Role of MRI from the view of medical physics in determine T1and T2

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MRI RULES

For an MRI we need

1) a strong magnetic field and 2) radio frequency.

The magnetic resonance signal is taken from the protons present in hydrogen.

Electricity and magnetism are two sides of the same coin according to the laws of electromagnetism. Electric current can create a magnetic field. Conversely, a changing magnetic field can create an electric current in a physical phenomenon called **electro-magnetic induction.**

- The spin movement makes the proton look like a magnet with two poles, one north and the other south, in addition to a magnetic field.
- there is a magnetic field for protons inside the human body, the sum of their magnetic resultant is zero. This is because the direction of their magnetic fields is scattered and cancels out the effect of each other.

- When protons (the human body) are placed inside a strong magnetic field called the external or main magnetic **field B0** (magnetic resonance device), most of them are organized in the same direction as the magnetic field. The remainder is arranged opposite the direction of the magnetic field. Protons facing the magnetic field cancel out an equal number of protons facing the magnetic field. Since the number of the latter is greater, the final result is that the resultant direction of the total magnetic fields of the protons is in the direction of the main magnetic field.

- When protons are placed in an external magnetic field, we have a vector that represents the magnetic resultant of all protons that are in the direction of the external magnetic field. This vector is called **longitudinal magnetization**.
- When protons are placed in the main magnetic field, they acquire a rotational movement called **precession** around the magnetic field lines. This movement has a specific frequency that varies depending on
- The strength of the magnetic field. The relationship is direct, as the intensity of the magnetic field increases, the frequency of the Larmor rotational motion increases.

- When the longitudinal magnetization is in the direction of the external magnetic field, we call this state a **state of equilibrium**. No signal can be taken from this case and the protons must be excited to be in a direction other than the main magnetic field to obtain a signal.
- The desired protons are excited by sending an RF radio wave frequency equal to the precessional frequency of the Larmor rotation of the protons. Protons gain energy and are able to change the direction of their magnetic fields away from the main magnetic field. In the excited state, the longitudinal magnetization disappears and the transverse magnetization increases.

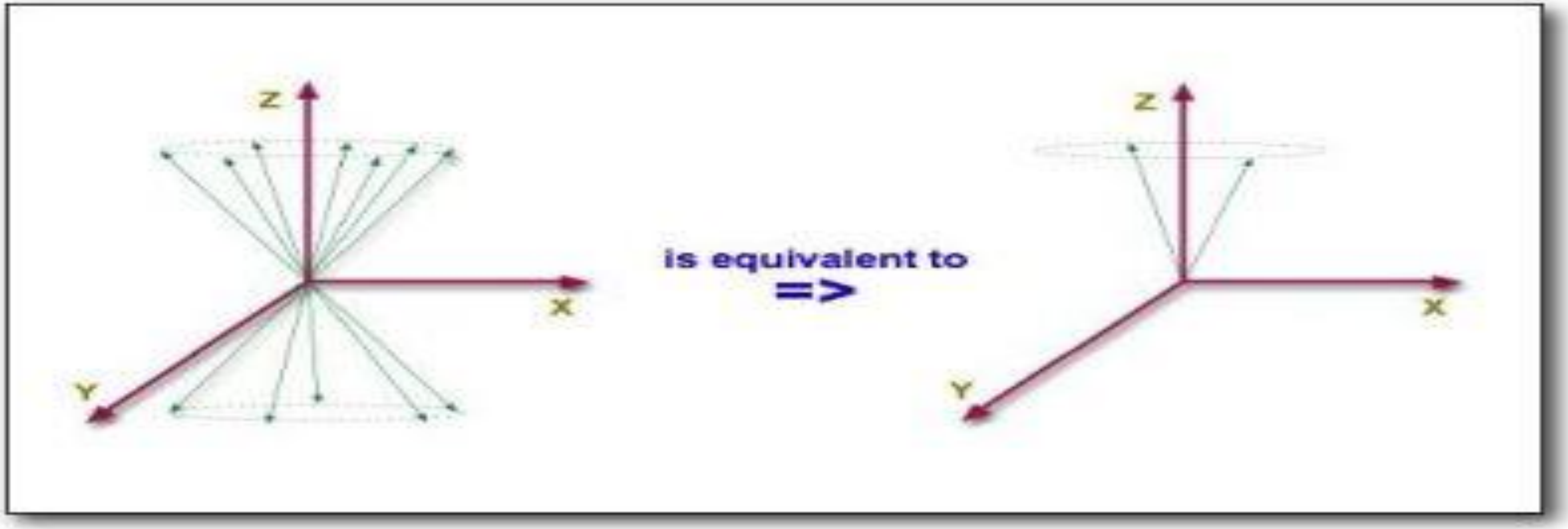
- After stopping the RF radio waves, the protons lose the energy they gained from these waves and return to their normal state of equilibrium. The MRI signal is this loss of energy.

This is the big idea of MRI in general.

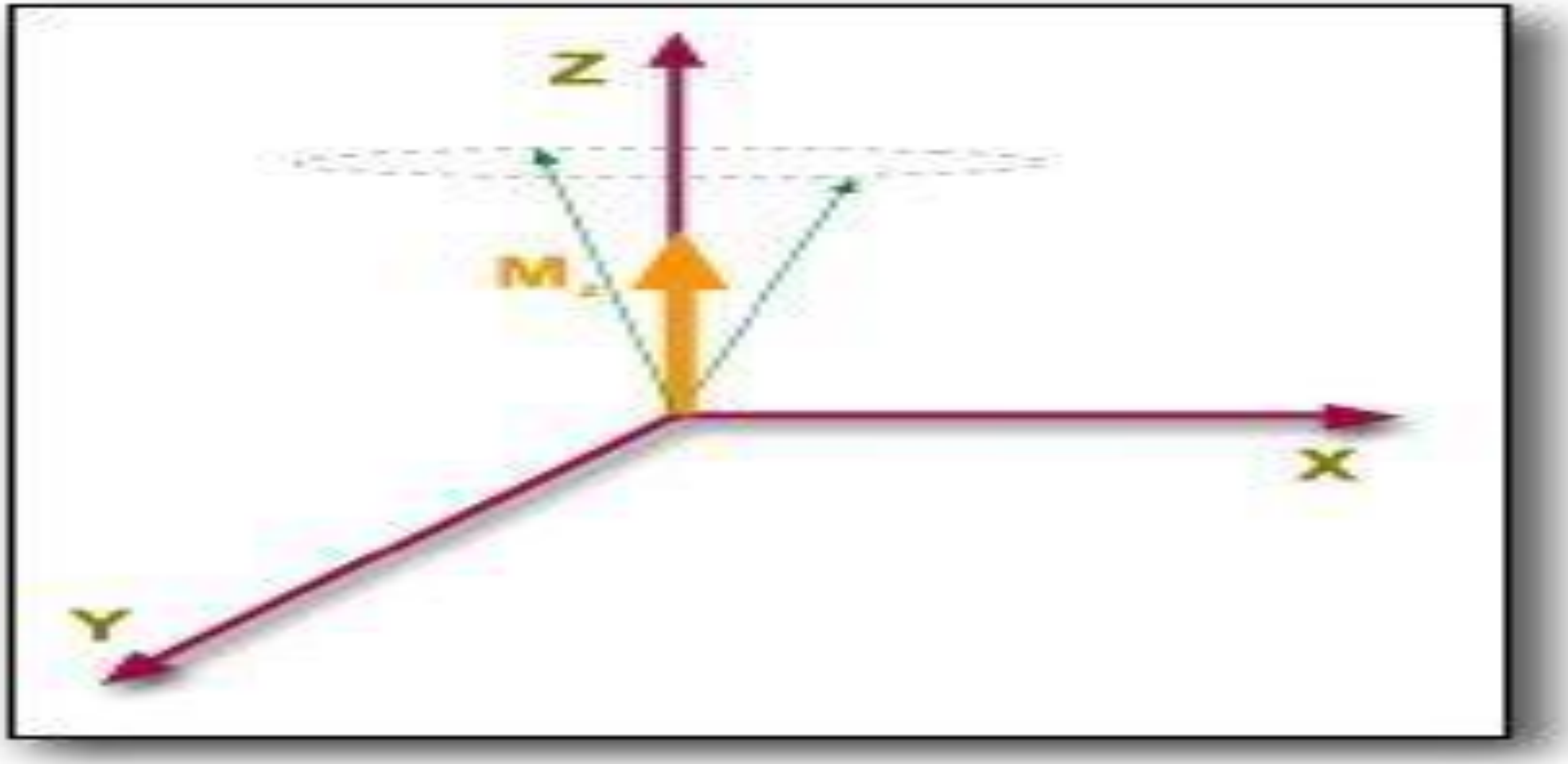
- The human body is made up of different components with different molecules. There is water, fat, bone, and blood… etc. The MRI signal varies depending on the structure of the molecules. Therefore, the MRI image is a **broad spectrum** between black and white through which we can distinguish between different organs and tissues.

Hydrogen protons exist in the human body as small magnets. In normal conditions, the directions of the magnetic resultant of hydrogen protons are scattered in all directions, which cancels their magnetic properties. But when the patient is placed inside the MRI machine, these protons are in one of two states: either **parallel** to the direction of the external magnetic field B0 or **opposite** to it. The number of protons that have weak energy (they will be in the direction of the external magnetic field) is greater than the number of protons that have high energy.

The sum of their resultants will be a magnetic vector that is in the direction of the external magnetic field. As shown in orange at the bottom, its name is longitudinal magnetization M0. This is exactly how longitudinal magnetization occurs.



The longitudinal magnetization is the sum of the remaining protons in the direction of the external magnetic field



- RF waves have two effects on protons: **The first** is to give some of them energy so that they are able to rotate against the main magnetic field. **The second** effect is to make them rotate in-phase. So the end result is the disappearance of longitudinal magnetization and the emergence of transverse magnetization.
- As we previously know, the protons relax after stopping the RF waves from them.

The MRI signal occurs when the energy of the acquired RF waves is relaxed and lost.

How does the transverse magnetization disappear and the longitudinal magnetization rise? When is the MRI signal?

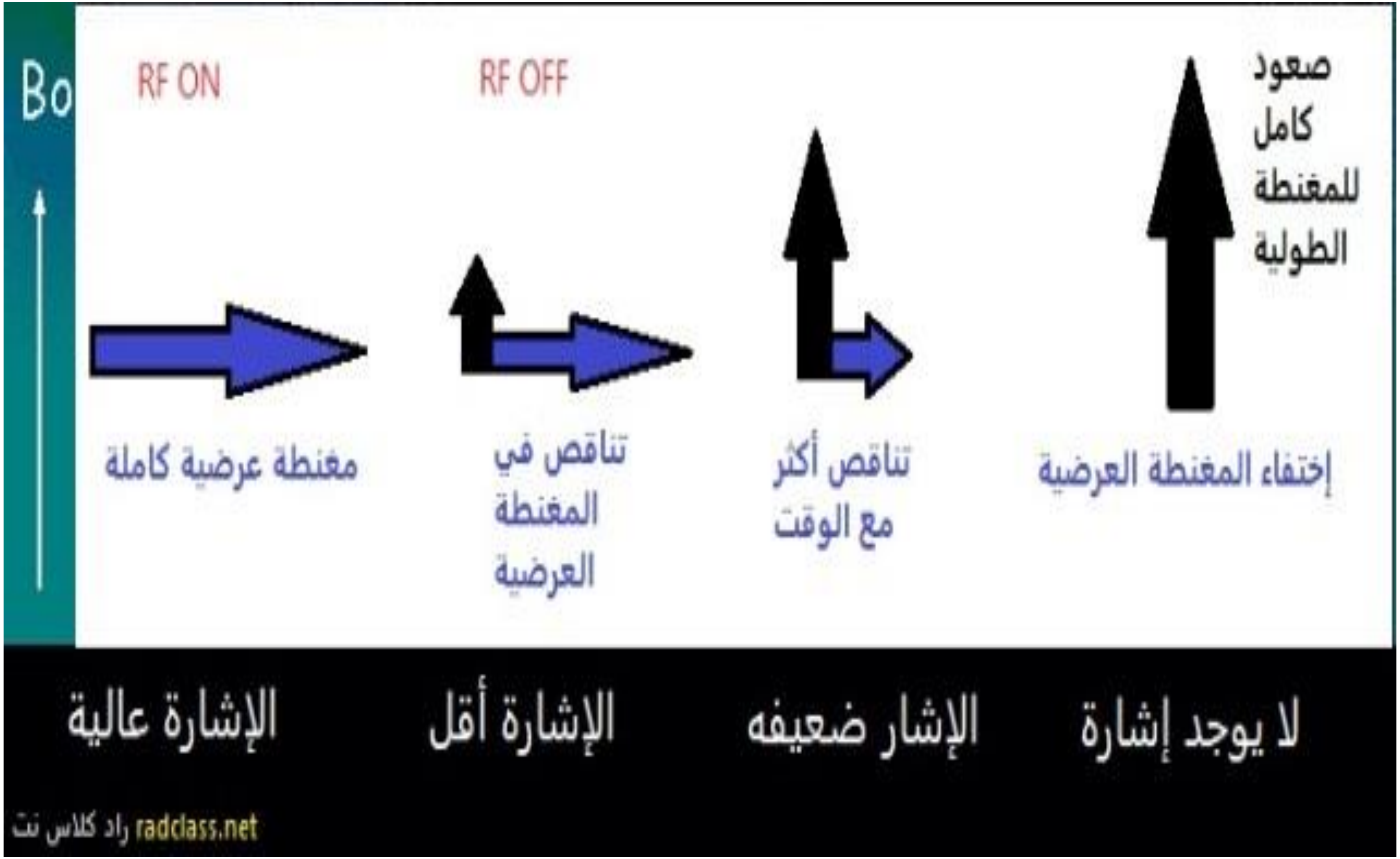
When RF waves are stopped, the protons that gained energy lose energy and return to their normal state of equilibrium. This happens in two stages. **First**, the protons go out of rotation in the same phase and are out of phase. Then the direction of the protons (their magnetic field) rotates again in the direction of the main magnetic field. That is, what happens to protons is the opposite of what happened to them after they were exposed to RF radio frequency waves.

