

SUMMARY OF MRI PHYSICS & Techniques

➤ **Energy Used :**

- **Magnet** → Magnetic Field
- **Coil** → Radio Waves

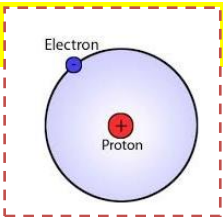
MRI
Benefits of Heaven
Physics of Hell!!

➤ **Nuclear Magnetic Resonance :**

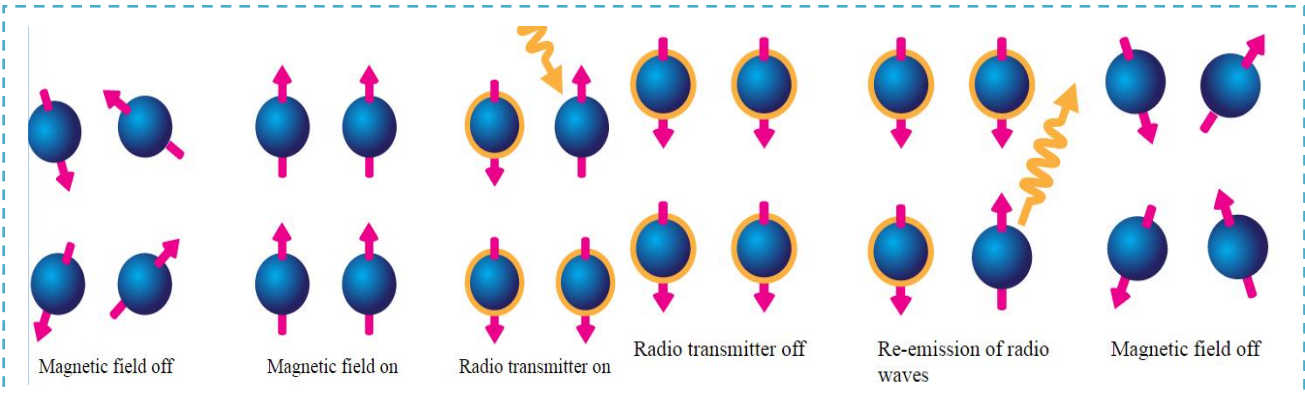
- ✓ Nuclei of all atoms contain protons,
- ✓ Only those with an **odd number** has nuclear magnetic resonance.
- ✓ Hydrogen has a single proton and abundant in the body, in :
 - **Water** (free or attached to other molecules) and
 - **Fat**, and so provides the best MRI signals.

➤ **MRI** measures the hydrogen content of **voxels** in each transverse slice → corresponding image pixel on the screen.

Summary of MRI Work

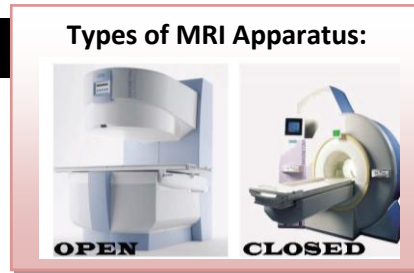


- Protons has **+Ve** charge.
- **H**ydrogen nucleus contains **1 Proton**.
- Protons are rotating → Act as small magnet → Magnetic field around.
- (**Body net magnetization = near 0**) - Although all these H protons, as small magnets within the body , But due to direction of rotation is variable & against each others.
- **Magnet** → Uniting the direction of rotation of protons.
- **Coil** → Radiofrequency "**RF**" → Change angle of protons by acquiring energy
- "**RF**" stop → Protons miss energy → apparatus receive energy & forming Image from it.



⇒ **Types of Magnets : "3 Types"**

- 1- Permanent
- 2- Electric
- 3- Super conducting



	Permanent	Electric	Super conducting
Core	Natural Magnet	Metallic Coil + Electric current	Superconducting Coil + Liquid He (-300 c)
Magnetic Field	Permanent	Electric current	Permanent alloy that Helium in the core
How to Stop Magnetic Field	Destroy by heat or beat	Just Cut electric current	Quench = Liberate Liquid He
(Earth's Magnetic Field: 5×10^{-5} T) * 1 Tesla = 20.000 time of Gravity			
Quench = Liberate Liquid He → Gas , in cases of emergency → Loss of Magnetization			

⇒ **Super conducting Magnet & Helium :**

- Very cold Temp. of liquid helium "- 300" → Super conducting coil loss resistance → electric current rotating forever in it → core become electric magnet with out outer source of electricity.

