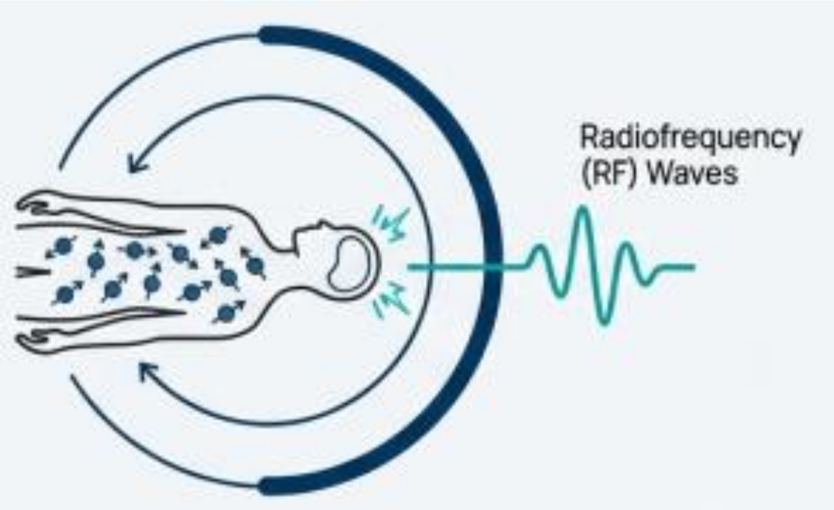
Magnetic Resonance Imaging (MRI)

