4.1 Principles of MRI

Nuclei, Excitation, Relaxation

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Outline

- What nuclei are MR active?
  - Hydrogen (fat & water)
  - Other Nuclei
- Why are they MR active?
  - Mass Number
- How do they behave in the magnet?
- Excitation
  - RF excitation
- Radiofrequency Pulses
  - Larmor Frequency
- Relaxation
  - T1
  - T2

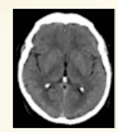
Objectives

Upon completion of this course, the attendee should…

1. **Learn the various nuclei that are MR active**
2. **Understand why certain nuclei are MR active**
3. **Realize how nuclei behave in the presence of the magnetic field.**
4. **Understand Excitation**
5. **Understand Relaxation**
6. **Learn T1 & T2 weighted imaging**

What Do We Image?

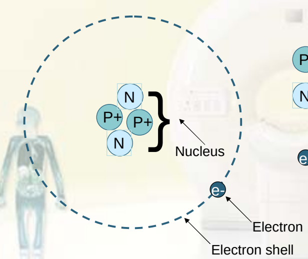
- What do we image … with CT?
  - Soft tissues?
  - Bones?
- What do we image with MRI?
  - Soft tissues?
  - Bones?



Axial CT

T1 PD T2

What's in an Atom?



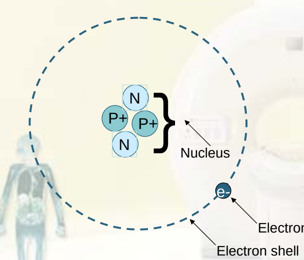
Atoms have a nucleus

- P+ Protons (+ positive charge)
- N Neutrons (neutral)

Orbiting the nucleus

- e- Electrons (- negative charge)

The Nucleus, What Counts?



Mass Number

- P+ Number of Protons
- Plus (+)
- N Number of Neutrons

Atomic Number

- P+ Number of Protons

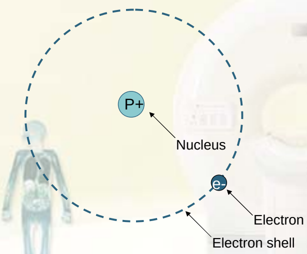
What Elements are MR Active?

- **Periodic Table**
  Elements
  Unique Atomic Structure
- **Odd Mass Number**
  Hydrogen
  Phosphorous
  Others?

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Unq	105 Unp	106 Unh	107 Uns	108 Uno	109 Une	110 Unn								

58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

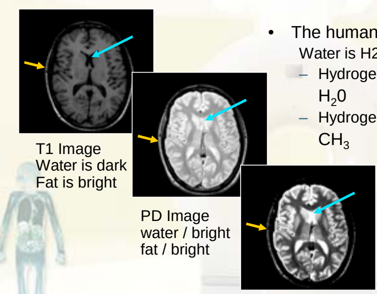
Proton Imaging



Mass Number
- P+ Number of Protons
  Plus (+)
- N Number of Neutrons
  = 1

Atomic Number
- P+ Number of Protons
  = 1

Hydrogen Imaging

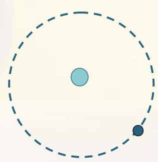


T1 Image
Water is dark
Fat is bright

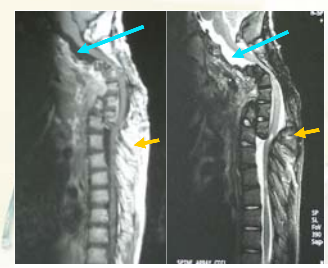
PD Image
water / bright
fat / bright

T2 Image
water /bright
fat / darker

- The human body is roughly 75% water
  Water is H20
  - Hydrogen in Water
    H_20
  - Hydrogen in Fat
    CH_3



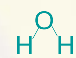
Why do fat & water appear differently?



Sagittal Cervical & Thoracic Spine
T1 Image
Fat is bright
Water is dark

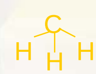
T2 Image
Fat is bright
Water is dark

- Hydrogen in Water



Water Molecule
H_2O

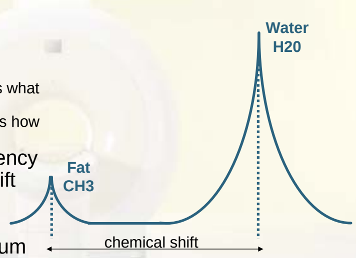
- Hydrogen in Fat



Fat Molecule
CH_3

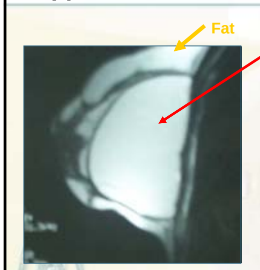
Before there was imaging… Spectroscopy

- Each chemical has a different Frequency like (fat & water)
  - The location of the peak tells what chemical
  - The area under the peak tells how much of that chemical
- The difference in frequency is known as Chemical Shift
- MR Spectrum displays Chemical Shift
- The study of the spectrum is known as Spectroscopy

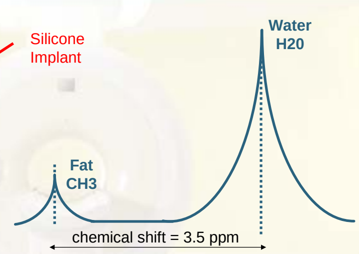


MR Spectrum

Suppression of fat and/or water…

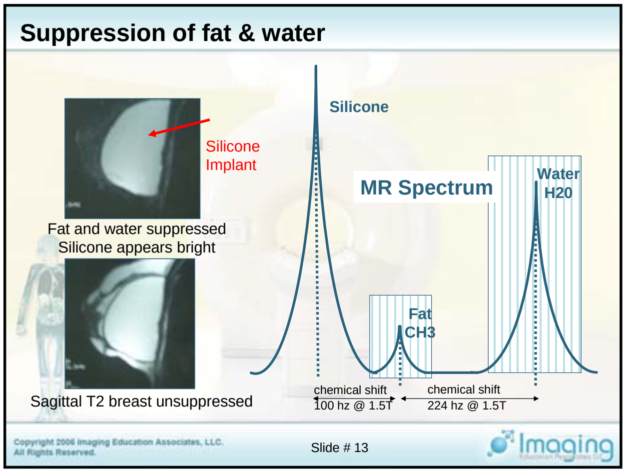


Sagittal T2 breast unsuppressed



MR Spectrum

3.5 ppm…	@ 1.5T = 220 H @ 3.0T = 440 Hz @ 0.3T = 73 Hz


Suppression of fat & water
Silicone
Implant
Fat and water suppressed
Silicone appears bright
Sagittal T2 breast unsuppressed
Silicone
MR Spectrum
Water
H20
Fat
CH3
chemical shift
100 hz @ 1.5T
chemical shift
224 hz @ 1.5T
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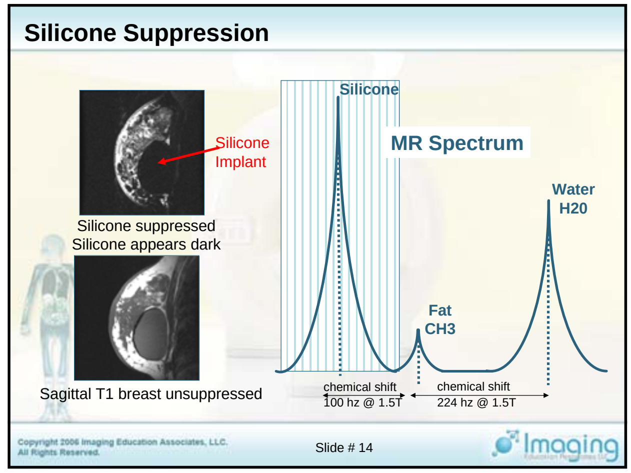
Imaging


