Basic Physics

We all are made up of elements

- 92 elements occur naturally on earth.
- Human body is built of only 26 elements.
- Oxygen, hydrogen, carbon, nitrogen elements constitute 96 % of human body mass.
- The adult human body is ~53% water, and water is ~11% hydrogen by mass but ~67% hydrogen by atomic percent.
- Thus, most of the mass of the human body is oxygen, but most of the atoms in the human body are hydrogen atoms.
- The average 70 kg adult human body contains approximately 3 x 10^{27} atoms of which 67% are hydrogen atoms.

MR active nuclei:

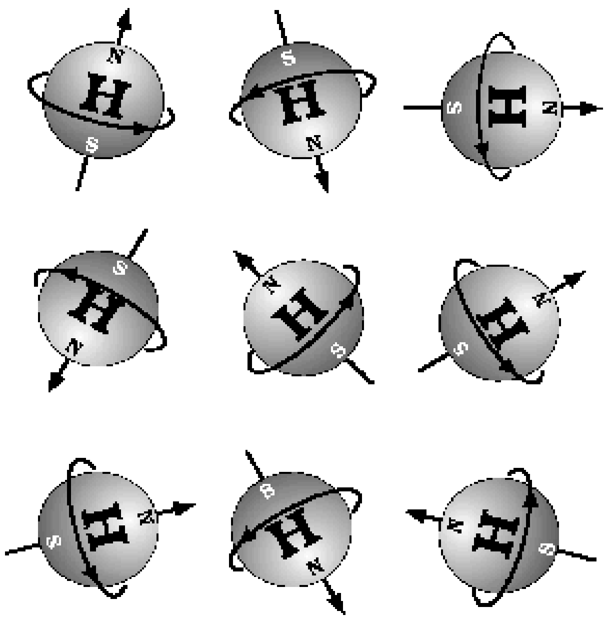
- ✓C13
- ✓F19
- ✓P31
- ✓N15
- ✓O17

- ***Due to unpaired Proton nuclei of these elements act as a tiny magnet.***

Why hydrogen?

- Simplest element with atomic number of 1 and atomic weight of 1
- When in ionic state (H+), it is nothing but a proton.
- Proton is not only positively charged, but also has magnetic spin (wobble)!
- MRI utilizes this magnetic spin property of protons of hydrogen to elicit images!!
- Essentially all MRI is hydrogen (proton) imaging

But why we can't act like magnets?



- The protons (i.e. Hydrogen ions) in body are spinning in a hap hazard fashion, and cancel all the magnetism. That is our natural state!
- We need to discipline them first, how?

We need a big magnet from outside!

- Magnetic field strength: 0.3 – 7 T (2500 times more than earth's magnetic field {50 micro Tesla}). Average field strength – 1.5 T
- Open magnet – less field strength, less claustrophobic
- Closed magnet – more field strength, claustrophobic

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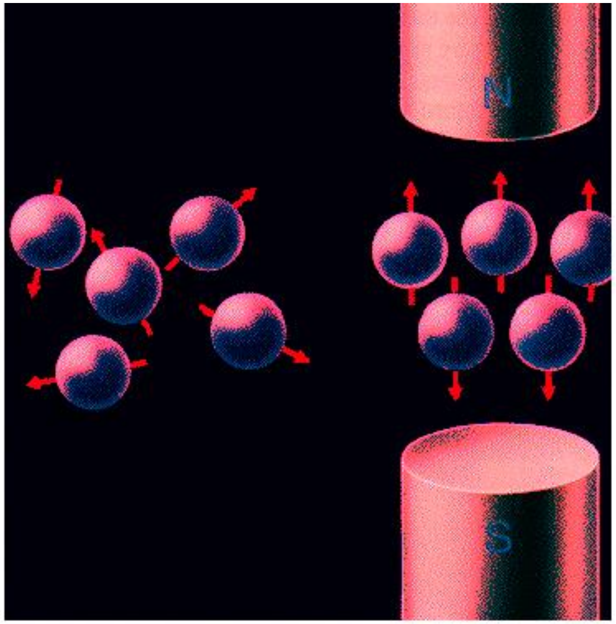
Body in an external magnetic field (B_0)

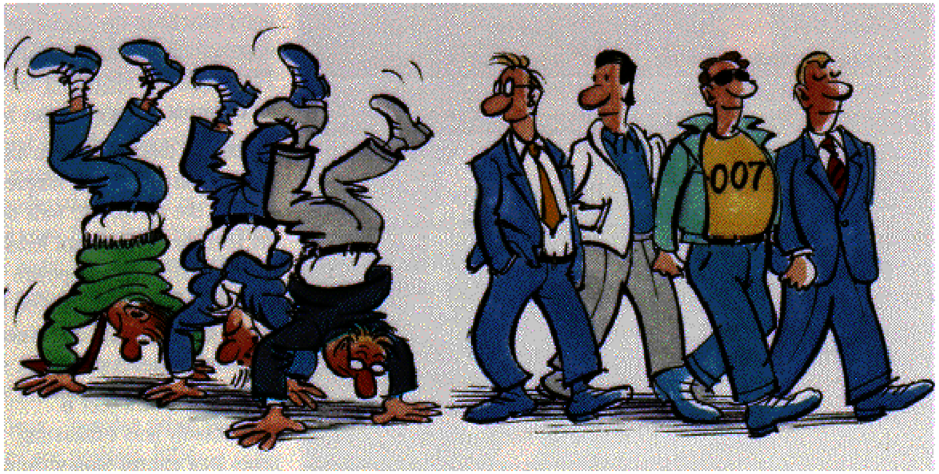
•In our natural state Hydrogen ions in body are spinning in a haphazard fashion, and cancel all the magnetism.
•When an external magnetic field is applied protons in the body align in one direction. (As the compass aligns in the presence of earth’s magnetic field)



Net magnetization

- Half of the protons align along the magnetic field and rest are aligned opposite

- At room temperature, the population ratio of anti-parallel versus parallel protons is roughly 100,000 to 100,007 per Tesla of B_0



- These extra protons produce net magnetization vector (M)

- Net magnetization depends on B_0 and temperature

B_0 Magnetic Field Strength

Manipulating the net magnetization

- Magnetization can be manipulated by changing the magnetic field environment (static, gradient, and RF fields)

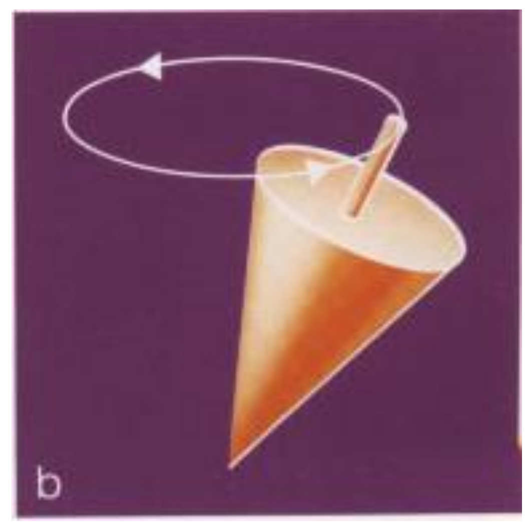
- RF waves are used to manipulate the magnetization of H nuclei