- Apparatus core contains **1400 L** of liquid He
- **Price:** 1 Liter He = 20 \$, X 1400 = 28000 \$
- 1 Liter of He → 700 L Gas

NB. **Protective Valve** → Keep Pressure constant

by liberate over recompressed He → Avoid Explosion

TO KEEP LOW TEMPERATURE OF LIQUID He:

- 1- Layers of **Iron** & Temperature reflecting Layers
- 2- Vacuum in-between layers
- 3- Cooled Head in (- 200 & - 280 C.)
- "Main Insulator"
- 4- Compressor → to decompressed Gas

A. ELGHORAB

Open

↑ **patient friendly**
Cheap

↓ **low field**
Low image Quality
Sensitive to interference
Sensitive to temperature

Closed

↑ **High field**
High image Quality
Less sensitive

↓ **Expensive**
Less patient friendly

WHICH PART of MAGNET CORE USED IN IMAGING?

THE SITE OF THE HOMOGENOUS MAGNETIZATION,

WHERE RADIOGRAPHED ORGAN BE WITH IN

- Gradient coil inside the core is grading magnetic field inside اي انه يدرج المجال لمناطق مختلفه فبذلك يتم العمل على كل شريحة كانها مجال مغناطيسي مختلف فلا يحدث تداخل فى الصورة المأخوذه
- Without Protection, 1.5 Tesla magnetic field → 9 m Vertical & 11 m Horizontal.

⇒ How to Protect From Magnetic field?

- 1- **Passive Shielding:** Anti magnetic layer in the walls of the room.
- 2- **Active Shielding:** Protective magnetic coil, around core, with magnetic field against the diagnostic field → make it limited to the room.

و هو ملف مغناطيسى فى اتجاه عكس الملف الاصلى للجهاز ، مما يحدث مجال مغناطيسى معاكس فيضعف كلا منهما الاخر خارجيا .

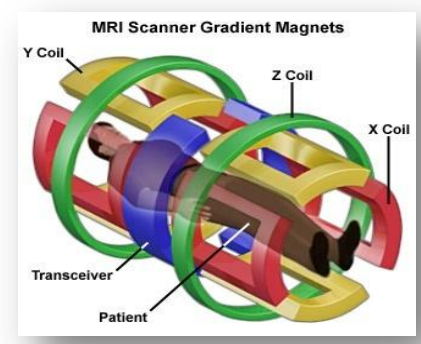
NB → We need to protect outside from Our Magnet & Magnet From Outside sources of Magnetization!!

- So the room of MRI must be away from any magnetic source such as elevators.
- Protective coil , when exposed to cretin Magnetic field → It produce similar field against it → Protect Magnet in side It.

⇒ Why MRI is Muti-planner ?

- ⇒ MRI Gradient coils , are present in the 3 Planes , X , Y & Z → So it can Acquire images in this main 3 Planes or any oblique plane.

⇒

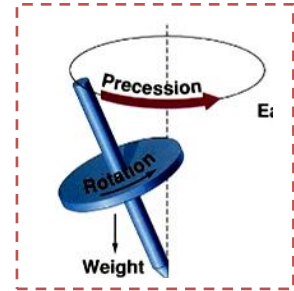


Protons & Movements

- ✓ **Rotation of Spin vector:** Proton rotation around its axis ,
Causing surrounding magnetic field due to its +ve charge.
- ✓ **Precession:** Proton wobbles around the direction of magnetic field.

Precession is related to power of Magnetic field

اي ان البروتون له حركتان دائريتان في نفس الوقت
دوران حول محوره "مثل دوران الارض"
و تأرجح حول محور المجال المغناطيسي للجهاز
"مثل تأرجح المغزل او النحلة"



Frequency of precession (f) = **Larmor frequency**

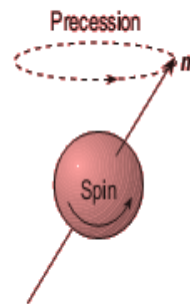
- is proportional to the product of:

- Magnetic field strength, &
- Constant property of the nucleus called **gyromagnetic ratio γ**

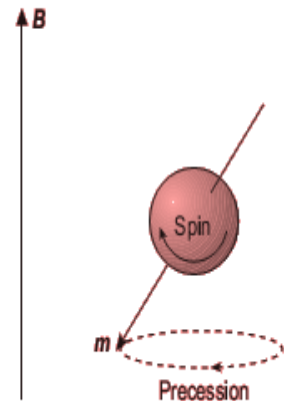
For hydrogen nuclei in a field of 1 T,

f =42.6 MHz.

(a)



(b)



Larmor frequency

Omega

$$\omega = \gamma \cdot B$$

Magnetic Field Strength in Tesla

= About 40 MHz at 1 Tesla

oS Stronger magnetic field,

→ Faster proton precession

1 Tesla = 10,000 Gauss
Typical MRI magnet = 1.5 T = 15,000 Gauss
Earths magnetic field = 0.5 Gauss

➔ How Do we get MR signal ?

