Lecture 20 – Relaxation Time

This lecture will cover:

– Relaxation time (弛豫时间)

– Free induction decay

Relaxation time

- The equilibrium magnetization state
  - The z-component, M_z equal to M_0
  - The transverse components, M_x and M_y , equal to zero
- Two relaxation time (弛豫时间)
  - T_1-relaxation (纵向弛豫): the z-component from M_z to M_0 (spin-lattice relaxation, 自旋-晶格弛豫)
  - T_2-relaxation (横向弛豫): the transverse components from M_x and M_y to 0 (spin-spin relaxation, 自旋-自旋弛豫)

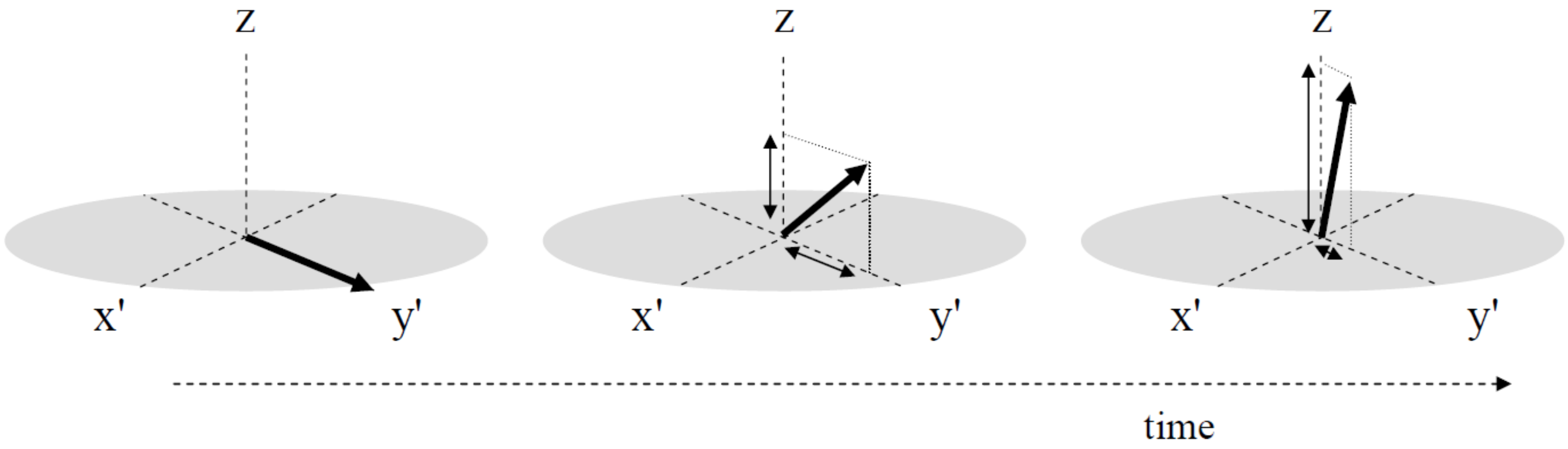

Fig. (left) Magnetization vector after a 90° RF pulse about the x-axis. (centre) T_1 and T_2 relaxation of the magnetization a certain time after the pulse has been applied results in an increased M_z component and reduced My component, respectively. (right) After a further time, the M_z and M_y components have almost returned to their equilibrium values of M_0 and zero, respectively.

Relaxation time

- For an arbitrary tip angle α for M_z component:

$$M_z(t) = M_0\cos\alpha + (M_0 - M_0\cos\alpha)(1 - e^{-\frac{t}{T_1}})$$

- For an arbitrary tip angle α for $M_{x,y}$ component:

$$M_{x,y}(t) = M_0\sin\alpha e^{-\frac{t}{T_2}}$$

Table Tissue relaxation times (ms) at 1.5 and 3 Tesla

Tissue	T_1 (1.5 T)	T_1 (3 T)	T_2 (1.5 T)	T_2 (3 T)
Brain (white matter)	790	1100	90	60
Brain (grey matter)	920	1600	100	80
Liver	500	800	50	40
Skeletal muscle	870	1420	60	30
Lipid (subcutaneous)	290	360	160	130
Cartilage	1060	1240	42	37

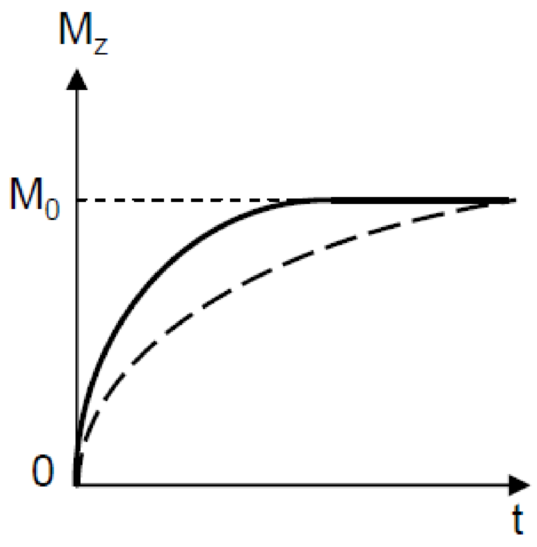

Fig. The recovery of M_z magnetization as a function of time after a 90 pulse for a tissue with short T_1 relaxation time (solid line) and long T_1 relaxation time (dashed line). When $t = 5*T_1$, M_z~99%M_0,which is assumed to be full recovery.