- ***<u>Externally applied RF waves perturb magnetization into different axis (transverse axis). Only transverse magnetization produces signal.</u>***

- When perturbed nuclei return to their original state they emit RF signals which can be detected with the help of receiving coils

Precession

Proton moves in like spinning top. In two axis wobbling motion called Precession, depends on magnetic field strength



Precession frequency

- Precession frequency is dependent on strength of external magnet field
- It is determined by Larmor Equation

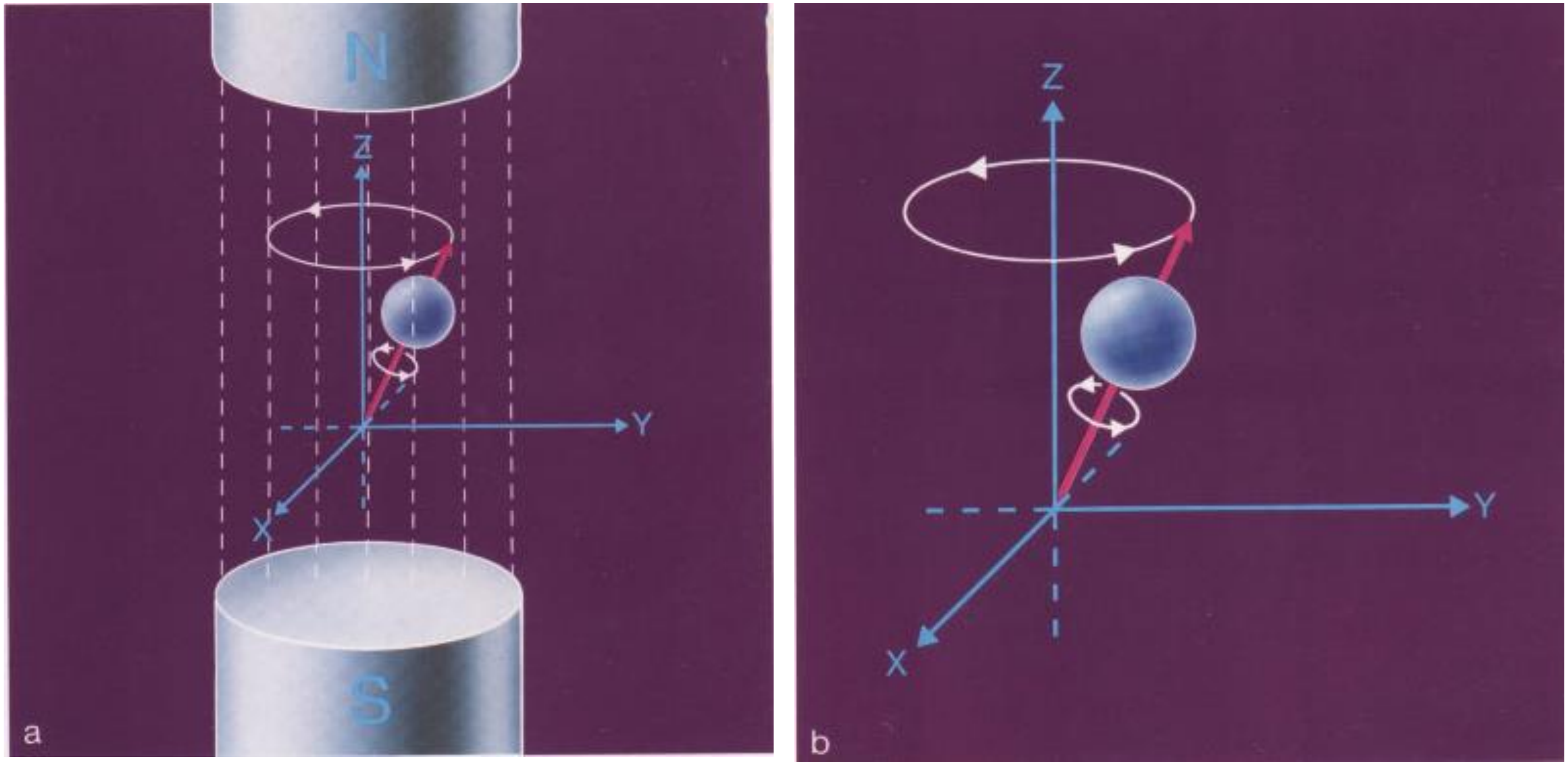
$$\mathbf{f = \gamma \times B_0}$$

  - **f** is precession frequency in Hz or MHz
  - **Bo** in magnetic field strength in Tesla
  - γ is gyro-magnetic ratio, for proton is 42.6 MHz/Tesla
  - Stronger the external magnetic field higher the precession frequency

Larmor frequencies

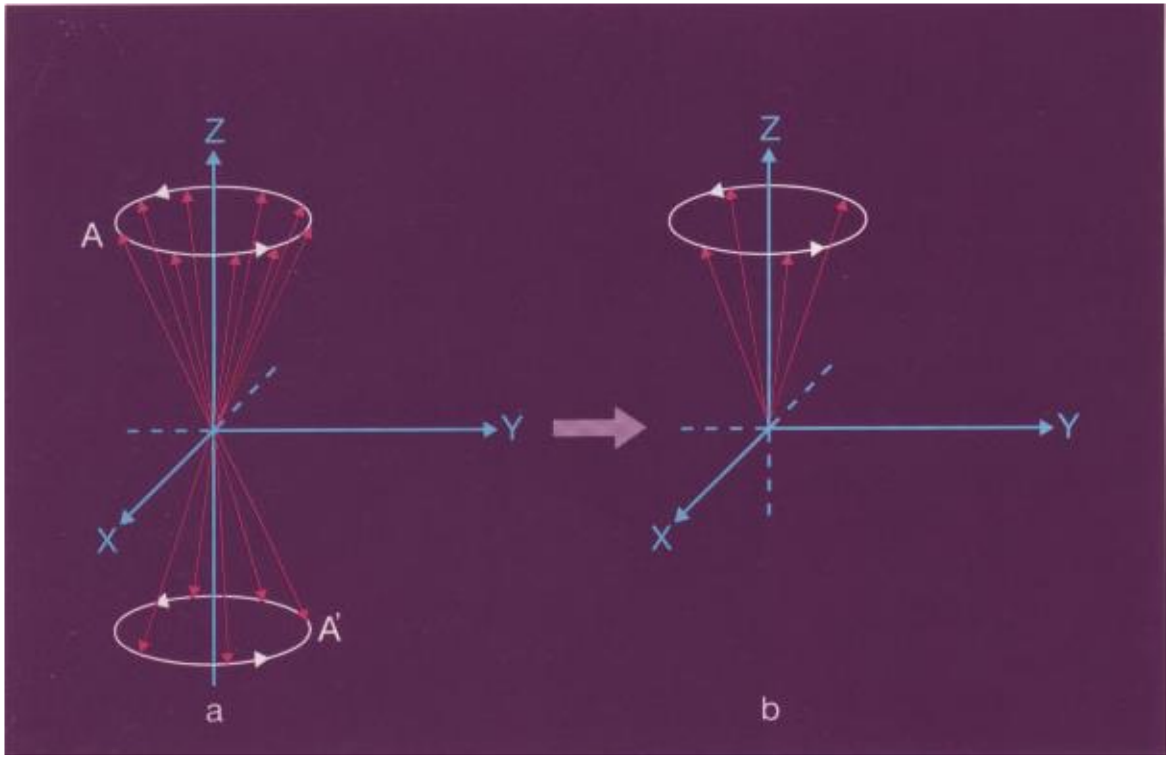
- **3T ~ 130 mHz**
- **7T ~ 300 mHz**
- **11.7T ~ 500 mHz**