Silicone Suppression
Silicone
Implant
Silicone suppressed
Silicone appears dark
Sagittal T1 breast unsuppressed
Silicone
MR Spectrum
Water
H20
Fat
CH3
chemical shift
100 hz @ 1.5T
chemical shift
224 hz @ 1.5T
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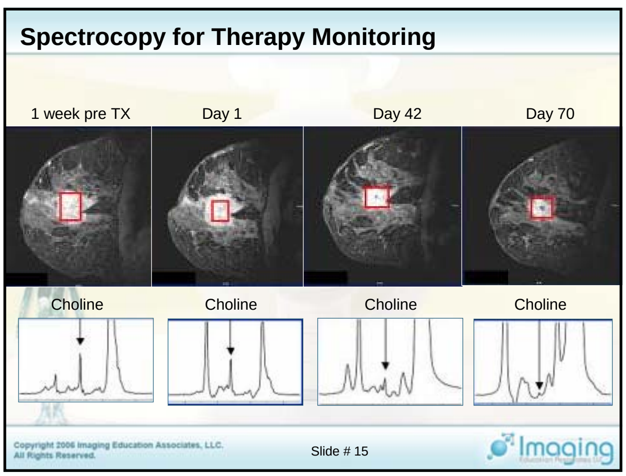
Spectrocopy for Therapy Monitoring
1 week pre TX
Day 1
Day 42
Day 70
Choline
Choline
Choline
Choline
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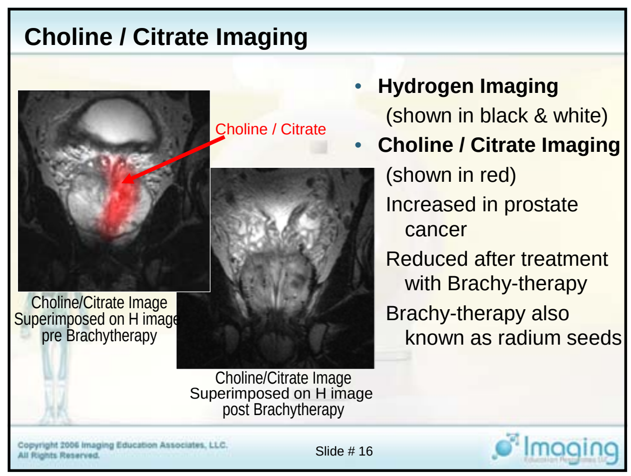
Choline / Citrate Imaging
Choline / Citrate
Choline/Citrate Image
Superimposed on H image
pre Brachytherapy
Choline/Citrate Image
Superimposed on H image
post Brachytherapy
• Hydrogen Imaging
(shown in black & white)
• Choline / Citrate Imaging
(shown in red)
Increased in prostate cancer
Reduced after treatment with Brachy-therapy
Brachy-therapy also known as radium seeds
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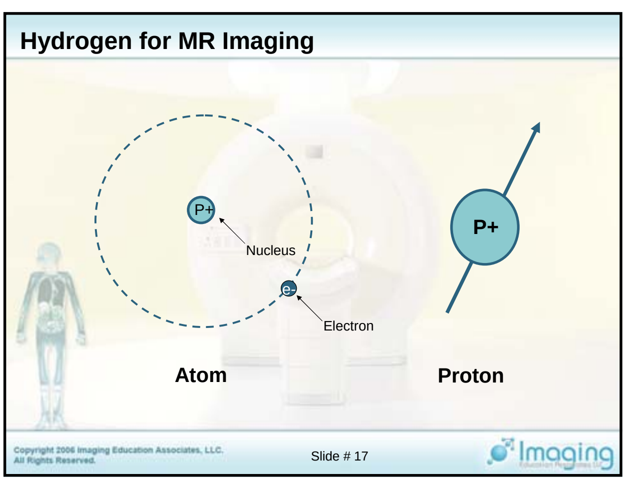
Hydrogen for MR Imaging
P+
Nucleus
e-
Electron
Atom
P+
Proton
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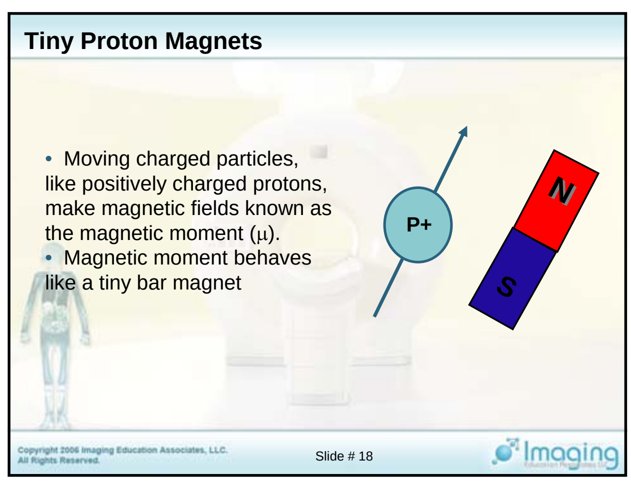
Tiny Proton Magnets
• Moving charged particles, like positively charged protons, make magnetic fields known as the magnetic moment (μ).
• Magnetic moment behaves like a tiny bar magnet
P+
N
S
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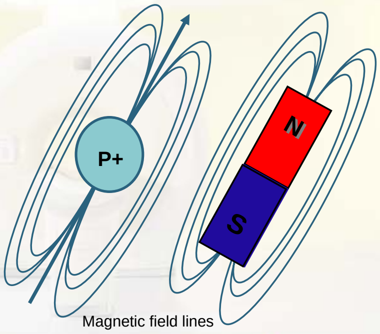
The Magnetic Moment

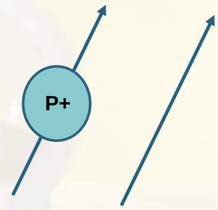
- Bipolar magnets
  - •Magnetic moments
  - •Bar magnets
- Two Poles
  - •North pole
  - •South pole
- Magnetic field lines run from the south pole to the north pole



Magnetic field lines

Vector… Magnetic Moment

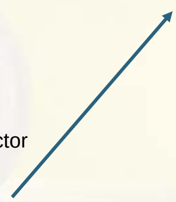
- The magnetic moment is represented by a vector



Vector represents magnetic moment (μ).

Review Vectors

- The vector has two properties
  - Magnitude
    - the length of the vector
  - Direction
    - the "direction" to which it points
- •The vector can be added to another vector

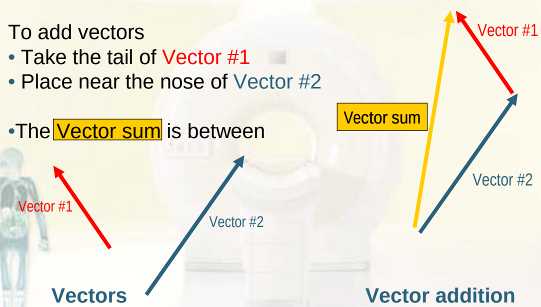


Vector

Vector Addition

To add vectors
- Take the tail of Vector #1
- Place near the nose of Vector #2

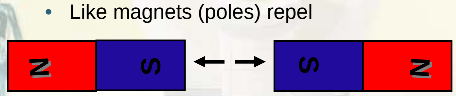
•The Vector sum is between



Magnet to Magnet

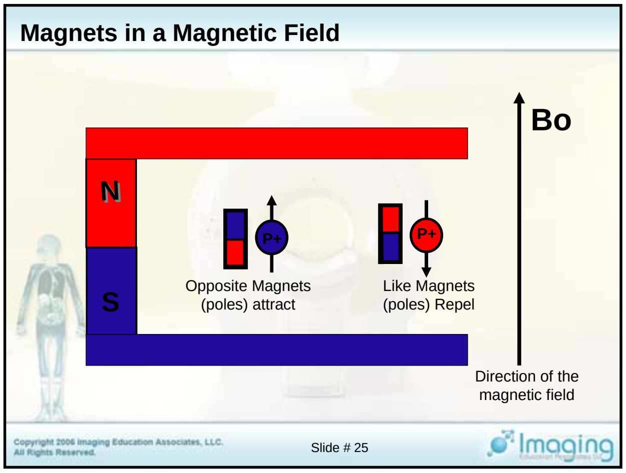
What happens when two magnets are together
- Opposite Magnets (poles) attract

- Like magnets (poles) repel



Outline

- What nuclei are MR active?
  - Hydrogen (fat & water)
  - Other Nuclei
- Why are they MR active?
  - Mass Number
- How do they behave in the magnet?
- Excitation
  - RF excitation
- Radiofrequency Pulses
  - Larmor Frequency
- Relaxation
  - -T1
  - -T2