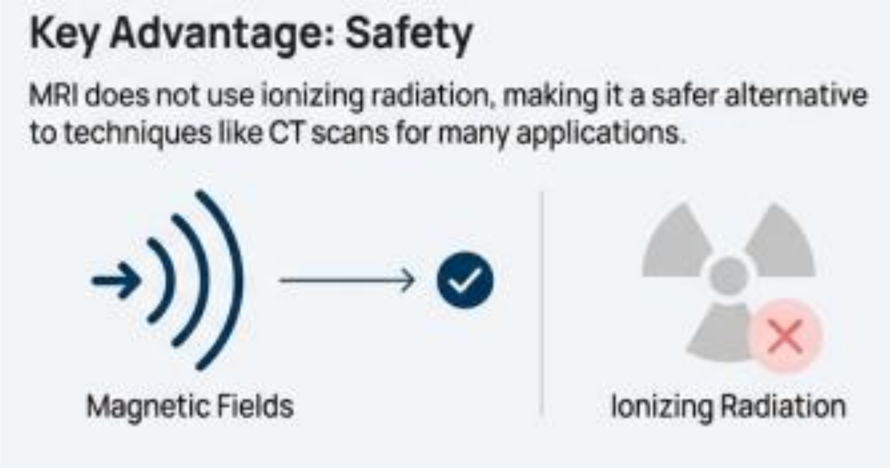
MRI scan of brain

MRI scan of knee

Principles and Applications of Magnetic Resonance Imaging

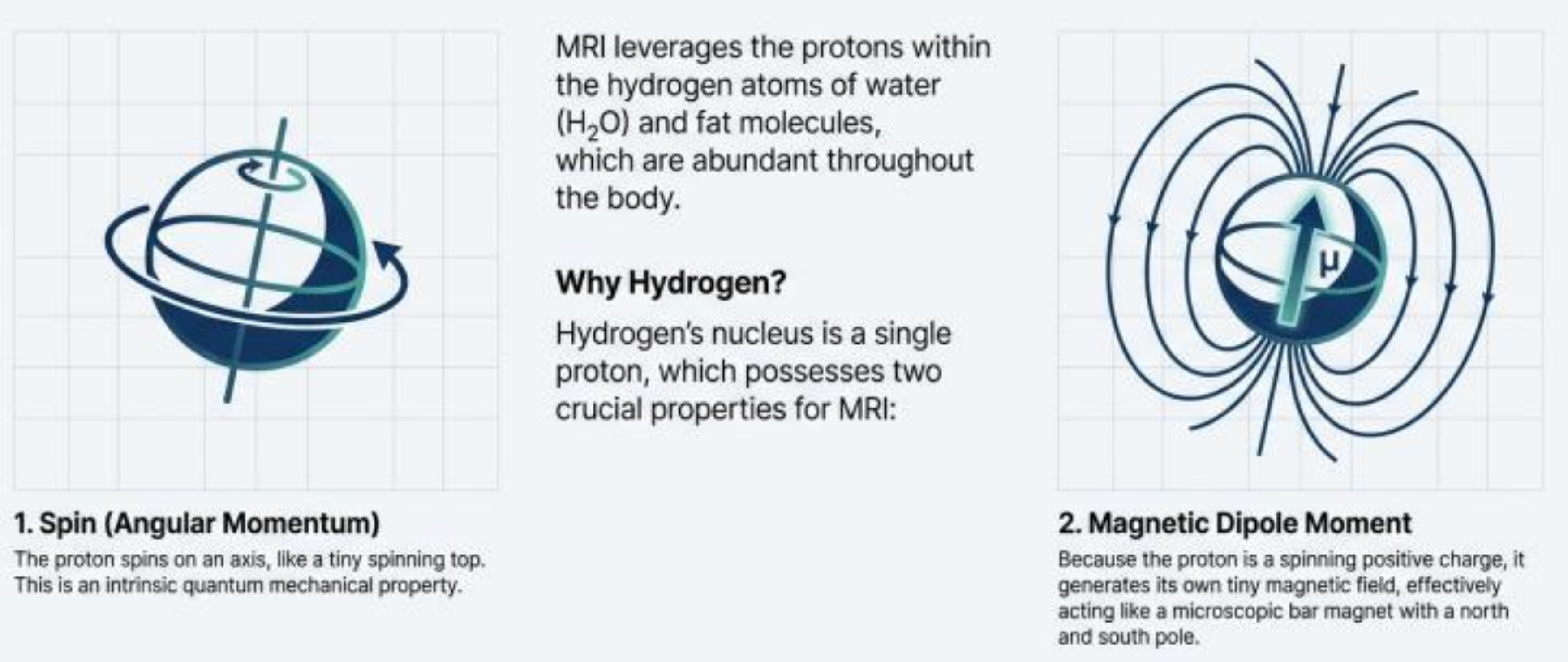
- Magnetic Resonance Imaging (MRI) is a noninvasive medical tool used to create high-resolution 3D images of the body. The process relies on the interaction between strong magnetic fields and the hydrogen protons found in human tissue, utilizing the phenomenon of nuclear magnetic resonance to generate data.





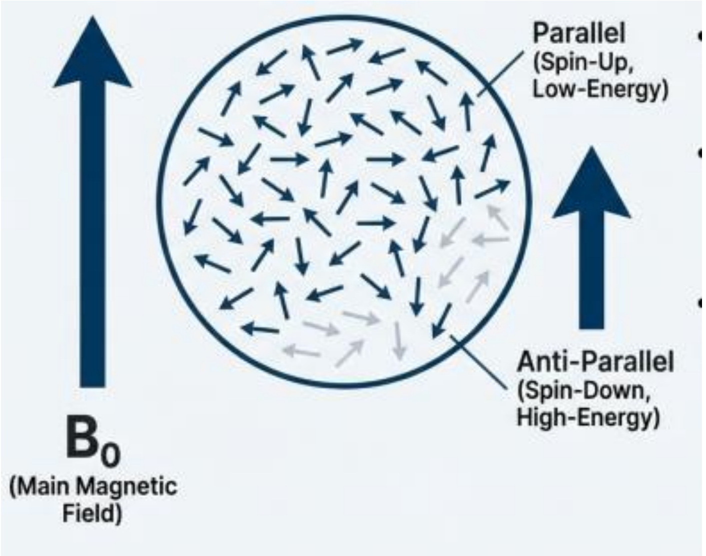
Principles and Applications of Magnetic Resonance Imaging

- Hydrogen protons are the primary subjects of MRI scanning because of their vast abundance in the body's water and fat tissues. These protons possess a property called magnetic dipole moment (MDM), which means they behave like tiny individual magnets with north and south poles