➔ ➔ Signal From Precession more at XY “The state Like Dynamo”

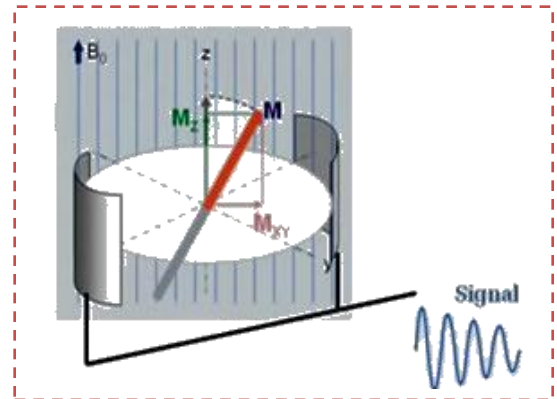
& Least At “Z” ,

i.e. during relaxation "ie stopped RF"

librated signal continuously Decreased

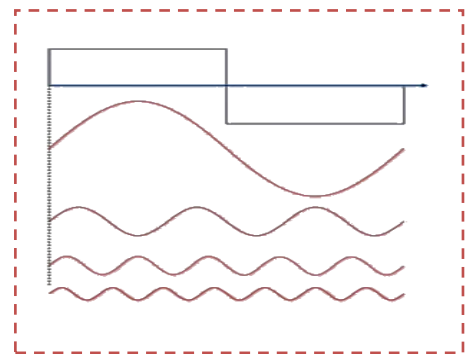
✓ **Signals** obtained from Different Protons

are heterogonous & of widely different signal intensity.



➔ *Foreier Equations*

can analyze This different Transformations signals. “Convert it to *Square*”



➔ *Gradient*

What is & Why?

➔ The large Magnet Has *single Tesla* Power → *Single Larmor* frequency of precession → All Protons Under the coil acquire & release energy at the same time & of the same rate → *Thus How to acquire image ??*

➔ Gradient : *is a magnetic coil , convert the magnetic field from single unique to* → GRADIENT

➔ *Thus Frequency of Precession will be different from section to another.*

Is The Gradient of Single Direction & Type? “NO “

1- The Gradient Directed **From Head To Feet**

→ Named “**Frequency Gradient**” ,

As it cause change in Frequency of Precession.

2- The Gradient Directed **From Side to side**

→ Named “**Phase Gradient**” ,

As it Not changing Frequency But changing phase of Precession.

Pixel & Voxel :

⇒ **Pixel** : Point with in a square forming image

مربع مسطح جزء من الصورة ،

و تجميع هذه المربعات يكون الصورة

More Pixels / area → Better image quality.

⇒ **Voxel** :

Small cubic with in the slice

و هو مكعب صغير جزء من المقطع

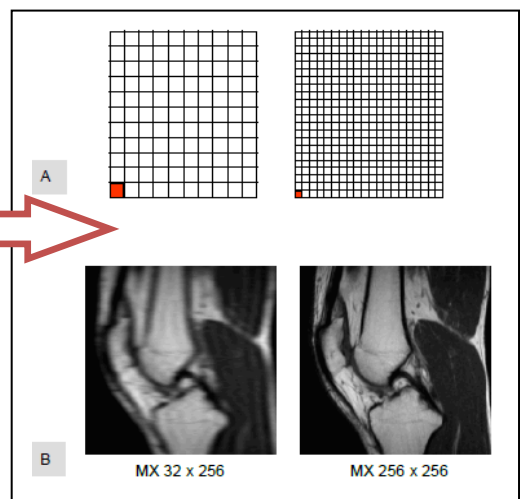
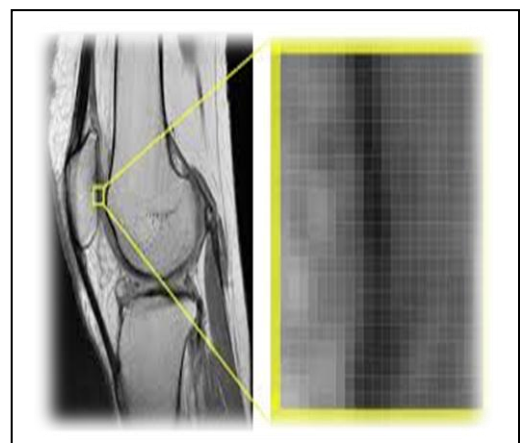


Image Formation & Reconstruction occurs by

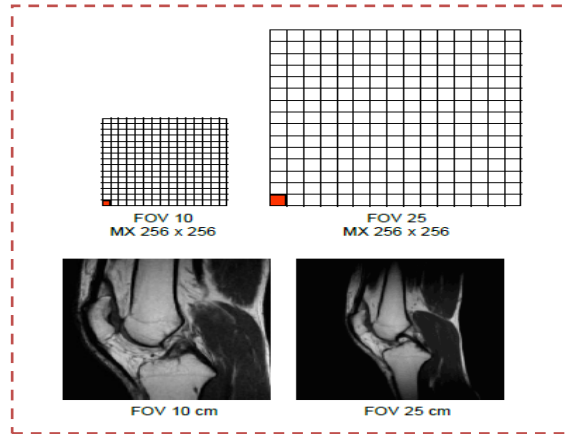
- The different Gradients in Multiple direction
- Each voxel give a different signal
- Translated in Gray Scale → Part of Image



