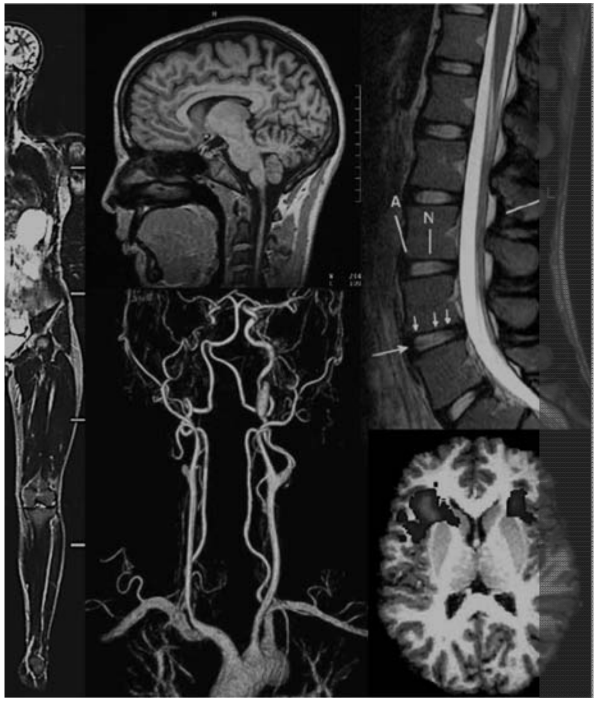

射頻脈衝
A Course of MRI

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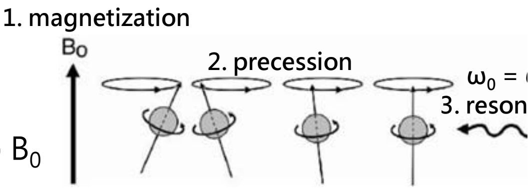
本週課程內容

- 射頻脈衝（Radio Frequency Pulse）
- T1, T2, T2*（Relaxation Time）

Procedure of MRI



- 1. Alignment (magnetization) B_0
- 2. Precession $\omega_0 = \gamma B_0$
- 3. Resonance (given B_1 by RF with ω_2) $\omega_1 = \gamma B_1$, $B_1 \perp B_0$
- 4. MR signal (EMF, electromotive force)
- 5. Relaxation time
  - T1 (recovery rate of M along B_0),
  - T2 (decay rate of transverse M),
  - T2* (consider both T2 and B_0 inhomogeneities)
- The most effective resonance is produced when $\omega_0 = \omega_2$

射頻脈衝
RF Pulse

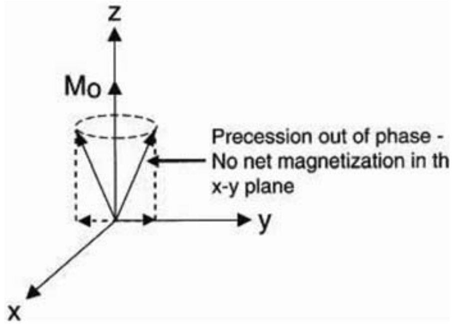
A Readable Signal

- We can only transmit and receive oscillated signals (like an AC voltage).
- We are only sensitive to oscillations along certain axes.

- The longitudinal magnetization is *not* an oscillating function (like a DC voltage).
- The longitudinal magnetization needs to be "flipped" into the transverse x-y planes (where it can oscillated or precess about z axis) to generate a readable signal.

Magnetization Vector M_0

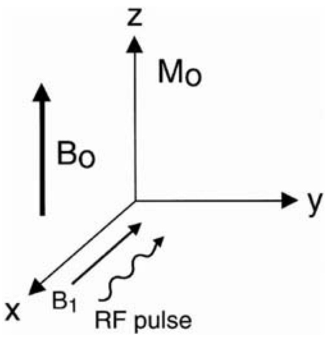
- The individual spins are precessing along z-axis and "*out of phase*" with each other.
- The x and y components cancel each other out.
- The net vector of magnetization *does not* precess initially.



