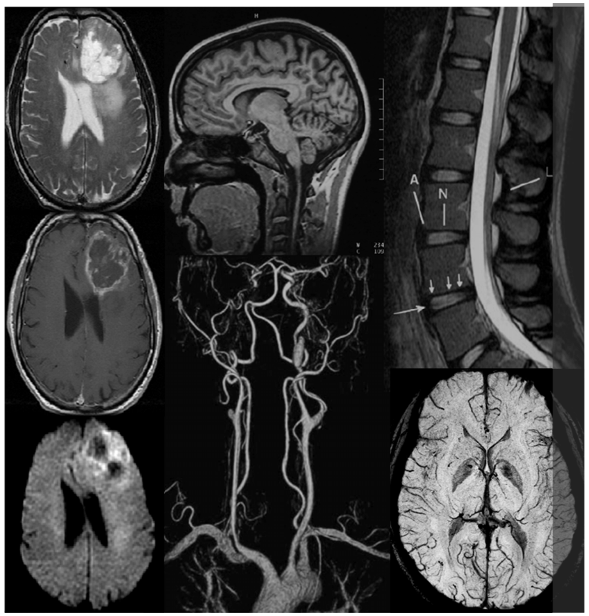

磁振影像學MRI
鬆弛時間

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生物醫學影像暨放射科學系
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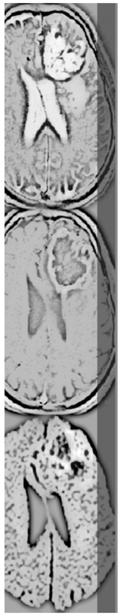
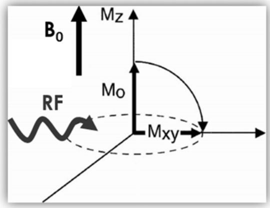
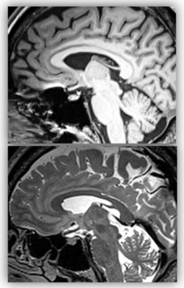
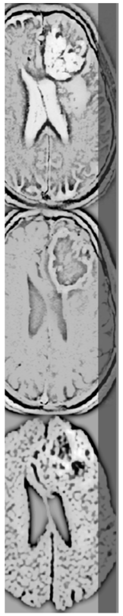


Procedure of MRI



- ☑ Alignment (magnetization) B_0
- ☑ Precession $\omega_0 = \gamma B_0$
- ☑ Resonance (given B_1 by RF with ω_2) $\omega_1 = \gamma B_1$, $B_1 \perp B_0$
  - The most effective resonance is produced when $\omega_0 = \omega_2$
- ☐ MR signal (EMF, relaxation time)
- ☐ Imaging (Pulse sequencing)
  - ☐ Tissue Contrast: Image weighting
  - ☐ Spatial localization: Spatial Encoding

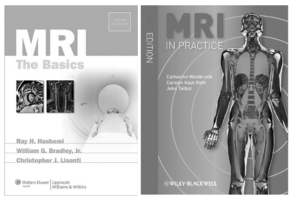




本週課程內容 http://cflu.lab.nycu.edu.tw

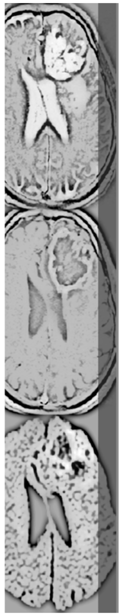
- 鬆弛時間
- 組織鬆弛時間

- MRI The Basics (3rd edition)
  - Chapter 4: T1, T2, and T2*
- MRI in Practice, (4th edition)
  - Chapter 1: Basic Principles
  - Chapter 2: Image Weighting and Contrast



鬆弛時間T1, T2, T2*

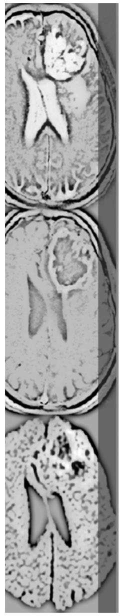
Relaxation Time



Relaxation

- During relaxation, hydrogen nuclei give up absorbed RF energy and the NMV returns to B_0 direction.
- The magnetic moments of hydrogen lose coherency due to dephasing.

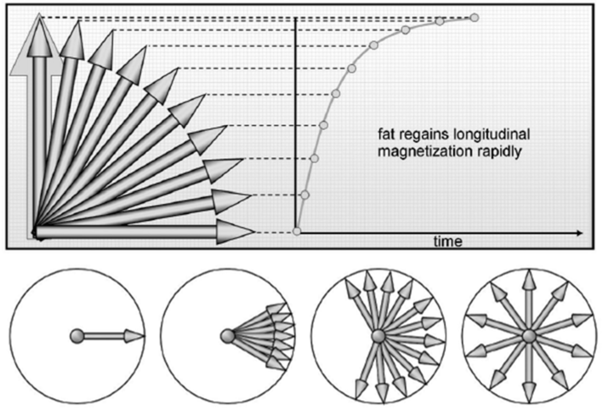
- 1. Recovery of longitudinal magnetization (M_z) → T1 recovery
- 2. Decay of transverse magnetization (M_{xy}) → T2 decay

