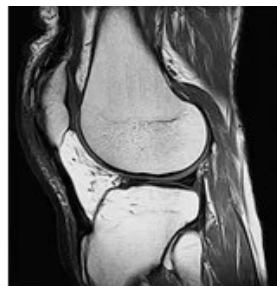


Magnetic Resonance Imaging (MRI)



MRI scan of brain

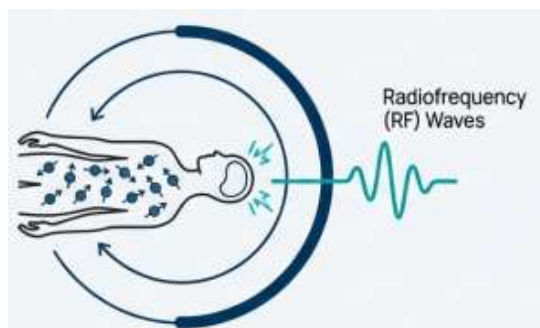


MRI scan of knee



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.



Key Advantage: Safety

MRI does not use ionizing radiation, making it a safer alternative to techniques like CT scans for many applications.



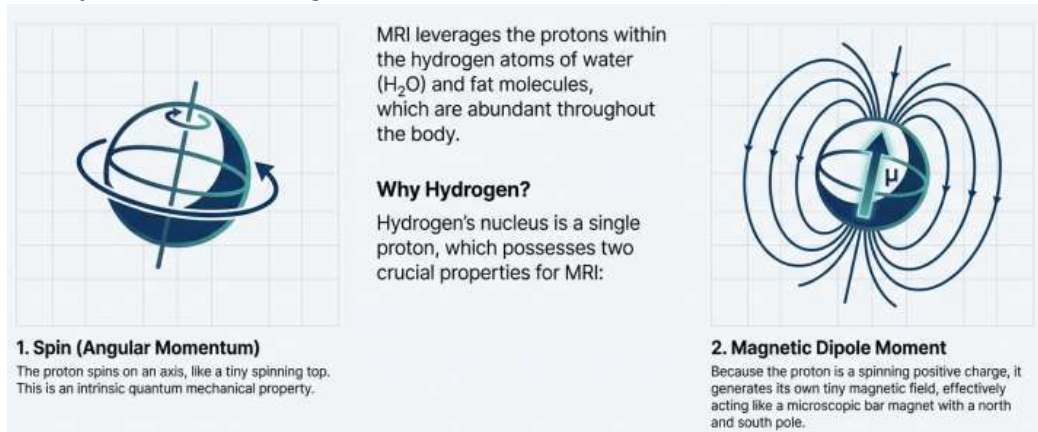
Magnetic Fields



Ionizing Radiation

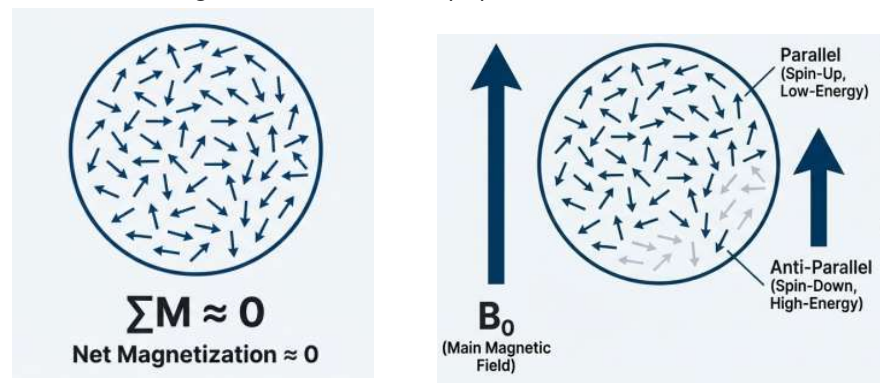
Principles and Applications of Magnetic Resonance Imaging

- 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



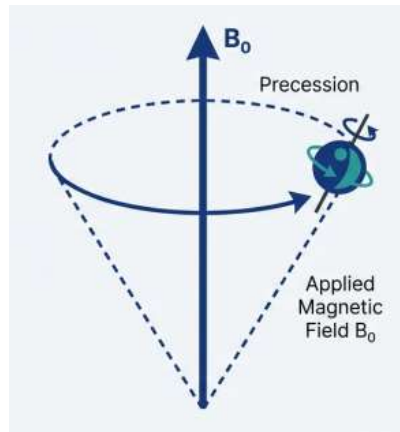
1. Alignment and Net Magnetization

- 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_0). 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_0 , 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.