Radio Frequency Pulse B_1

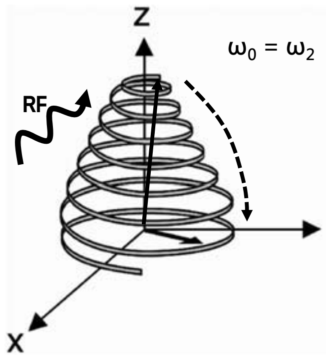
- Two different magnetic fields:
  - B_0 = a very strong external magnetic field (e.g., 1.5T~3.0T)
  - B_1 = a very weak magnetic field generated by the RF pulse (e.g., 0.5~5 mT)
- Two types of precessions
  - $\omega_0 = \gamma B_0$, along z-axis
  - $\omega_1 = \gamma B_1$, along x-axis
- Since $B_1 << B_0$

  then $\omega_1 << \omega_0$



Radio Frequency Pulse B_1

- B_0 is a fixed magnetic field (much like a DC voltage)
- B_1 is an oscillating magnetic field (much like an AC voltage)
  - It is derived from the magnetic component of an oscillating electromagnetic wave.
- The RF pulse has a $\cos(\omega_2 t)$ wave form.
- Precessing along z-axis at frequency ω_0 and x-axis at frequency ω_1 simultaneously.
  ➔ spiral motion (nutation)

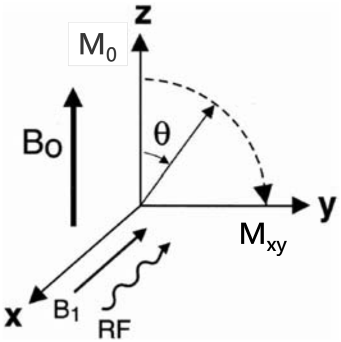


Resonance $\omega_0 = \omega_2$

- By introducing the B1, the spinning protons will then be in phase ➔ creates transverse magnetization
- The B1 field also causes a spiral downward motion of the protons ➔ flipping
- The flip angle is determined by

$$\theta = \gamma B_1 \tau = \omega_1 \tau$$

  - τ is the duration of the RF pulse
  - B_1 is the strength of the RF pulse
  - γ is the gyromagnetic ration of protons

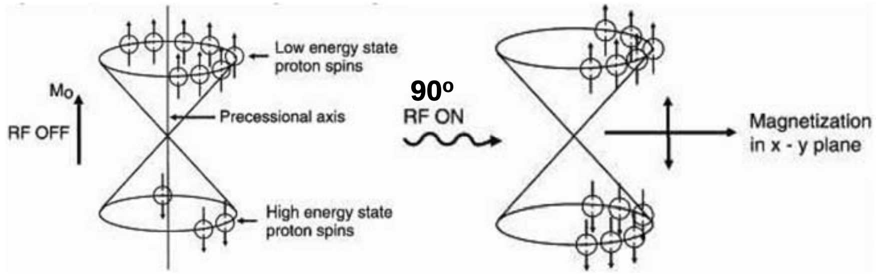


90° RF Pulse

- The pulse that causes the 90° flip is called a 90° RF pulse.
- The entire magnetization vector flips into the x-y plane

  ➔ $M_{xy} = M_0$

- $\tau_{\pi/2} = (\pi/2)/(\gamma B_1)$



180° RF Pulse

- A 180o pulse exactly reverses the equilibrium northward-pointing excess without inducing phase coherece (transverse magnetization).
- $\tau_\pi = \pi/(\gamma B_1)$
- Used in the pulse sequence of inversion recovery

Partial Flip

- A partial flip has a flip less than 90°
- $M_{xy} = M_0 \cdot \sin\theta < M_0$
- Commonly used in gradient echo imaging.

Auto RF

- Prescan is the process of preparing the scanner for a specific patient.
- 1. It sets transmit gain.
  - The flip angle is proportional to the square root of the transmit power.
- 2. It sets the receive gain.
- 3. It sets the optimum ω_0.

T1, T2, T2*

Relaxation Time

T1, T2, T2*

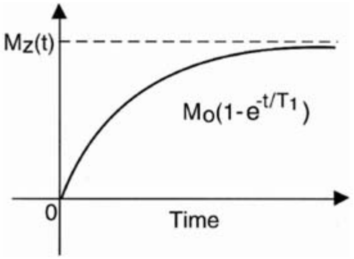
- Inherent properties: T1 and T2
  - Fixed for a specific tissue at a given B_0 strength
- T2*
  - The effects of T2 and inhomogeneities in the B_0
  - Fixed for a specific tissue within a given external magnetic enviroment

T1 Relaxation Time

- Relaxation: the spins are relaxing back into their lowest energy state or back to the equilibrium state.
- T1: the longitudinal relaxation time
  - It refers to the time it takes for the spins to realign along the longitudinal (z) axis.
- T1: the spin-lattice relaxation time
  - It refers to the time it takes for the spins to give the energy they obtained from the RF pulse back to the surrounding lattice in order to go back to their equilibrium state.