Coordinate system



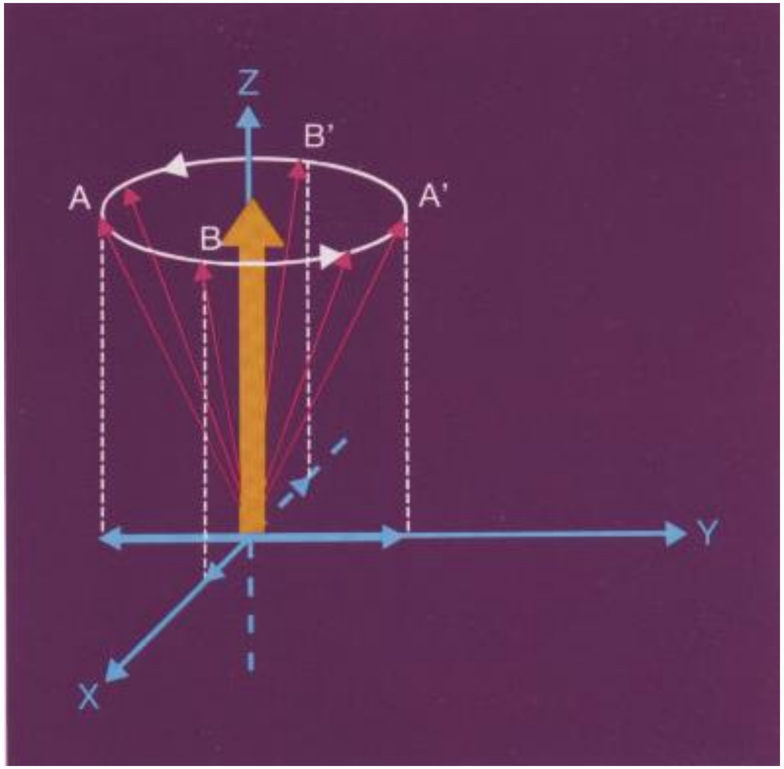
Representation of magnetic force in Z axis, Proton vector as red arrow

Net magnetic force



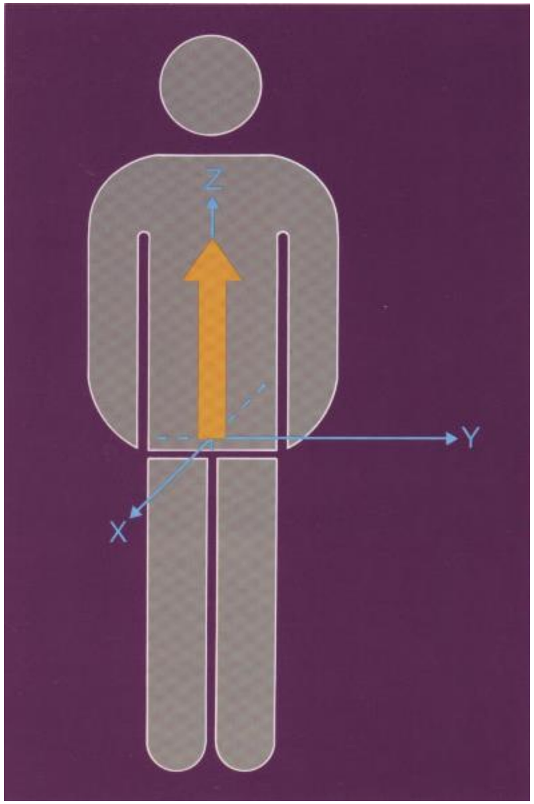
Proton pointing in opposite direction cancels each others magnetic effect in respective direction.
9 proton align up and 5 down, resulting in 4 proton up force

Net magnetic force



As there are more protons aligned parallel to the external magnetic filed, there is a net magnetic movement aligned with or longitudinal to the external magnetic field

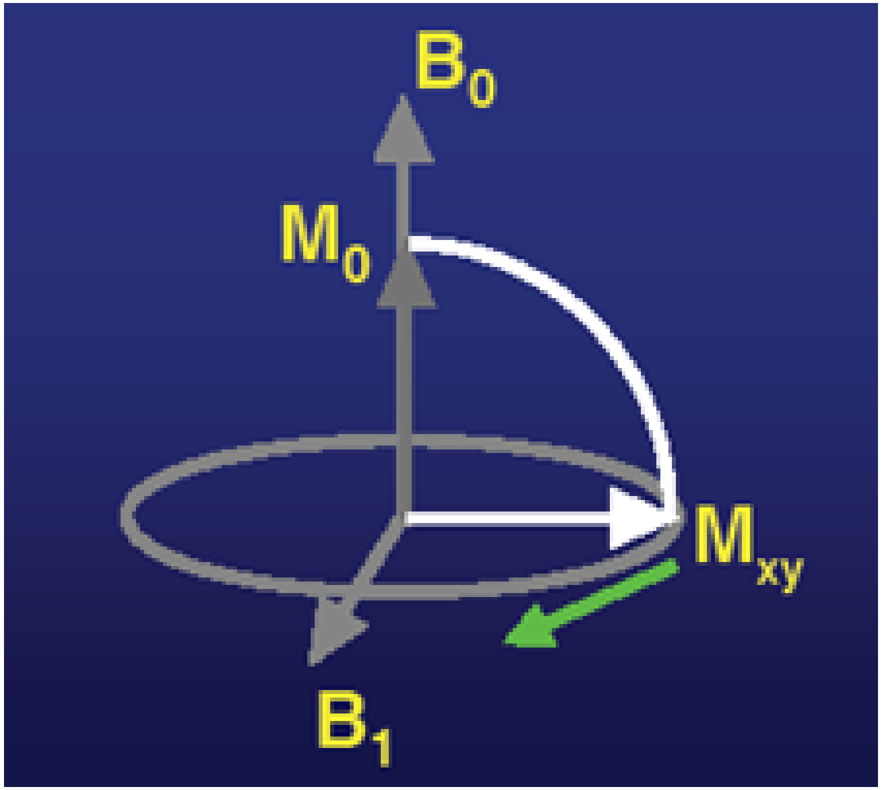
Human magnetic vector



- In a strong external magnetic field a new magnetic vector is induced in the patient, who becomes a magnet himself.
- This new magnetic vector is aligned with the external magnetic field

Magnetic Vector Components

- Magnetic Vector Mo
- Two components.
  - **Mz** along magnetic field called longitudinal magnetic vector
  - **Mxy** along transverse plane called Transverse magnetization.



