes

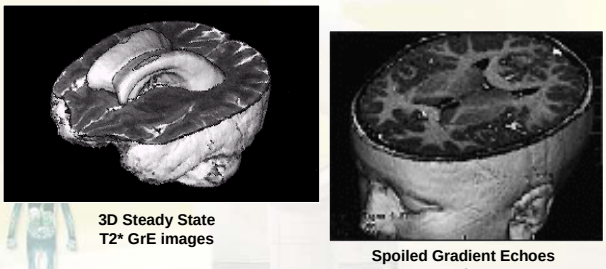


Steady State
T2* FFE
Coherent Gradient Echo

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

Slide # 70
Imaging

3D Steady State vs 3D Spoiled Gradient Echoes

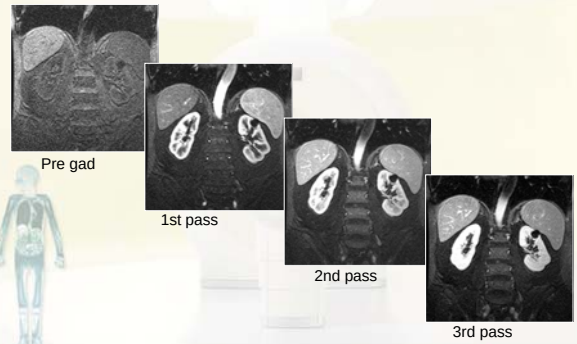


3D Steady State
T2* GrE images

Spoiled Gradient Echoes
T1 GrE images

Slide # 71
Imaging

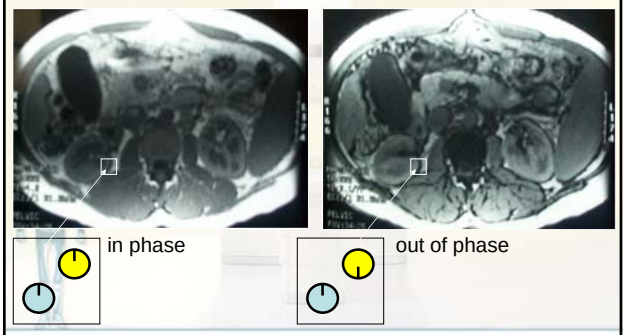
Dynamic Enhanced (T1) Spoiled Gradient Echoes



Pre gad
1st pass
2nd pass
3rd pass

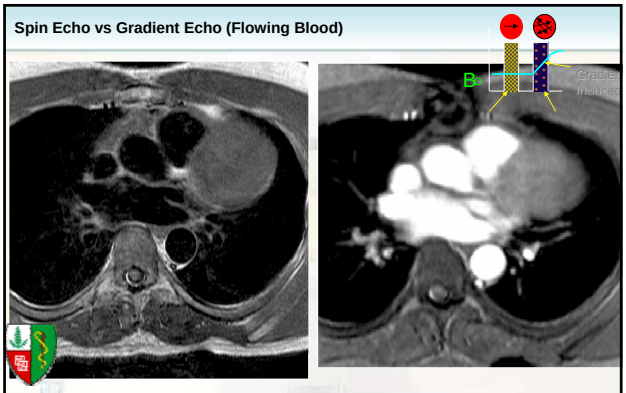
Slide # 72
Imaging

Chemical Shift Artifact on Gradient Echoes



Slide # 73

Spin Echo vs Gradient Echo (Flowing Blood)