When is the MRI signal and how can we differentiate between two different tissues?

In MRI we can only image or capture **transvers magnetization**. Why? Also, the protons must be in the same phase in order for us to receive the MRI signal.

Answer: because we cannot distinguish the magnetic resonance signal immersed in the direction of the main magnetic field.

MRI signal receiver (RF coil) receives the signal only from transverse magnetization. If the transverse magnetization is larger, the signal will be larger. As the transverse magnetization becomes smaller, the signal decreases with it until it disappears completely.


Bo
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مع الوقت
إختفاء المغنطة العرضية
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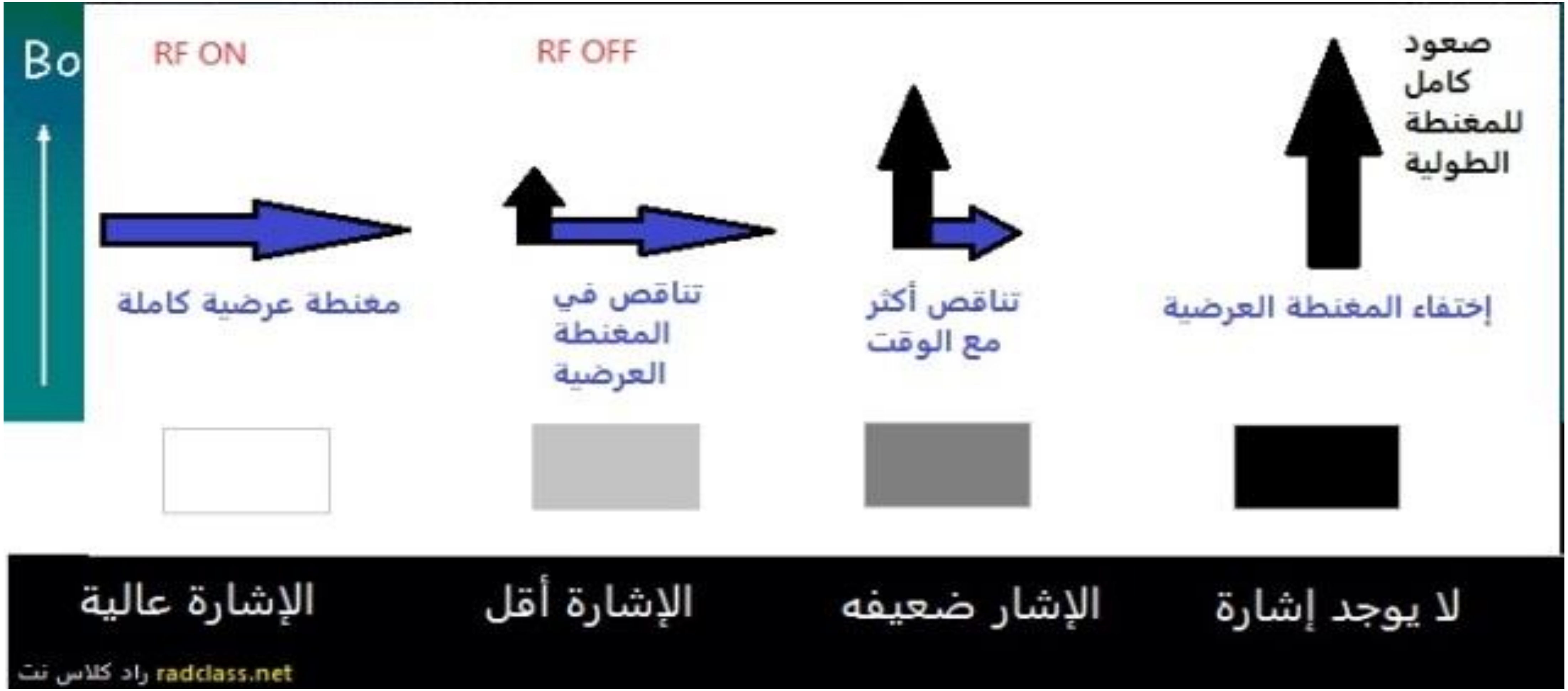
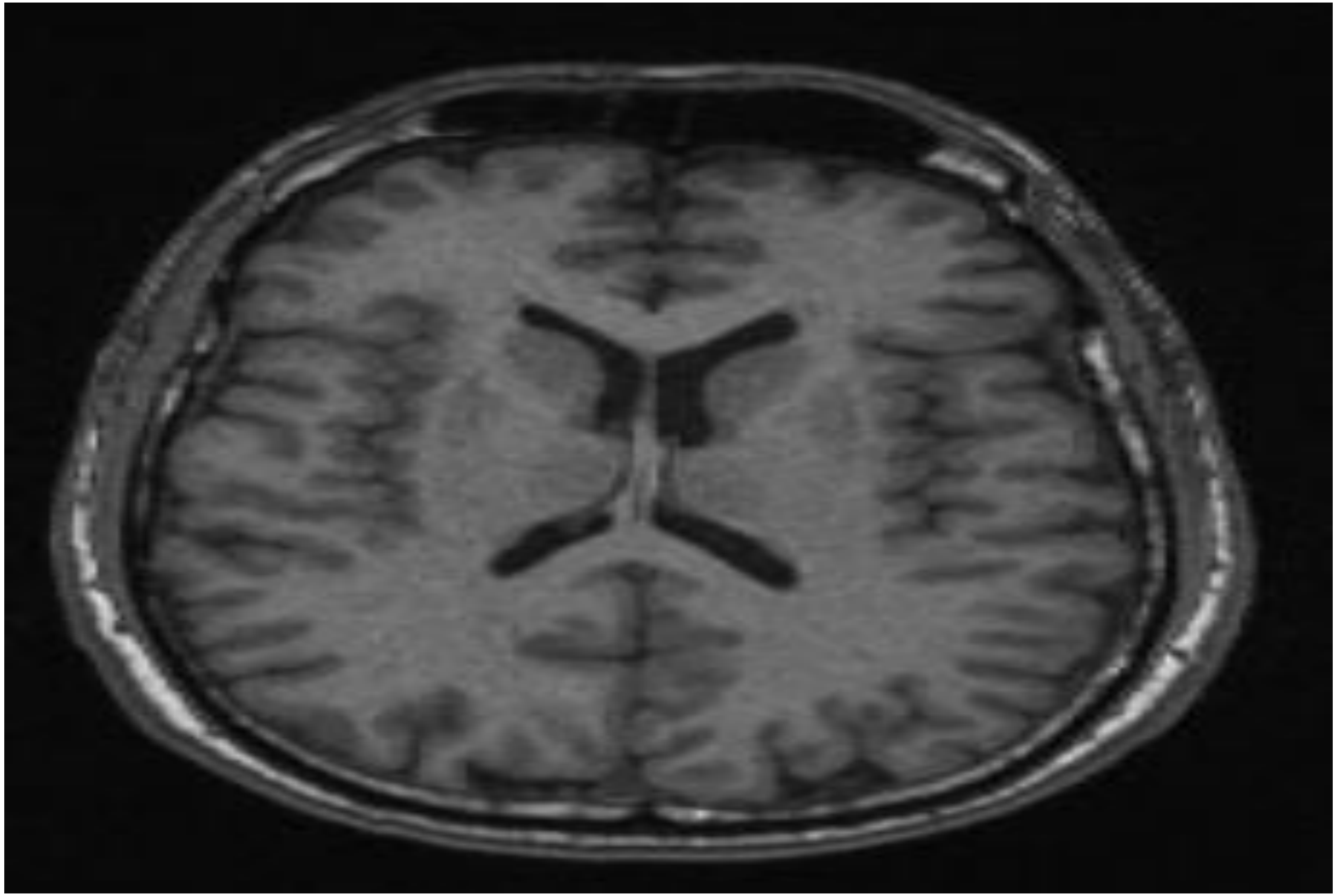


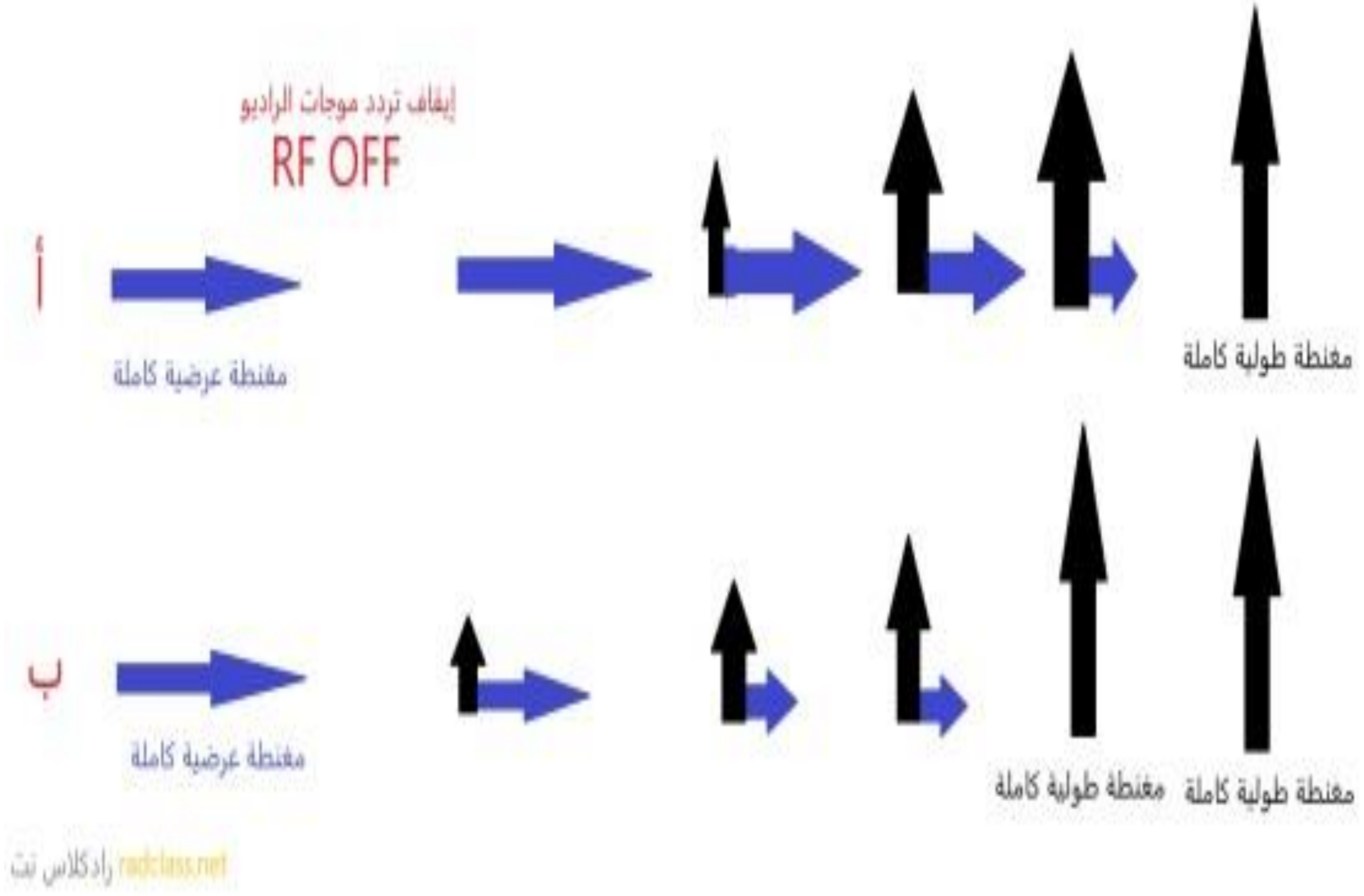
The white color in the image means that the signal is strong. Black means no signal. The grayscale between black and white reflects the strength of the signal. The stronger the signal, the closer to white.