➔ “Field Of View” FOV:

- Smaller Field of View → more details in small area → better image , but need longer time

و لذلك بعض الفنيين يستسهل استخدام الاكبر لتسريع الفحص ، على حساب جودة الصورة



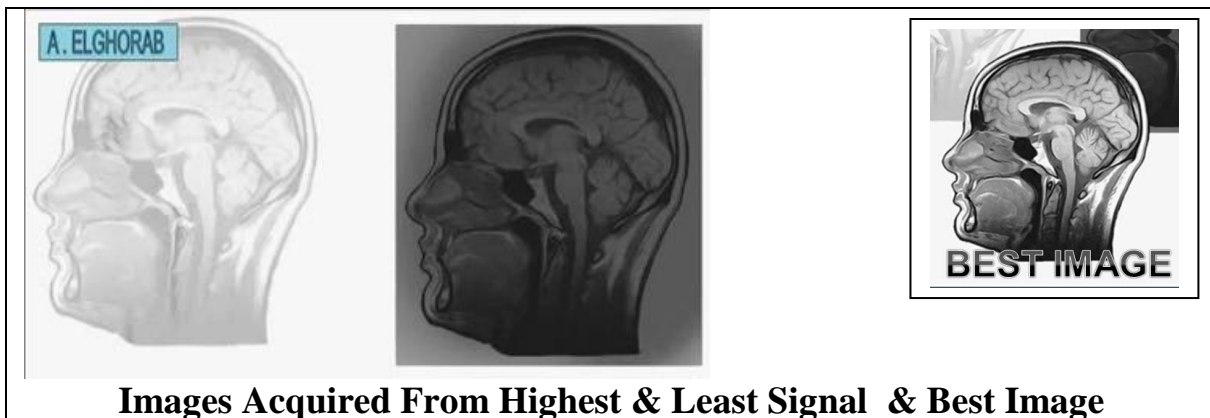
✓ WHAT IS SEQUENCE

It is The different changes in Gradients in Different Intervals → Different sequences of signal relaxation from different Voxels → MRI is Multi sequences.

Contrast = تباين

- *The More contrast in Image → The more Details & good image.*
- *Thus , which signal will be used to form image*
- *Most Powerful → Very Bright image with less details*
- *Most weak → Very Dark Image with more less details*

But We need Good image ...of Good detailsi.e. of good contrast !!!



Images Acquired From Highest & Least Signal & Best Image

⇒ Resonance

- ✓ **The frequency of the RF generator** must very accurately match the Larmor precession or resonant frequency of the Protons.

⇒ 180° pulse:

- ✓ An RF pulse of a certain total energy → give to each and every dipole "Rotating proton" → temporarily reverses tip them through 180°.
- ✓ This 180 Pulse , Role is to make Protons Precession of slower one reaching the faster , & both become in the same phase → Solve dephasing occurred & signal return high again

توضيح : عند اكتمال استثارة البروتونات و دورانها حول المحور الافقي ، يظل هناك فارق في السرعة بينها لاختلافات طفيفة في المجال المغنطيسي ، لذا بمرور بعض الوقت يزداد التباعد بينها و يلغي كل منها مجال الاخر ، لكن نبضه ال 180 ، تساعد على اقترابهم من بعض مرة اخري فتكون الاشارة الصادرة منهم واحدة و تزداد قوتها مرة اخري .

⇒ 90° pulse:

- ✓ An RF pulse of half that total energy (i.e. half the intensity or half the duration)
- ✓ will tip half of the dipoles so that equal numbers point spin up and spin down,
 - Mobile protons only give signals;
 - Protons in large molecules or immobilized in **bone** → no signals



⇒ for example,

Air, in sinus having no hydrogen, produces no signal

→ always appears **black**.

Fat has higher PD "Proton Density" than other soft tissues.

➤ Factors Control Image CONTRAST :

➔ Signal or Spin echo

= signal liberated from different H protons in different Tissue.

This is the main cause CONTRAST, which depend on:

▪ Factors of The Tissue :

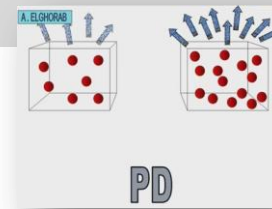
- Proton Density “PD”
- T1
- T2

▪ Factors of The working System or Protocol of Examination:

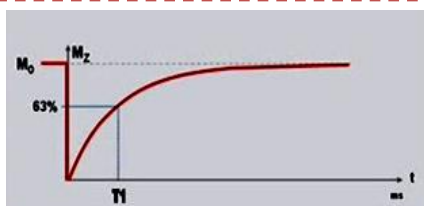
- TR : “Time of Repetition “ = Time between every 2 Excitation.
- TE : “ Time of Echo” = Time between Excitation & Reading “i.e Receiving signal of Relaxation”