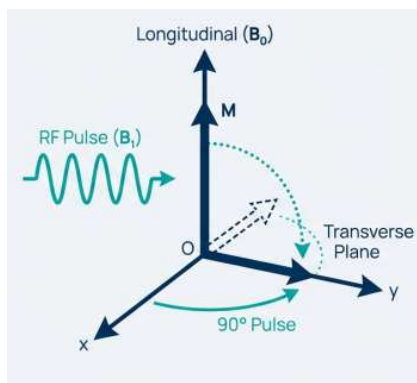
The rate of this precession is called the **Larmor Frequency**, and it is directly proportional to the strength of the magnetic field (B_0).

$$\omega = \gamma B_0$$

- 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_0 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:

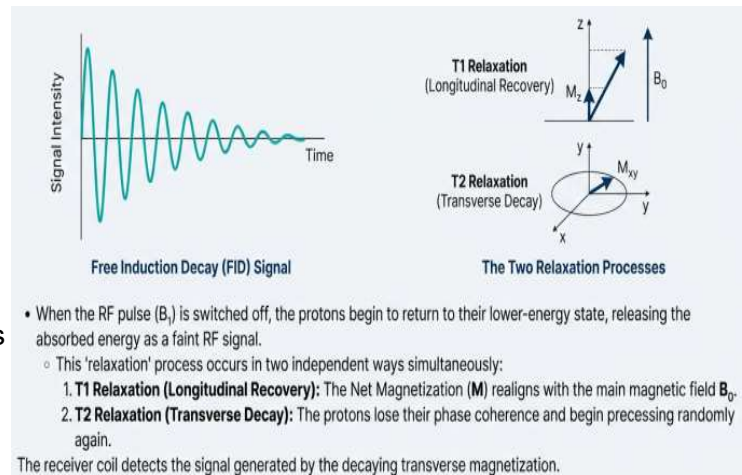
For this pulse to have an effect, its frequency must exactly match the Larmor frequency of the precessing protons. When it matches, the protons absorb energy from the pulse.

This energy absorption has two effects:

- It forces the precessing protons into **phase coherence** (they spin together).
- 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_0 , 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:

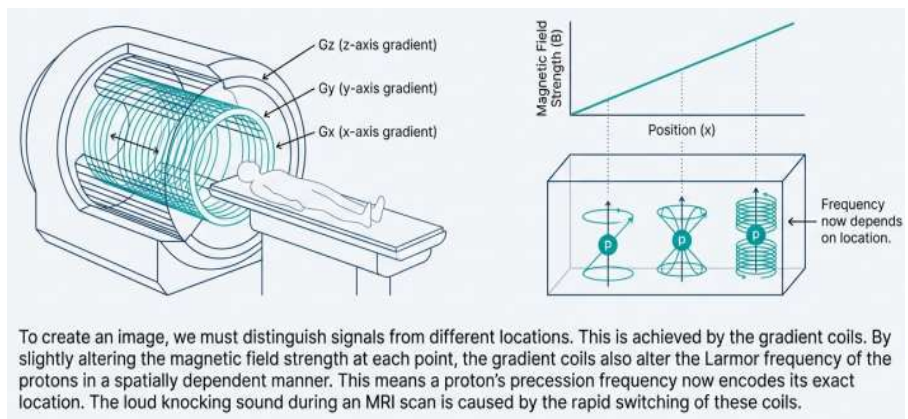


- **T1 (Longitudinal) Relaxation:** The time it takes for the magnetization to recover its original vertical alignment.

- **T2 (Transverse) Relaxation:** The time it takes for the protons to stop spinning in phase with each other.

