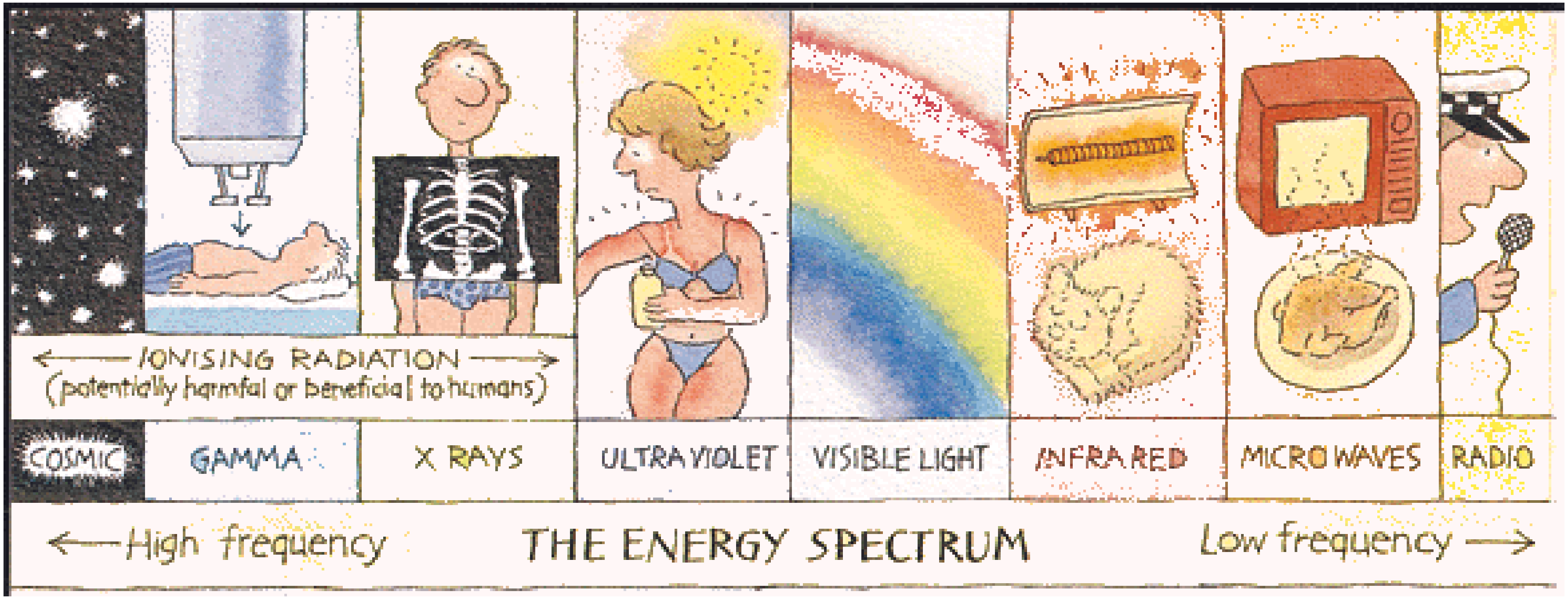
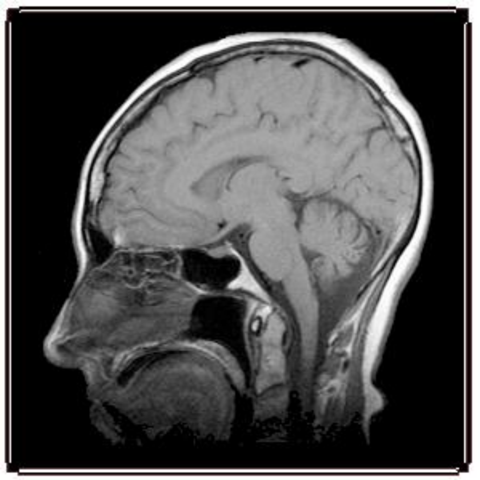

IONISING RADIATION
(potentially harmful or beneficial to humans)
COSMIC
GAMMA
X RAYS
ULTRA VIOLET
VISIBLE LIGHT
INFRA RED
MICRO WAVES
RADIO
High frequency
THE ENERGY SPECTRUM
Low frequency

… e nella diagnosi …

Risonanza magnetica

Imaging basato sull'assorbimento e l'emissione di energia nel range delle radiofrequenze



(oltre agli ultrasuoni)

Ecografia

Immagini generate dagli echi prodotti nell'interazione coi tessuti di un fascio di ultrasuoni

Radiazioni ionizzanti nella diagnosi:

Imaging radiologico

Immagini della trasmissione attraverso il corpo di un fascio di raggi X di frenamento prodotto da un apparecchio

Radiologia tradizionale

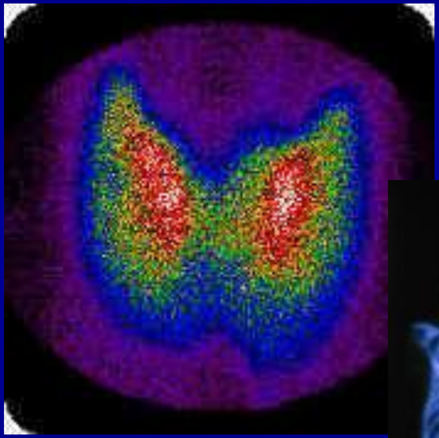
TAC

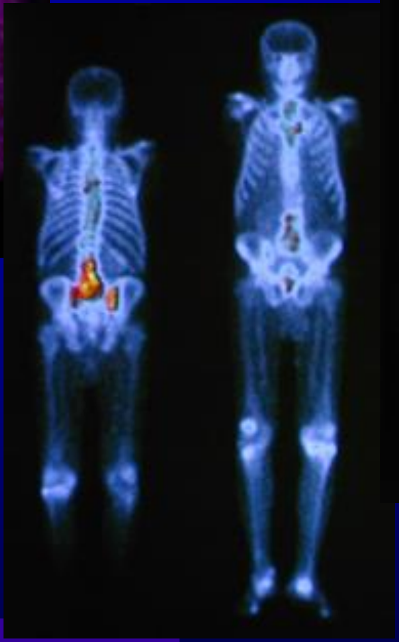
Applicazioni angiografiche, vascolari

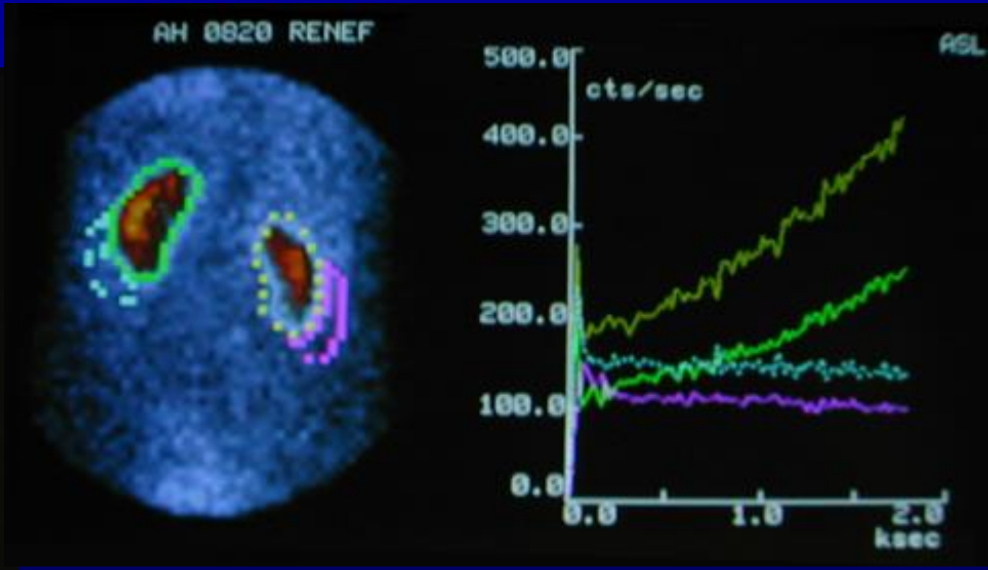
Radiazioni ionizzanti nella diagnosi:

Medicina nucleare

Immagini della distribuzione nel corpo di un farmaco marcato con un radionuclide emettitore di radiazioni γ o di positroni







Outline

- Standard MRI techniques (T1, T2, FLAIR …) and clinical applications;
- Perfusion MRI
- Angio MRI
- fMRI;
- DTI;
- MRI and multimodal imaging;
- Very high and ultra-low field MRI

Introduction

MRI applications can be grouped into:

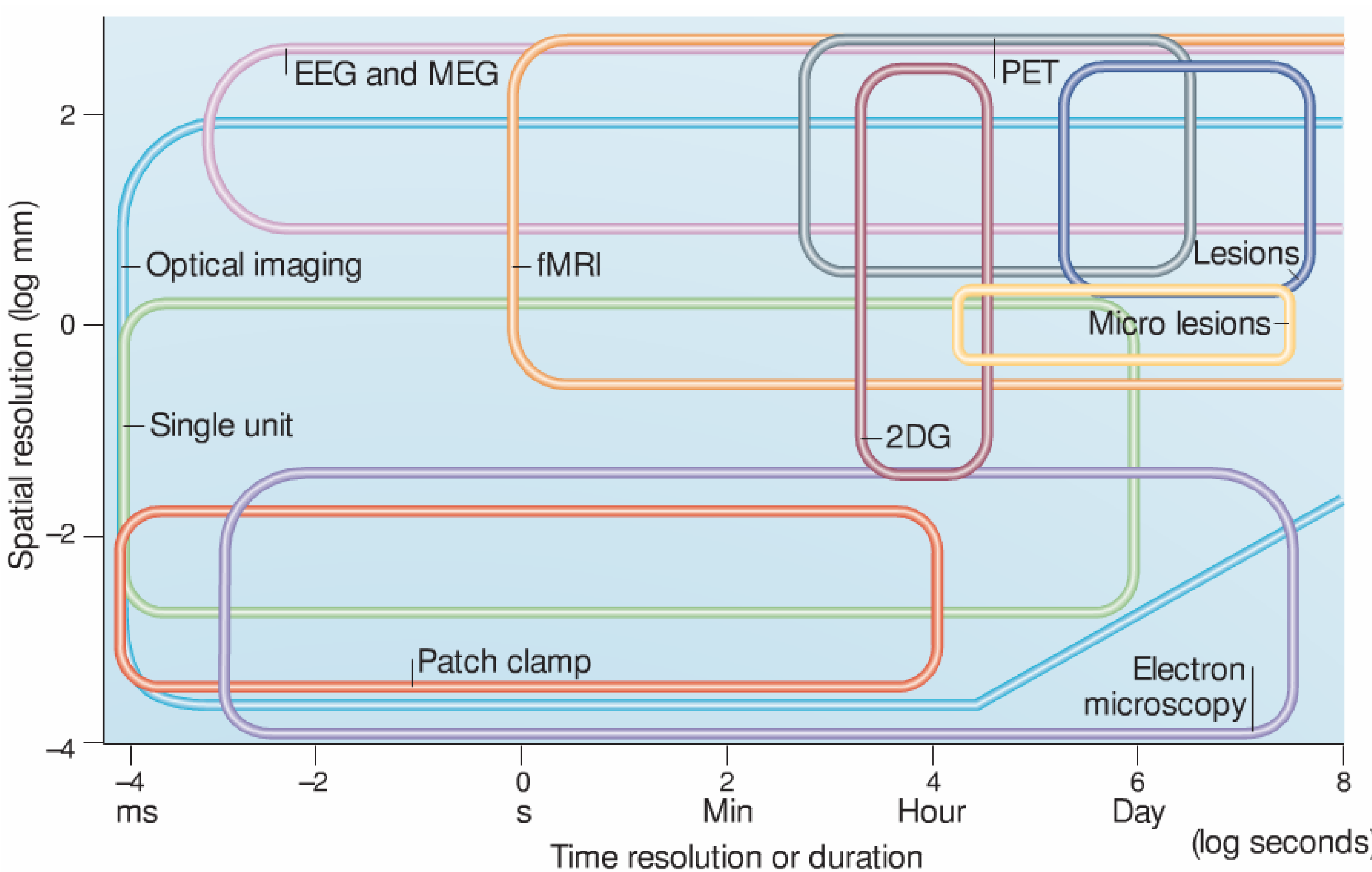
- Clinical Neurology
  - Neuroimaging, e.g. demyelinating diseases, dementia, cerebrovascular disease, neurodegenerative diseases (Epilepsy, Parkinson, Alzeiheimer, Huntington …), in general functional and structural brain abnormalities, development and aging

- Cancer
  - Breast, colorectal, Brain
  - MRI guided stereotactic surgery and radiosurgery

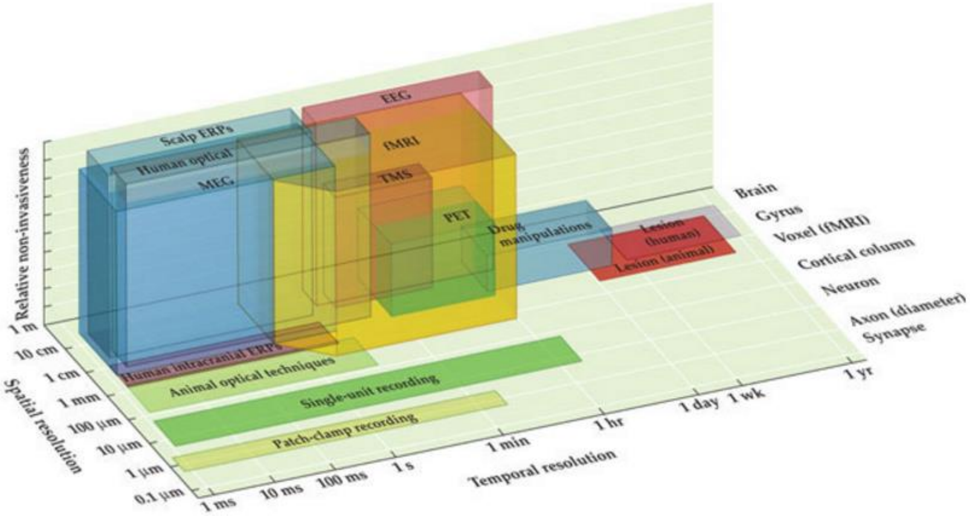
Introduction

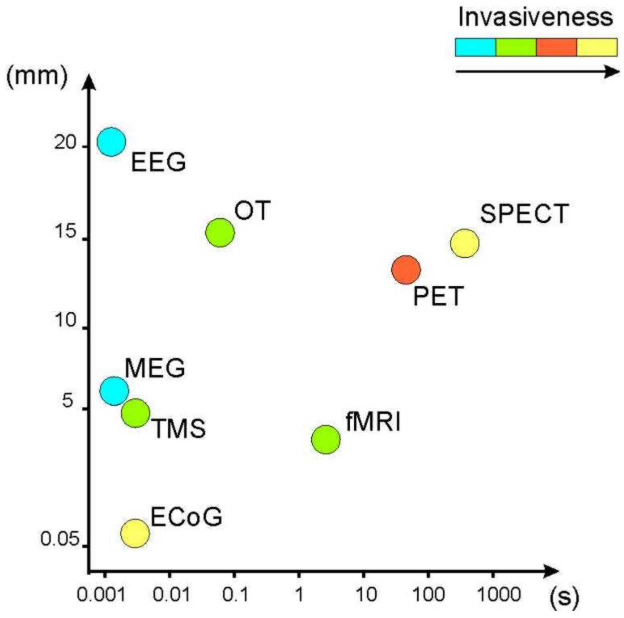
- Cardiovascular
    - Myocardial ischemia and viability, cardiomyopathies, myocarditis, iron overload, vascular diseases and congenital heart disease
- Muscoloskeletal
    - Spinal imaging, assessment of joint disease and soft tissue tumors
- Liver and gatrointestinal

Comparison MRI vs other imaging techniques in terms of spatial and temporal resolution



Comparison MRI vs other imaging techniques in terms of invasiveness





MRI advantages

- Excellent soft tissue contrast resolution
- Ability to obtain direct transverse, sagittal, coronal and oblique images
- No ionizing radiation
- No bone-air artifacts
- A very rich information coming from a large set of parameters determining the MRI contrast

"OK, Mrs. Dunn. We'll slide you in there, scan your brain, and see if we can find out why you've been having these spells of claustrophobia."

MRI disadvantages

- Long imaging time
- Complexity of equipment and scan acquisition
- High cost
- Low resolution for calcification or bone details
- Not all subjects can undergo MRI (any metallic fragment may become projectile, no pace maker, dental implants, heart valves, aneurism clips, claustrophobia?)

MRI compared to CT

COMPARISON	MRI	CT SCAN
Soft Tissue	Much higher detail in soft tissues	Less detailed in soft tissue
Bony Structures	Less detailed when compared with CT Scan	More detail about bony structures
Effects on the body	No hazards reported	Small risk of irradiation
Cost	Cost can vary from $1400 to $4000 (when used with contrast). Generally more expensive than CT Scans and x-rays	Cost ranges from $1200 to $3200. Generally less than MRIs
Also known as:	Magnetic Resonance Imaging	Computed Tomography
Exposure to Radiation	None	Moderate
Time Taken to scan	Typically 30 to 45 minutes	Generally within 5 minutes

MR missile effect

Two magnets close to each other:

- Align themselves to one another positive-to-negative. In the case of a ferromagnetic object brought near an MRI, one weighs perhaps 12 tons and is bolted to the floor, the other is a pair of scissors that weigh a few ounces. Which of these two things is going to rotate to align itself?