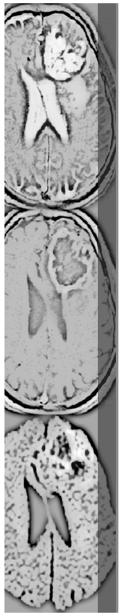


Relaxation

T1 recovery
(slower)

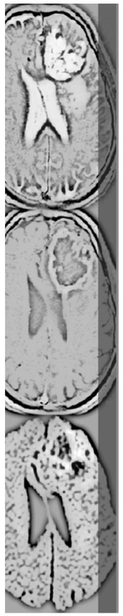
T2 decay
(faster)





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 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 Characteristics

- Determined by how well the protons can give off their energy to the surrounding lattice.
- The most efficient energy transfer occurs when the **natural motional frequencies (ω)** of the protons are at the **Larmor frequency (ω_0)**.
- If the efficiency of energy transfer from the protons to the lattice is increased, the T1 becomes shorter.
- Range of $\omega(H_2O) >> \omega_0$, $\omega(\text{solids}) < \omega_0$, $\omega(\text{fat}) \fallingdotseq \omega_0$

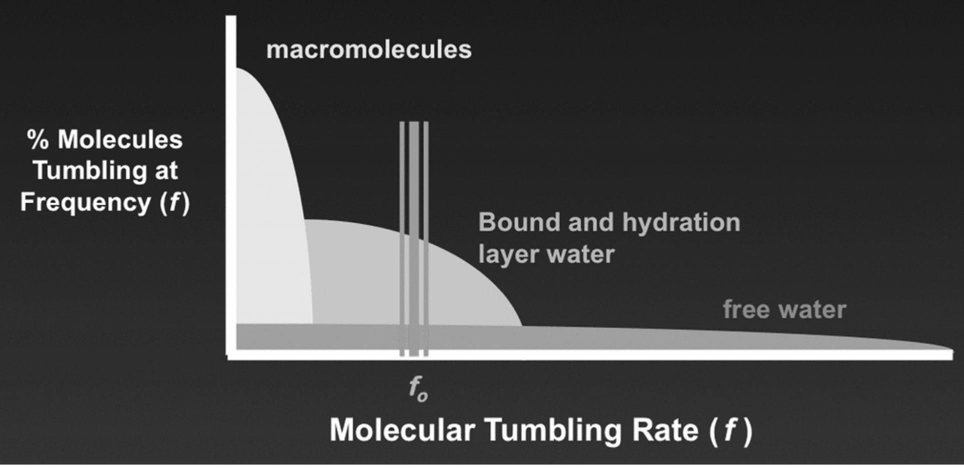
Longer T_1 at Higher Field B_0

Over range of field strengths used for clinical MRI (0.3 T – 3.0 T)
- T1 approximately doubles
- T2 is relatively unchanged

- ~~A higher magnetic field is stronger, it will pull the net magnetization vector back to it's original position in the z-direction more quickly, producing shorter T1.~~
- **What is the number of resonant protons that are available to transfer energy to the "lattice"**?
- Increase the magnetic field strength B_0 ➔ the Larmor frequency increases ➔ fewer protons experience an oscillating magnetic field at or near the Larmor frequency ➔fewer protons available to transfer energy efficiently to the lattice, and the T1 time is lengthened.

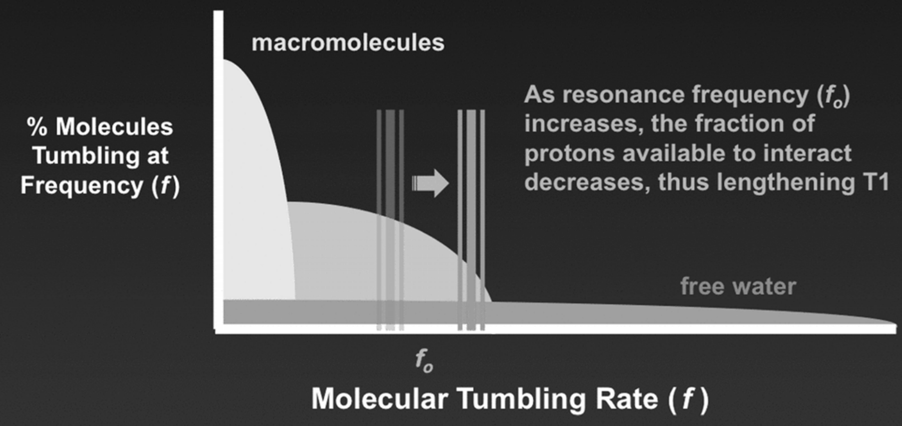
Distribution of Molecular Motion in Tissue

https://mriquestions.com/bo-effect-on-t1--t2.html



Field Strength Dependence of T1

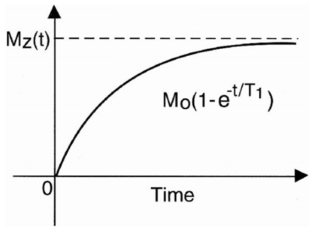
https://mriquestions.com/bo-effect-on-t1--t2.html



T1 Recovery

- After the RF pulse is turned off …
  - The M_{xy} component of the magnetization vector decreases rapidly.
  - The M_z component slowly recovers along the z axis.