T_2-relaxation time

- T_2-relaxation time is affected by the spatial inhomogeneity in the B_0 field which is caused by
  - Non-uniform B_0 over the entire imaging volume
  - Different magnetic susceptibilities (磁化率) of different parts of the body, i.e. metal implant.
- The combined relaxation time

$$\frac{1}{T_2^*} = \frac{1}{T_2^+} + \frac{1}{T_2}$$

Where T_2^+: a relaxation time characterized by B_0 inhomogeneity

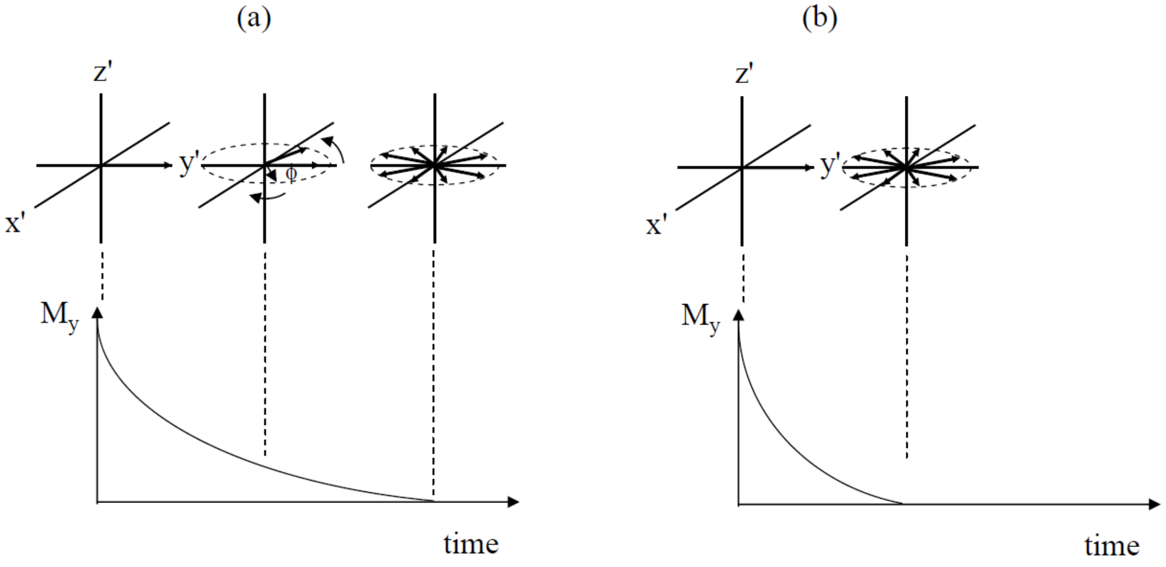

Fig. The time-dependence of the M_y component of magnetization for (a) a tissue with relatively long T_2* and (b) one with a shorter T_2*. The decrease in signal occurs due to the loss of phase coherence of the protons, i.e. protons precess at slightly different frequencies, thus acquiring different phases and reducing the net magnetization along the y-axis. The faster the dephasing process the shorter the T_2* relaxation time.

Chemical shift (化学位移)

- Protons resonate very close to the same frequency for water within tissue, but protons in lipid resonate at a significantly different frequency.

- The effective magnetic field:

$$B_{\text{eff}} = B_0(1 - \sigma)$$

where σ is the shielding constant;

- The resonant frequency of the proton in lipid:

$$\omega = \gamma B_{\text{eff}} = \gamma B_0(1 - \sigma)$$

- Magnetic resonance spectroscopy (MRS): study metabolic changes in organs or tissues based on the resonant frequency and intensity