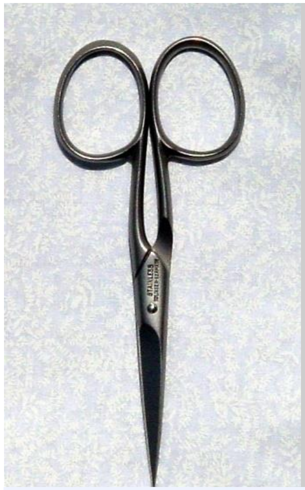
- Smaller ferromagnetic objects that we wear, carry, or have placed within our bodies can twist, turn and even tear whatever may be trying to hold them in place.

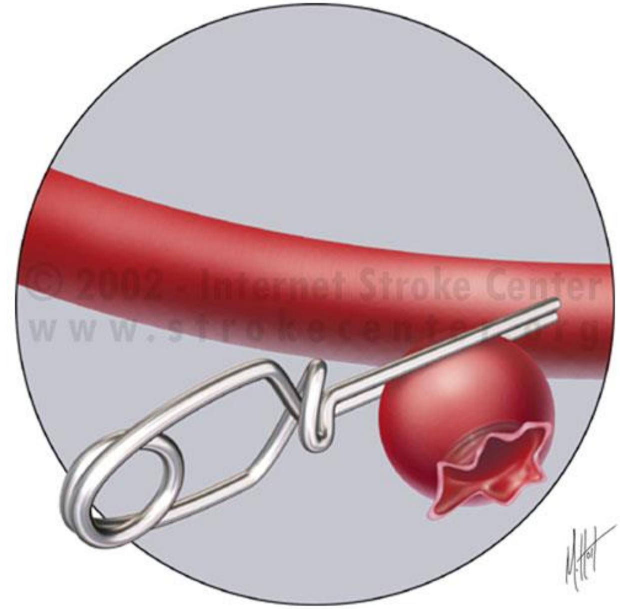
MR missile effect

- Attractive force: two aligned magnets are attracted (think about a magnet on the fridge door). Missile effect because ferromagnetic objects, propelled by enormous amounts of magnetic energy, can launch across the room with tremendous force towards an MRI. towards the peak of the magnetic field (typically the center of the MRI).

Oxygen tank example

MR safety



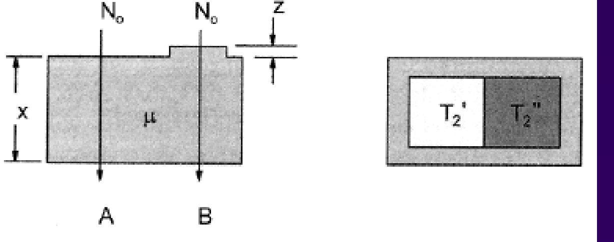


Aneurysm clips can be stripped away from the blood vesseles leading to death

Oggetti volanti possono uccidere la gente.
Anche se non creano incidenti gravi, possono volare nel magnete e danneggiarlo o richiedono un arresto costoso del sistema.

Image Contrast – What does it depend on?

- Remember: radiation needs to interact with the body's tissues in some differential manner to provide contrast
- X-ray/CT: differences in e^- density ($e^-/cm^3 = \rho \cdot e^-/g$)
- Ultrasound: differences in acoustic impedance ($Z = \rho \cdot c$)
- Nuclear Medicine: differences in tracer concentration (ρ)
- MRI: many intrinsic and extrinsic factors affect contrast
  - intrinsic: ρ_H, T1, T2, flow, perfusion, diffusion, ...
  - extrinsic: TR, TE, TI, flip angle, ...



(A) X-ray Imaging (B) MR Imaging

MRI parameters

MRI contrast depends on a large set of parameters:

- Intrinsic parameters include:

  proton density velocity

  spin-lattice relaxation time (T1) diffusion

  spin-spin relaxation time (T2) perfusion

  chemical environment temperature

- Extrinsic parameters include:

  echo time (TE) saturation pulses

  repetition time (TR)

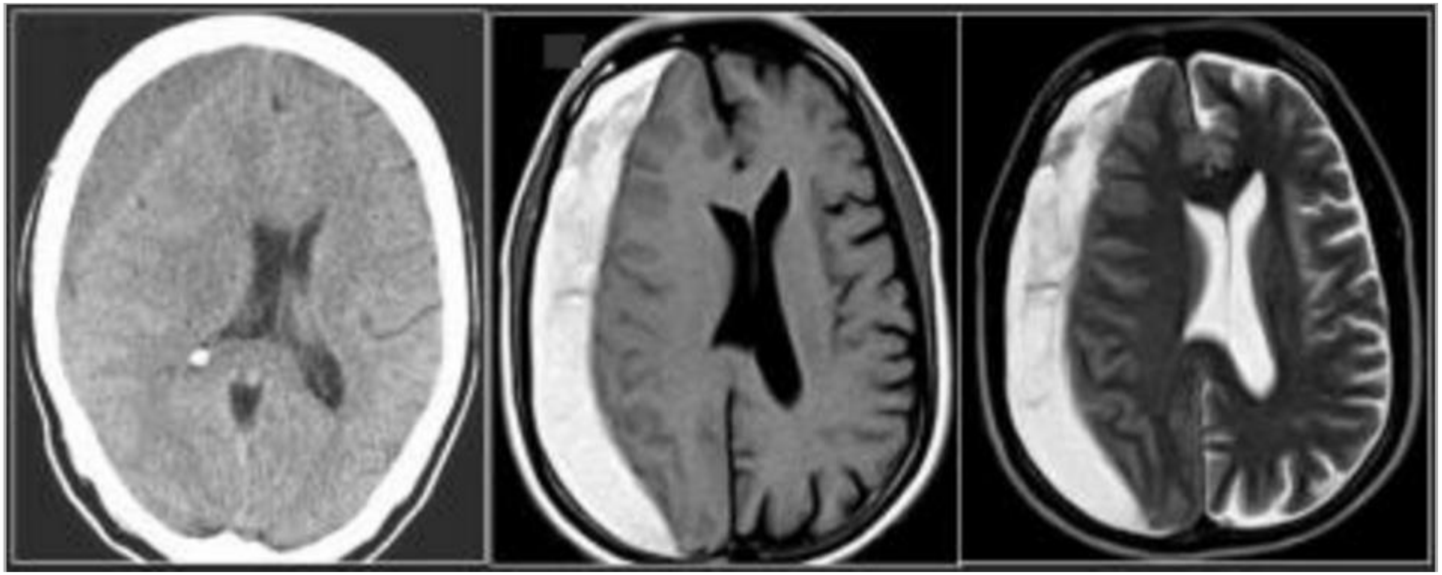
  inversion pulses flip angle (α)

  flow compensation pulses

  contrast agents

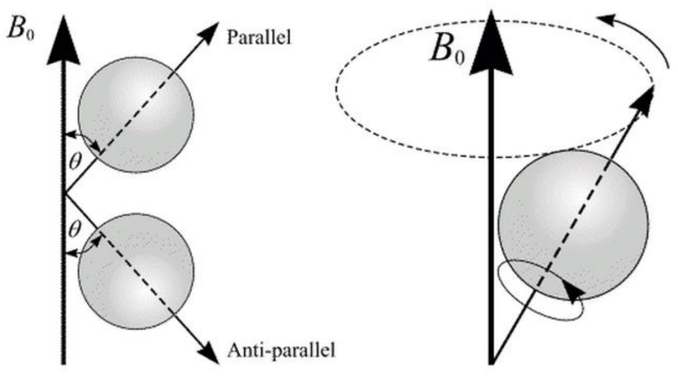
  diffusion sensitization pulses

Where do these parameters come from?