The MRI image has a grayscale spectrum between black and white



T1& T2

The return of transverse magnetization to longitudinal magnetization has a specific time for each fabric. This time varies depending on the type of fabric or material. Some tissues come back quickly and others come back slowly. Suppose we have two different fabrics, one with a slow return time (A) and the other with a fast return time (B), as shown below.


إيقاف تردد موجات الراديو
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مغنطة عرضية كاملة
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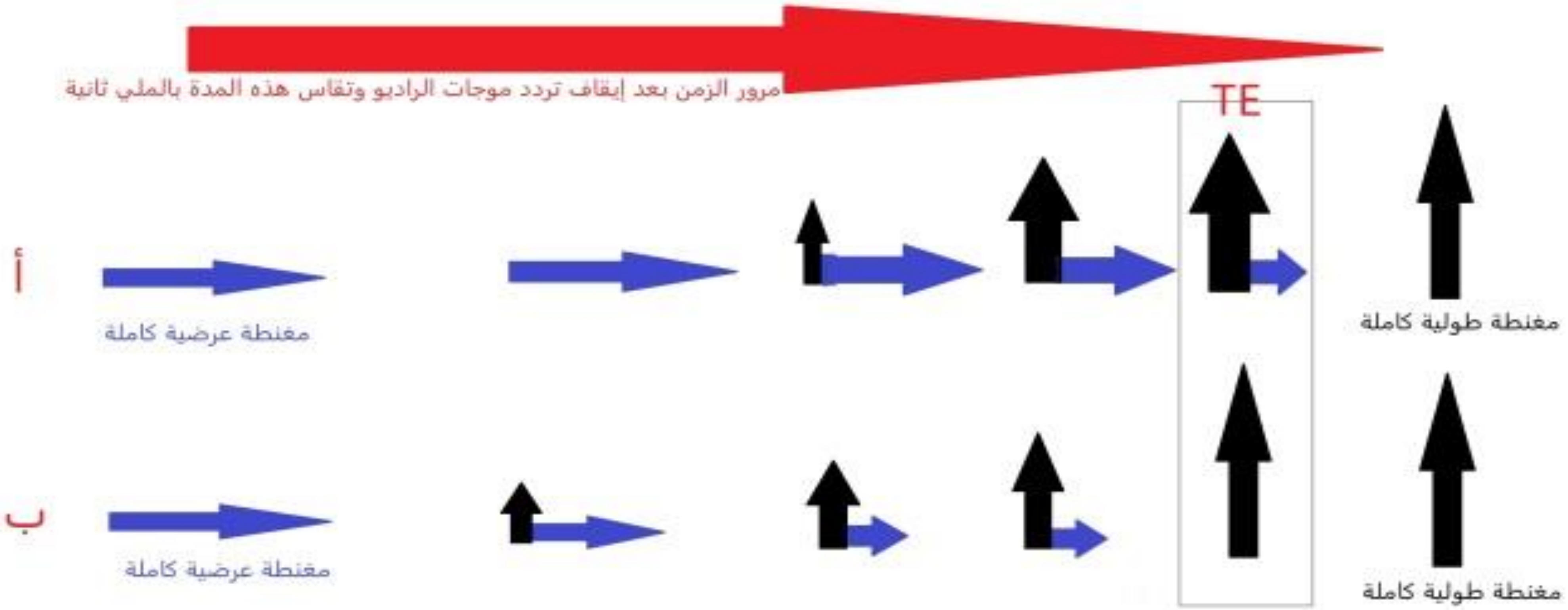
TE (time to echo)

We notice that tissue B returned to equilibrium faster than tissue A. But how can we apply this to MRI images?

Suppose we choose to photograph at a specific time after stopping the RF and call it the echo time TE (time to echo).

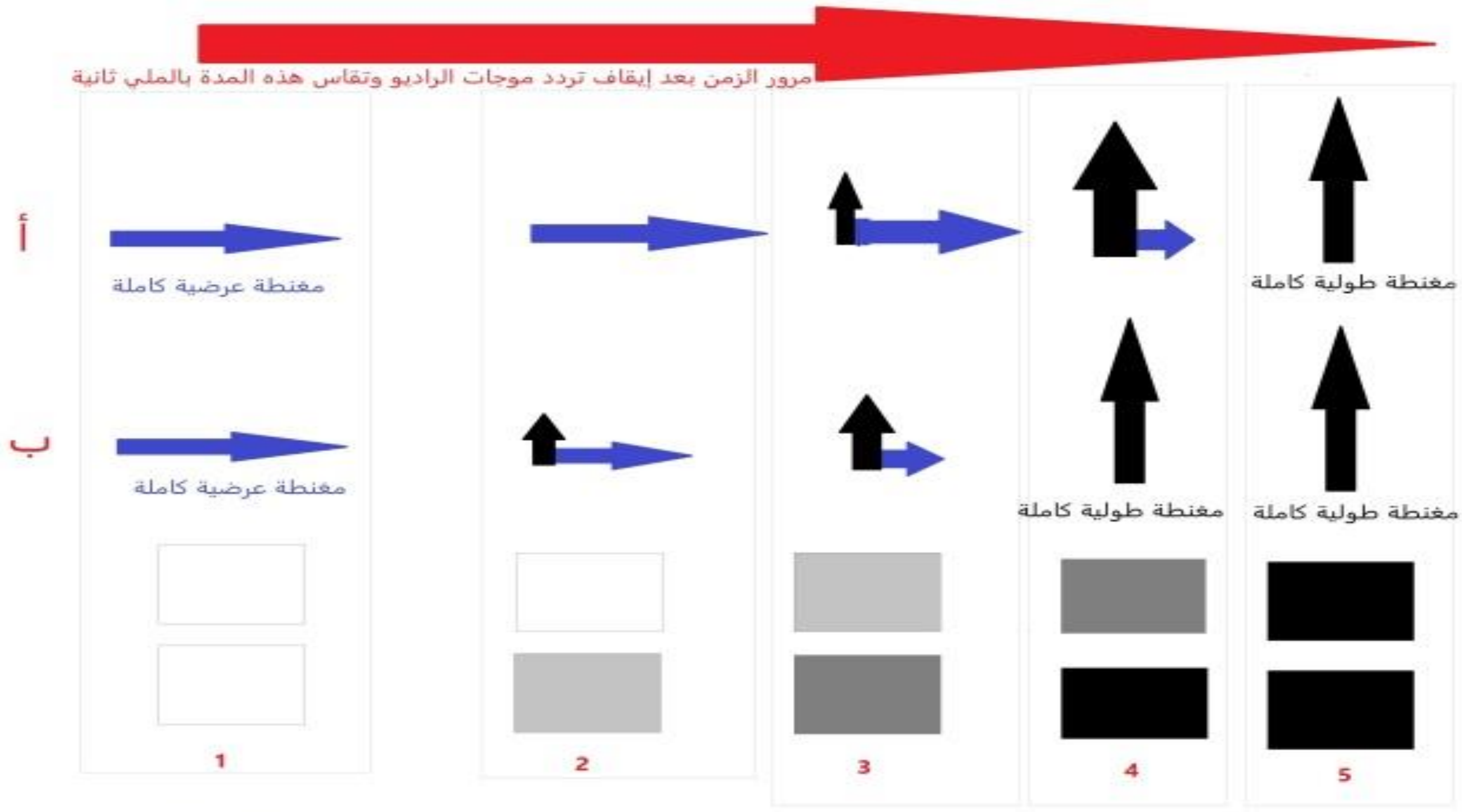


يكون اللون رمادي لوجود بعض من المغنطة العرضية عند هذا الزمن

لون نسيج أ في الصورة

يكون اللون أسود لعدم وجود المغنطة العرضية، إذن لا يوجد أي إشارة

لون نسيج ب في الصورة



مرور الزمن بعد إيقاف تردد موجات الراديو وتقاس هذه المدة بالملي ثانية
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What is the use of a picture if it does not explain the components of the fabric?!

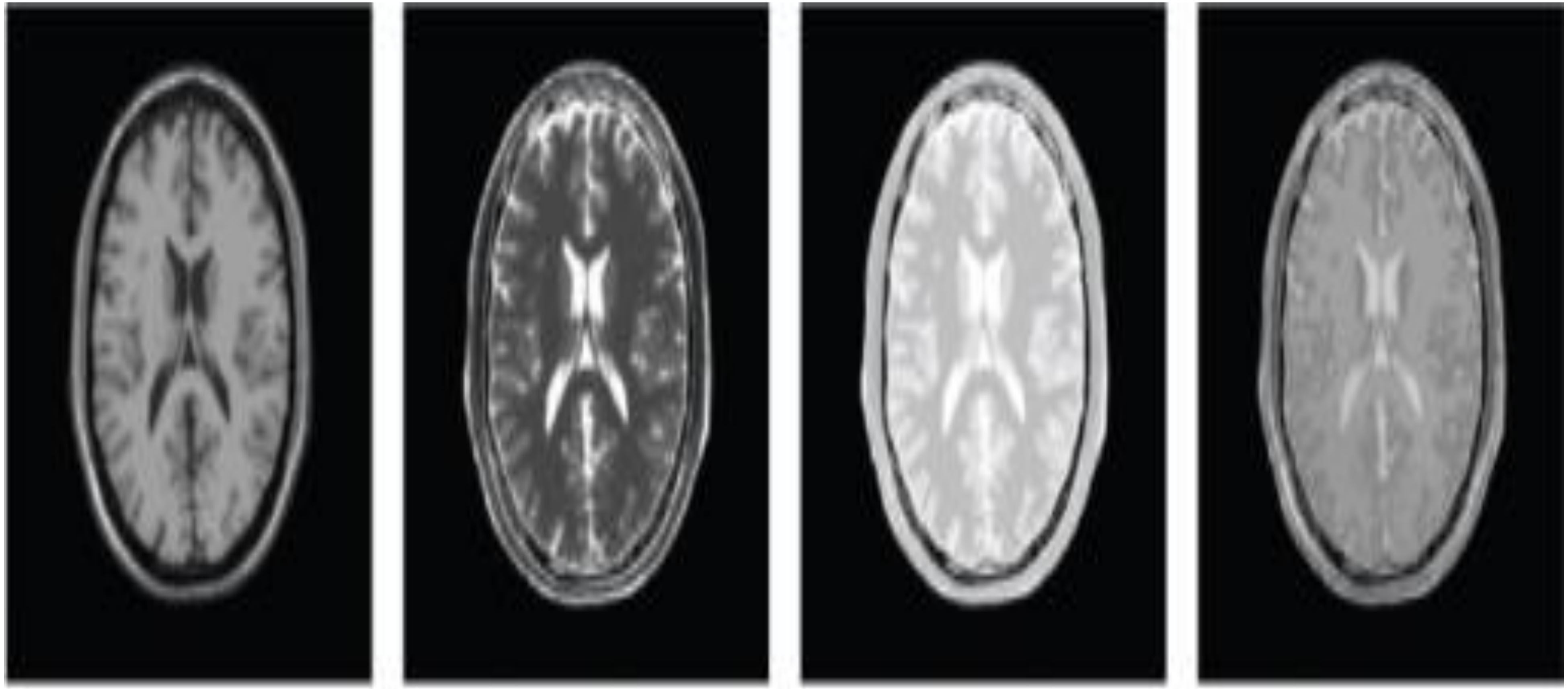
- we conclude that to get a good image, we must wait for a specific time (we can determine it according to the type of image we want, we must wait for a specific time, which we call the echo time (TE), otherwise we will not get the contrast between the tissues.