Magnets in a Magnetic Field
Bo
N
S
P+
P+
Opposite Magnets (poles) attract
Like Magnets (poles) Repel
Direction of the magnetic field
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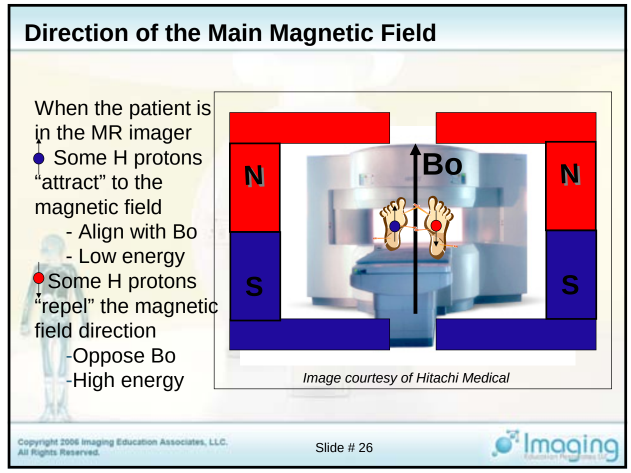
Direction of the Main Magnetic Field
When the patient is in the MR imager
Some H protons "attract" to the magnetic field
- Align with Bo
- Low energy
Some H protons "repel" the magnetic field direction
-Oppose Bo
-High energy
Bo
N
S
N
S
Image courtesy of Hitachi Medical
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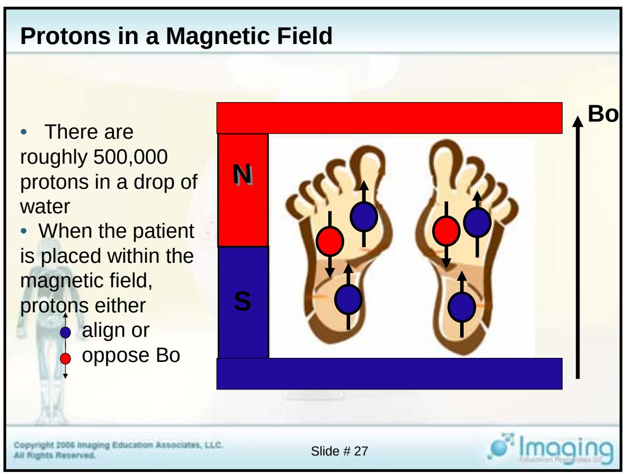
Protons in a Magnetic Field
• There are roughly 500,000 protons in a drop of water
• When the patient is placed within the magnetic field, protons either
align or
oppose Bo
Bo
N
S
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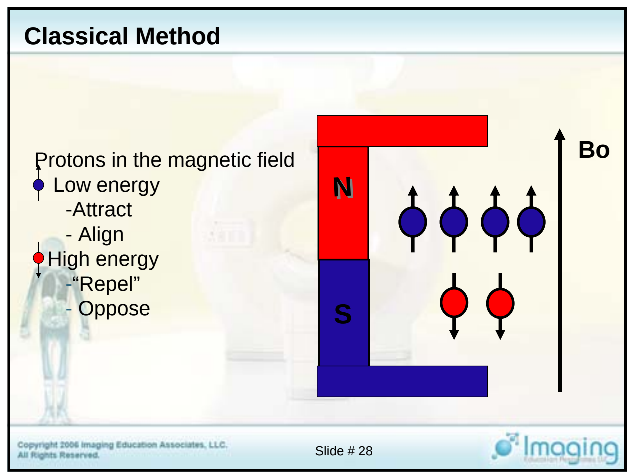
Classical Method
Protons in the magnetic field
Low energy
-Attract
- Align
High energy
-"Repel"
- Oppose
N
S
Bo
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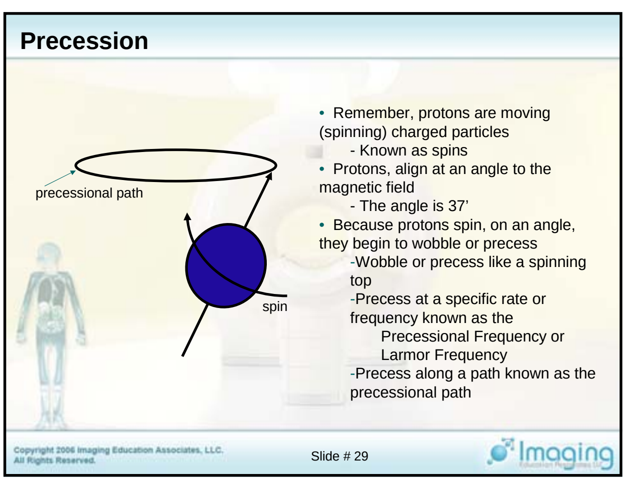
Precession
precessional path
spin
• Remember, protons are moving (spinning) charged particles
- Known as spins
• Protons, align at an angle to the magnetic field
- The angle is 37'
• Because protons spin, on an angle, they begin to wobble or precess
-Wobble or precess like a spinning top
-Precess at a specific rate or frequency known as the
Precessional Frequency or
Larmor Frequency
-Precess along a path known as the precessional path
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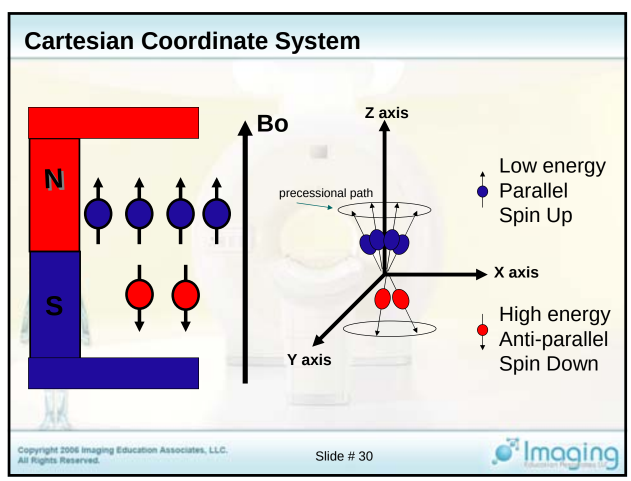
Cartesian Coordinate System
N
S
Bo
Z axis
precessional path
X axis
Y axis
Low energy
Parallel
Spin Up
High energy
Anti-parallel
Spin Down
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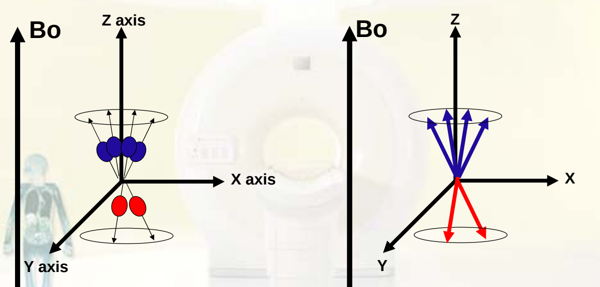
Protons to Vectors



Protons are replaced by vectors on the Cartesian coordinates

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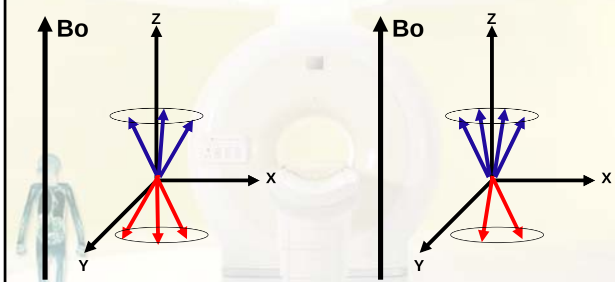
Thermal Equilibrium



Immediately after the patient is placed within the magnetic field, there are an even number of spins in the high & low energy states

After a few seconds, there are more spins in the low energy state. This condition is known as thermal equilibrium

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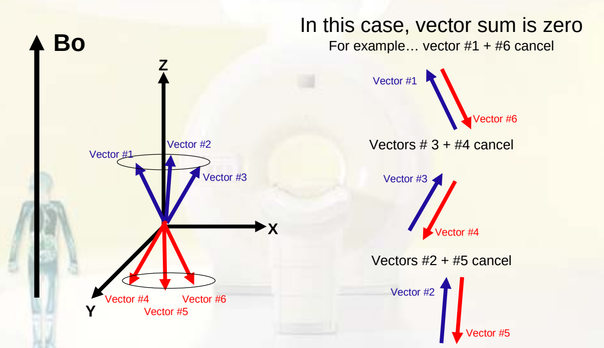
Vector Sum



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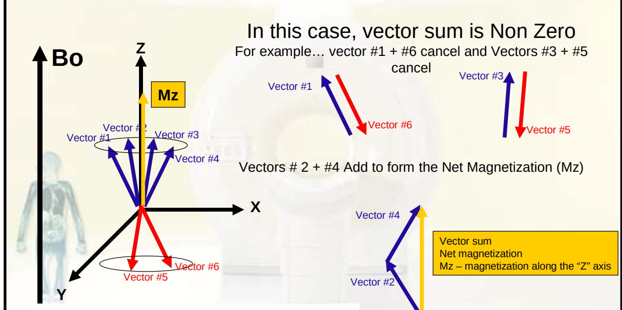
Net Magnetization (Mz)



The net magnetization is responsible for MR images

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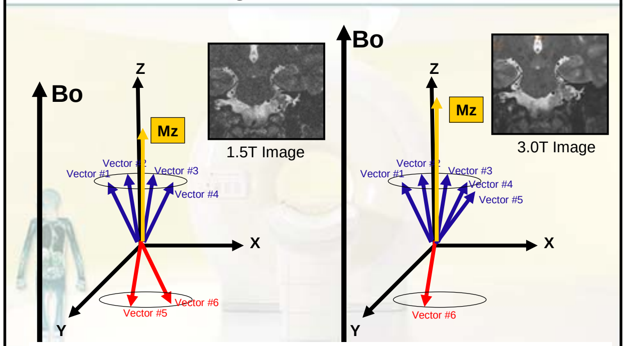
Mz and Field Strength



As field strength increases, more spins in line, greater net magnetization, higher image signal.