➤ PD Proton Density :

- Density of Proton in Every Unit of Substance
- The more PD → The more signal



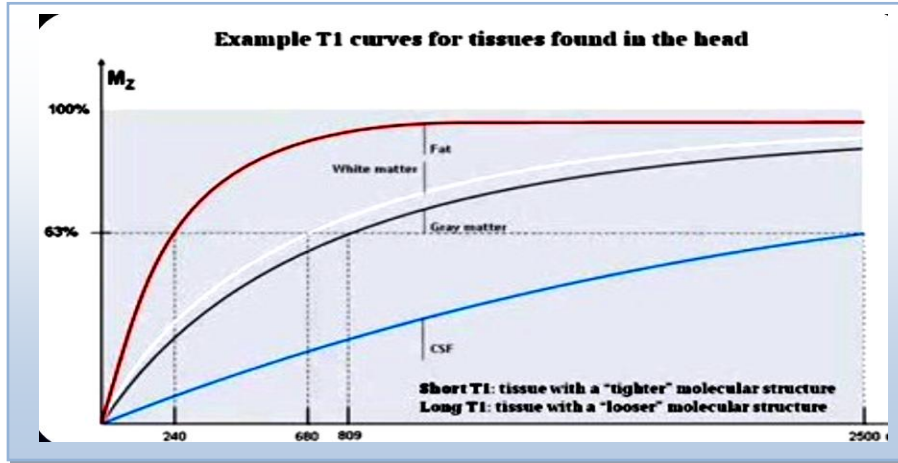
➤ T1 :



- It is a factor measured during Relaxation.
- It is the time of Certain Proton to return to 63 % of its initial State before Excitation .

➔ T1 is Long in Looser substance:

- i.e. fluid need more tome to reach this state ,
- While fat reach this state faster → at the same point of time → Fat will liberate more signal than Fluid → FAT Appear Bright



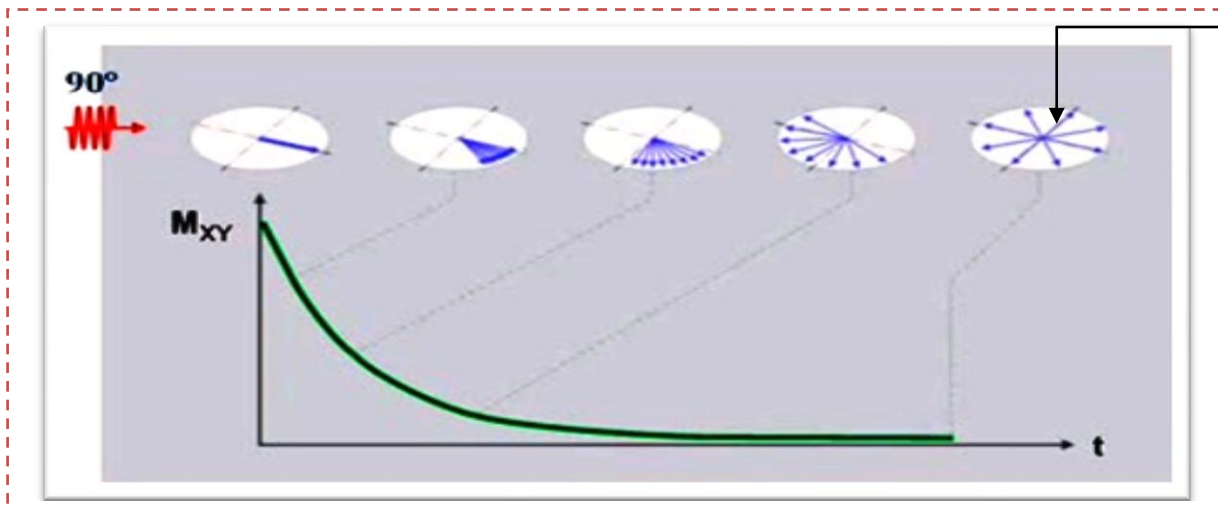
⇒ T2 :

Not Related to Relaxation Occurrence , But calculated at Complete Excitation in XY Plan

- After Complete Excitation → Protons precess at **Horizontal Plan** “XY Plan”
- But there is minute difference in the state of this precession = “De phasing”
- by more time → more difference → until each proton precess in direction against another one → **signal decrease near 0.**