- In the second image , we get some contrast between the two textures when choosing a low echo time. The situation is almost the same in the third and fourth pictures . In the fifth image , when the TE was very long the transverse magnetization completely vanished and we could no longer get any signal.

- We can (choose) the imaging time (echo time TE) so that we control the strength and weakness of the signal in different tissues. This enables us to see the contrast between different tissues.

For example

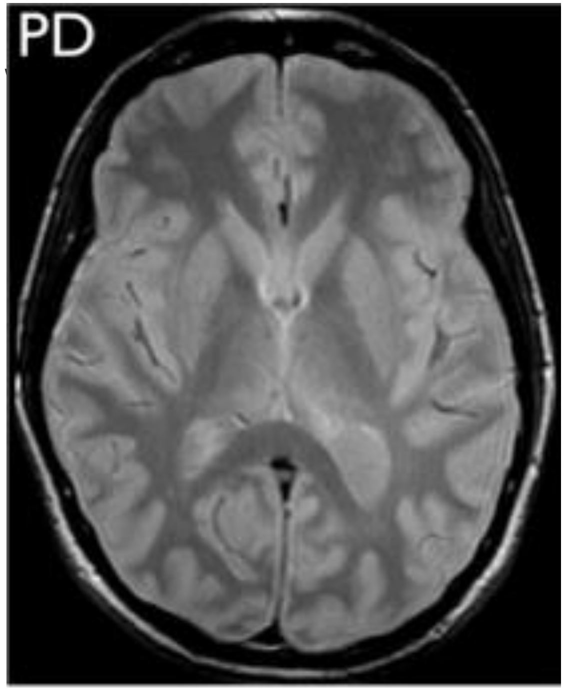
we can choose the appropriate time so that the cerebrospinal fluid in the brain (CSF) is white and the brain tissue is black. This image is called the weighted second-time image (second images from the left below) . Or vice versa, when the fluids in the brain are black while the brain tissue is white, this is called a first-time weighted image (the first image on the left) . The different types of images enable us to diagnose different diseases that may not appear in one image and be clear in the other.



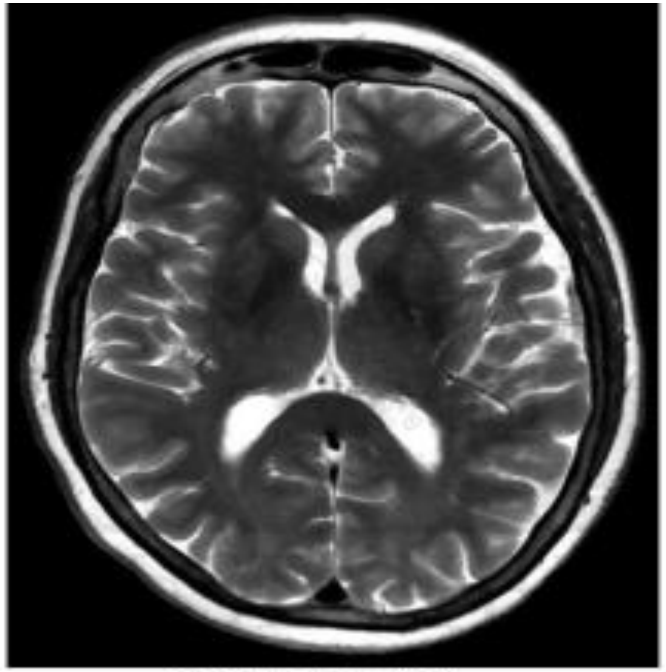
Explaining the physics of magnetic resonance

- The phenomenon of first time relaxation (T1-Relaxation).
- T1-weighted image
- The phenomenon of T2-Relaxation
- T2-weighted image
- Proton Density image
- **In principle, we can say that there are three main types of MRI images**:

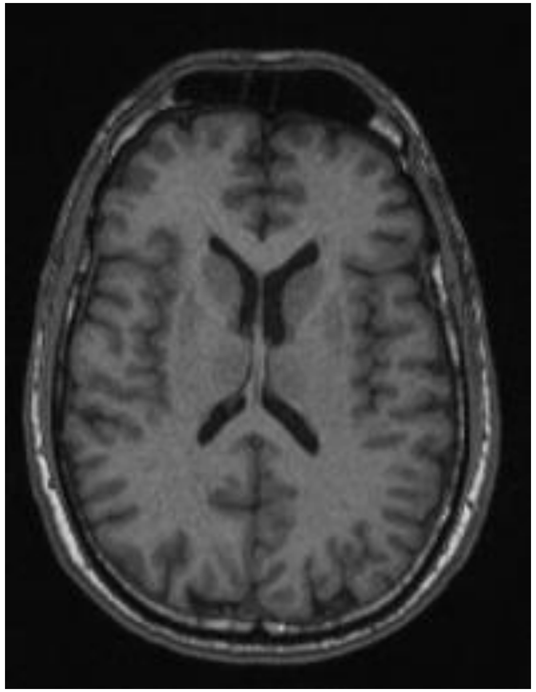
1. T1-Weighted Image
2. T2-Weighted Image
3. Proton Density Weighted Image



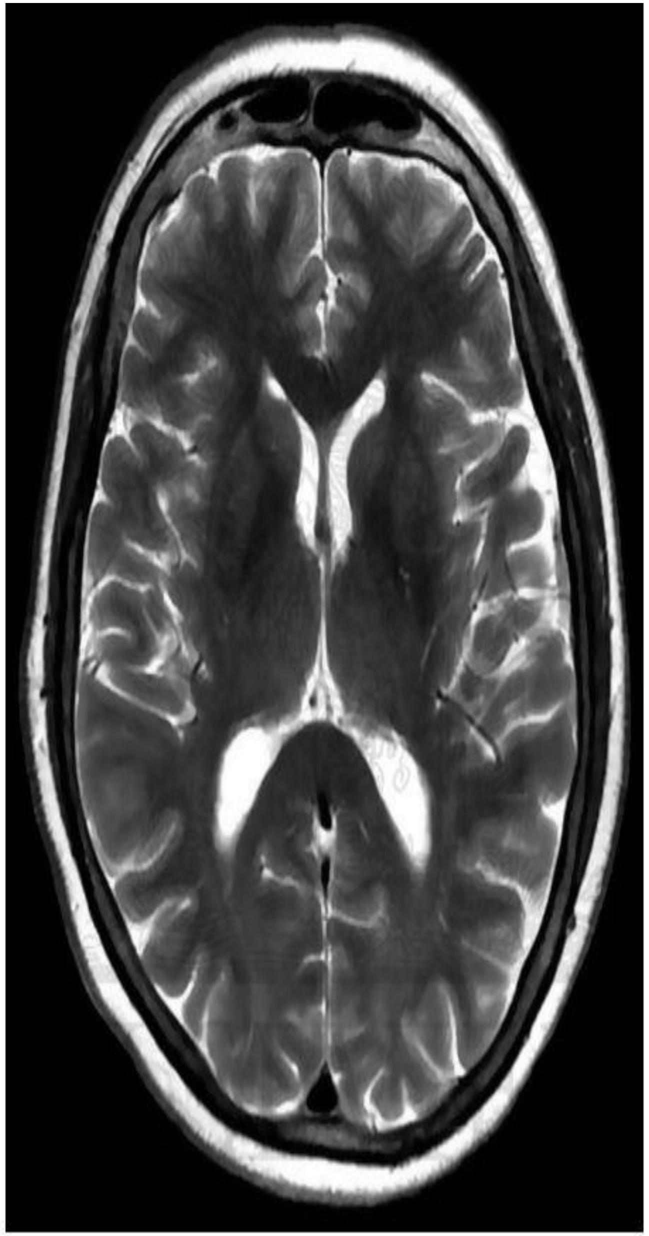
The MRI image has a grayscale spectrum between black and white



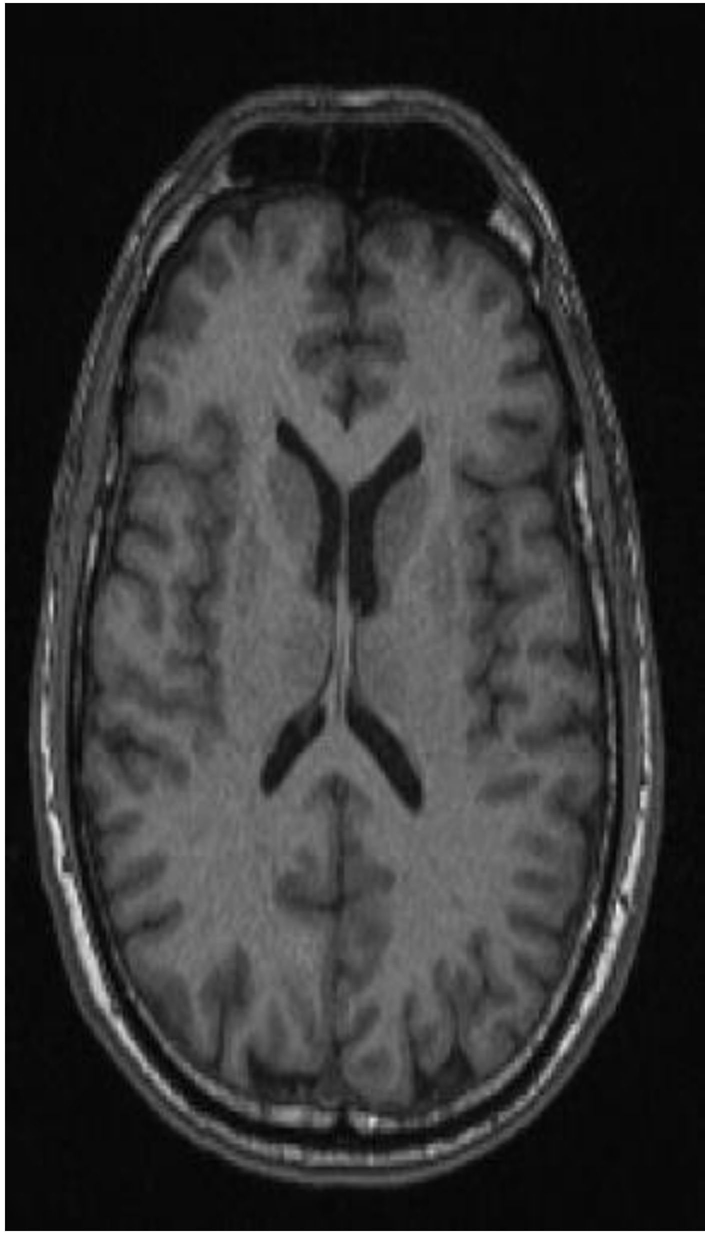
T2 Weighted Image



PD Density Weighted



- every image differs from the other image in factors and components of the image. We notice that in the image on the right, we cannot see the cerebrospinal fluid (CSF) and the signal coming out of it has been weakened, while its counterpart in the middle shows all the fluids, including the CSF, in white. This is because diseases have different components, so for a complete diagnosis, several types of images must be taken. Of course, this does not happen in other types of radiation. This is what makes the MRI device distinct, as if it is more than one device.



There are three characteristics (main - there are other factors) that control the contrast in MRI images. All MRI images must have these characteristics, but in different proportions. These three properties are internal characteristics (or phenomena) of protons that differ depending on the protons of one tissue from another.

What are these characteristics?

1. T1-Relaxation Time
2. T2-Relaxation Time
3. Proton density in tissue

- Note: There is a difference between the T1-Relaxation phenomenon and the T1-weighted image. Knowing that there is a relationship between them but they are not the same thing. The same difference also applies to the phenomenon of the second time and the balanced form of the second time.

- All MRI images must have all of these characteristics or phenomena. But the percentage varies. These characteristics are all related to each other, and the occurrence of one is linked to the occurrence of the other, but by changing several factors, we can play with the ratios between one phenomenon and another. For example, if we wanted to take a weighted first-time image, we could change some factors to increase the first-time phenomenon in the image and weaken the second-time and proton density phenomena, and so on.