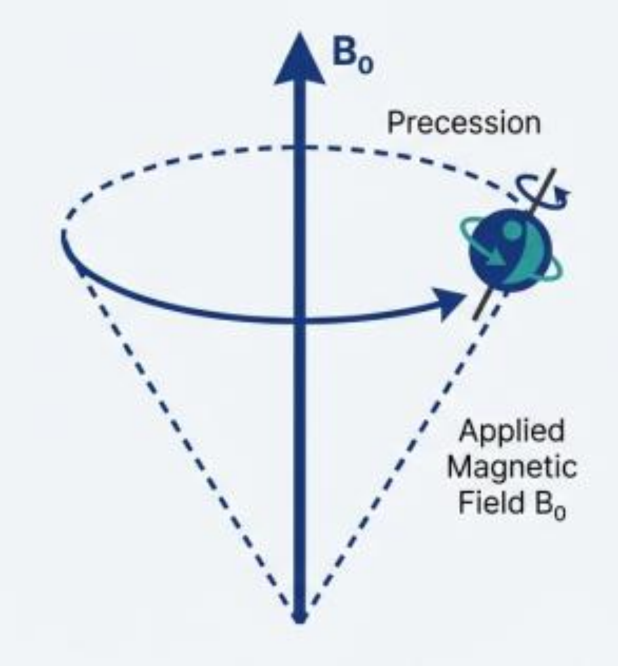
1. Alignment and Net Magnetization

- In their natural state, the magnetic fields of these protons are distributed randomly, resulting in no detectable net magnetic field. When a patient enters an MRI machine, they are placed within a strong, static external magnetic field (B_o). This field causes a small fraction of the millions of protons to realign themselves either parallel (spin up) or anti-parallel (spin down) to the direction of B_0. Because slightly more protons align in the spin-up state, a net magnetization vector (M) is created in the direction of the external field



2. Precession and the Larmor Frequency

- While aligned with B_o, protons do not simply sit still; they precess, or wobble, around the axis of the external magnetic field, similar to how the Earth rotates on its axis. The rate at which they wobble is known as the Larmor frequency. This frequency is critical because it is unique to the type of nucleus and the strength of the magnetic field



The main magnetic field B_0 exerts a torque on the spinning protons, causing their axis of rotation to wobble, or "precess," around the direction of B_0. This is analogous to a spinning top wobbling in the Earth's gravitational field.

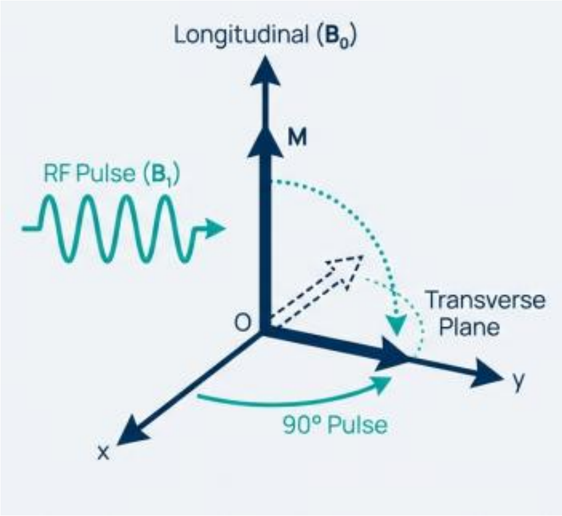
The rate of this precession is called the **Larmor Frequency**, and it is directly proportional to the strength of the magnetic field (B_0).

$$\omega = \gamma B_0$$

- ω = Larmor Frequency
- B_0 = Strength of the main magnetic field
- γ = Gyromagnetic Ratio (a constant for each nucleus; for hydrogen, $\gamma \approx 42.58$ MHz/Tesla)

3. Resonance and Excitation

- To create an image, the MRI machine transmits Radio Frequency (RF) pulses at the exact Larmor frequency of the hydrogen protons. This phenomenon is called magnetic resonance. During this phase:• The protons absorb the energy from the RF waves, causing them to flip their spin states.• The net magnetization vector (M) is pushed away from its original longitudinal alignment with B_o into a transverse plane.• While in this "excited" state, the protons begin to spin together in phase



A second, much weaker magnetic field (**B_1**) is applied as a brief radiofrequency pulse from an RF coil.