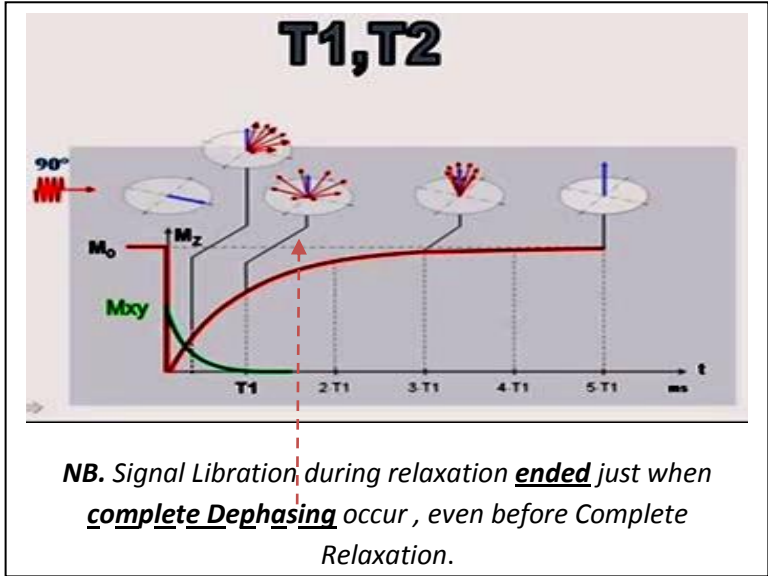
اي ان البروتونات بعد اكتمال اثارها بموجاد الراديو ، تبءء فى التآرجح معا و لكن بفارق زمنى بسيط ، و كلما مر وقت اتسع فترق التآرجح حتى تصل لمرحلة التباعء الكامل و يلغى كلا منها الطاقة الصاءءة من الاخر .

- T2 is the time needed to protons of the substance to **reach 37 %** of this State .



Tissue	T2 [ms]
Liver	43 ±6
Skeletal Muscle	47 ±6
Heart Muscle	57 ±9
Kidneys	58 ±8
Spleen	62 ±17
Fat	80 ±36
White Brain Matter	92 ±20
Gray Brain Matter	101 ±13
CSF (estimated)	1400 ±250

CSF = cerebrospinal fluid



- At T1WI → **Short TR** , **Short TE**
- At T2WI → **Long TR** , **Long TE**

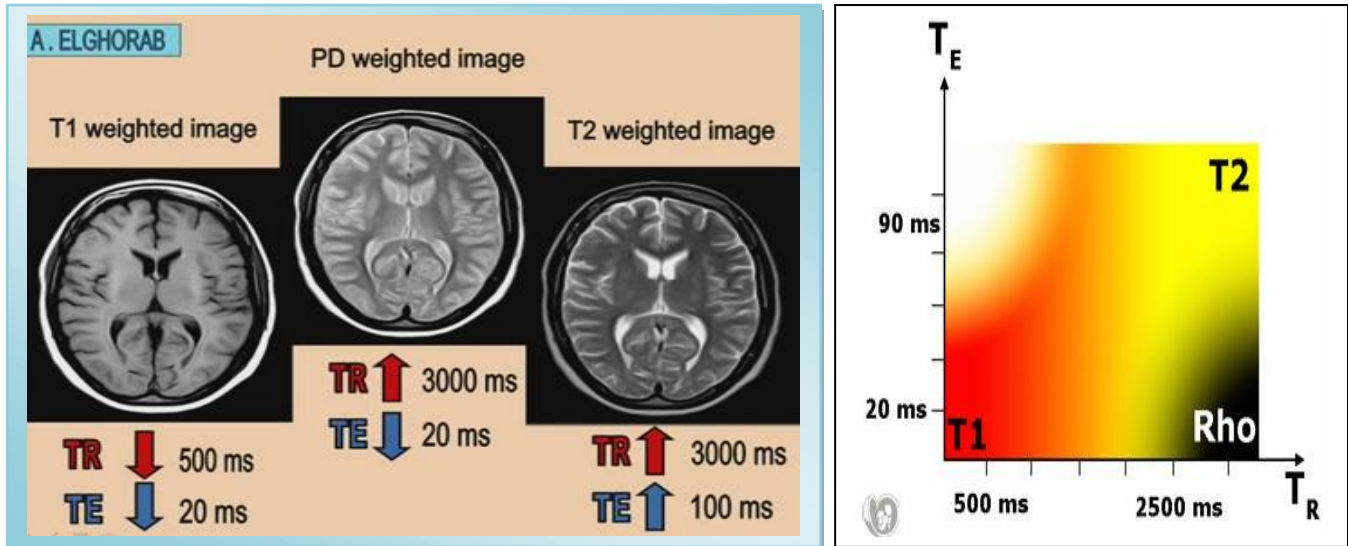
→ Is simple manner "Not very accurate scientific" **Why short TR in T1WI ?**

to acquire signal depending upon T1 bases, rapidly before complete dephasing of T2 occur & signal lost.

- So, we repeat RF to delay complete dephasing occurrence "Role of 180 RF pulse" .

→ **PDWI:**

reading of signal occurs in a state **during which T1 & T2 are nearly equal** , But the difference in Librated signal is related To the **density of H proton** in Tissues.