Effect of Radiofrequency Pulse

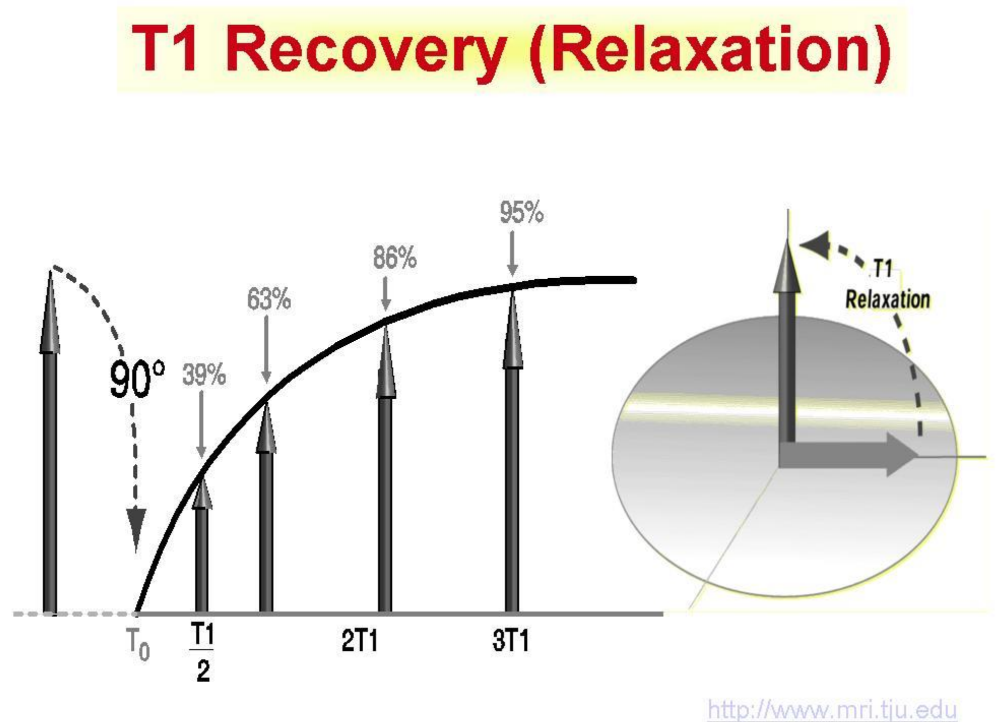
- After radiofrequency pulse longitudinal magnetization Mz decreases and transverse magnetization Mxy increases.

T1 and T2 relaxation

- When RF pulse is stopped higher energy gained by proton is retransmitted and hydrogen nuclei relax by two mechanisms
- ***T1 or spin lattice relaxation-*** by which original magnetization (Mz) begins to recover.
- ***T2 relaxation or spin spin relaxation*** - by which magnetization in X-Y plane decays towards zero in an exponential fashion. It is due to incoherence of H nuclei.
- T1 is usually larger than T2.
- T2 values of CNS tissues are shorter than T1 values

T1 relaxation

- After protons are Excited with RF pulse They move out of Alignment with B_0
- But once the RF Pulse is stopped they realign after some time and this is called t1 relaxation
- T1 is defined as the time it takes for the hydrogen nucleus **to recover 63%** of its longitudinal magnetization

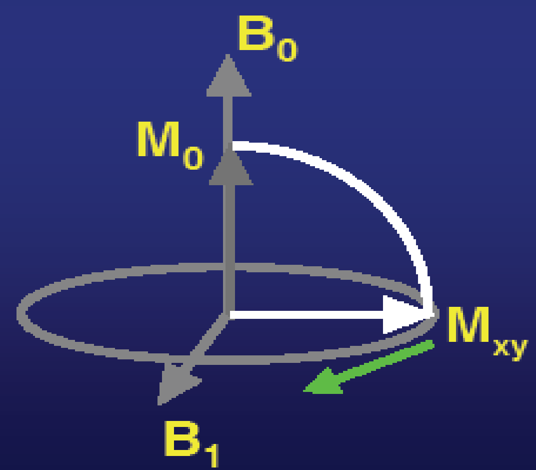


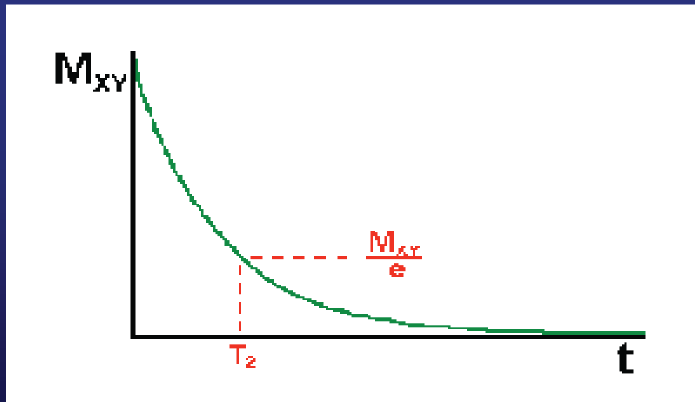
Factors Effecting T1

- T1 depends on the surrounding tissue composition and structure
- The **shorter the T1, the quicker the protons exchange thermal energy with the** lattice
- **Liquids have a long T1:**
  - Difficult to hand over thermal energy as the surrounding molecules are moving too rapidly
- **Fat has a short T1:**
  - The carbon bonds at the ends of fatty acids have frequencies near the Larmor frequency: Thus energy transfer is easier
- **T1 increases as the strength of the external magnetic field (B) increases:**
- The protons precess faster (Larmor frequency increases)
- Faster moving protons are less efficient at transferring energy to the slower moving lattice

T2 Relaxation

- When the tipped spins are precessing, they "dephase" as they do not spin at precisely the same speed. As they get out of phase, the magnetization is no longer coherent and the signal decays.





T2 relaxation time is the time for 63% of the protons to become dephased owing to interactions among nearby protons.