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Outline

- What nuclei are MR active?
  - Hydrogen (fat & water)
  - Other Nuclei
- Why are they MR active?
  - Mass Number
- How do they behave in the magnet?
- Excitation
  - RF excitation
- Radiofrequency Pulses
  - Larmor Frequency
- Relaxation
  - T1
  - T2

Imaging

How is excitation achieved?

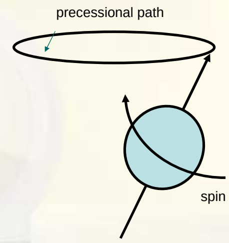
- Alignment
  - –Protons in the magnetic field
  - –Thermal equilibrium
- RF Pulse
  - –Larmor Frequency
- Resonance

Precession

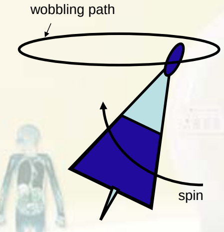
- Remember, protons are moving (spinning) charged particles, Known as spins
- Protons, align at an angle to the magnetic field
- Because protons spin, on an angle, they begin to wobble or precess
  - -Wobble or precess like a spinning top
  - -Precess at a specific rate, or frequency known as the

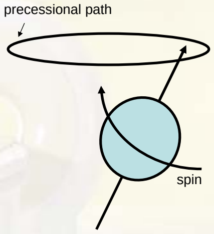
Precessional Frequency or the Larmor Frequency

- This frequency describes the energy that keeps the spins in thermal equilibrium
- It is this energy that can "knock" the spins from thermal equilibrium (excite the spins)



Wobbling Top & Precession





A Top wobbles because of
- •The weight of the top
- •The rate of spin (how fast it spins)
- The gravity of the earth

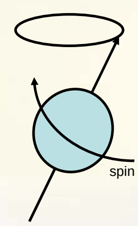
A proton precessses (in the magnet) because of
- The magnetic moment of the proton
- The rate of spin (spin angular momentum)
- The magnetic field strength

Precessional frequency

- We can determine the energy required to "excite" the spins
- In order to calculate this energy we need several components
  - •The magnetic moment of the proton
  - •The spin angular momentum of the proton
  - •The field strength of the magnet

Precessional Frequency

- This frequency describes the energy that keep the spins in thermal equilibrium
- It is this energy that can "knock" the spins from thermal equilibrium



Larmor Frequency

In order to calculate the precessional (Larmor) frequency
- •The magnetic moment of the proton
- •The spin angular momentum of the proton

Gyro-magnetic ratio = γ
Magneto-gyric ratio = γ

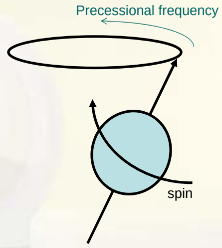
- •The field strength of the magnet

Magnetic field strength = Bo

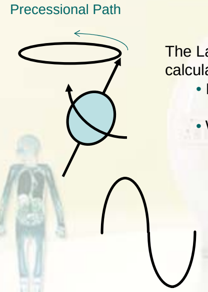
This is known as the Larmor equation

$$\omega_o = B_o \gamma$$

Larmor or Precessional Frequency = ω_o
Magnetic field strength = B_o
Gyro-magnetic ratio = γ
Magneto-gyric ratio = γ



Units of Measure for Frequency



The Larmor Equation calculates the precessional frequency
- Precessional Frequency or Larmor frequency
  - - The rate at which the spins wobble, or precess
- Wobble or precess in cycles per second
  - -One cycle is once around the processional path
  - -One cycle is one sine wave
  - -One cycle per second = I Hertz (Hz)
  - - MHz , megahertz = 1,000,000 cycles per second

Larmor Equation

A trick to remember the Larmor Equation

Whoa Boy!

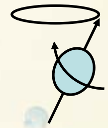
One can imagine that a proton wobbles pretty rapidly, hence whoa!

$$\omega_o = B_o\gamma$$

Here's the actual equation

Gyromagnetic Ratio

The gyro-magnetic ratio is constant for each chemical.



$$\omega_o = B_o \gamma$$

Frequency = ω_o

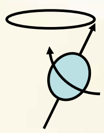
Magnetic field strength = B_o

Gyro-magnetic ratio = γ
Magneto-gyric ratio = γ

Gyromagnetic ratio (γ) or the Magneto-gyric ratio (γ) for several chemicals

1H (hydrogen)	42.6 MHz/T
19F (fluorine)	40.1 MHz/T
31P (phosphorous)	17.2 MHz/T

Calculating the Larmor Frequency



$$\omega_o = B_o \gamma$$

γ for 1H (hydrogen) = 42.6 MHz/T
If the Field strength (Bo) is 1.0 Tesla

Then…

ω_o = (1.0T) x (42.6 MHz/T)

ω_o = 42.6 MHz (Megahertz)

γ for 1H (hydrogen) = 42.6 MHz/T
If the Field strength (Bo) is 1.5 Tesla

Then…

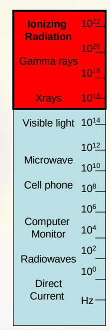
ω_o = (1.5T) x (42.6 MHz/T)

ω_o = 63.9 MHz (Megahertz)

Radiofrequency Energy?

Do we use radiation in MR?

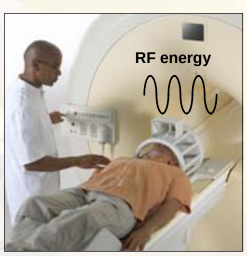
- Electromagnetic spectrum
- X-rays
  - –High energy
  - –Ionizing radiation
- MR Radiofrequency
  - –Low energy
  - –Non-ionizing



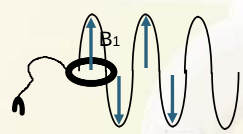
At 1.5T the frequency is roughly 64 MHz.
In most cities, channel 3 broadcasts at roughly 64 Mhz.

Resonance

- Once the Larmor frequency is calculated
- Spins can be excited by the radiofrequency pulse – at the Larmor frequency
- If the RF energy matches the precessional frequency of the spins…
- Resonance is achieved

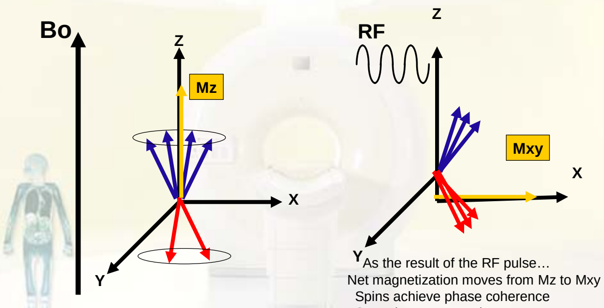


RF Transmitter Configurations



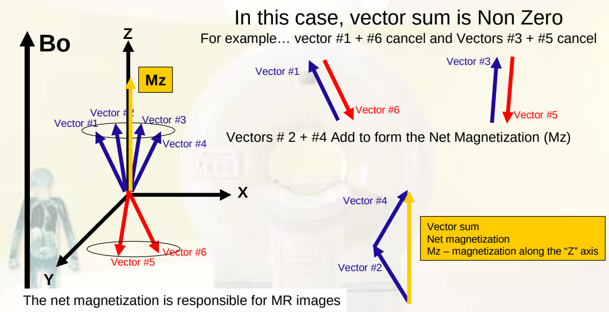
RF Transmitters

Excitation

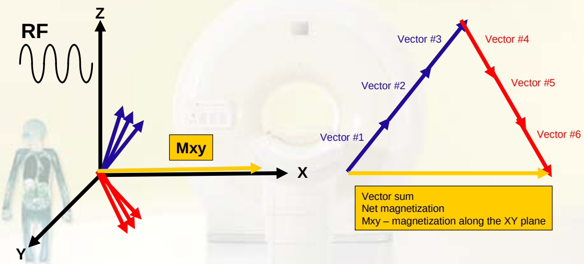


As the result of the RF pulse…
Net magnetization moves from Mz to Mxy
Spins achieve phase coherence
Some low energy spins
- absorb energy
- enter the high energy state

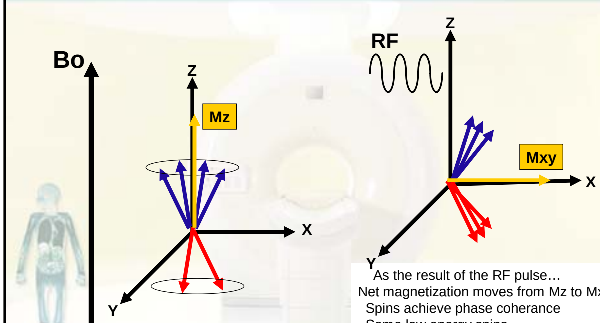
Net Magnetization (Mz)



