本週課程內容

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

射頻脈衝
A Course of MRI
盧家鋒 助理教授
國立陽明大學 物理治療暨輔助科技學系
alvin4016@ym.edu.tw

Procedure of MRI

1. Alignment (magnetization) \(B_0\)
2. Precession \(\omega_0 = \gamma B_0\)
3. Resonance (given \(B_1\) by RF with \(\omega_2\)) \(\omega_1 = \gamma B_1\), \(B_1 \perp B_0\)
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 \(\omega_0 = \omega_2\)
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 \( B_1 \ll B_0 \) and \( \omega_1 \ll \omega_0 \)

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 \( \omega_0 \) and x-axis at frequency \( \omega_1 \) simultaneously, \( \Rightarrow \) spiral motion (nutation)
Resonance $\omega_0 = \omega_2$

- By introducing the B1, the spinning protons will then be in phase $\rightarrow$ creates transverse magnetization
- The B1 field also causes a spiral downward motion of the protons $\rightarrow$ flipping
- The flip angle is determined by $\theta = \gamma B_1 \tau = \omega_1 \tau$
  - $\tau$ is the duration of the RF pulse
  - $B_1$ is the strength of the RF pulse
  - $\gamma$ is the gyromagnetic ratio 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 $\rightarrow$ $M_{xy} = M_0$
- $\tau_{\pi/2} = (\pi/2)/(\gamma B_1)$

180° RF Pulse

- A 180° pulse exactly reverses the equilibrium northward-pointing excess without inducing phase coherence (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.
  - It sets transmit gain.
    - The flip angle is proportional to the square root of the transmit power.
  - It sets the receive gain.
  - It sets the optimum $\omega_0$.

T1, T2, T2* 
Relaxation Time

- 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 environment

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.

$$M_z(t) = M_0(1 - e^{-t/T_1})$$

T2 Relaxation Time

- As the $M_z$ recovers, the transverse vector $M_{xy}$ decays at a rate characterized by $T_2$
  - $M_{xy}(t) = M_0 e^{-t/T_2}$
  - $T_2$ decay occurs 5 to 10 times more rapidly than $T_1$ recovery.

Dephasing

- 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)...
    - $\omega$(proton #1) = $\gamma(B_0 + \Delta B)$
    - $\omega$(proton #2) = $\gamma(B_0 - \Delta B)$
    - Depends to a degree on the proximity of the spins to each other.
- External magnetic field inhomogeneity
  - Protons in different locations precess at different frequencies.

$\Delta B_{\text{int}}$ $\Delta B_{\text{ext}}$ $\gamma$ $\omega$ $T_1$ $T_2$ $M_0$ $M_z(t)$ $M_{xy}(t)$
**T1, T2, T2*\n\n- T1 > T2 > T2*\n- \(1/T2^* = 1/T2 + \gamma \Delta B_{\text{ext}}\)**

**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.

**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