- **STIR** (Short Tau Inversion Recovery) Sequence
- **FLAIR** (Fluid Attenuated Inversion Recovery) Sequence

Summary: Process Involved in MRI

- Put patient in a static field B_0 in z-direction
- (step 1) Wait until the bulk magnetization reaches an equilibrium (align with B_0)
- Apply a rotating field (alpha pulse) in the xy plane to bring M to an initial angle α with B_0 . Typically $\alpha = \pi/2$
- $M(t)$ precesses around B_0 (z direction) at Larmor freq. with angle α
- The component in z increases in time (longitudinal relaxation) with time constant T_1
- The component in x-y plane reduces in time (transverse relaxation) with time constant T_2
- Apply π pulse to induce echo to bring transverse components in phase to increase signal strength
- Measure the transverse component at different times (NMR signal), to deduce T_1 or T_2
- Go back to step 1
- By using different excitation pulse sequences (differing in TE, TR, α), the signal amplitude can reflect mainly the proton density, T_1 or T_2 at a given voxel

⇒ TERMS : in Arabic

- **Spinning** = دوران البروتون حول محوره ، و هو بمعدل ثابت
- **PRECESSION** = تأرجح البروتون عند تعرضه لمجال مغناطيسي
- Larmor Frequency “ Ω ” =

تردد التأرجح ، و الذي يزيد بزيادة قوة المجال المغناطيسي

- **Flip Angle “Alpha α ”** : زاوية ميل تأرجح البروتونات و التي تتعلق بموجات الراديو (—)
- **Excitation** = اكتساب البروتون للطاقة تغير زاوية التأرجح
- **Relaxation** = فقد الطاقة المكتسبة من بعد ايقافه و تحرير الطاقة يؤدي الى اشارة تكوين الصورة
- **K space** : memory of saving signals from Different Voxeles.
- **T1**: the time needed to the excited to return to 63% of its relaxing state.
- **T2** : it is the time needed to the matter protons to gain 37% of its de-phasing state.

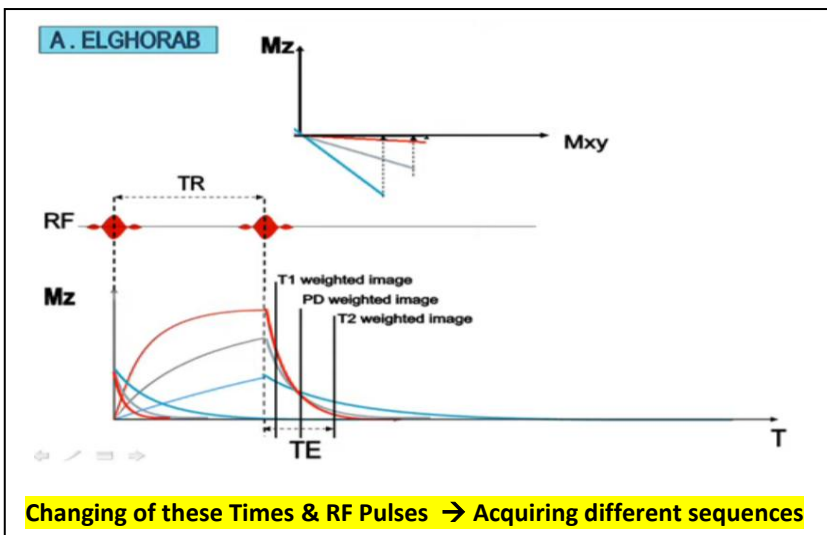
SUMMARY OF MRI PHYSICS

The following table shows T1 and T2 relaxation times for various tissues at 1.5 T.

For example:

- A tissue with a long T1 & T2 (like water) :
→ **dark in T1-weighted** image and **bright in T2-weighted** image.
- A tissue with a short T1 & a long T2 is
bright in the T1-weighted image and **gray in the T2-weighted** image.
- **Gadolinium contrast agents** reduce T1 and T2 times,
→ enhanced signal in the T1-weighted image and a reduced signal in the T2-weighted image.

	T1 (ms)	T2 (ms)
Water	3000	3000
Gray matter	810	100
White matter	680	90
Liver	420	45
Fat	240	85
Gadolinium	Reduces T1	Reduces T2



IN CLINICAL PRACTICE :

- ✓ **Always TE < TR**
- ✓ **Short TR = Average T1 value**, usually < **500 ms**
- ✓ **Long TR = 3 X short TR**, Usually > **1500 ms**
- ✓ **Short TE < 30 ms**
- ✓ **Long TE = 3 X short TE**, Usually > **90 ms**

⇒ DIFFUSION DWI

Sequences & parameters in DWI are the same in T2, But The Gradient added in Diffusion

- The gradient Causing inversion of T2 effect on fluids

.....i.e. **physiological fluids** in Diffusion appears of **low signal "Black"**.