Factors Effecting T2

- **Dephasing is caused by inhomogeneities in:**
  - The **external magnetic field (B)**
  - **Local magnetic fields in the surrounding tissue**
- The **shorter the T2, the more inhomogeneous the local magnetic field is**

Factors Effecting T2

- **Liquids:**
- The molecules within liquids move relatively quickly. This means the local magnetic fields of those molecules also move quickly. The magnetic fields “average out” to give a relatively homogeneous magnetic field Protons, therefore, stay in phase for longer **T2 is long**
- **Impure liquids:**
- Large molecules move relatively slowly. This means that the local magnetic field is more inhomogeneous. Protons, therefore, dephase more quickly **T2 is short**

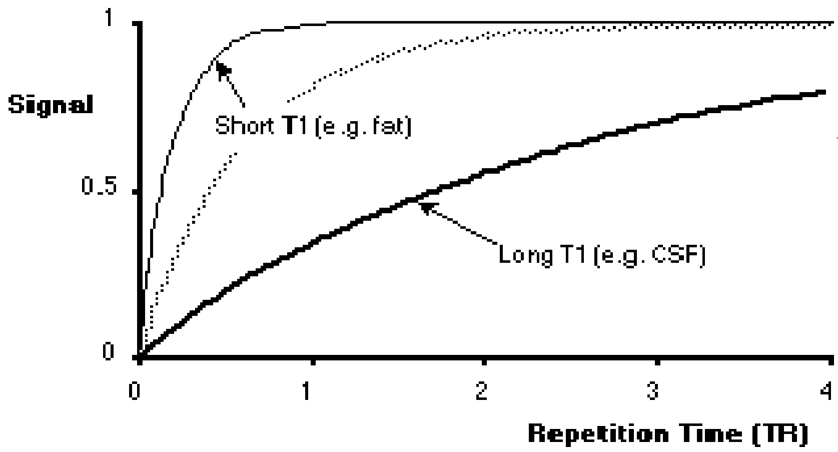
How MR Signal Produced?

- After radiofrequency pulse Mz Reduces and Mxy develop.
- When pulse is switched off Mxy decreases and excess energy handed over which is picked up by the receivers and amplified, computered analyzed and postulated to MR Grey signal.
- ***So only Mxy component produces signals.***

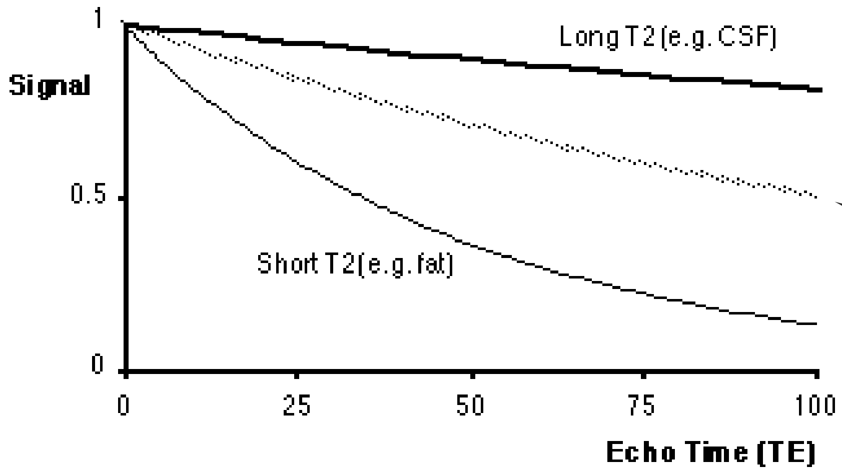
Properties of Body Tissues

Material	T1 (ms)	T2 (ms)
Fat	250	80
Liver	400	40
Kidney	550	60
Spleen	400	60
White Matter	650	90
Grey matter	800	100
CSF	2000	150
Water	3000	3000
Bone, Teeth	Very long	Very short

Basic Physics of MRI: T1 and T2



T1 is shorter in fat (large molecules) and longer in CSF (small molecules). T1 contrast is higher for lower TRs.



T2 is shorter in fat and longer in CSF. Signal contrast increased with TE.

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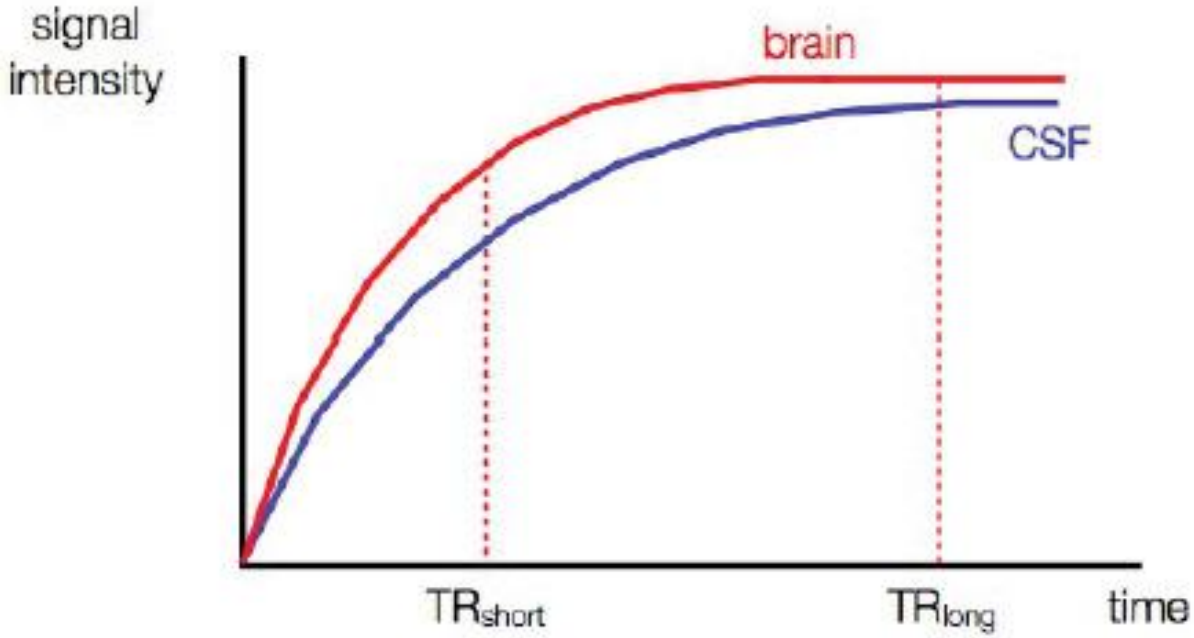
In a Nutshell

TR determines T1 contrast

TE determines T2 contrast.

TR-----Time to Repeat

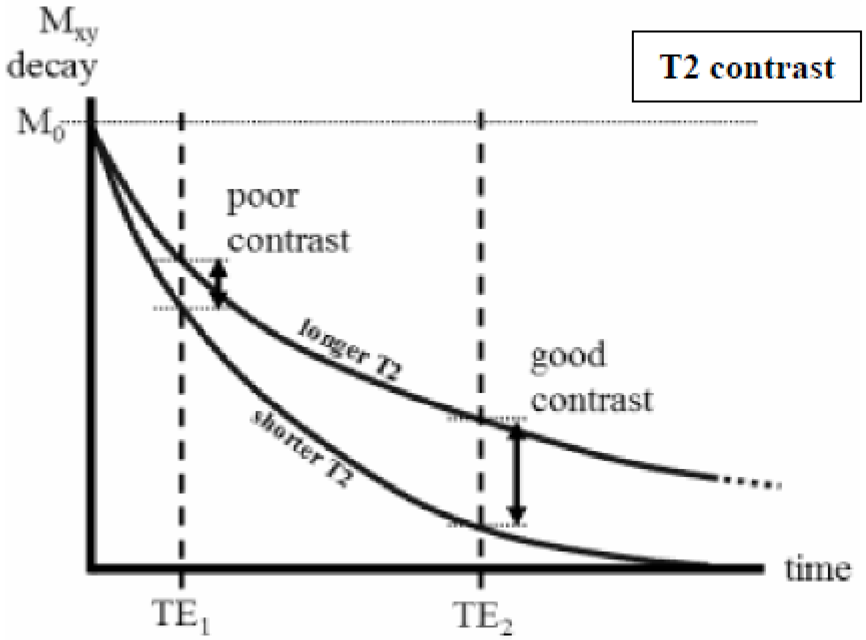
- **TR is the time between 90° RF pulses**
- TR varies depending on the study and can be set by the operator:
- **Long TR > 1500 msec**
- **Short TR < 500 msec**