Vector Sum

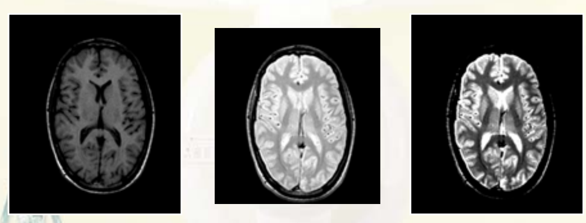


Excitation



As the result of the RF pulse…
Net magnetization moves from Mz to Mxy
Spins achieve phase coherance
Some low energy spins
- absorb energy
- enter the high energy state

Image Contrast Parameters

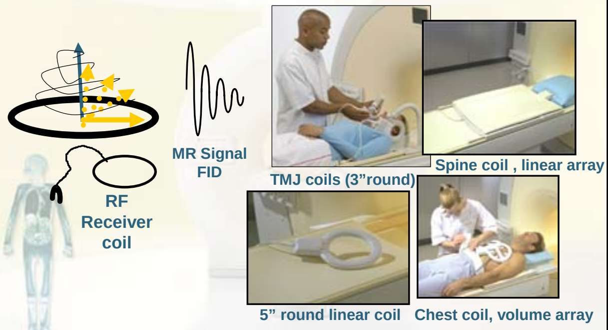


T1WI	PDWI	T2WI
Short TR	Long TR	Long TR
Short TE	Short TE	Long TE
Bright fat	Bright fat & water	Bright water

Outline

- What nuclei are MR active?
  - Hydrogen (fat & water)
  - Other Nuclei
- Why are they MR active?
  - Mass Number
- How do they behave in the magnet?
- Excitation
  - RF excitation
- Radiofrequency Pulses
  - Larmor Frequency
- Relaxation
  - Signal Induction
  - T1
  - T2

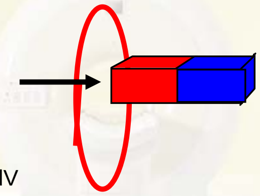
RF Receiver Configurations



Slide # 55

Faraday's Law of Induction

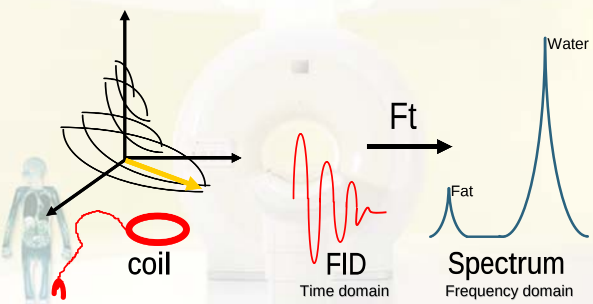
- Drag a magnet across a conductor,
a voltage is created (induced) within the conductor



- dB / dt = dV
Change of magnet divided by time = voltage
- ΔB / Δt = ΔV

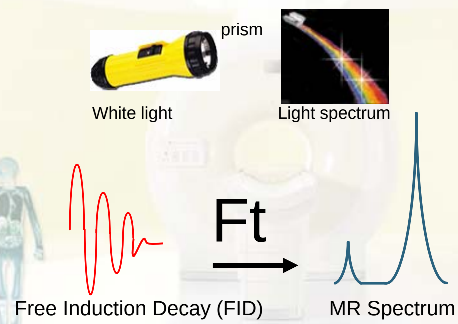
Slide # 56

Fourier Transformation



Slide # 57

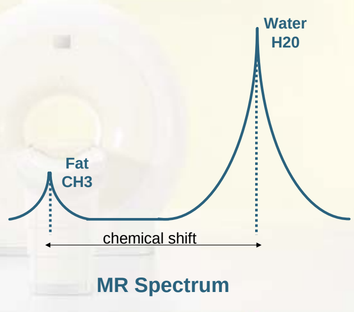
Converting MR Signal



Slide # 58

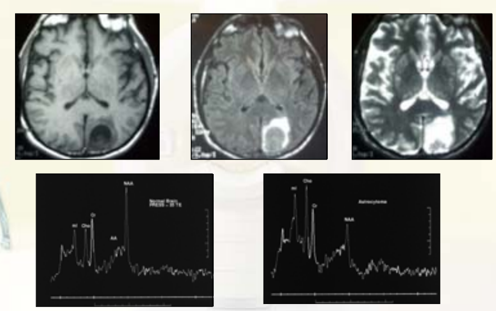
Chemical shift

- Each chemical has a different Frequency like (fat & water)
- Parts per million (PPM)
- Fat / water 3.5 ppm
- @ 1.5T = 224 Hz
- Varies with field strength

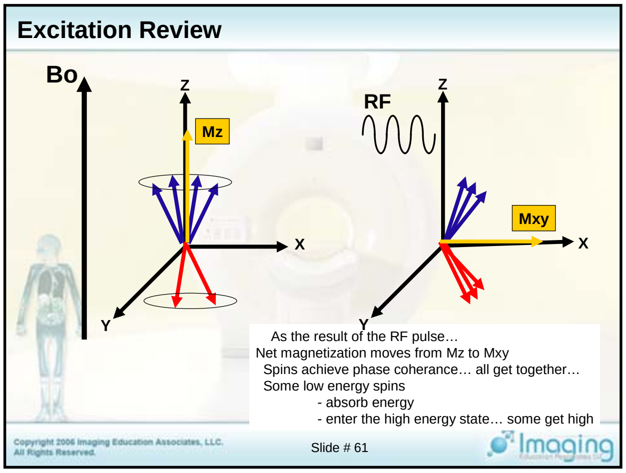


Slide # 59

Imaging and Spectroscopy



Slide # 60


Excitation Review
Bo
Z
Mz
X
Y
RF
Z
Mxy
X
Y
As the result of the RF pulse…
Net magnetization moves from Mz to Mxy
Spins achieve phase coherance… all get together…
Some low energy spins
- absorb energy
- enter the high energy state… some get high
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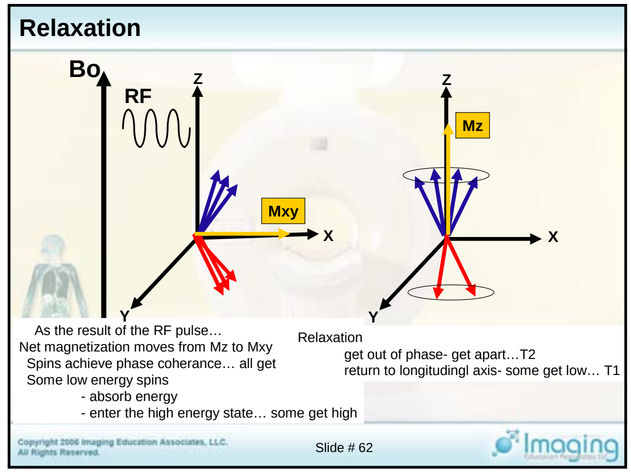
Slide # 61
Imaging


Relaxation
Bo
RF
Z
Mxy
X
Y
Z
Mz
X
Y
As the result of the RF pulse…
Net magnetization moves from Mz to Mxy
Spins achieve phase coherance… all get
Some low energy spins
- absorb energy
- enter the high energy state… some get high
Relaxation
get out of phase- get apart…T2
return to longitudingl axis- some get low… T1
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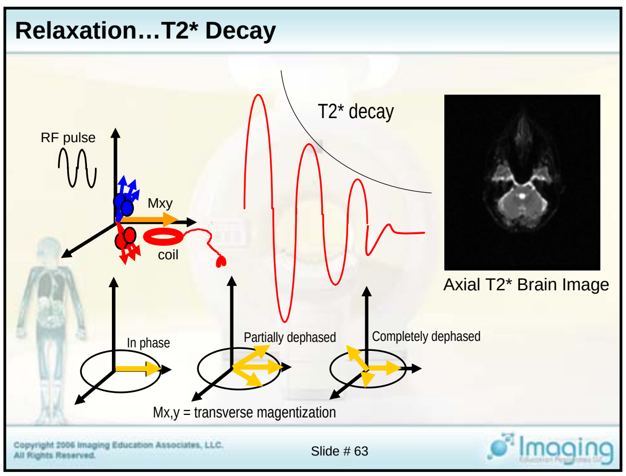
Slide # 62
Imaging


Relaxation…T2* Decay
RF pulse
Mxy
coil
T2* decay
Axial T2* Brain Image
In phase
Partially dephased
Completely dephased
Mx,y = transverse magentization
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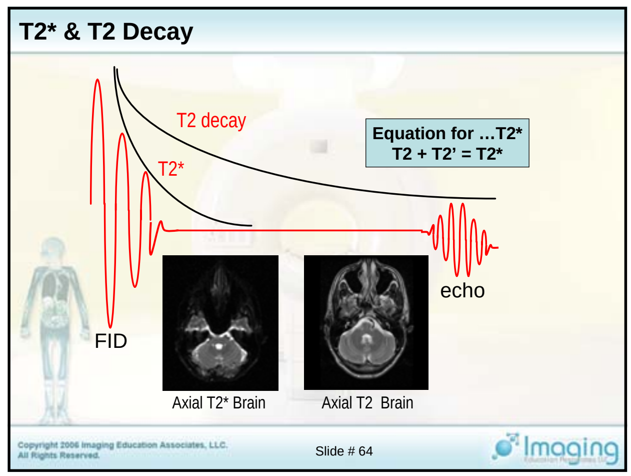
Slide # 63
Imaging