Ican say that

- There are three main types of magnetic resonance images that are controlled by three phenomena that are related to the internal properties of protons:
- The balanced first-time image is mainly controlled by the first-time phenomenon .
- The balanced second-time image is mainly controlled by the second-time phenomenon
- Weighted proton density image is mainly controlled by the number of protons in the tissue

What is the reason for calling images weighted?

- Any type of image contains all three characteristics or phenomena, but one of them is present in a greater proportion. This can be controlled by several factors, as if we were using a scale to choose the image we want. Manipulating or controlling the timing of these factors enables us to increase the effect of one of these phenomena in the image and weaken the other two phenomena.

The main factors that control contrast in MRI images:

TR repetition time : What is meant here is the repetition of RF radio frequency waves. This means the waiting time between RF waves. This means that it is not just one wave, but successive. This enables us to control the image TE echo time. It is the time during which we photograph (the imaging time is called echo here, because we give radio waves and then they return to us when we relax and we photograph them). What is meant here is the waiting time after sending the RF radio frequency wave in order for us to take the picture. We can control that too.

I means that

- There are two main factors that control the contrast or type of MRI image:

1. Repetition time TR
2. Echo time TE

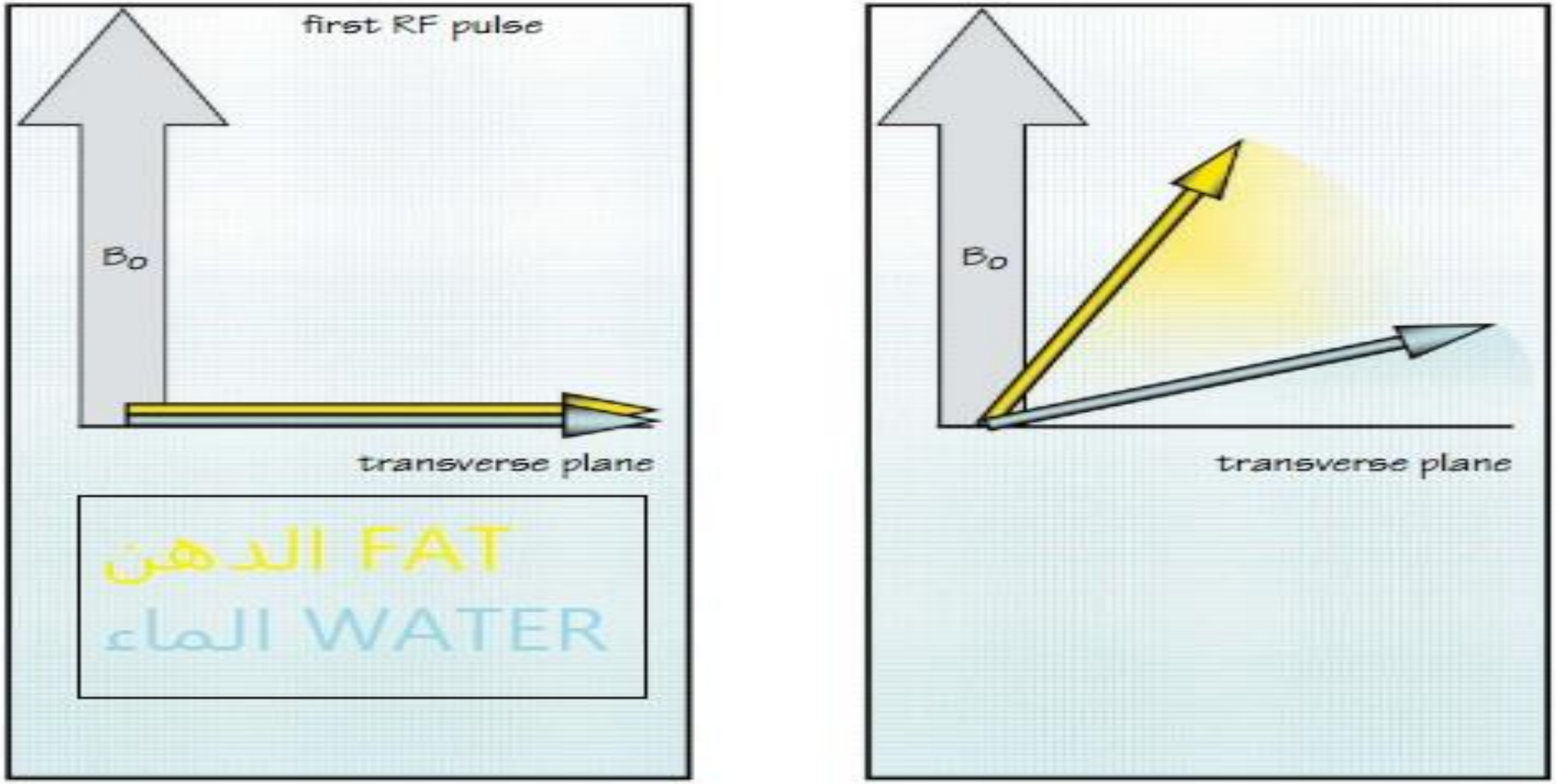
The phenomenon of first time relaxation (T1-Relaxation).

This relaxation results from the loss of energy from the protons to their surroundings, and this is called **Spin-Lattice Energy Transfer**. When protons lose energy, the transverse magnetization gradually weakens until it disappears completely with the completion of its longitudinal magnetization counterpart. This means returning to a state of equilibrium. The speed at which transverse magnetization reverts to longitudinal magnetization varies between tissues. But in magnetic resonance imaging, water and fat are on opposite sides, and everything else is in the middle.

- The relaxation time for protons in the fat during the first time relaxation phenomenon is short. That is, relaxation occurs quickly (which means that the transverse magnetization disappears quickly). As for water, it is the opposite. The time it takes for water protons to relax in the first time phenomenon is considered long (so it takes a long time for water protons to return).

Let me say it in another way, after the protons in the fat and water are excited by RF waves, they all become completely transversely magnetized. After stopping the RF waves, the protons in the fat return faster than the protons in the water. If we wait and do nothing, the fat will return first and then the water will return to longitudinal magnetization.

Fat and water have different relaxation times, fat returns faster than water

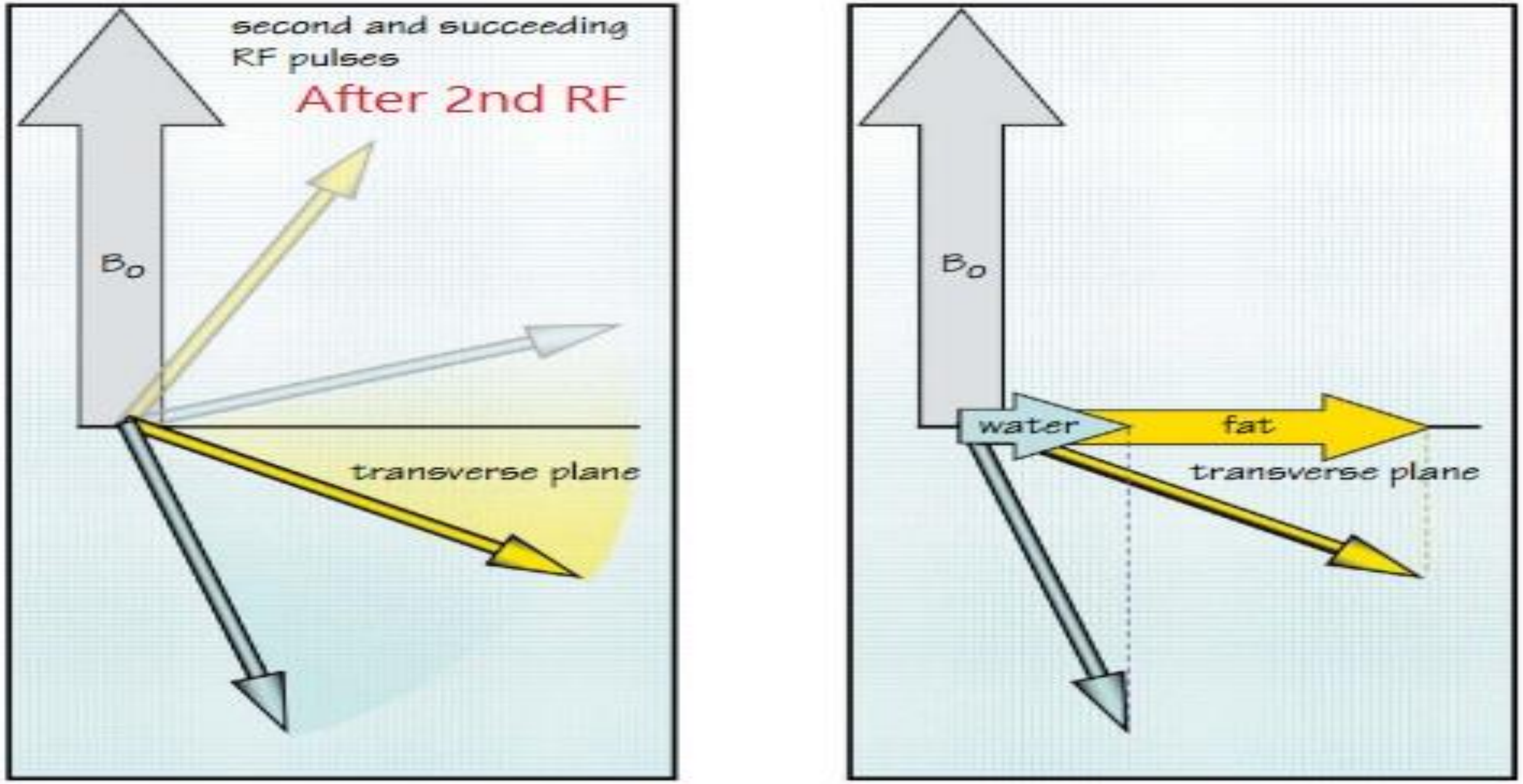


But how do we take T1-weighted images?

The truth is that we do not wait for it to return completely in the first-time phenomenon, because we want to exploit the difference in the transverse magnetization between fat and water and represent that in the weighted first-time image. (If we wait a long time, we will increase the phenomenon of the second time in the picture. This is done by repeating the transmission of an RF radio frequency wave after a certain time, which we call the repetition time (TR). Here we must not wait too long to send the second RF wave, because if we wait too long both of them will return to longitudinal magnetization and the difference between the fat and the water will disappear. For this reason, the repetition time TR controls the first time phenomenon. **So we wait a short time and send the second radio frequency wave.**

When we wait for a short TR time, there is a difference between the fat and the water. The fat returns a longer distance than the water because it is faster. But when we send another RF wave, the water is moved further away from the fat, as in the picture below. Thus, fat is closer to transverse magnetization than water. Then we wait for a short echo time (TE) to exploit this point and then we take our picture. Thus, the signal in fat is higher than the signal in water. This gives us a T1-weighted image.

With the second radio frequency wave, the water is pushed away by a larger area than the fat. Fat is closer to the accidental magnetization and the signal from it is greater, while the signal from water is weak because it is far from the accidental magnetization.