- We can see that brain has a shorter T1 than CSF
- If we wait a long time between RF pulses (TR) there is very little difference in signal intensity between brain and CSF
- If we repeat the RF pulse sooner (TR) there will be a greater difference in signal intensity because the longitudinal magnetisation of brain will have recovered and will lead to a greater transverse magnetisation after the flip following the RF pulse

TE----Time to Echo (Signal)

- TE (echo time) : time interval in which ***signals are measured*** after RF excitation.
- Short TE < 45 msec
- Long TE > 45 msec



- Here we see that the longer the TE greater will be the contrast between the different tissues.

Different tissues have different relaxation times. These relaxation time differences is used to generate image contrast.

T1W, T2W PD

- In general a short TR (<800ms) and short TE (15–45 ms) scan is **T1WI**
- Long TR (>2000ms) and long TE (90–140ms) scan is **T2WI**
- Long TR (1000–3000ms) and short TE (<45ms, usually 15 ms) scan is **proton density image**

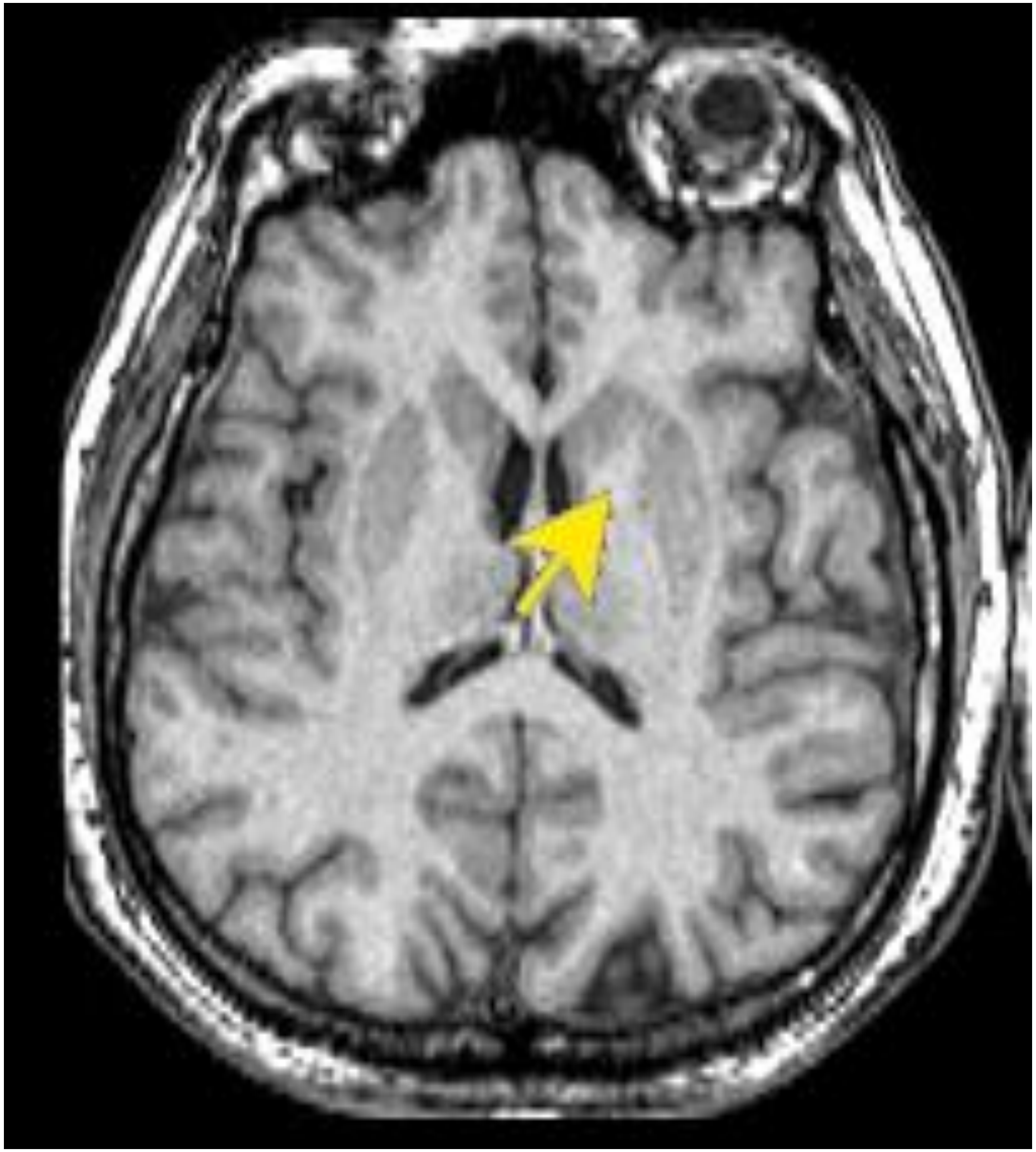
Basic Sequences

Basic Sequences

- T1W
- T2W
- PD
- Fluid-attenuated inversion-recovery (FLAIR) sequence.
- Short TI inversion-recovery (STIR) sequence

Bright on T1

- Fat
- subacute hemorrhage,
- melanin,
- protein rich fluid.
- Slowly flowing blood
- Paramagnetic substances(gadolinium, copper, manganese)