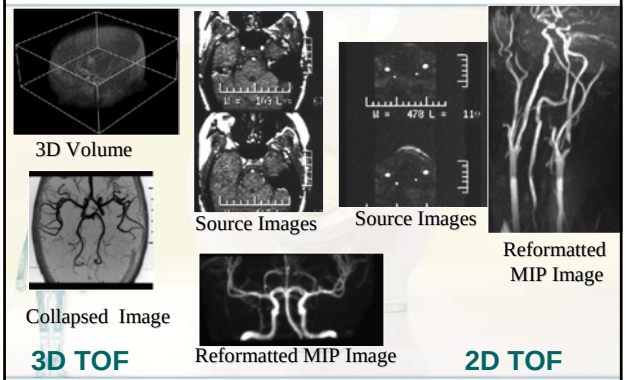


Slide # 74

Cardiac Perfusion

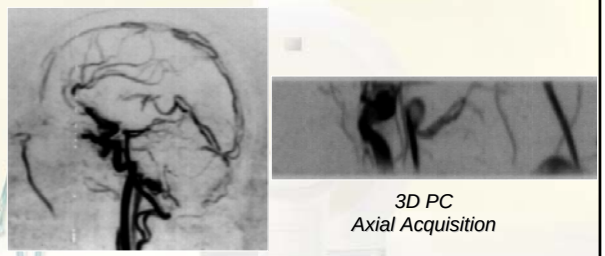
Slide # 75

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



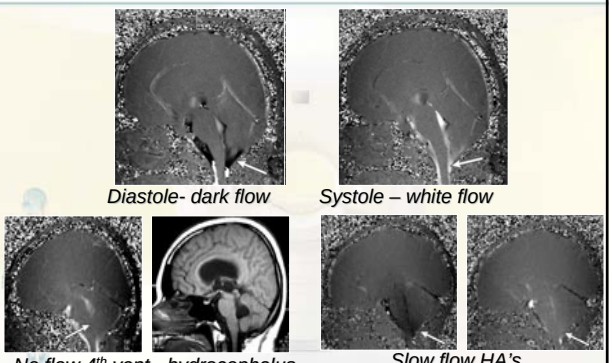
Slide # 76

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



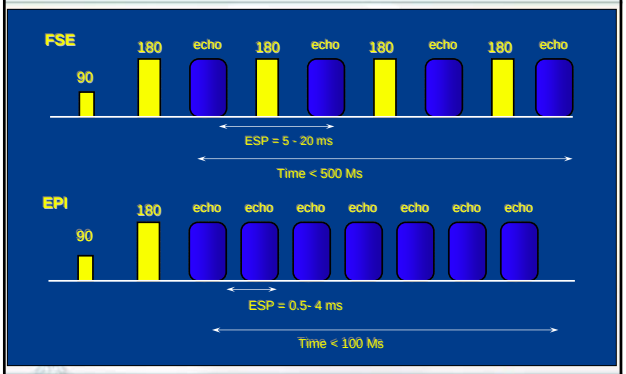
Slide # 77

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



Slide # 78

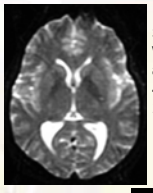
EPI Speed Compared to FSE



Slide # 79

Single-Shot vs. Multi Shot EPI

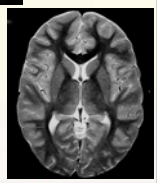
- **Single-Shot** EPI fills all lines of k-space in a single TR period
- Fastest Scan Times
- Most useful for functional imaging techniques



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



Slide # 80

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

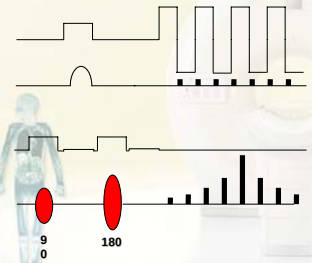
Tissue Sample A
Normal Diffusion

Tissue Sample B
Restricted Diffusion

Edema results in restricted diffusion

Slide # 81

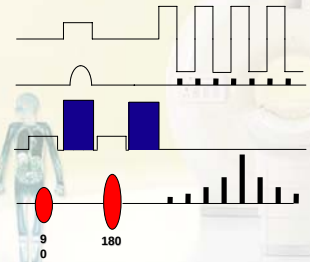
b-value = 0

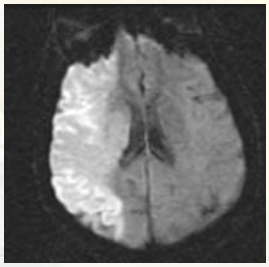


T2-weighted Image
(b-value = 0)

Slide # 82

b-value = 1000





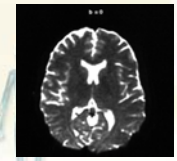
Diffusion-weighted Image
(b-value = 1000)