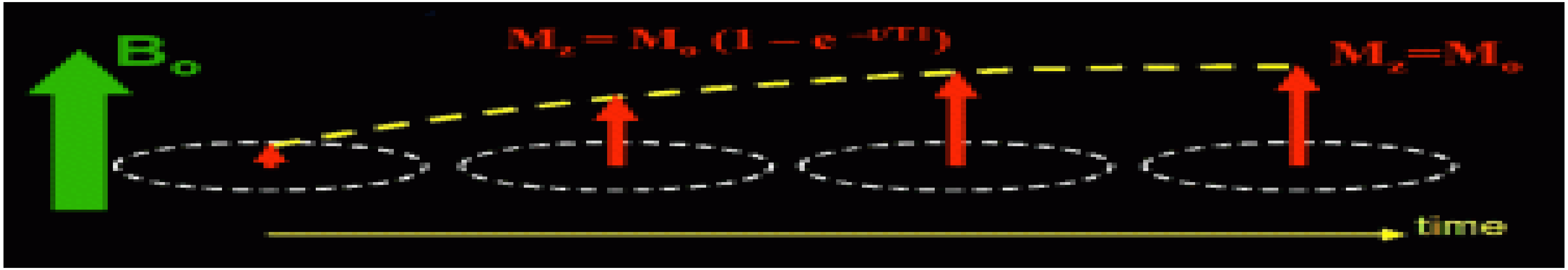


- Since the signal from the fat is larger, it appears on the first-time image weighted in white. As for water, it is black in the picture because it is far from accidental magnetization. If we take the first-time image weighted on the brain, the brain tissue (fat) will be white, while the cerebrospinal fluid (CSF) will be black. This image is known as an anatomy image because it clearly shows the components. For example, in the brain, gray matter is gray in the image. The white matter is white in the image. (Inversely weighted second time image)

The phenomenon of first-time relaxation

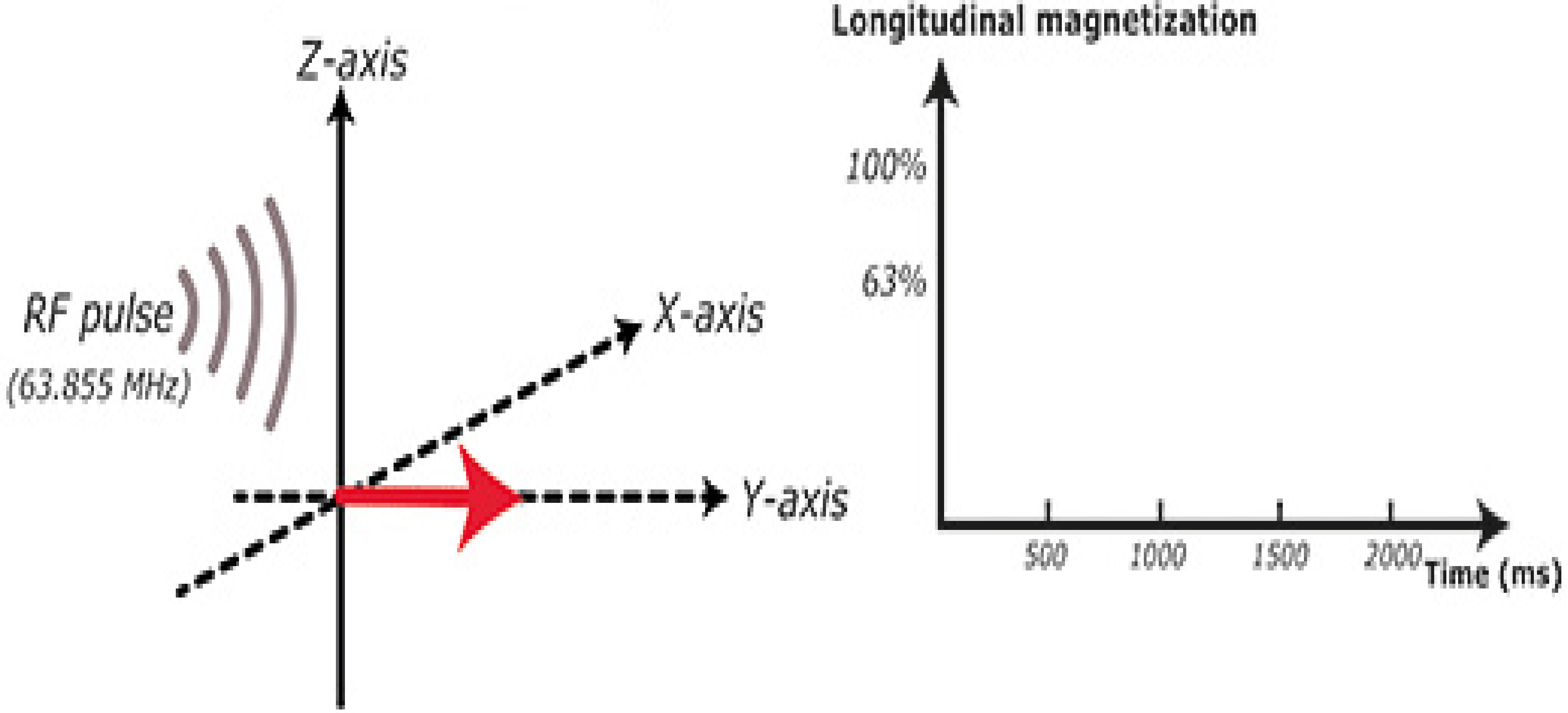
depends on the return of the longitudinal magnetization to the state of equilibrium. In the T1-Relaxation phenomenon, after stopping the RF waves, the protons in the fat quickly return to equilibrium. The protons in the water return slowly. Here the energy loss to adjacent tissues is **spin-lattice relaxation.**

- The repetition time TR is the primary control in the T1-weighted image. The repetition time TR and echo time TE must be short to obtain a first-time weighted image. Fat has a high signal in white, while water has a weak signal in black.

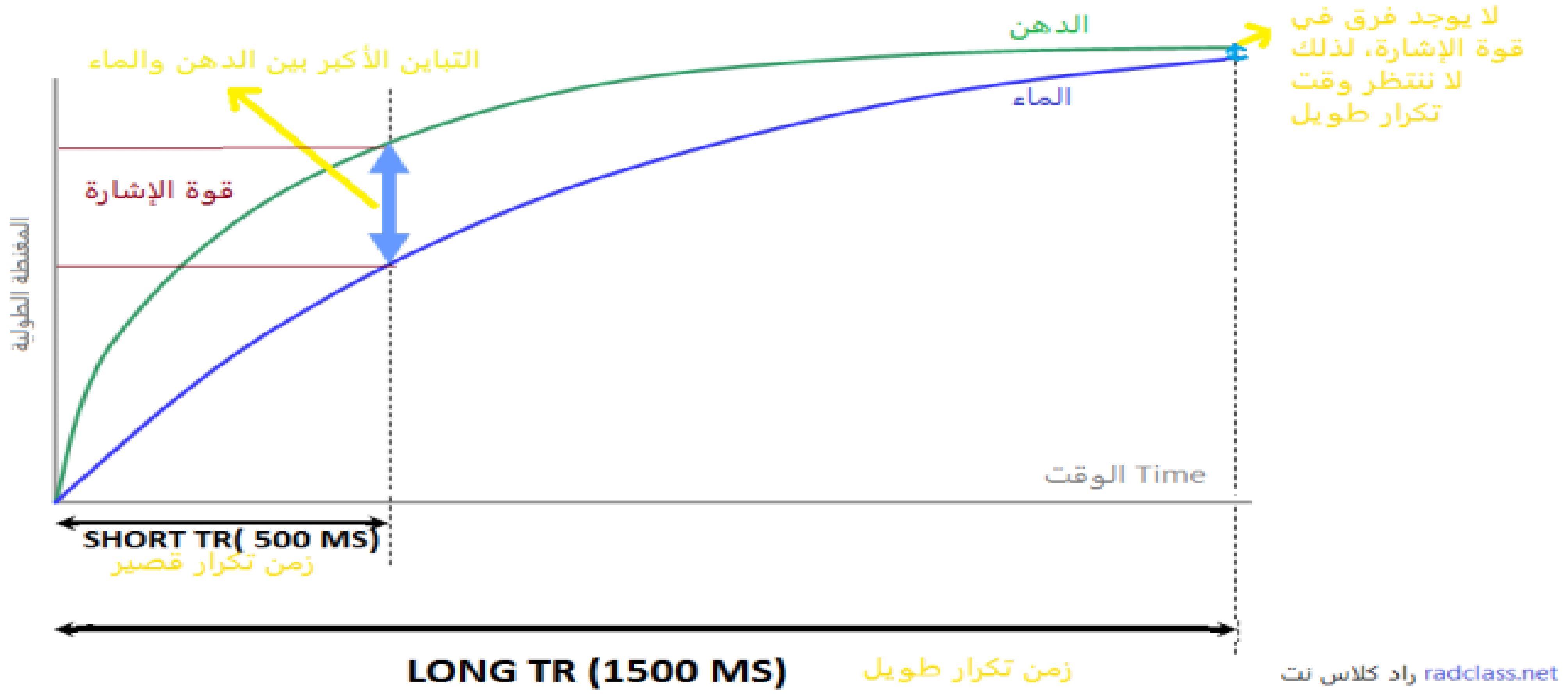


The phenomenon of the first time depends on the return of the longitudinal magnetization to the equilibrium position the signal that we capture is the transverse magnetization, both are related to each other but Timing varies . With RF waves, the longitudinal magnetization is almost zero. After stopping the RF, the longitudinal magnetization gradually returns or rises until it is completely in balance when it reaches a state of equilibrium, as in the pictures above.

T1 relaxation



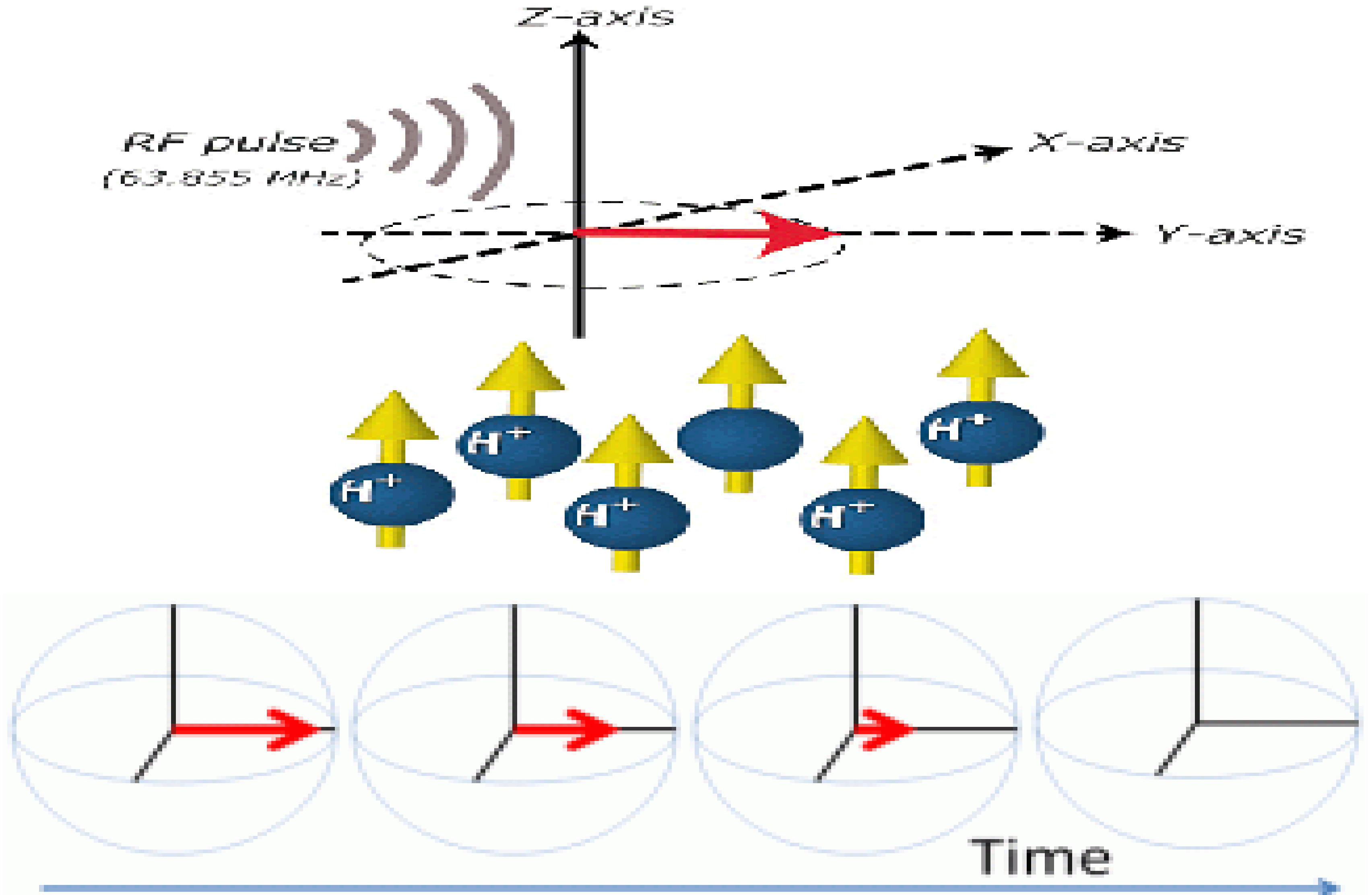
As a reminder: an MRI image does not consist of only fat and water. This is used for simplicity. See the image below to bring the idea closer:



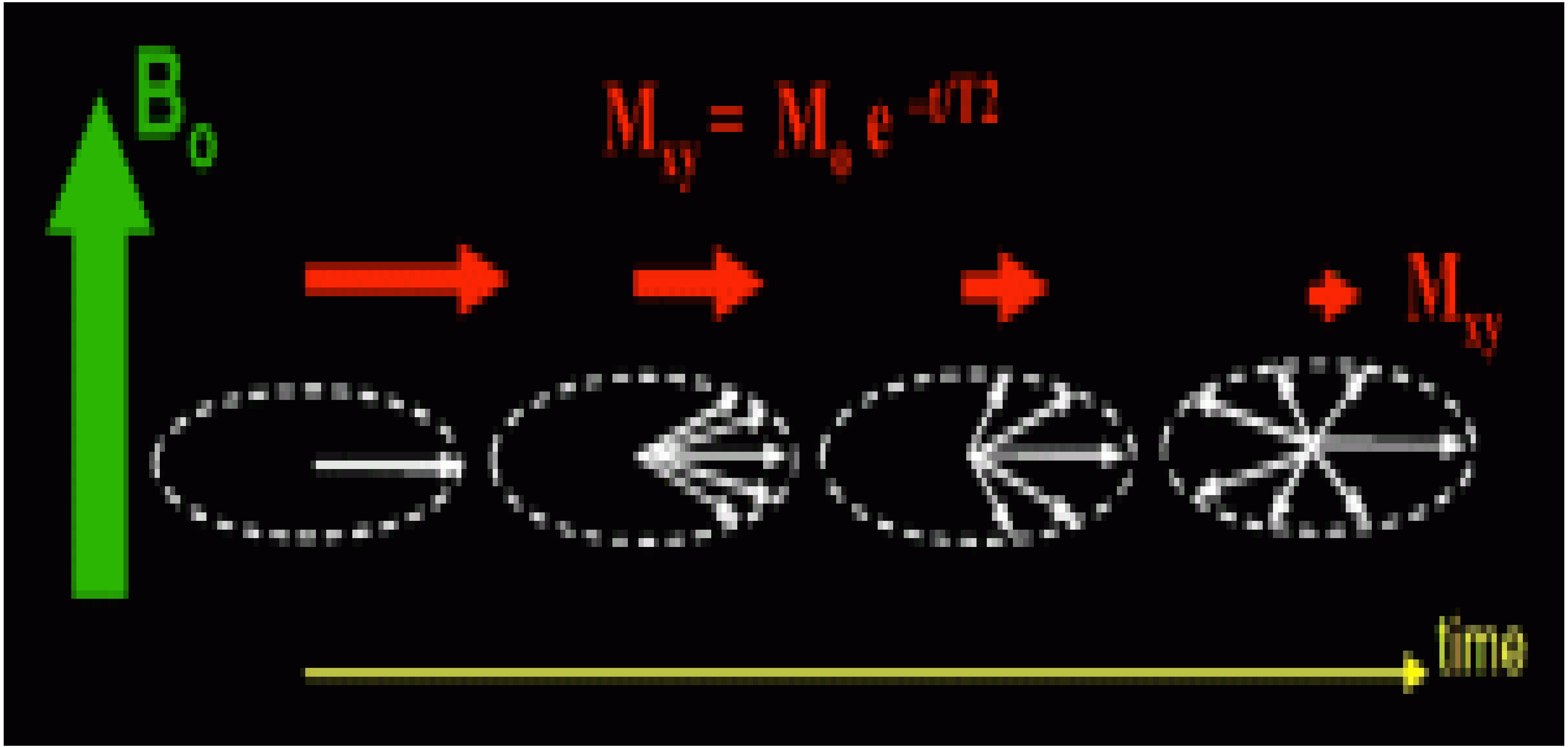
The phenomenon of T2-Relaxation

As for the phenomenon of the second time, it depends on the disappearance and decrease of the transverse magnetization as a result of the protons losing energy to their neighboring protons, and it can be called spin-spin relaxation. In the second-time relaxation phenomenon (as in the first-time phenomenon), energy loss occurs to neighboring protons as a result of the protons losing the property of rotating in the same phase. The time for protons to lose energy for fats is short. As for water, it takes a long time.

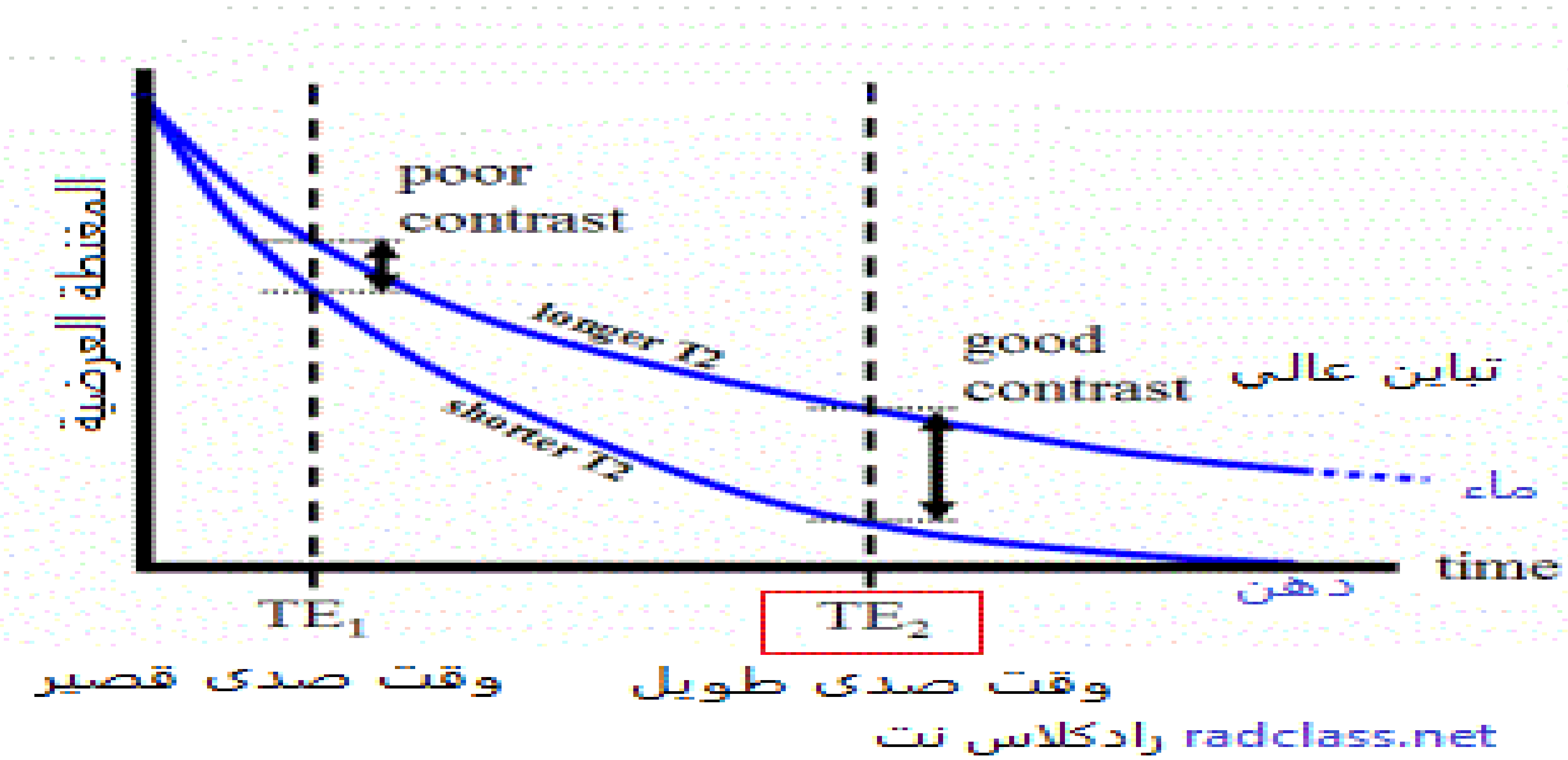
Decrease in transverse magnetization as a result of protons falling out of rotation in the same phase



We can draw the relationship between transverse magnetization and time in the second time relaxation phenomenon as follows:



In the second-time weighted image, we choose a long echo time because there is an increase in the contrast between the two tissues



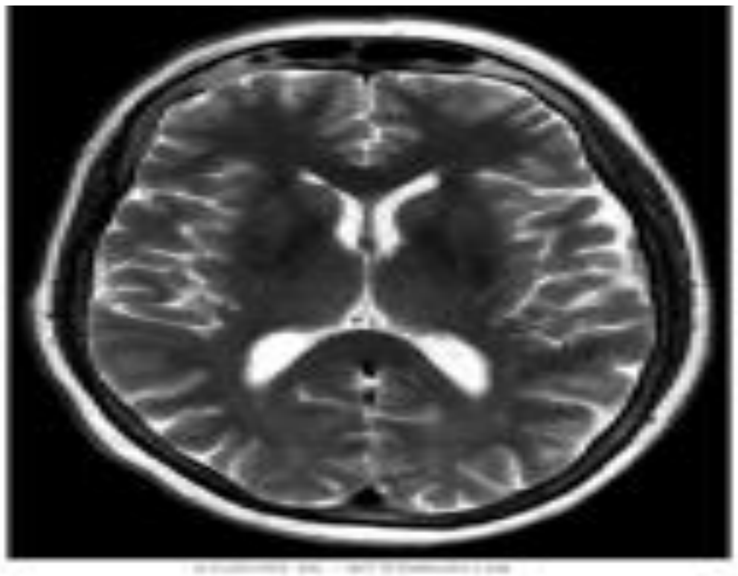
This means that the transverse magnetization of fat decays faster than the transverse magnetization of water in the second-time phenomenon. In other words, water protons take longer to lose energy to neighboring protons than fat.

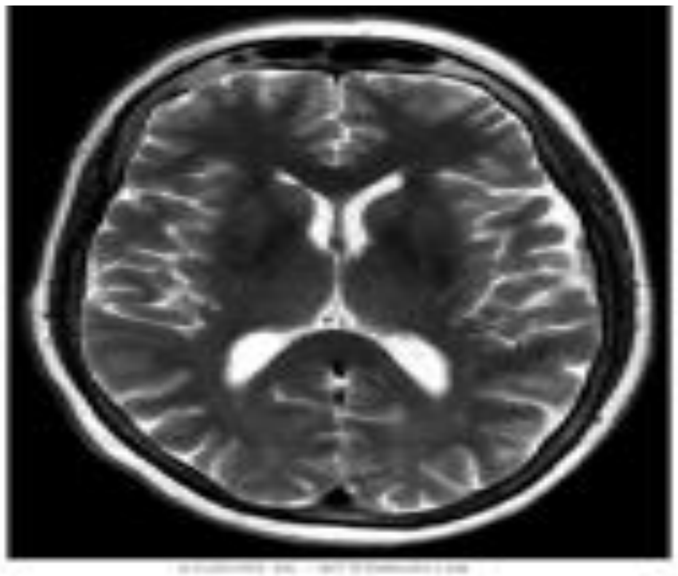
The phenomenon of second-time relaxation

depends on the disappearance or decrease of transverse magnetization. In the phenomenon of T2-Relaxation, after stopping the RF waves, the protons first lose the property of rotating in the same in-phase and become dephasing. The time for protons to lose energy for fats is short. As for water, it takes a long time. The energy loss here to neighboring protons is spin-spin relaxation.

T2-weighted image

- The controlling factor in the weighted second time image is the echo time (TE). It must be long so that there is a contrast between the water and the fat in the image. If we choose a short echo time, the contrast between fat and water will be small. We notice in the graph above that the signal in water is higher than the signal from fat. This is what gives us the weighted second time picture. Water is white and fat is black. The TR must also be long. Why?





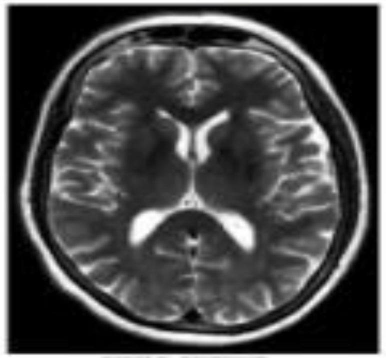
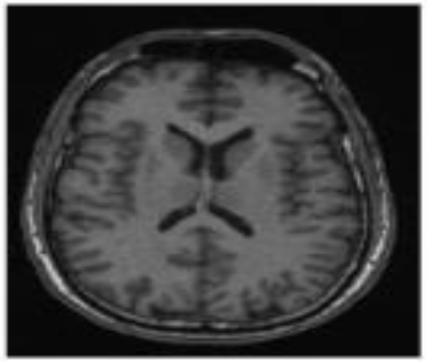
T2 Weighted Image

Additional information (clarification): Because if we choose a short TR repetition time, we will allow the properties of the first time phenomenon to appear in our image. We don't want that. We want to obtain the weighted second-time image, which is done by:

- We choose a long resonance time TR, as it is the factor controlling the second time phenomenon.
- We choose a long TR repetition time in order to avoid or reduce the first-time phenomenon.