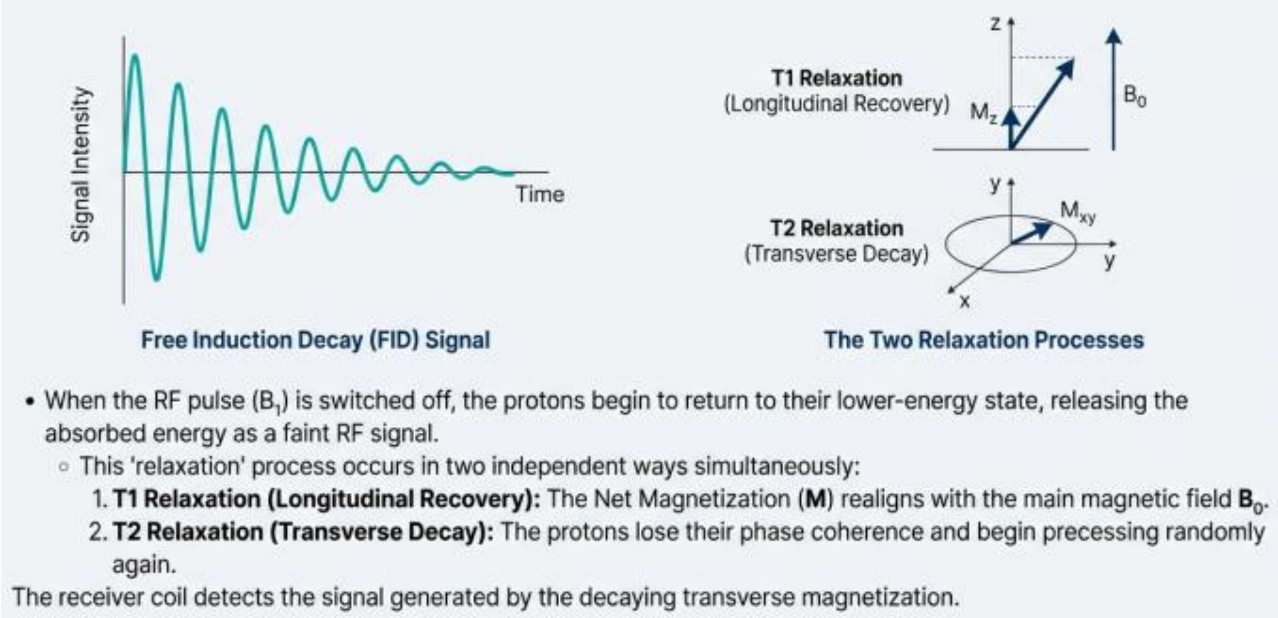
Resonance:
For this pulse to have an effect, its frequency must exactly match the Larmor frequency of the precessing protons. When it matches, the protons absorb energy from the pulse.

This energy absorption has two effects:

1. It forces the precessing protons into **phase coherence** (they spin together).
2. It tips the Net Magnetization vector (**M**) away from the longitudinal axis and **into the transverse plane**.