Slide # 83

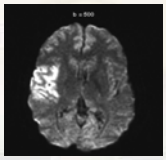
Diffusion Weighting and b-value

b-value determines the strength of the diffusion gradients

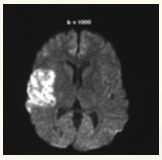
Increasing the b-value increased diffusion weighting



b-value = 0



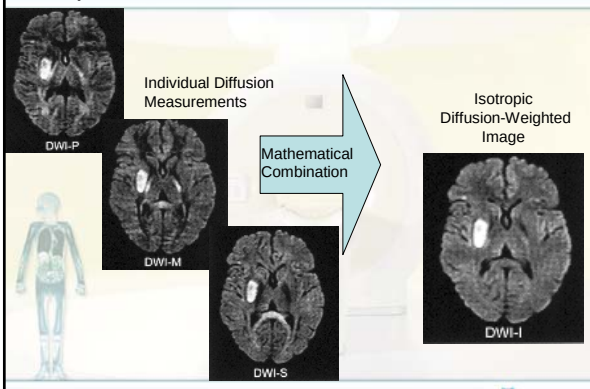
b-value = 500



b-value = 1000

Slide # 84

Isotropic Diffusion



Slide # 85
Imaging

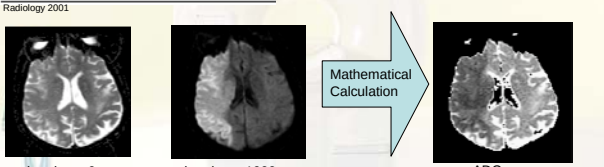
Apparent Diffusion Coefficient (ADC)

ADC expresses the amount of diffusion

Tissue	ADC_1 (μm^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"**



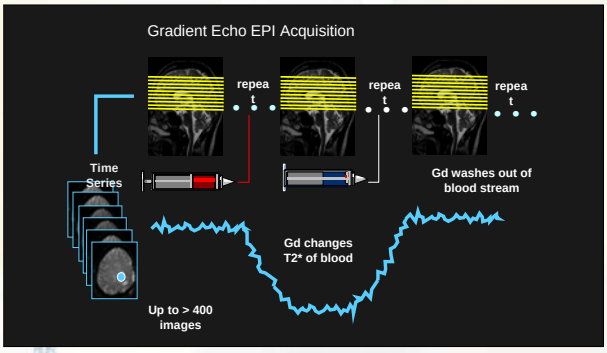
b-value = 0
T2-weighted

b-value = 1000
Diffusion-weighted + T2

ADC map
Reduced ADC = Reduced Signal

Slide # 86
Imaging

Perfusion Acquisition

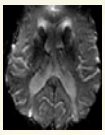


Slide # 87
Imaging

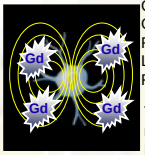
Perfusion Contrast

Small Magnetic Field Gradient

Brain Cell

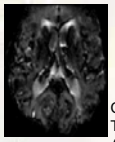


Gradient Echo EPI
TE = 60



Concentrated Gadolinium Results in a Larger Magnetic Field Gradient

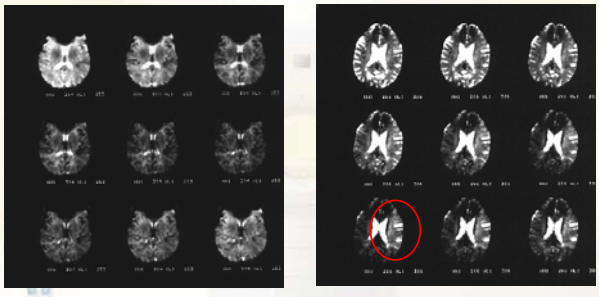
T2* shortening results in loss of MR signal



Gradient Echo EPI
TE = 60
Acquired at Peak Bolus

Slide # 88
Imaging

Perfusion of Stroke



Normal

Abnormal

Slide # 89
Imaging

BOLD (fMRI)

Blood **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

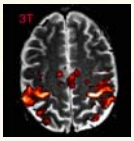


Image courtesy Stanford University

Slide # 90
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

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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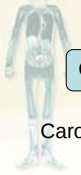

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