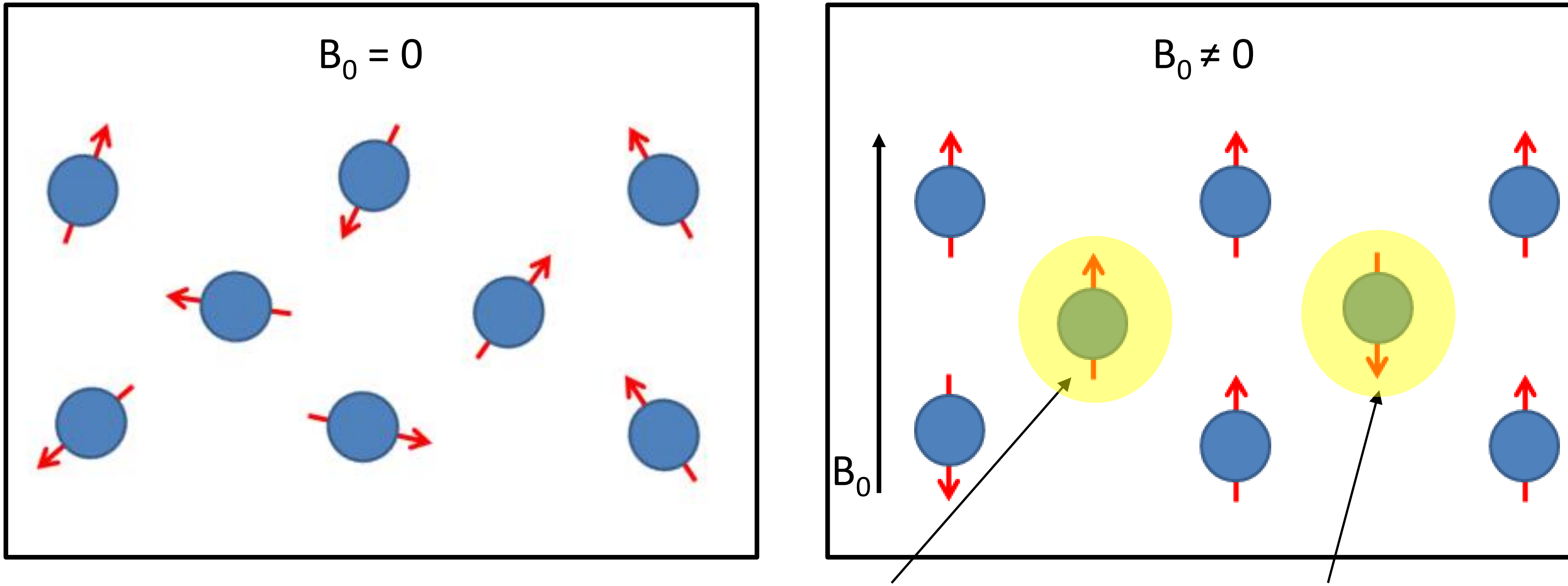


Magnetic Moment and Spin

Atomic nuclei with an odd number of neutrons and/or protons have a small *magnetic moment* and an angular momentum called *nuclear spin* *(e.g. H_2O)*



Nuclei	Unpaired Protons	Unpaired Neutrons	Net Spin	γ(MHz/T)
^{1}H	1	0	1/2	42.58
^{2}H	1	1	1	6.54
^{31}P	1	0	1/2	17.25
^{23}Na	1	2	3/2	11.27
^{14}N	1	1	1	3.08
^{13}C	0	1	1/2	10.71
^{19}F	1	0	1/2	40.08

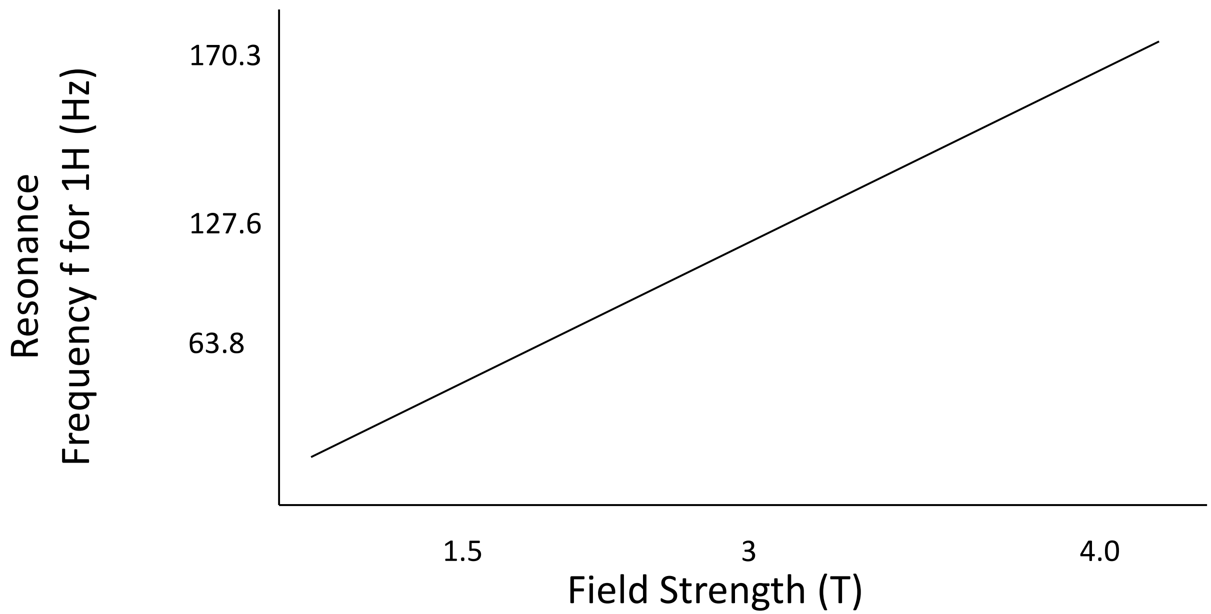


When $B_0 \neq 0$ protons will either align *parallel* to the magnetic field or *anti-parallel* to it and a small excess ($1/10^5$) of parallel vs antiparallel spins leads to a net magnetization M_0

Larmor equation

the energy difference between the high (antiparallel) and low (parallel) energy states is expressed by the Larmor equation:

$$f = \gamma B_0 \text{ with } (\gamma = 42.58 \text{ MHz/T})$$

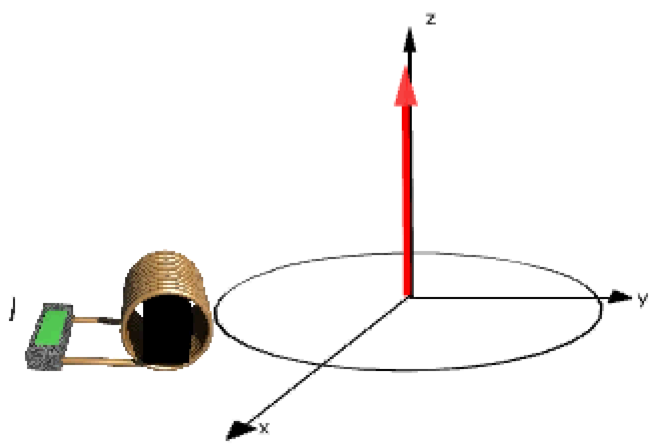


Resonance

Through Resonance protons can flip between energy states as long as the specific frequency is used

RF excitation

This is achieved by RF pulses used to flip M_0 out of alignment with B_0

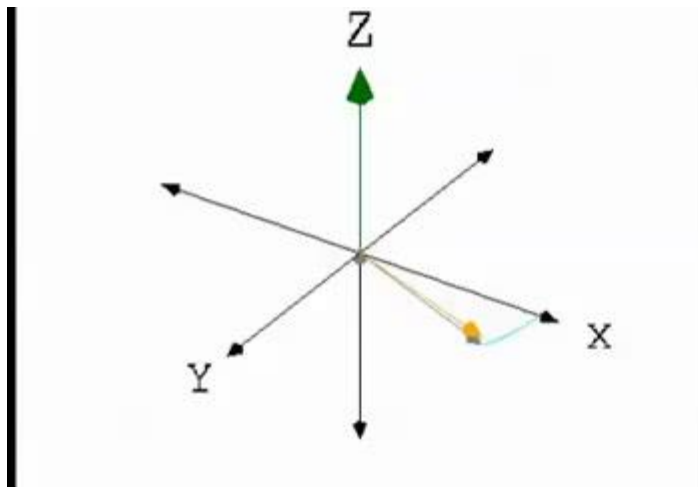


M_0 from a non-equilibrium state returns to the equilibrium distribution.

These two principal relaxation processes are described in terms of T_1 and T_2 relaxation times respectively.

T1 (Spin-Lattice) relaxation

T_1 relaxation involves redistributing the populations of the nuclear spin states to reach the thermal equilibrium distribution.