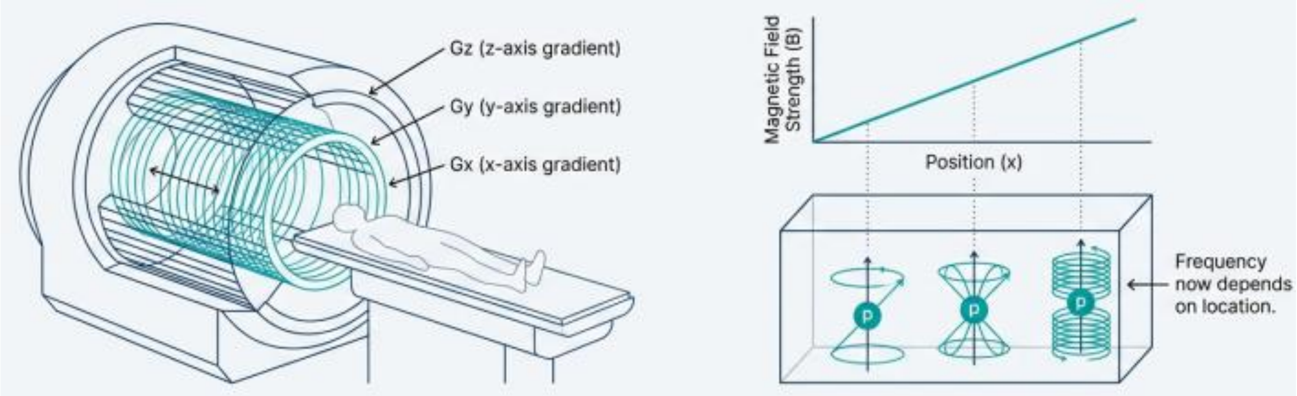
4. Relaxation and Signal Emission

- Once the RF pulse is turned off, the protons gradually release their absorbed energy as they return to their original alignment with B_o, a process known as relaxation. As they relax, they emit RF signals that are picked up by receiver coils. There are two main types of relaxation that provide the contrast for detailed images:• T1 (Longitudinal) Relaxation: The time it takes for the magnetization to recover its original vertical alignment.• T2 (Transverse) Relaxation: The time it takes for the protons to stop spinning in phase with each other.



5. Creating the Detailed Image

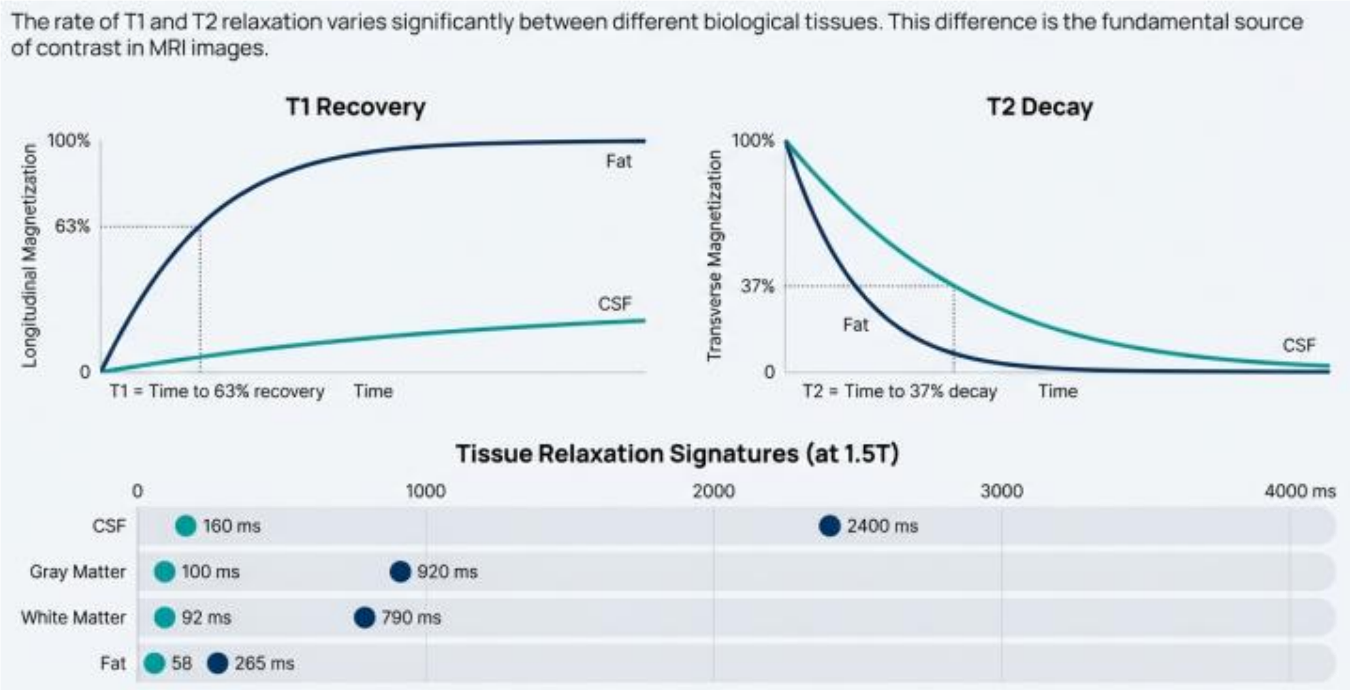
- To distinguish where these signals are coming from in the body, gradient coils apply varying magnetic fields that slightly distort B_o in a controlled way. This ensures that protons at different physical locations precess at slightly different frequencies, allowing for spatial encoding in 2D or 3D. Finally, an advanced computer uses a mathematical process called Fourier transformation to convert these complex RF signals and relaxation times into the various shades of grey seen in a medical image. These variations in signal intensity allow radiologists to distinguish between soft tissues, bones, and diseased areas like tumors or inflammation