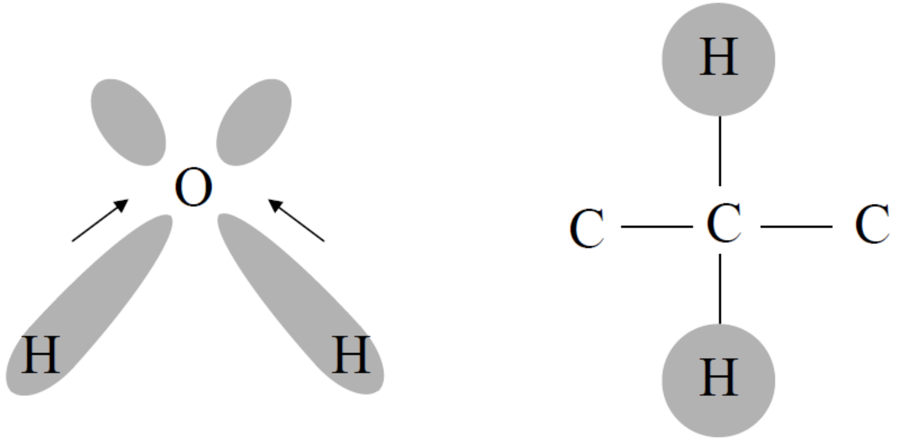

Fig. The electron density distribution (shaded area) surrounding protons in water and lipid. The strong electronegativity of the oxygen atom in water pulls electrons away from the proton, leaving it unshielded compared to the protons in lipid.

Tissue relaxation time

- Free water (自由/游离水) and bound water (束缚/结合水)
  - Free water (~90%): longer T_1 and T_2
  - bound water (~10%): bound with large molecules, shorter T_1 and T_2
- Factors affecting relaxation time
  - Water content (free water)
  - The movement of water molecules
  - The movement of large molecules
  - Lipid content
  - Paramagnetic particles (顺磁粒子)

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Free induction decay

The free induction decay (FID, 自由感应衰减)

- The measured MR signal from tissues;
- Caused by the change of magnetization during the relaxation;
- The signal precessed freely after the RF pulse has been turned off;
- Decay to a zero equilibrium value;
- Both M_x and M_y components can be detected;
- Electronic signal produced by EM induction with frequency of ω_0 and time constant T_2^*;
- Most convenient to observe in the frequency domain
- The linewidth of each peak give by $1/\pi T_2^*$

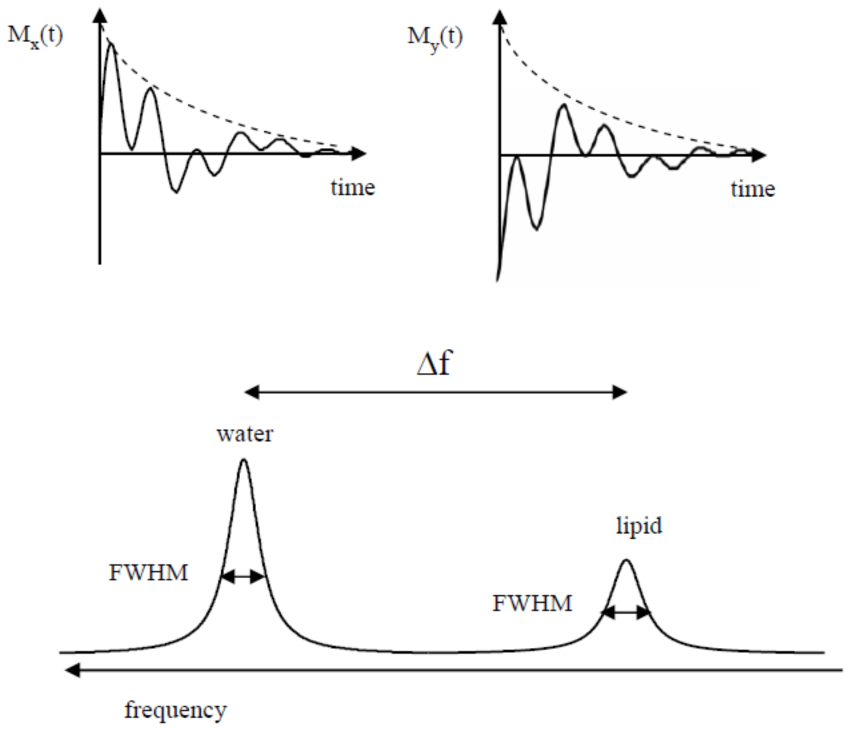

Fig. (top) x- and y-components of magnetization as a function of time, showing 'beat patterns' which come from the two different resonant frequencies of lipid and water. The real part of the frequency spectrum, shown on the bottom, shows the two peaks separated by Δf Hz.

FID signal

Characteristics of FID signals

- Only M_x and M_y can be measured, M_z can be measured if it is rotated to x-y plane;
- Initial amplitude of FID is proportional to the density of protons in tissues;
- Under the circumstance of same density of protons, the longer T_2 , the slower decay, the greater FID signal;
- Under the circumstance of same measurement time, the shorter T_1 , the greater FID signal;
- The intensity of FID signals are affected by density of protons, T_1 and T_2 , therefore MRI is multiple-parameter imaging.