Relaxation mechanisms allow nuclear spins to exchange energy with their surroundings (*lattice)*

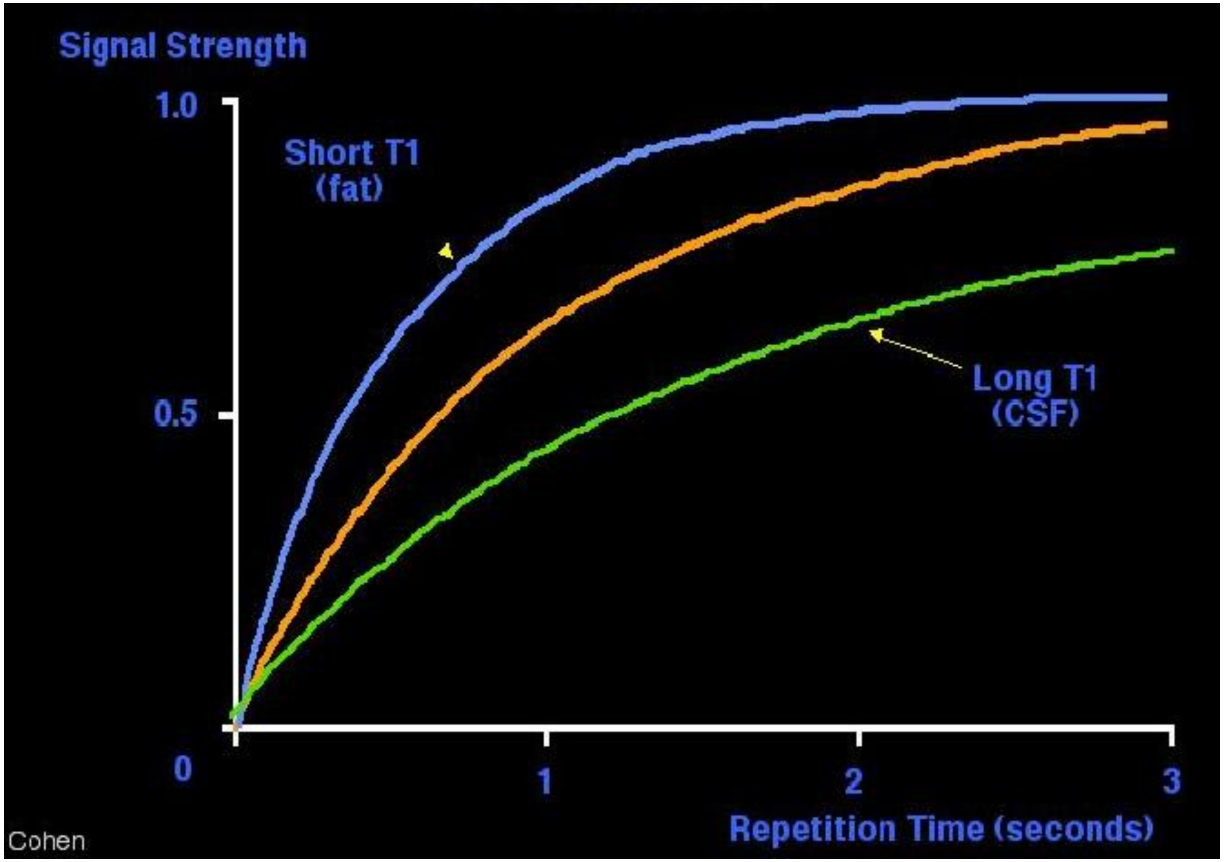
T_1 relaxation strongly depends on the NMR frequency and so varies considerably with B_0

T1 and TR

T1 = recovery of longitudinal (B_0) magnetization after the RF pulse

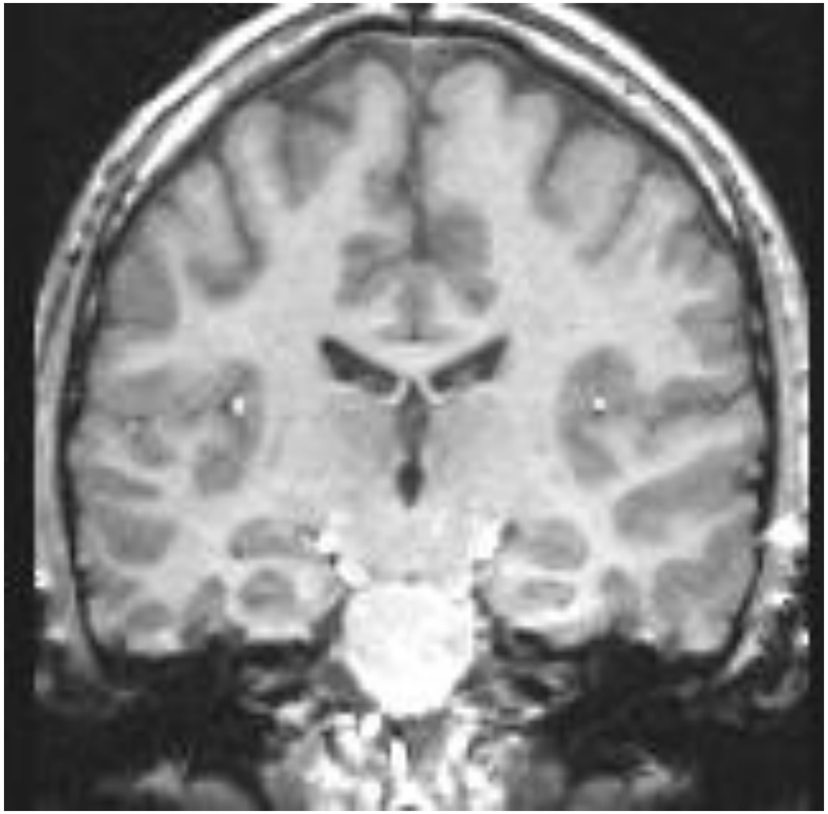
- used in anatomical images
- ~500-1000 msec (longer with bigger B_0)

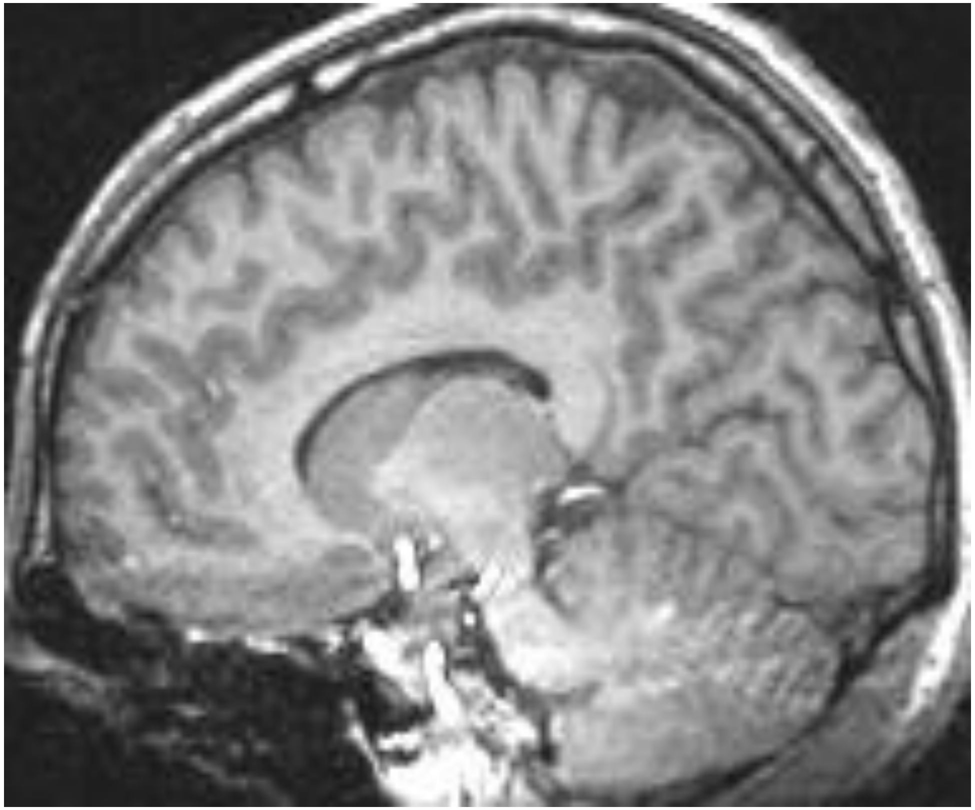
TR (repetition time) = time to wait after excitation before sampling T1



Developing Contrast Using Weighting

- *Contrast* = difference in image values between different tissues
- T1 weighted example: gray-white contrast is possible because T1 differs between these two types of tissue

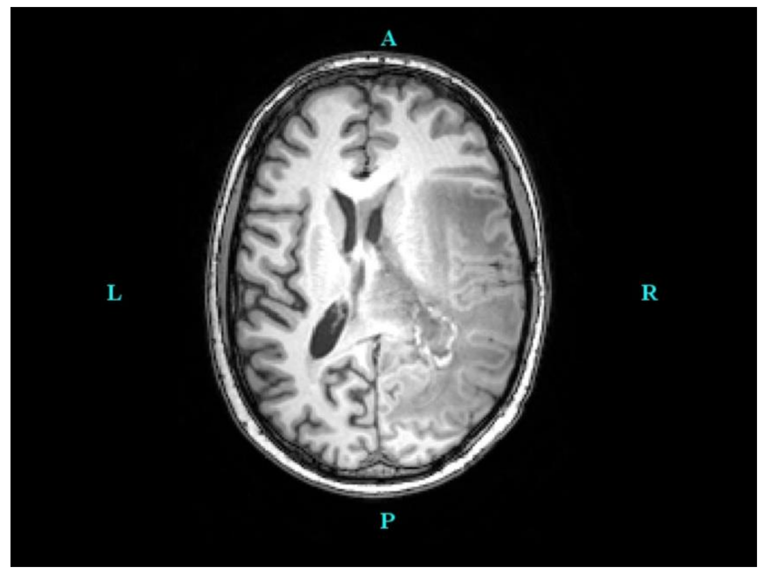




T1-weighted image (usually used for anatomical images) measures the rate at which different types of molecules (and by extension tissue) approach M_0 at different rates allowing us to differentiate things like white and grey matter:

Healthy subject

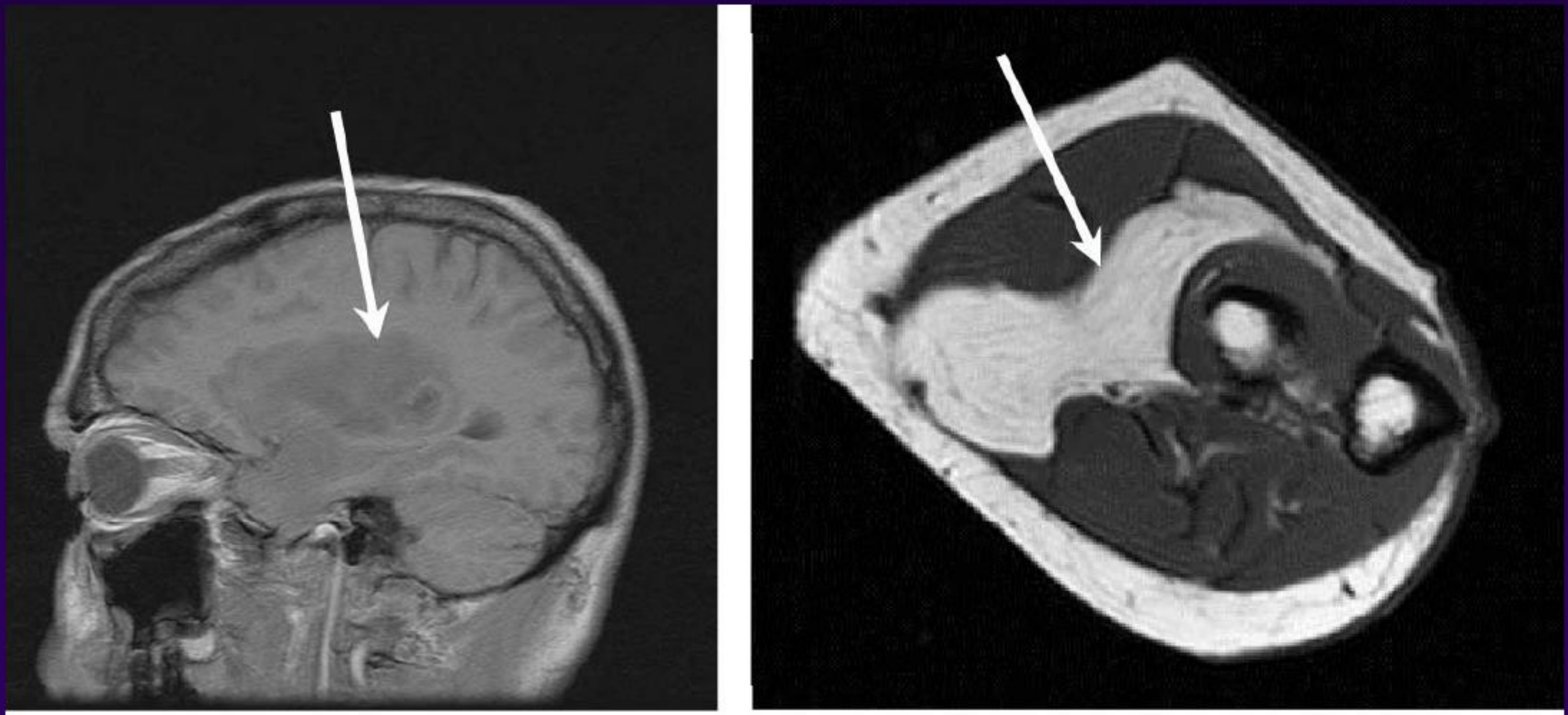
Tumor Patient



T1-weighted 'Anatomy' Images

Figure 3.2 T_1-weighted images of normal anatomy. (a) Oblique '4-chamber' view of the heart, (b) sagittal knee, (c) axial liver.

T1-weighted Pathology Images



(a) (b)

Figure 3.4 T_1-weighted images of pathology. (a) Sagittal slice through low-grade glioma, (b) lipoma in the forearm.

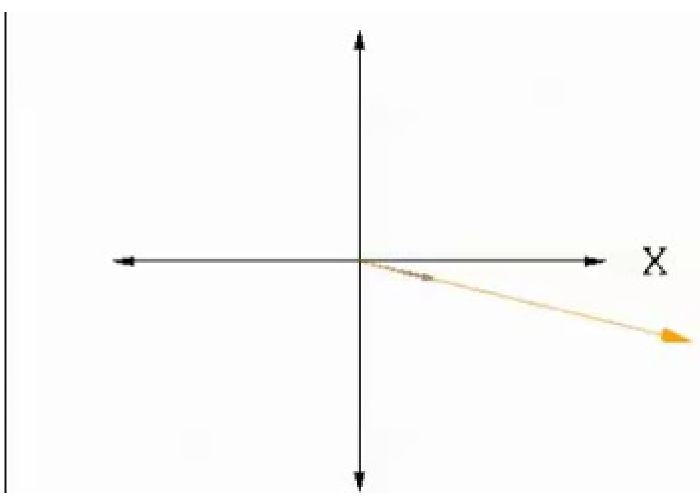
T2 (Spin-Spin) relaxation

T_2 relaxation corresponds to a decoherence of the M_{xy}

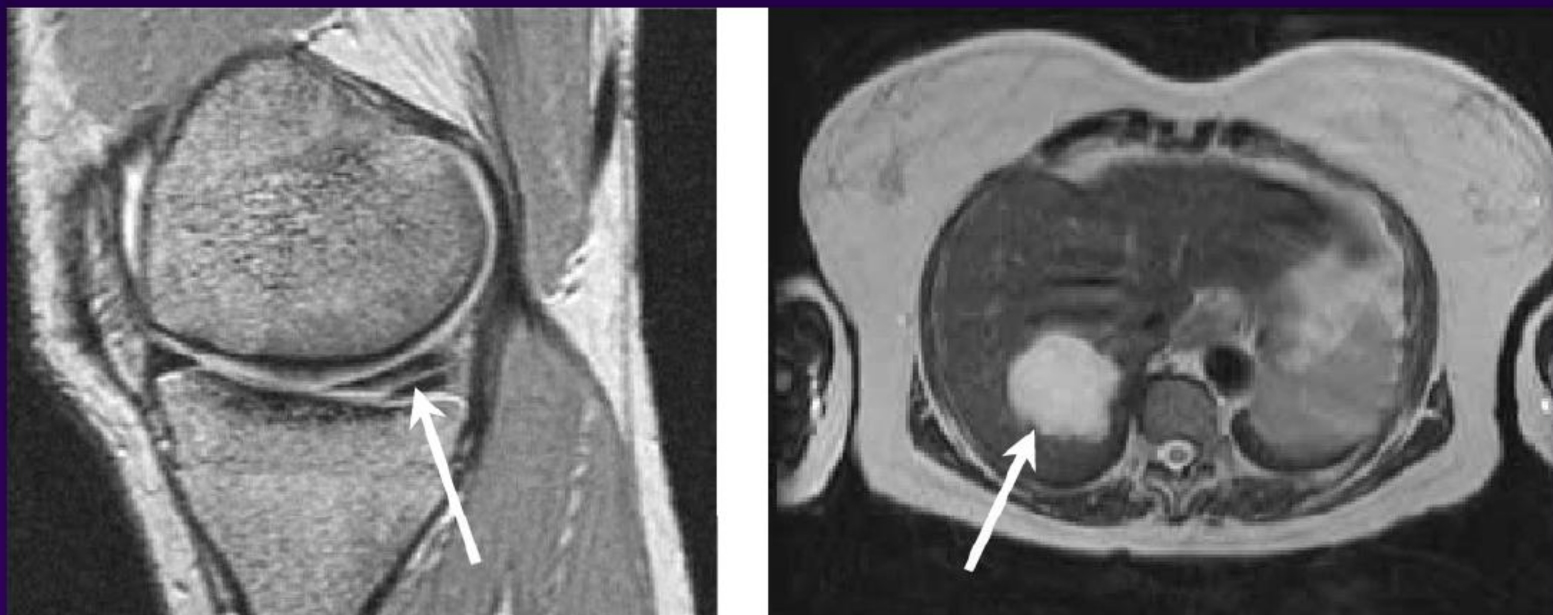
Random fluctuations of B lead to random variations of frequency of spins