To create an image, we must distinguish signals from different locations. This is achieved by the gradient coils. By slightly altering the magnetic field strength at each point, the gradient coils also alter the Larmor frequency of the protons in a spatially dependent manner. This means a proton's precession frequency now encodes its exact location. The loud knocking sound during an MRI scan is caused by the rapid switching of these coils.

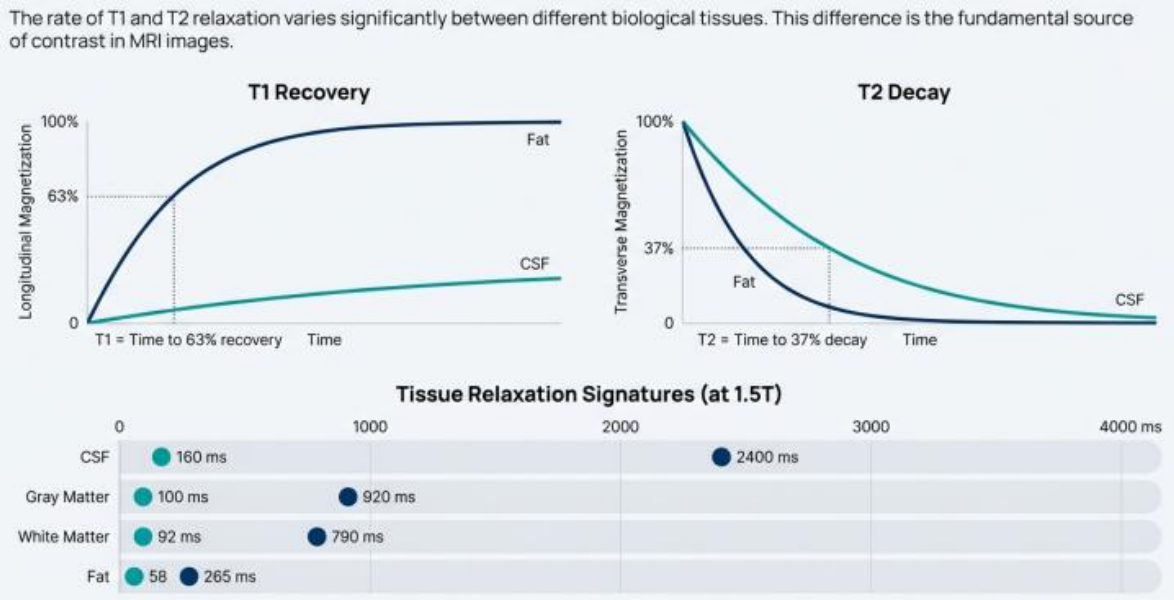
• T1 and T2 relaxation times

- In MRI, image contrast is primarily determined by the rate at which excited protons return to their equilibrium state after being disturbed by radiofrequency (RF) pulses. Because different tissues in the body possess unique physical characteristics, they relax at different speeds, which are measured as T1 and T2 relaxation times



T1 Relaxation (Longitudinal Recovery)