- ✓ **ADC Map** is a computerized image.
- ✓ Obtained by taking multiple Diffusion images on different b Factors.
- ✓ This series of images make the rate of diffusion of different molecules can be calculated in numbers.
- ✓ The ADC Map image is inverted in colors i.e. **restricted is black & Free is White**.
- ✓ Thus in ADC Map, moving cursor on any pixel → show value of protons diffusion in this site

SUMMARY OF MRI PHYSICS

⇒ “ADC Value”:

- ✓ ADC Value = the number obtained / 1000
- ✓ i.e. if SD/Mean = 752.5 ,

Thus value 0.7 52 i.e. about 0.7

= To interpret Image:

⇒ Look at Diffusion Image & ADC Map

- Area of Restricted Diffusion → High signal in DWI & Low in ADC & Vice versa
- As DWI & T2 are of the same sequence , T2 may affect on the nature of the image of DWI
- Gradient may be unable completely to mask the **T2 signal of free fluids**

Thus

→ IN DWI Restricted Diffusion & lesions of very high signal in T2 → appears **Bright**

How to Differentiate ?

-Area of Restriction = Bright in DWI / Dark in ADC

- Lesion of Very Hi T2 signal = Bright in DWI / Bright in ADC

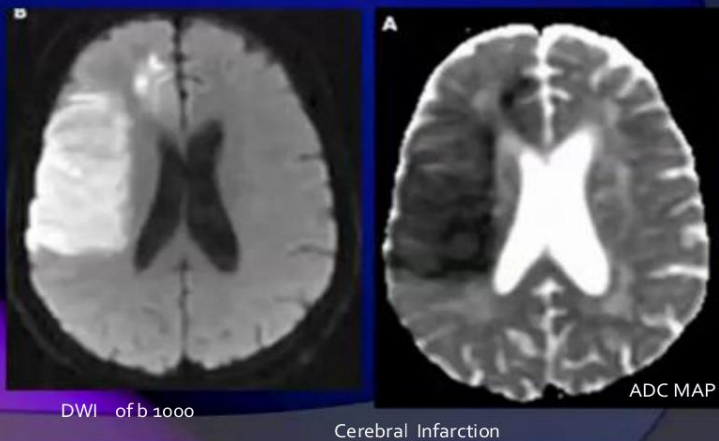
Use of Diffusion imaging in Differentiation between Medulloblastoma from Ependymoma

- **Medulloblastoma :**
high cellularityLow ADC value
- **Ependymoma:**
low cellularity... high ADC value

ADC Value in Glioma Grading :

- ✓ Low Grade → ADC > 1
- ✓ High Grade → ADC < 1

Diffusion Restriction



Tumor Cellularity

Tumors with high cellularity:

1. Lymphoma.ADC values 0.51 to 0.71
2. High grade glioma.....0.58 to 0.89
3. Metastasis.
4. Medulloblastoma.
5. DNET.

Tumors with low cellularity:

1. Low grade gliomaADC values >1.05

⇒ As diffusion in the brain tissue occurs :In between cells , i.e. In extracellular fluid

The restriction of Diffusion will be related to:

- ✓ Size of Cells eg. *Infarction* → as cells are swollen by it
- ✓ Numbers of the cells e.g. *Tumors*
- ✓ Viscosity of extracellular Fluid e.g. *Abscess*

Few Malignancies has Low cellularity

Ex. **Cordoma**

SUMMARY OF MRI PHYSICS

Most Essential Sequence For Every Scanned Organ of Part			
Organ	Sequence	PLAIN	Notes
Brain			
Orbit	T1 Fat suppressed Pre & Post Contrast	Axial	
Sella		Coronal	
Larynx	Fat suppression Pre & Post Contrast	Axial & Sagital	
Chest	T2		To differ Mass from consolidation Assess chest wall invasion
Knee	PD	Sagital	FOV 16
Hip	T1 & STIR	Coronal	FOV 30 : 42 cm
Ankle	T1, T2 , Gradient & STIR	Axial , Sagital & Coronal	FOV 8 cm
Shoulder	T1, T2, PD	Coronal Oplique	
Elbow			
Wrist			FOV 8 : 12
Infarction	Diffusion DWI		Fastest sequence to detect infarction
	ADD YOUR		

SOURCES

- **BASIC MRI LECTURES – Eng. AMR ELGHORAB**
<https://www.youtube.com/playlist?list=PLBD0BE7368C961619>
- MRI Physics By Dr. Hany A. Amer
[https://www.facebook.com/l.php?u=https%3A%2F%2Fwww.youtube.com%2Fwatch%3Fv%3detT6U79fs8U&h=kAQG3Mwsk](https://www.facebook.com/l.php?u=https%3A%2F%2Fwww.youtube.com%2Fwatch%3Fv%3DetT6U79fs8U&h=kAQG3Mwsk)
<https://www.youtube.com/watch?v=zf5oX01bRgk>
- **Introductory NMR & MRI by Paul Callaghan**
<https://www.youtube.com/watch?v=7aRKAXD4dAg&list=PLB787BD679BAAEC2E>
- DIFFUSION WEIGHTED MRI - PROF DR OSAMA ABD-ELWADOOD