T2* & T2 Decay
T2 decay
T2*
Equation for …T2*
T2 + T2' = T2*
FID
echo
Axial T2* Brain
Axial T2 Brain
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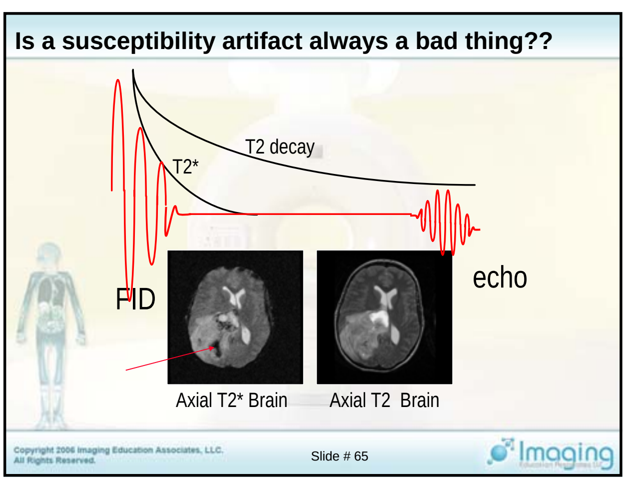
Slide # 64
Imaging


Is a susceptibility artifact always a bad thing??
T2 decay
T2*
FID
echo
Axial T2* Brain
Axial T2 Brain
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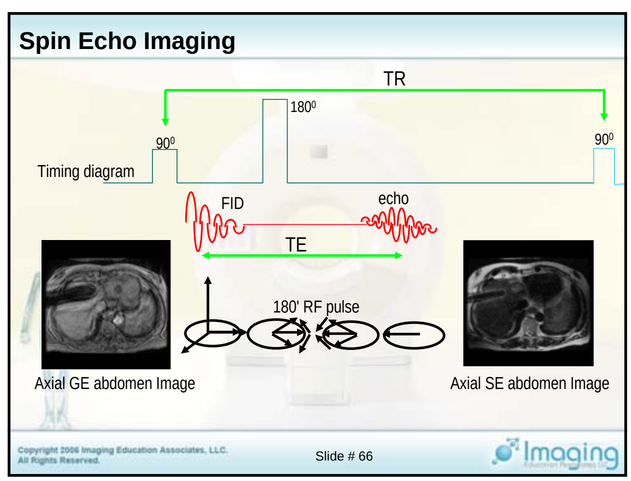
All Rights Reserved.
Slide # 65
Imaging


Spin Echo Imaging
TR
180⁰
90⁰
90⁰
Timing diagram
FID
echo
TE
180' RF pulse
Axial GE abdomen Image
Axial SE abdomen Image
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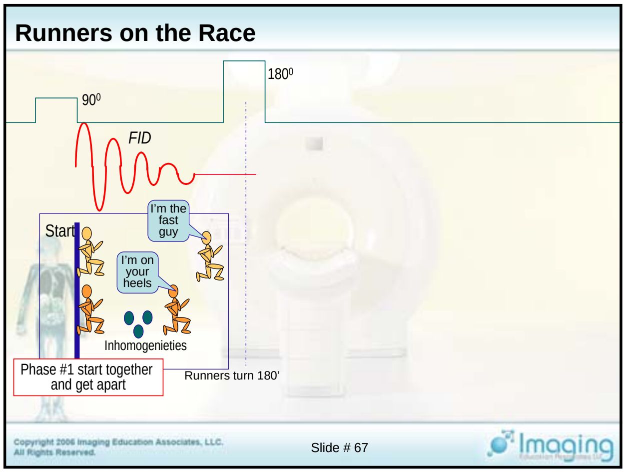
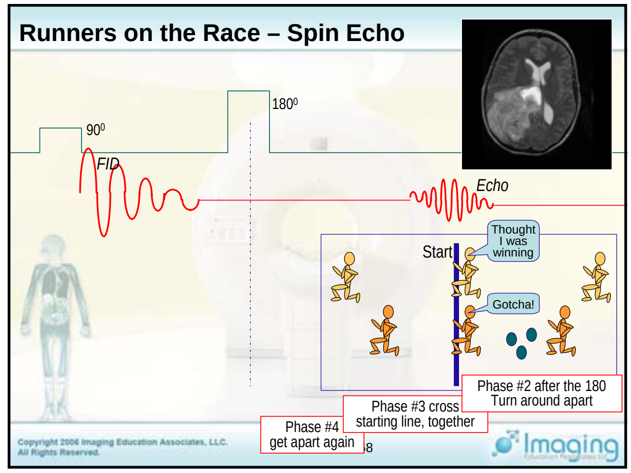
Slide # 66
Imaging


Runners on the Race
90⁰
180⁰
FID
Start
I'm the fast guy
I'm on your heels
Inhomogenieties
Phase #1 start together and get apart
Runners turn 180'
Copyright 2006 Imaging Education Associates, LLC. All Rights Reserved.
Slide # 67
Imaging


Runners on the Race – Spin Echo
90⁰
180⁰
FID
Echo
Start
Thought I was winning
Gotcha!
Phase #2 after the 180 Turn around apart
Phase #3 cross starting line, together
Phase #4 get apart again
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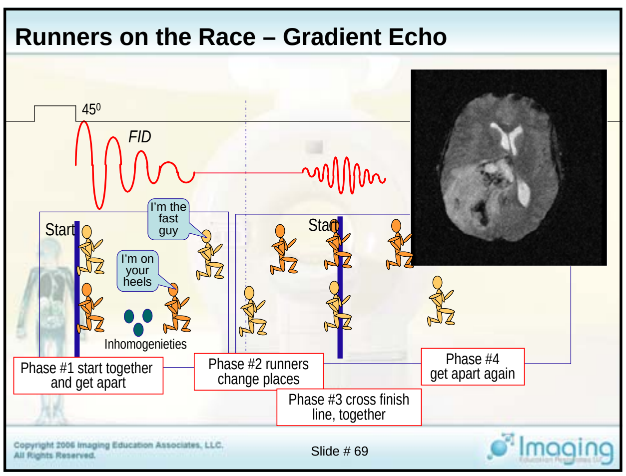
Imaging


Runners on the Race – Gradient Echo
45⁰
FID
Start
I'm the fast guy
I'm on your heels
Inhomogenieties
Start
Phase #1 start together and get apart
Phase #2 runners change places
Phase #3 cross finish line, together
Phase #4 get apart again
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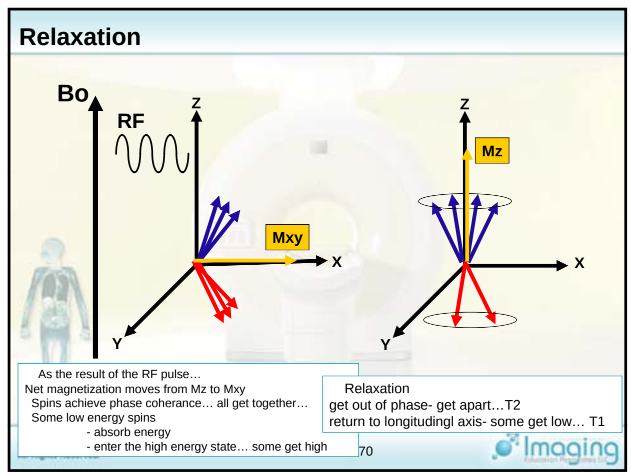
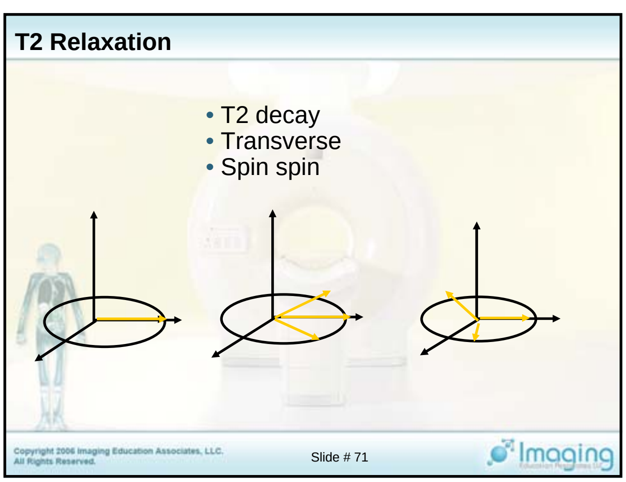
Slide # 69
Imaging