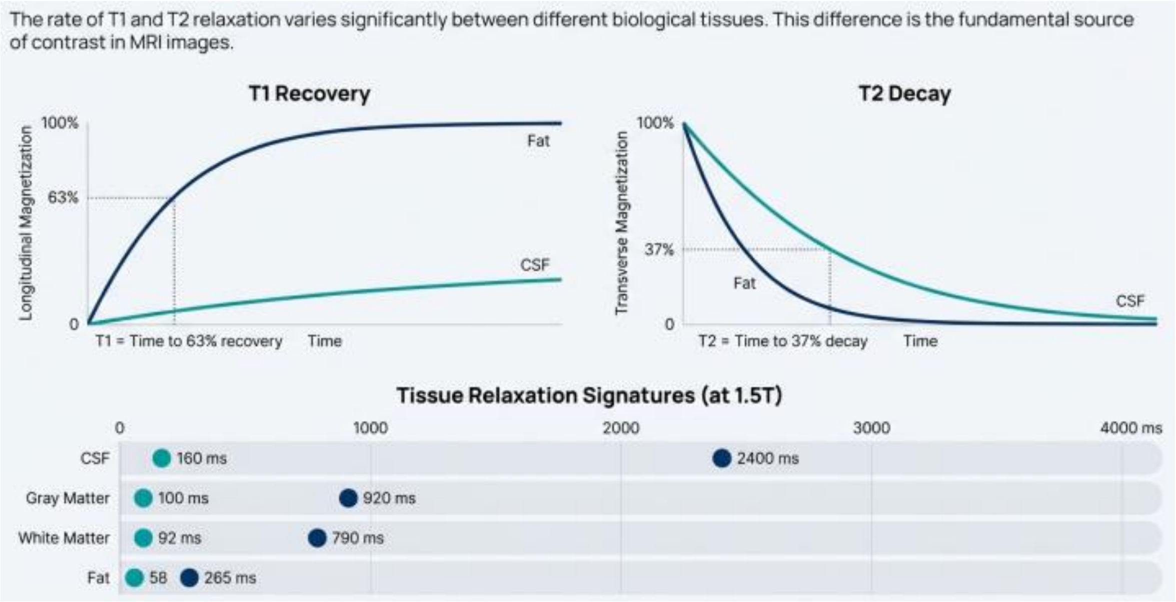
- T1 relaxation, also known as longitudinal relaxation, is the time constant that determines the rate at which protons recover their vertical alignment with the main magnetic field (B_o).• Fat vs. Water Contrast: Fat tissue has a short T1 relaxation time, meaning it realigns with the magnetic field quickly; consequently, it appears very bright on T1-weighted images. Conversely, water and fluids have a much slower realignment rate (long T1) and therefore appear black or dark.



T1 Relaxation (Longitudinal Recovery)

• Clinical Application: T1-weighted images are frequently used to highlight fatty tissues and are sensitive to active current disease, specifically highlighting areas of active inflammation.

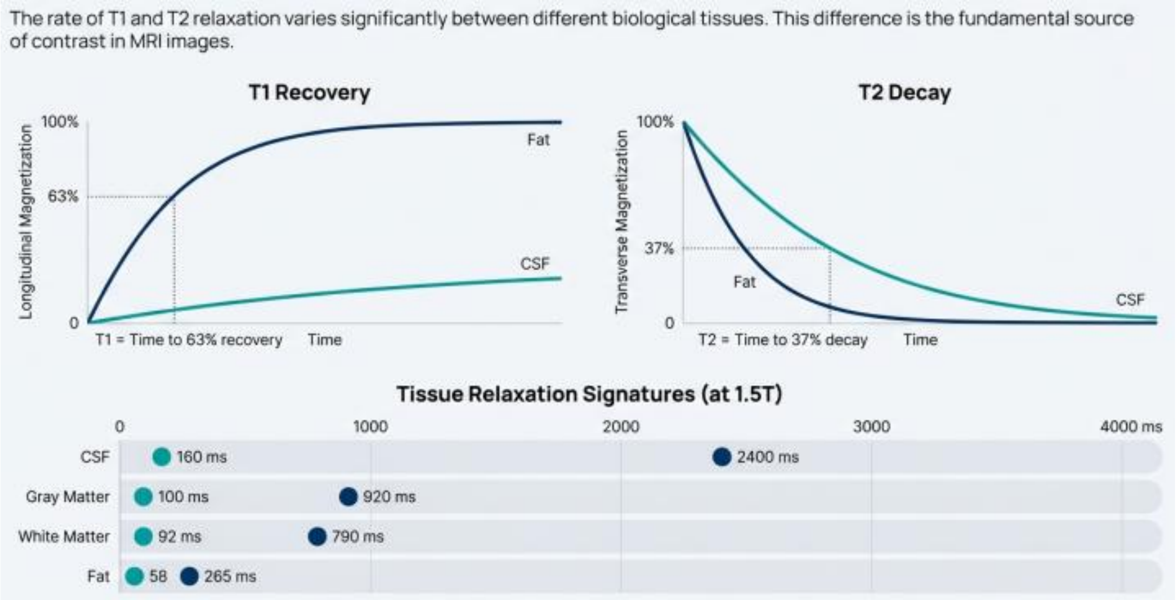
• Pulse Sequencing: To achieve this contrast, the scanner uses a short repetition time (TR); if the TR is too long, the protons will fully recover, and the image will lose its contrast



T2 Relaxation (Transverse Decay)

• T2 relaxation, or transverse relaxation, refers to the process where protons go out of phase with each other, causing the transverse magnetization signal to decay or vanish.