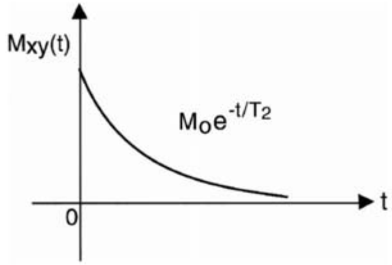
T1 Relaxation Time

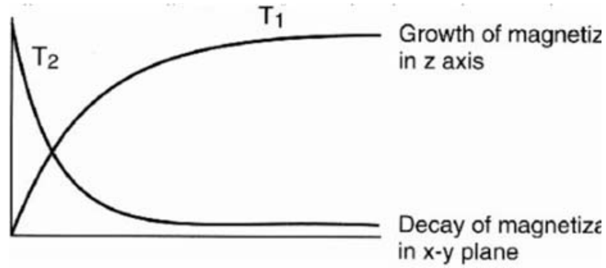
- After the RF pulse is turned off…
  - The spins will go back to the lowest energy state.
  - The spins will get out of phase with each other.
- These events result in…
  - The M_{xy} component of the magnetization vector decreases rapidly.
  - The M_z component slowly recovers along the z axis.
- $\mathbf{M_z(t)=M_0(1-e^{-t/T1})}$



T2 Relaxation Time

- As the M_z recovers, the transverse vector M_{xy} decays at a rate characterized by T2
- $\mathbf{M_{xy}(t)=M_0e^{-t/T2}}$
- T2 decay occurs 5 to 10 times more rapidly than T1 recovery.





Dephasing

ΔB_{int}
- Interactions between individual spins (internal inhomogeneities)
  - When two spins are next to each other (one is aligned with B_0 and the other is against it)…
  - ω(proton #1)=$\gamma(B_0+\Delta B)$
  - ω(proton #2)= $\gamma(B_0-\Delta B)$
  - Depends to a degree on *the proximity of the spins* to each other.

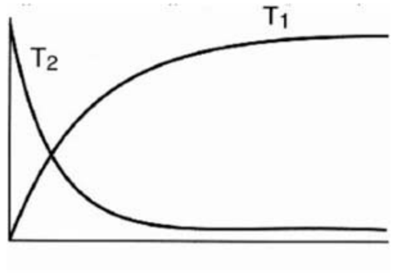
ΔB_{ext}
- External magnetic field inhomogeneity
  - Protons in different locations precess at different frequencies.

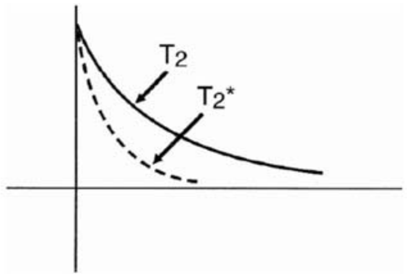
T2 Relaxation Time

- T2: transverse relaxation time
- T2: spin-spin relaxation time
- T2 decay depends only on
  - Spin-spin interactions
- T2* decay depends on both
  - External magnetic field
  - Spin-spin interactions

T1, T2, T2*

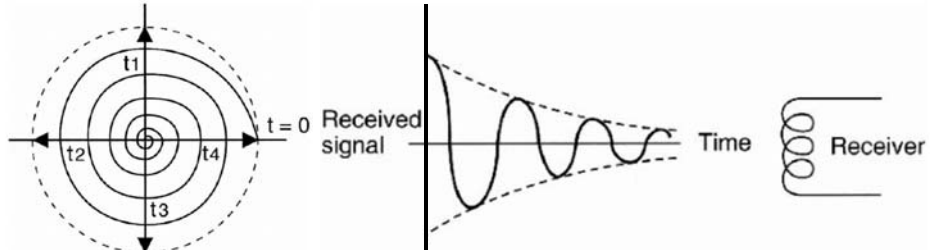
- T1>T2>T2*
- **$1/T2^* = 1/T2 + \gamma \Delta B_{ext}$**





The Received Signal

- A oscillated magnetic field causes movement of electrons, i.e., the current (signal).
- The RF coil can only detect the component of magnetization along the x axis.



The frequency of the received signal is also ω0.

Free Induction Decay

- The oscillating, decaying signal is called a free induction decay (FID).
- After we turn off the RF pulse…
  - The spins begin to precess *freely*.
  - The spins *induce* a current in the receiver coil.
  - The signal starts to *decay* with time.
- **$M_{xy}(t) = M_0 e^{-t/T2^*}(\cos\omega_0 t)$**

Video Demonstration

- Video 3 2:40 Terranova-MRI
  - Main Magnet, Gradient coils, Solenoid RF coils
- Video 4 3:23 FID & Larmor frequency
- Video 5 2:50/3:43 B0 inhomogeneity
- Video 5 4:30 shimming

magritek-youtube channel

THE END

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