Relaxation
Bo
RF
Z
Mxy
X
Y
Z
Mz
X
Y
As the result of the RF pulse…
Net magnetization moves from Mz to Mxy
Spins achieve phase coherance… all get together…
Some low energy spins
- absorb energy
- enter the high energy state… some get high
Relaxation
get out of phase- get apart…T2
return to longitudingl axis- some get low… T1
70
Imaging


T2 Relaxation
• T2 decay
• Transverse
• Spin spin
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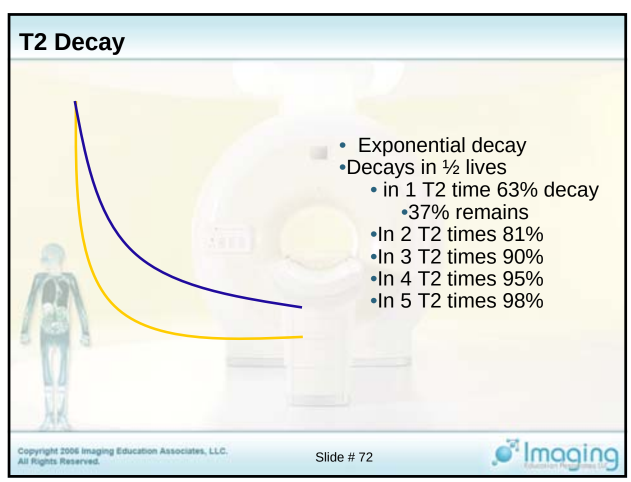
Slide # 71
Imaging


T2 Decay
• Exponential decay
•Decays in ½ lives
• in 1 T2 time 63% decay
•37% remains
•In 2 T2 times 81%
•In 3 T2 times 90%
•In 4 T2 times 95%
•In 5 T2 times 98%
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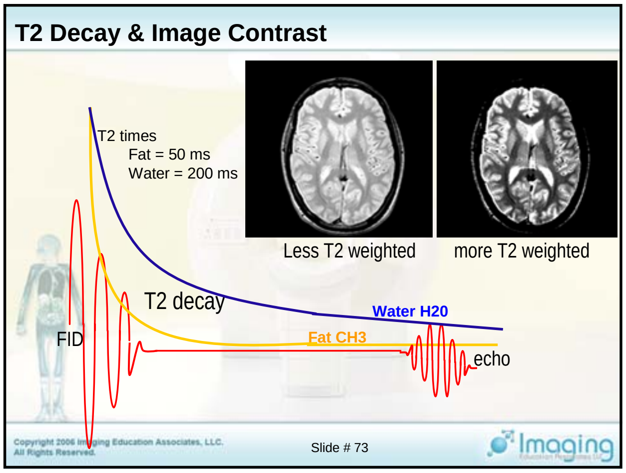
Slide # 72
Imaging


T2 Decay & Image Contrast
T2 times
Fat = 50 ms
Water = 200 ms
Less T2 weighted
more T2 weighted
T2 decay
FID
Water H20
Fat CH3
echo
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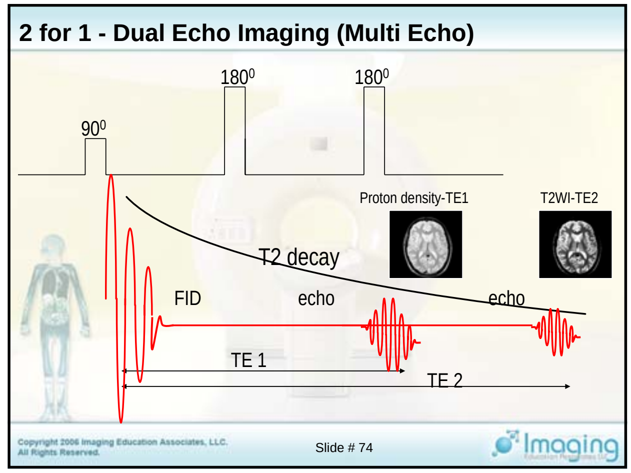
Slide # 73
Imaging


2 for 1 - Dual Echo Imaging (Multi Echo)
90⁰
180⁰
180⁰
Proton density-TE1
T2WI-TE2
T2 decay
FID
echo
echo
TE 1
TE 2
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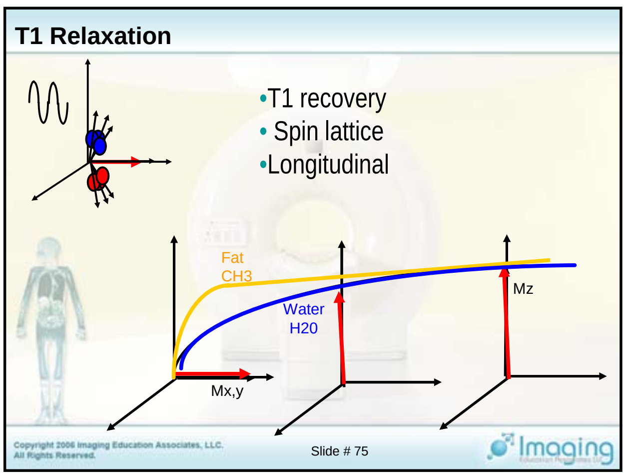
Slide # 74
Imaging


T1 Relaxation
•T1 recovery
• Spin lattice
•Longitudinal
Fat
CH3
Water
H20
Mz
Mx,y
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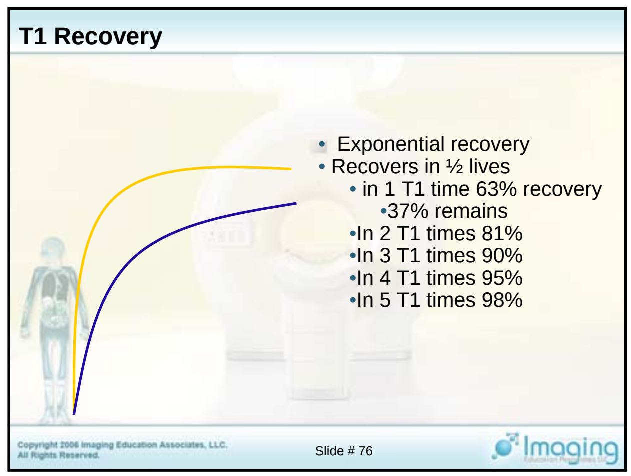
Slide # 75
Imaging


T1 Recovery
• Exponential recovery
• Recovers in ½ lives
• in 1 T1 time 63% recovery
•37% remains
•In 2 T1 times 81%
•In 3 T1 times 90%
•In 4 T1 times 95%
•In 5 T1 times 98%
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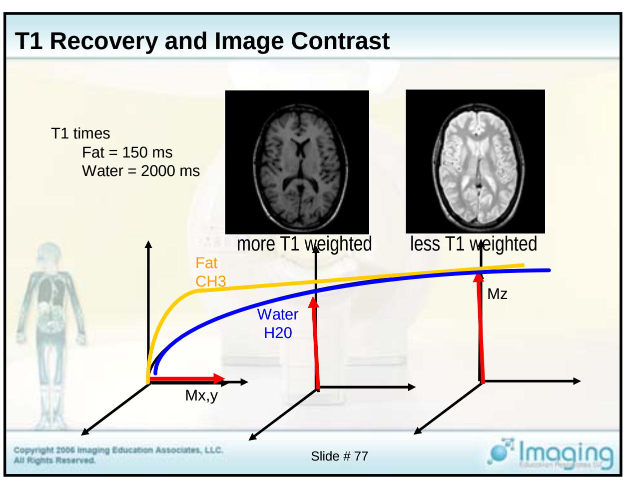
Slide # 76
Imaging


T1 Recovery and Image Contrast
T1 times
Fat = 150 ms
Water = 2000 ms
more T1 weighted
less T1 weighted
Fat
CH3
Water
H20
Mz
Mx,y
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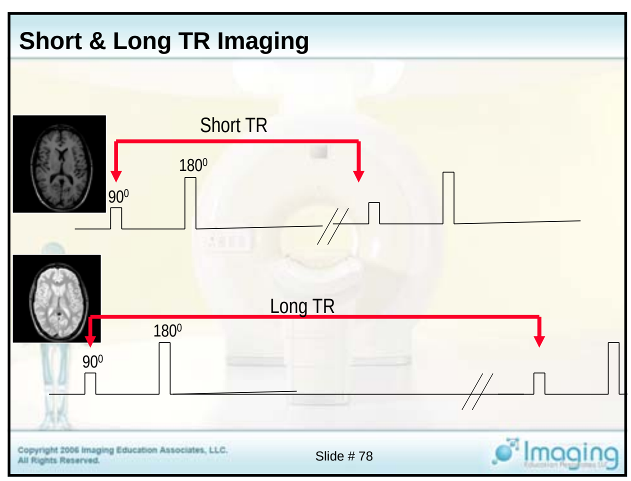
Slide # 77
Imaging