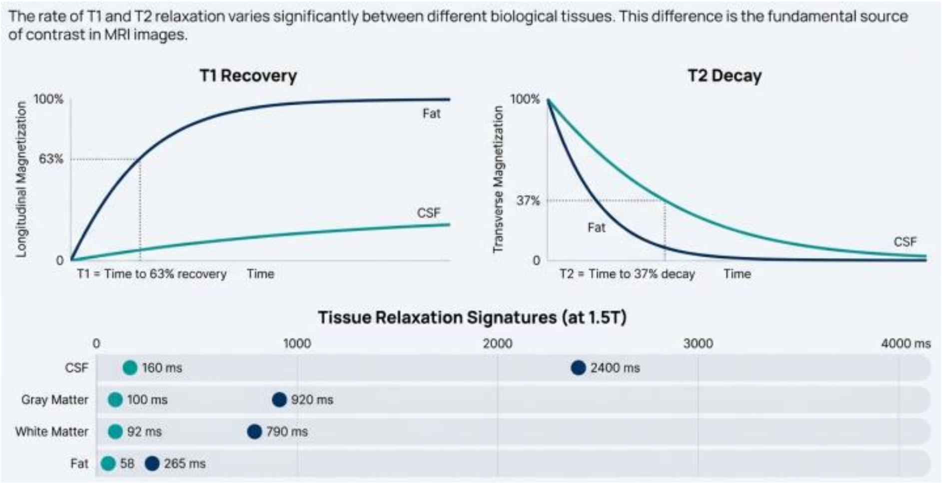
• Fluid and Water Contrast: T2-weighted images enhance the signals of water and liquid-based tissues. Tissues with long T2 values, such as cerebrospinal fluid (CSF), appear bright.



T2 Relaxation (Transverse Decay)

• Tissue Differentiation: While fat is bright on T1, it is generally less bright on T2 images. Comparing T1 and T2 images allows radiologists to distinguish between tissues; for instance, a structure that is bright on T2 but dark on T1 is identified as fluid-based.

• Clinical Application: T2 weighting is essential for detecting the total lesion area, which encompasses both old and new diseased regions. It can also indicate increased water content, which may signal infection, trauma, or cancer.



NO.	CT	MRI
1	Utilizes hazard X-ray radiation in diagnosis.	Utilizes magnetic fields which are not hazard.
2	Takes shorter time of scanning.	Takes longer time of scanning.
3	Concerns with scanning of anatomy of the body.	Concerns with the scanning of anatomy and function of the body.

4	Gives lower different diagnostic information.	Gives more different diagnostic information.
5	The scanning is quiet and comfort.	The scanning is loud and discomfort, except in the open types.
6	People with some medical implants and other non-removable metal inside the body are able to have safely CT scanning.	People with some medical implants or other non-removable metal inside the body are unable to have safely MRI scanning.

7	Less sensitive to patient's movement during scanning.	Sensitive to patient's movements during the scanning.
8	Ability to detect the flowing blood and cryptic vascular malformations.	More ability to detect the flowing blood and cryptic vascular malformation
9	Can detect the demyelinating disease, but with beam hardening artefacts, thus the posterior fossa cannot easily visualize.	Can detect the demyelinating disease without beam hardening artefacts, thus the posterior fossa can be easily visualized.

10	Commonly used for diagnosis of the tumors, cancer development, and its response for the treatment, internal bleeding, and bone fractures.	Commonly used for diagnosis of the heart, brain, spinal cord, vascular anatomy, breast, bones, and joints.
11	Reconstruct the images in 3 different planes, the axial, sagittal, and coronal planes.	Reconstruct the images in 3 different planes, the axial, sagittal, and coronal planes.