The initial phase coherence is eventually lost

T_2 values are generally much less dependent from B_0 than T_1 values



T2-weighted 'Pathology' Images

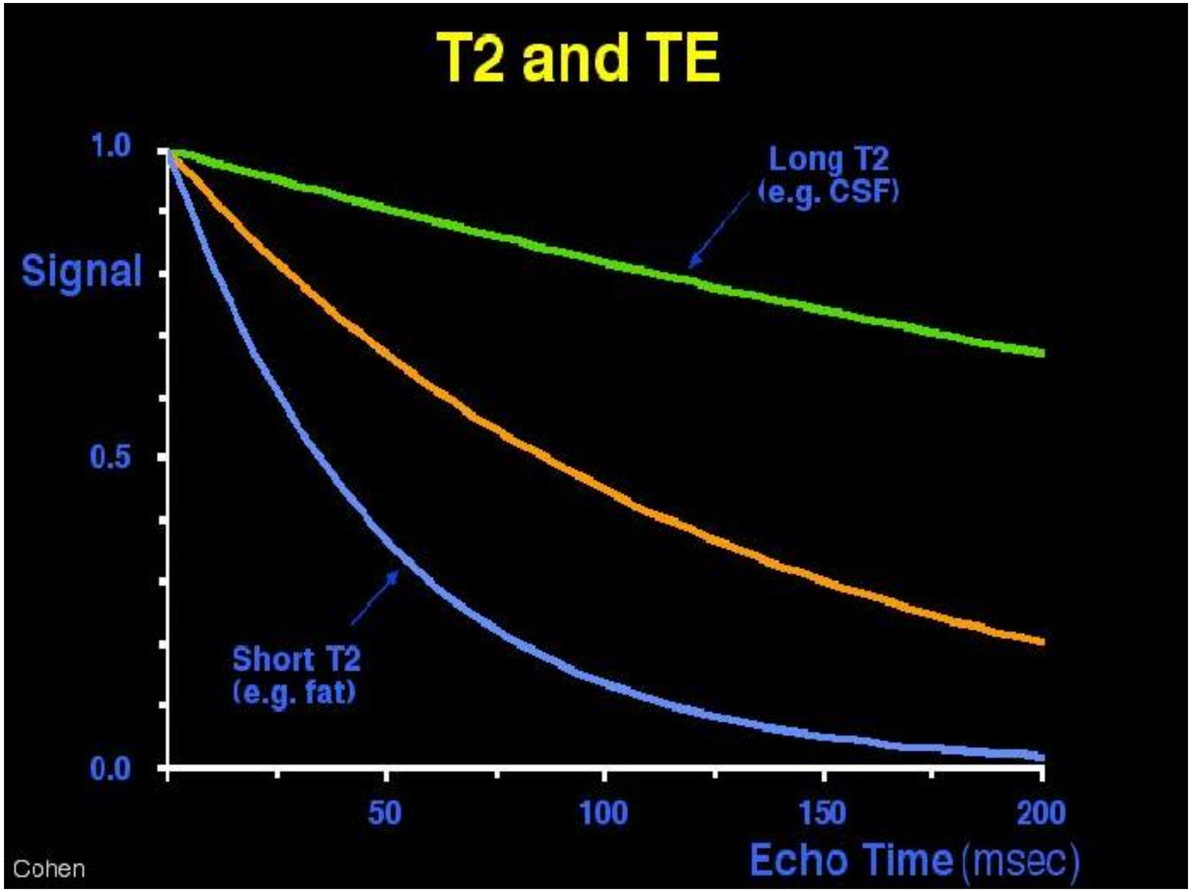


(a) (b)

Figure 3.5 T_2-weighted pathology images. (a) Sagittal image of meniscal tear (arrow) and (b) axial liver scan showing haemangioma.

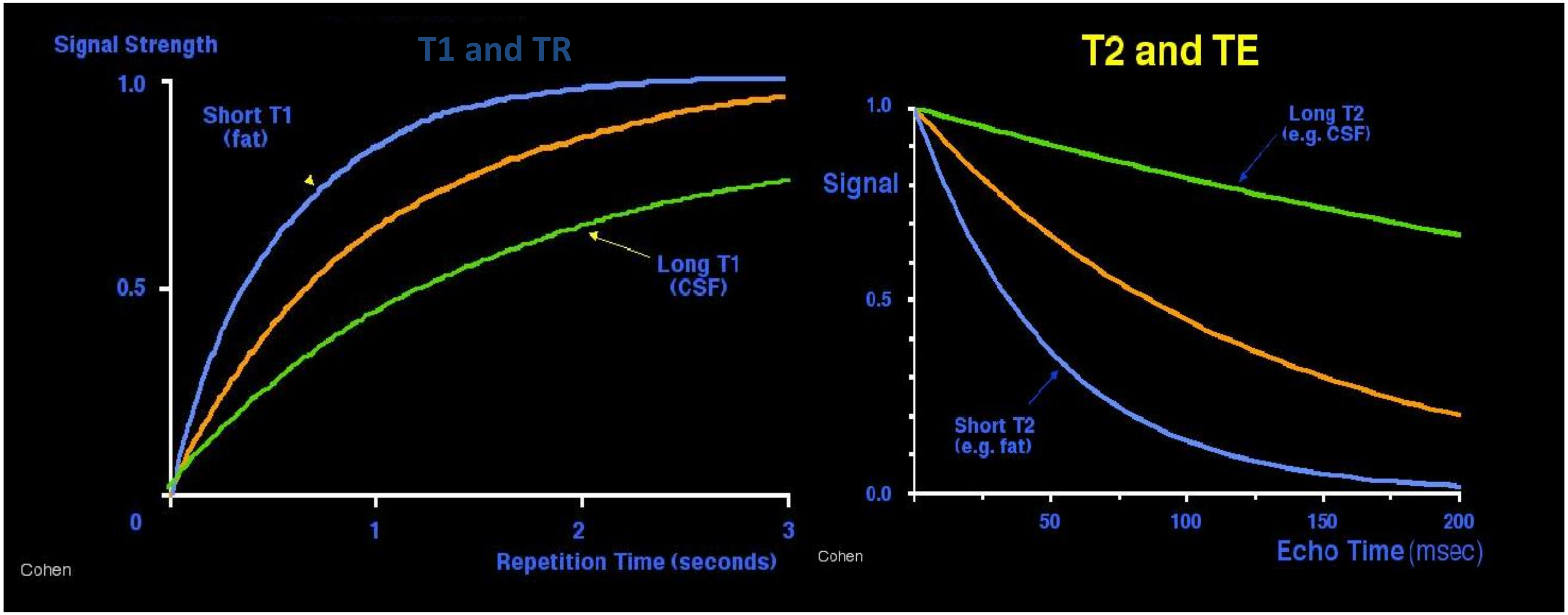
T2 and TE

T2 = decay of transverse magnetization after RF pulse
TE (time to echo) = time to wait to measure T2 or T2* (after re-focusing with spin echo)