The echo time (TE) is the primary control in the T2-weighted image. The repetition time TR and echo time TE must be long to obtain a second-time weighted image. Water has a high signal in white, while fat has a weak signal in black.

The difference between the first time weighted image and the second time weighted imageT1 Weighted Image VS T2 Weighted Image

T2-Weighted Image صورة الزمن الثاني الموزونة	T1-Weighted Image صورة الزمن الأول الموزونة	
		شكل الصورة
طويل Long لكي نقلل من ظاهرة الزمن الأول في الصورة	قصير Short هو العامل المتحكم في الزمن الأول	TR زمن التكرار
طويل Long هو العامل المتحكم في الزمن الثاني	قصير Short لكي نقلل من ظاهرة الزمن الثاني في الصورة	TE زمن الصدى
الماء يكون فاتح الدهن يكون غامق	الماء يكون غامق الدهن يكون فاتح	بعض خصائص الصورة
Pathology Picture صورة الأمراض	Anatomy Picture صورة التشريح	تشتهر بـ
ظاهرة إسترخاء الزمن الثاني أكبر	ظاهرة إسترخاء الزمن الأول أكبر	ظاهرة الإسترخاء المتسيدة

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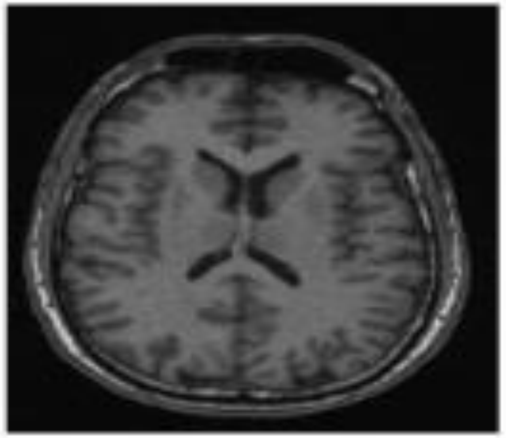
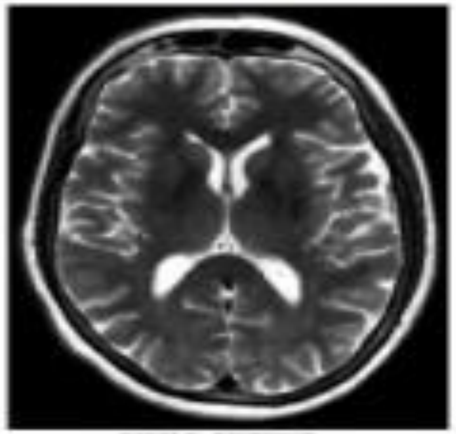
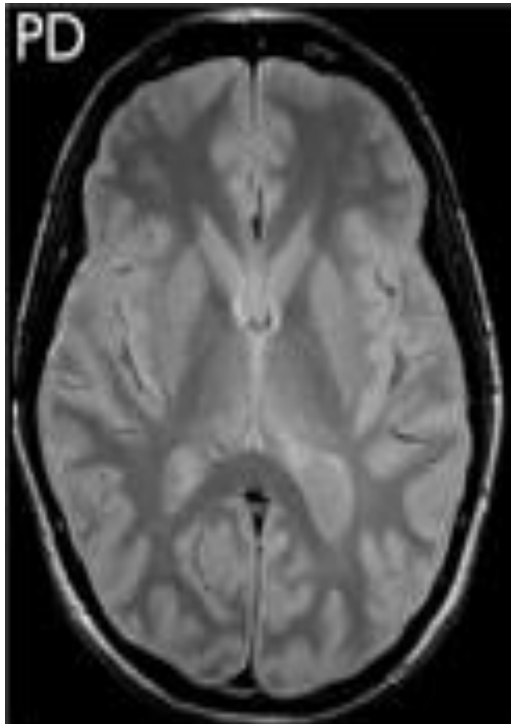
	T1-Weighted Image صورة الزمن الأول الموزونة	T2-Weighted Image صورة الزمن الثاني الموزونة
شكل الصورة		
TR زمن التكرار	Short قصير هو العامل المتحكم في الزمن الأول	Long طويل لكي تقلل من ظاهره الزمن الأول في الصوره
TE زمن الصدى	Short قصير لكي تقلل من ظاهره الزمن الثاني في الصوره	Long طويل هو العامل المتحكم في الزمن الثاني
بعض خصائص الصورة	الماء يكون غامق الدهن يكون فاتح	الماء يكون فاتح الدهن يكون غامق
تشتهر بـ	صورة التشريح Anatomy Picture	صورة الأمراض Pathology Picture
ظاهرة الإسترخاء المتسيدة	ظاهره إسترخاء الزمن الأول أكبر	ظاهره إسترخاء الزمن الثاني أكبر

Proton Density Weighted Image

We want an image that gives the difference in properties between the density (concentration or numbers) of protons in tissues. To obtain this image, it is necessary to choose the appropriate repetition time TR and echo time TE in order to reduce the effect of the first time phenomenon and the second time phenomenon in the image. The image is highly dependent on the proton density in the tissue.

PD Density Weighted

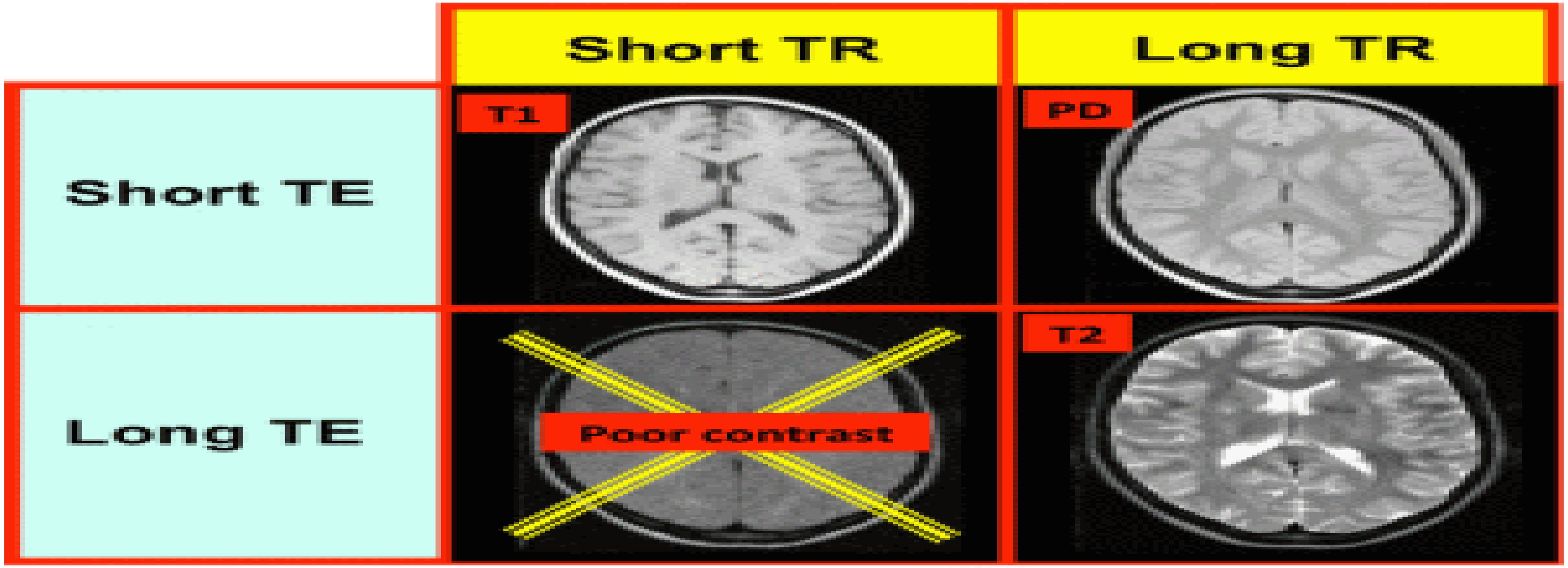


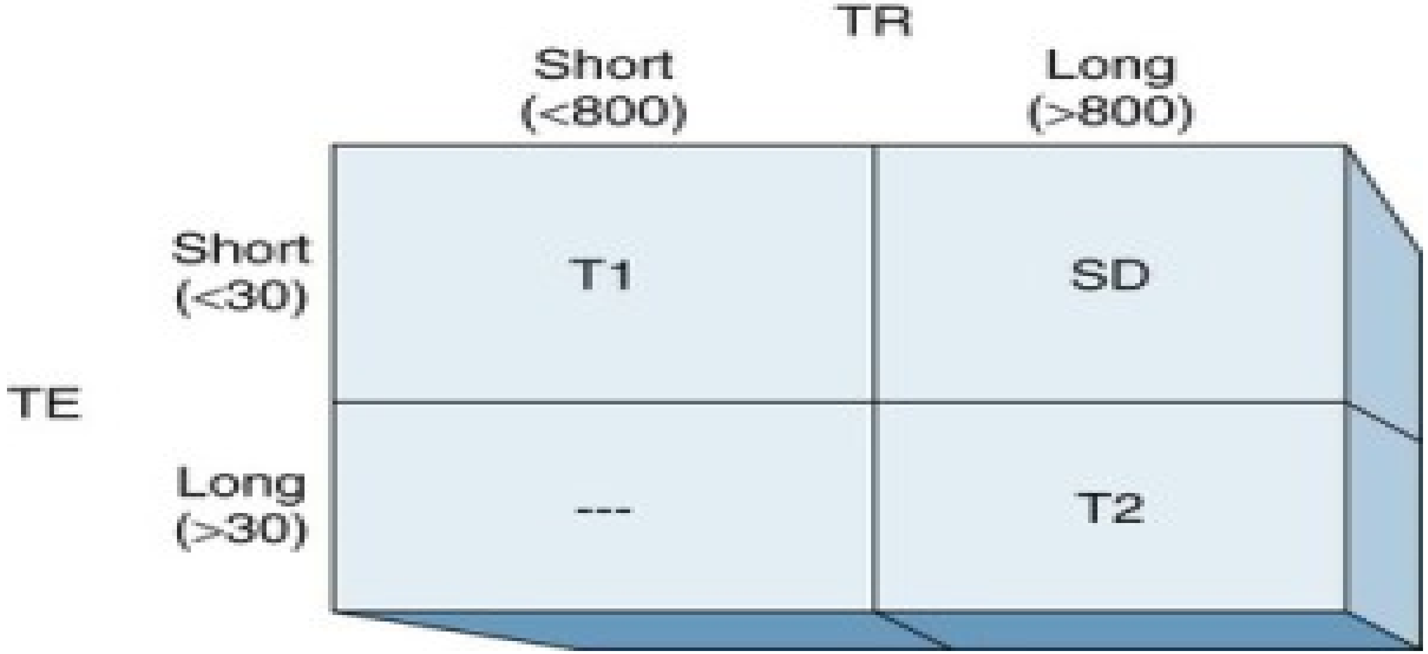
Important Notes

The PD-weighted proton density image gives the difference in properties between the density (concentration or numbers) of protons in tissues. To obtain this image, it is necessary to choose the appropriate repetition time TR and echo time TE in order to reduce the effect of the first time phenomenon and the second time phenomenon in the image. The image is highly dependent on the proton density in the tissue.

To obtain a good image we must

choose a long TR repetition time, and a short echo time. The first is to reduce the effect of the first time phenomenon, and the second is to reduce the effect of the second time phenomenon. Low proton density tissue is dark or black. Tissues with many protons are light in color or white.


Short TR
Long TR
Short TE
Long TE
T1
PD
T2
Poor contrast


TR
Short
(<800)
Long
(>800)
TE
Short
(<30)
Long
(>30)
T1
SD

T2




THANKS

THANK
YOU
so much
Roola Akbrian