Short & Long TR Imaging
Short TR
180⁰
90⁰
Long TR
180⁰
90⁰
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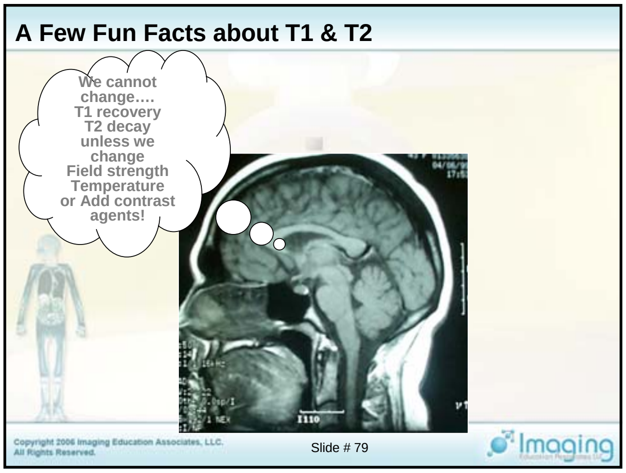
Slide # 78
Imaging


A Few Fun Facts about T1 & T2
We cannot change…. T1 recovery T2 decay unless we change Field strength Temperature or Add contrast agents!
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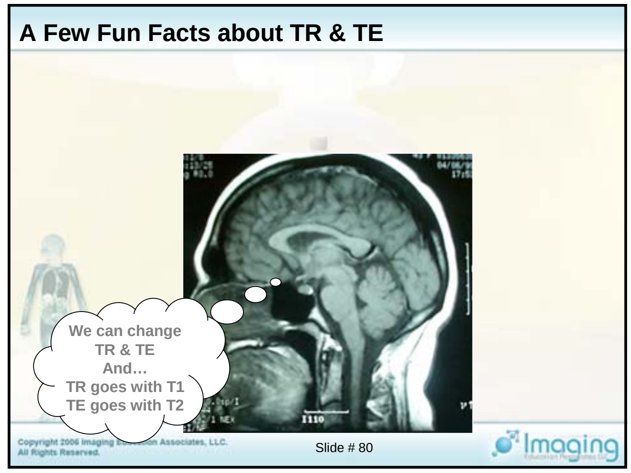
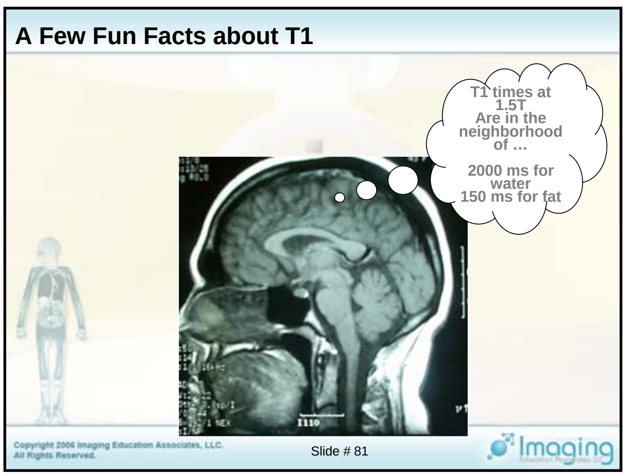
Slide # 79
Imaging


A Few Fun Facts about TR & TE
We can change TR & TE And… TR goes with T1 TE goes with T2
Slide # 80
Imaging


A Few Fun Facts about T1
T1 times at 1.5T Are in the neighborhood of … 2000 ms for water 150 ms for fat
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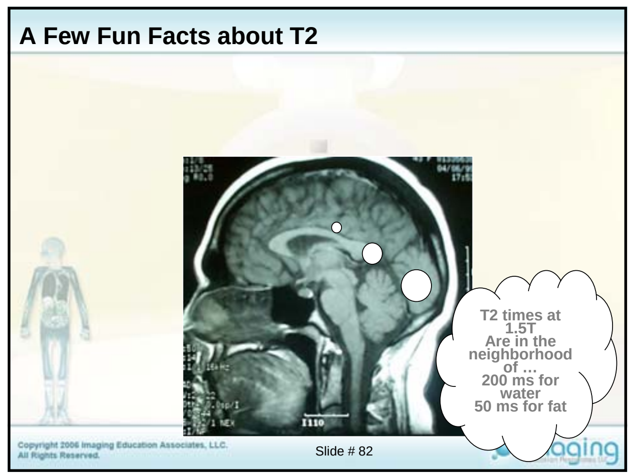
Slide # 81
Imaging


A Few Fun Facts about T2
T2 times at 1.5T Are in the neighborhood of … 200 ms for water 50 ms for fat
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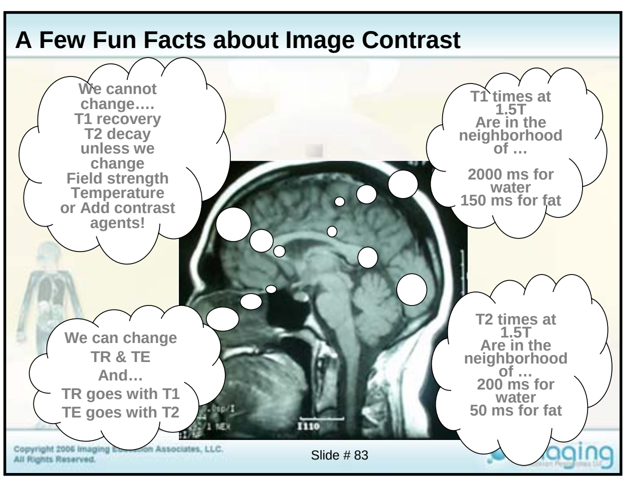
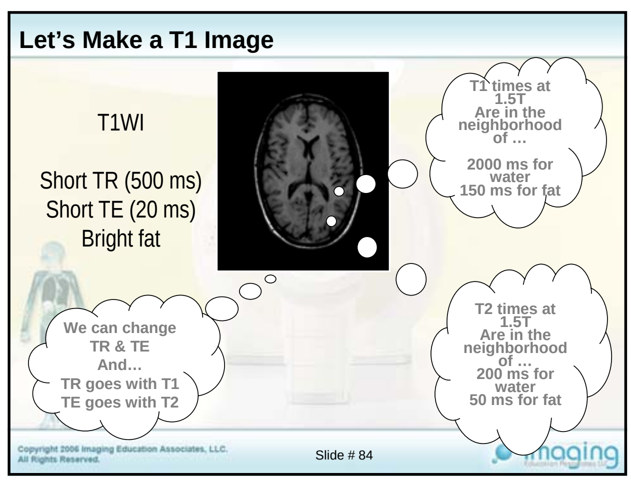
Slide # 82


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
Slide # 83


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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Slide # 84

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

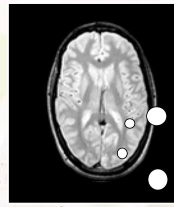
We can change TR & TE And…
TR goes with T1
TE goes with T2

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

Let's Make a PD Image

PDWI

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

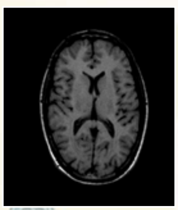
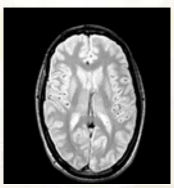
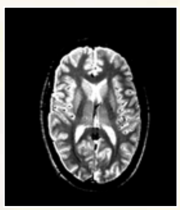


T1 times at 1.5T Are in the neighborhood of …
2000 ms for water
150 ms for fat

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

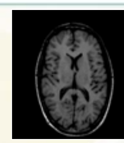
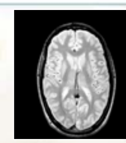
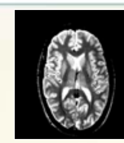
T2 times at 1.5T Are in the neighborhood of …
200 ms for water
50 ms for fat

Image Contrast Parameters

T1WI	PDWI	T2WI
Short TR	Long TR	Long TR
Short TE	Short TE	Long TE
Bright fat, short T1 time	Bright fat & water	Bright water, long T2 time

What is a Pulse Sequence?

	T1Weighted Image	PD Weighted Image	T2 Weighted Image
Spin echo family Longer Scan times Better quality	SE (TSE) FSE IR Fast IR	SE (TSE) FSE FLAIR Fast FLAIR Looks like PD	SE FSE STIR Fast STIR Looks like T2
Gradient echo family Faster Scan times lower quality	(T1 FFE) GrE spoiled TOF MRA Enhanced MRA	(PD FFE) GrE EPI Flair	T2* Weighted Image (T2* FFE) GrE PC MRA EPI Perfusion Diffusion

Outline

- What nuclei are MR active?
  - Hydrogen (fat & water)
  - Other Nuclei
- Why are they MR active?
  - Mass Number
- How do they behave in the magnet?
- Excitation
  - RF excitation
- Radiofrequency Pulses
  - Larmor Frequency
- Relaxation
  - T1
  - T2

4.1 Principles of MRI

Nuclei, Excitation, Relaxation

Thank you for your attention!

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