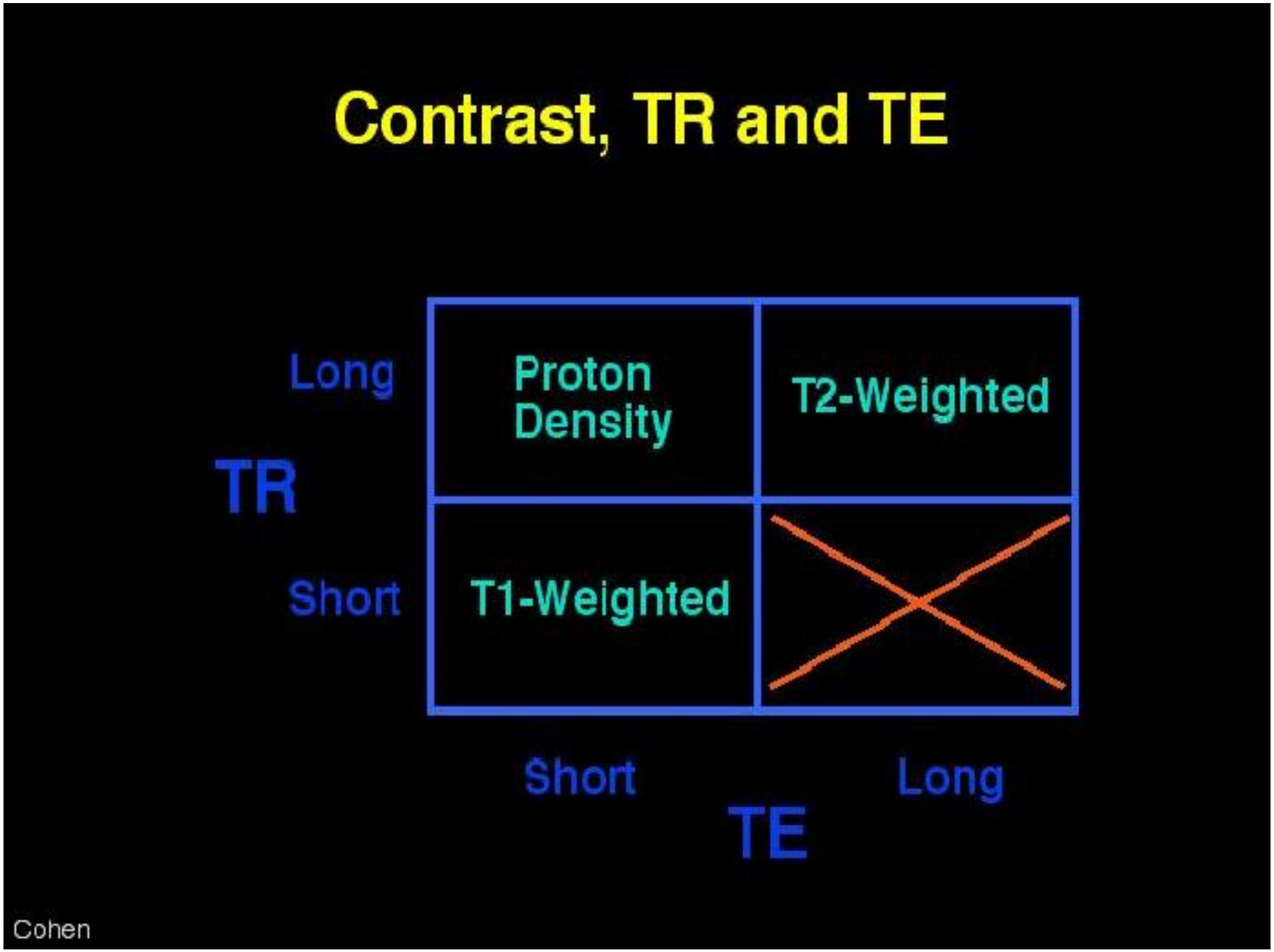


T1 vs. T2

- effectively, T1 and T2 images are the inverse of one another, with T1 typically used to form anatomical images and T2* used in fMRI



T1 vs. T2


Contrast, TR and TE
Long
Proton
Density
T2-Weighted
TR
Short
T1-Weighted
Short
Long
TE
Cohen

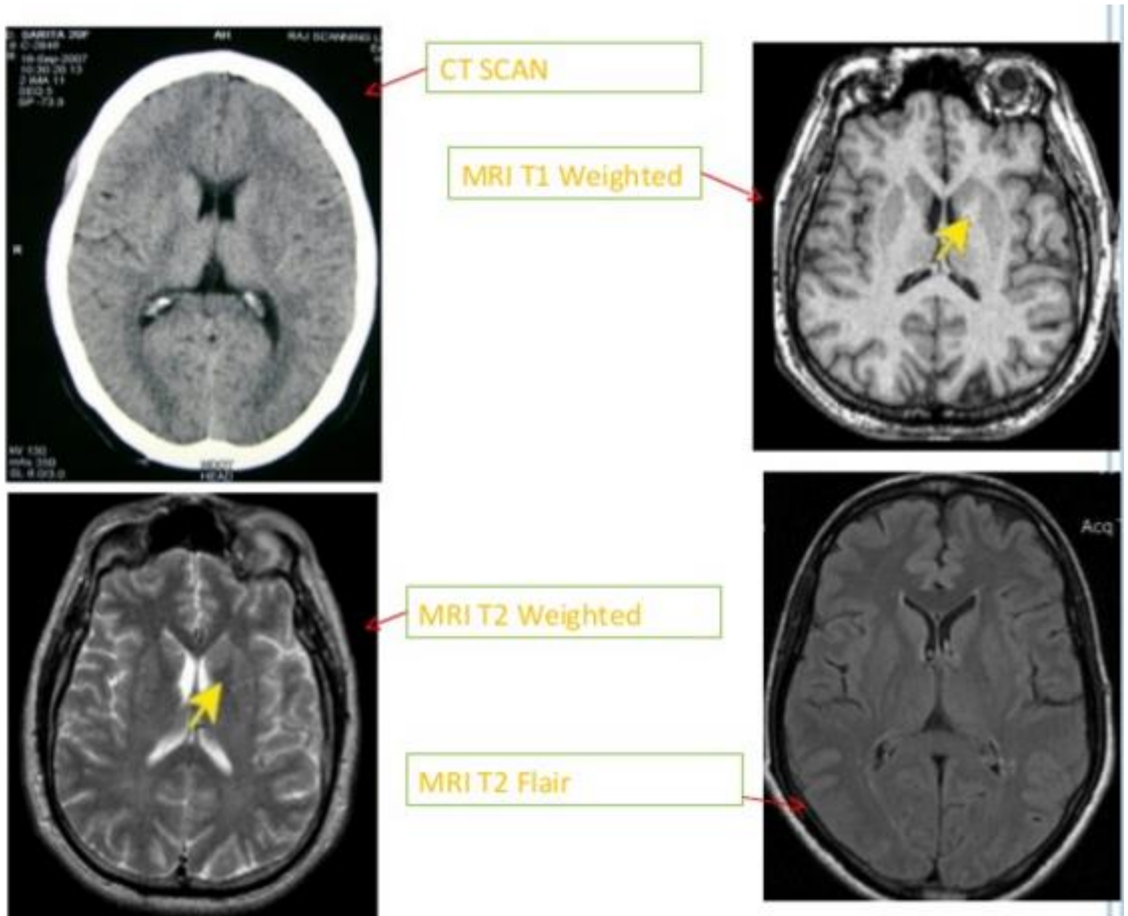
Properties of Body Tissues

Tissue	T1 (ms)	T2 (ms)
Grey Matter (GM)	950	100
White Matter (WM)	600	80
Muscle	900	50
Cerebrospinal Fluid(CSF)	4500	2200
Fat	250	60
Blood	1200	100-200

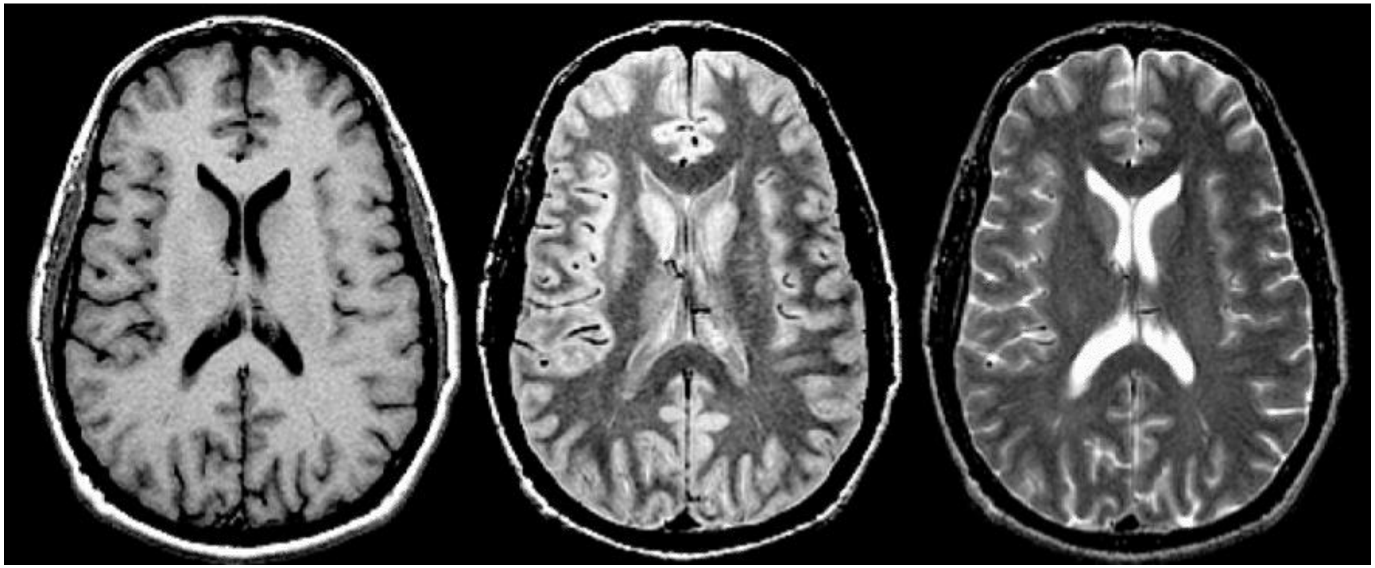
T1 values for B_0 ~ 1Tesla.
T2 ~ 1/10th T1 for soft tissues

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	Cartilag e	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

Proton density, recovery (T1) and decay (T2 and T2*) times.



T1 weighted Density weighted T2 weighted

- By 'weighting' the pulse sequence (and point at which data is collected) different images of the brain are obtained

- Weighting is achieved by manipulating TE (time to echo) and TR (time to repetition of the pulse sequence)