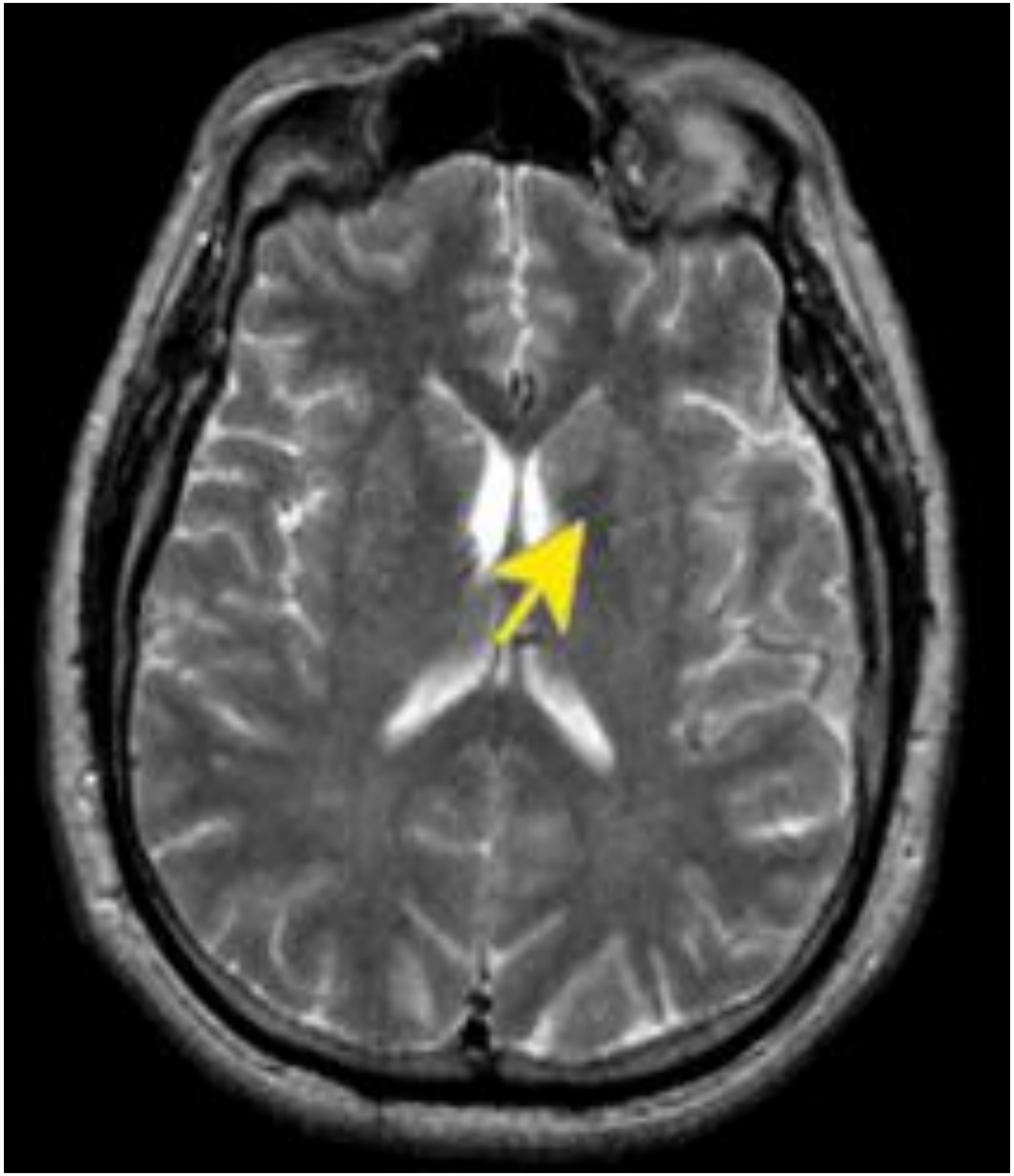


Dark on T1

- **Edema**
- **Tumor**
- **Infection**
- **Inflammation**
- **hemorrhage(hyperacute, chronic)**
- **Low proton density,**
- **calcification**
- **Flow void**

Bright on T2

- Edema,
- tumor,
- infection,
- inflammation,
- subdural collection
- Methemoglobin in late subacute hemorrhage

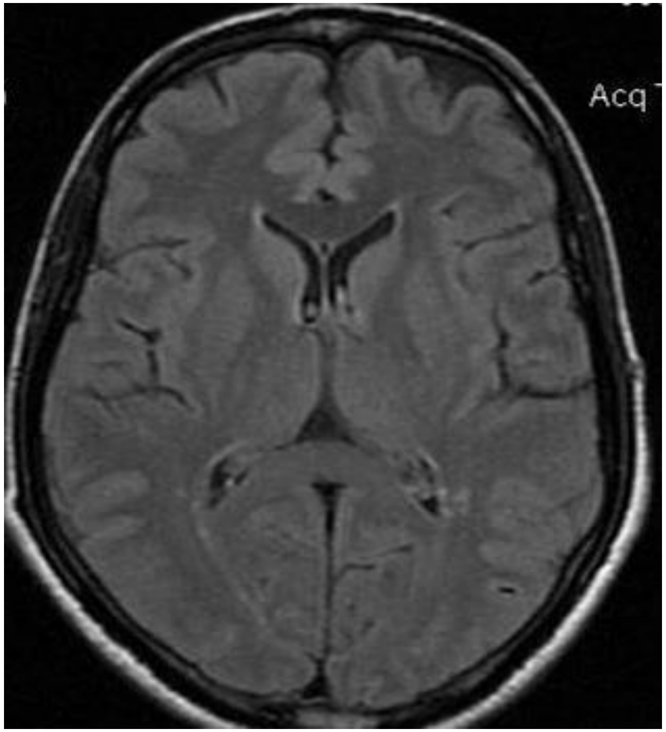


Dark on T2

- Low proton density, calcification,
- Fibrous tissue
- Paramagnetic substances(deoxyhemoglobin, methemoglobin (intracellular), ferritin, hemosiderin, melanin.
- Protein rich fluid
- Flow void