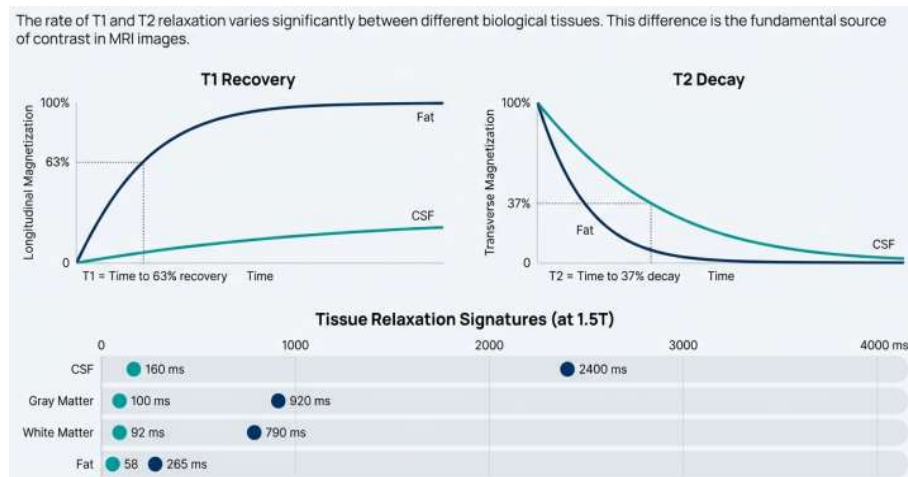
5. Creating the Detailed Image

- To distinguish where these signals are coming from in the body, gradient coils apply varying magnetic fields that slightly distort B_0 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



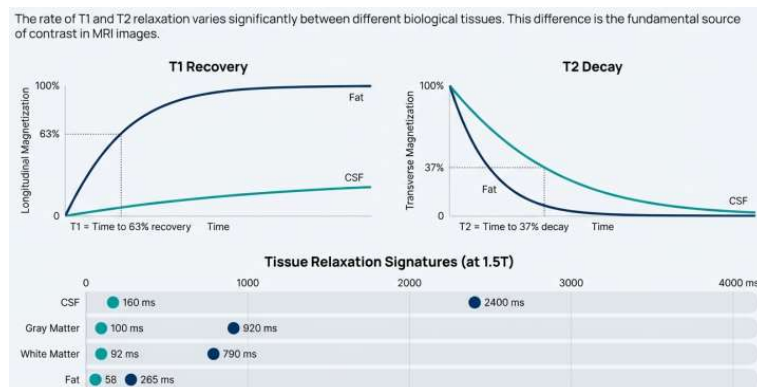
• T1 and T2 relaxation times

- 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



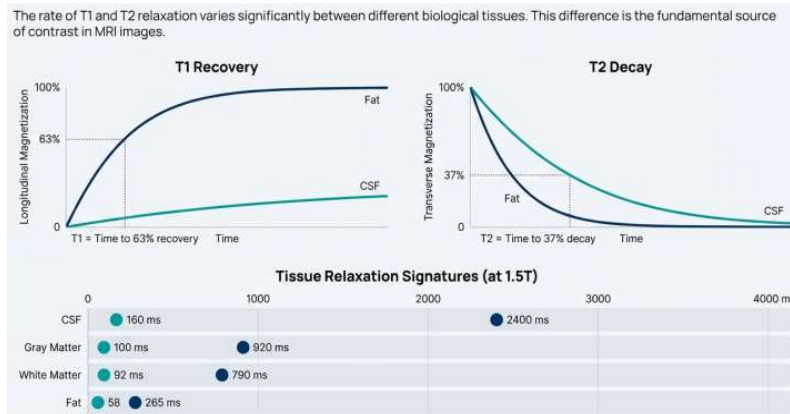
T1 Relaxation (Longitudinal Recovery)

- 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_0).
- **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.



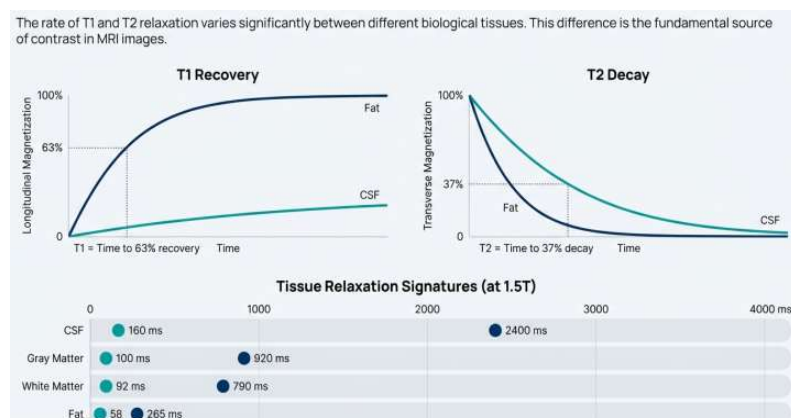
T1 Relaxation (Longitudinal Recovery)

- 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.