FLAIR

- Edema,
- Demyelination
- Infarction esp. in Periventricular location

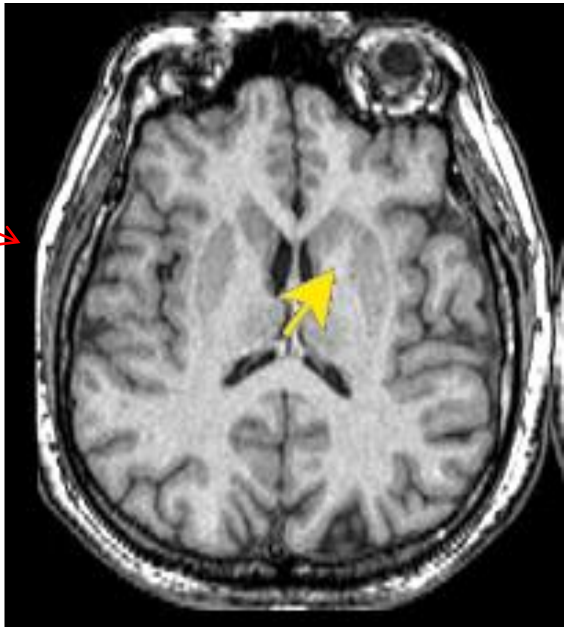


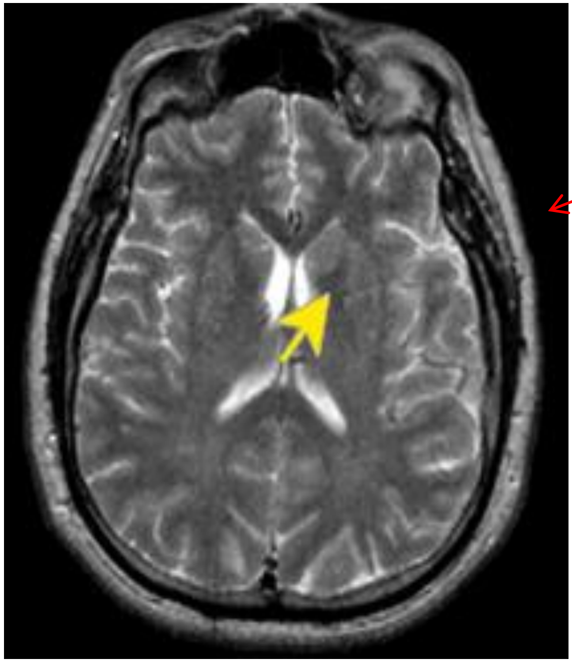
GRADATION OF INTENSITY

IMAGING						
CT SCAN	CSF	Edema	White Matter	Gray Matter	Blood	Bone
MRI T1	CSF	Edema	Gray Matter	White Matter	Cartilage	Fat
MRI T2	Cartilage	Fat	White Matter	Gray Matter	Edema	CSF
MRI T2 Flair	CSF	Cartilage	Fat	White Matter	Gray Matter	Edema

CT SCAN

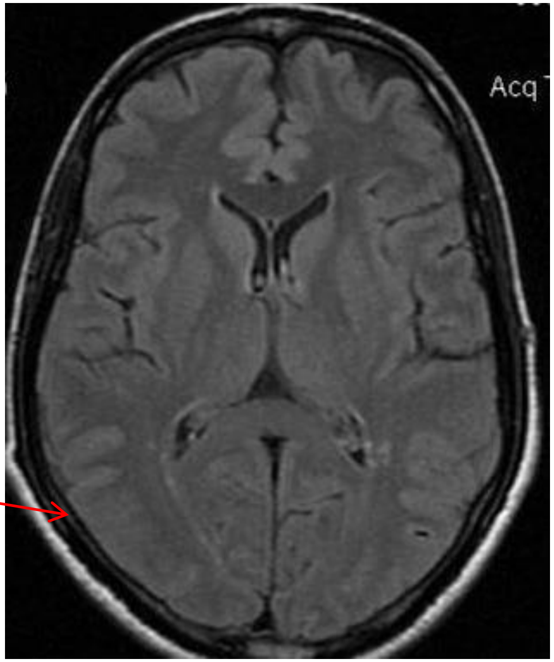
MRI T1 Weighted



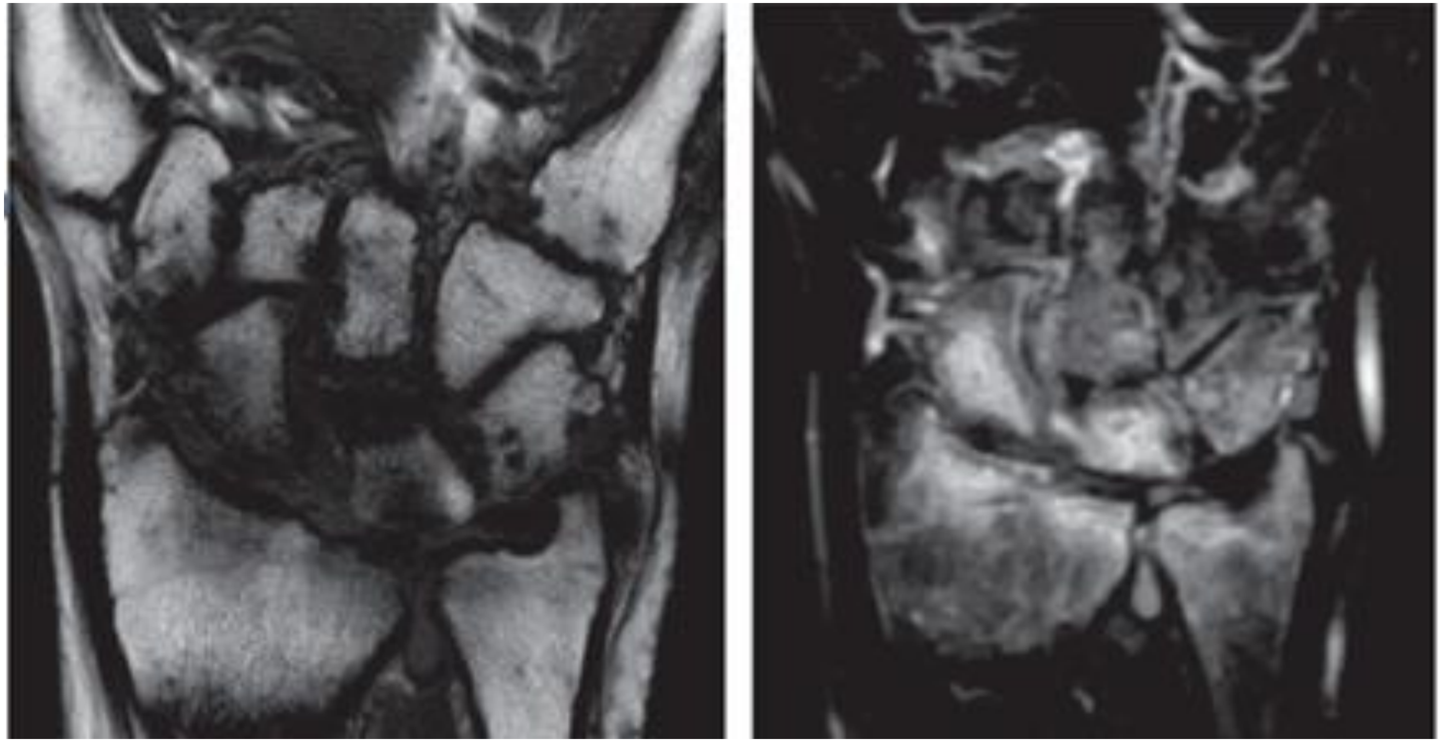


MRI T2 Weighted

MRI T2 Flair



STIR



- STIR sequences provide excellent depiction of bone marrow edema which may be the only indication of an occult fracture.

Which scan best defines the abnormality

T1 W Images:

Subacute Hemorrhage

Fat-containing structures

Anatomical Details

T2 W Images:

Edema

Demyelination

Infarction

Chronic Hemorrhage

FLAIR Images:

Edema,

Demyelination

Infarction esp. in Periventricular location

Reason for Brightness

Logic—Y bright on T1

- Short T1— Bright e.g. Fat, protein, melanin, white matter.
- Paramagnetic effect e.g. Gadolinium, methemoglobin.
- Slow flowing blood.

Logic—Y bright on T2

- All Substances with Long T1 and T2 relaxation time appears bright. e.g Water, CSF, White matter.
- All diseases with more water contents appear bright. Inflammation, Tumors, Infection, edema.

Bright on STIR

- Fat Suppressed, so anything left bright is water.

Bright on DWI

- No Diffusion – Bright
- Diffusion – Dark

It's a no-brainer!

THANK YOU!!!