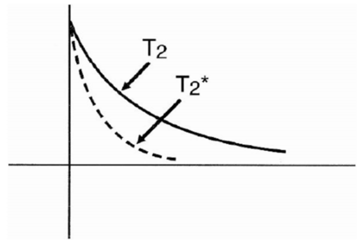
- **$M_z(t)=M_0(1-e^{-t/T1})$**



T2 Relaxation Time

- T2: transverse relaxation time
- T2: spin-spin relaxation time

T2>T2*, T2* decay is quicker than T2 decay



- T2 decay depends only on
  - Spin-spin interactions
- T2* decay depends on both
  - External magnetic field
  - Spin-spin interactions

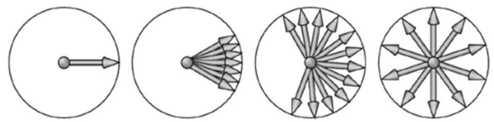
T2 Characteristics

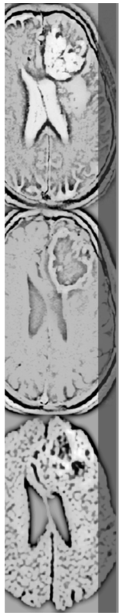
- Determined by how fast the proton spins in that tissue dephase.
- If they dephase rapidly, we get a short T2.
- If they dephase slowly, we get a longer T2.

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.

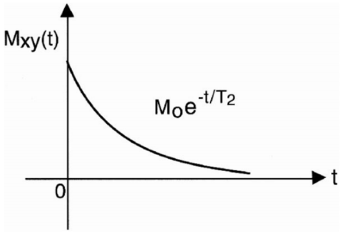


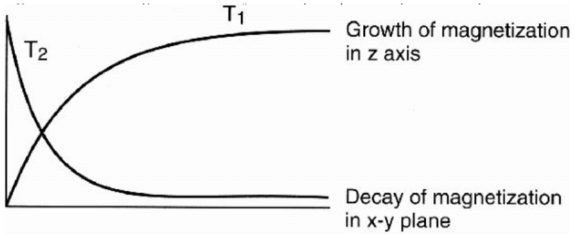


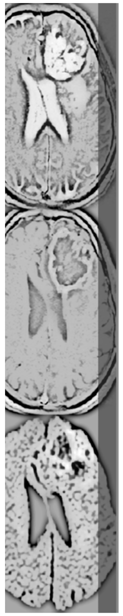
T2 Relaxation Time

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

T1> T2

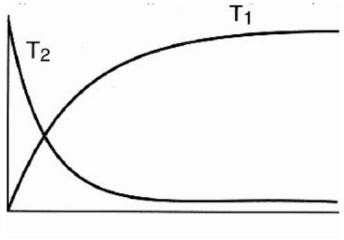


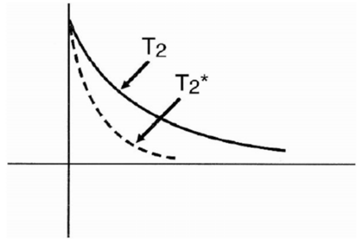


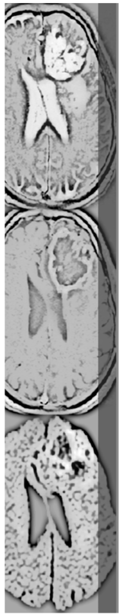


T1, T2, T2*

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

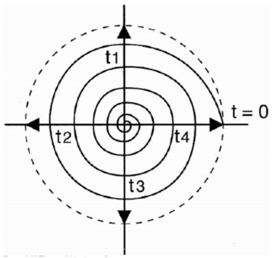


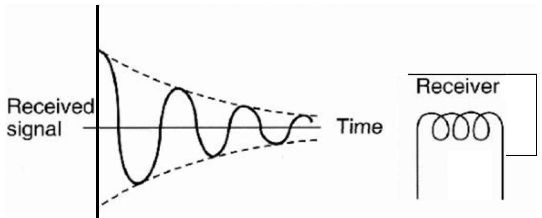




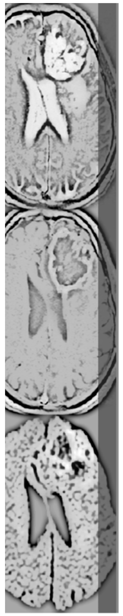
The Received Signal

- A oscillated magnetic field causes movement of electrons, i.e., the current (signal).
- A single RF coil can only detect the component of magnetization along a specific axis on the XY plane.



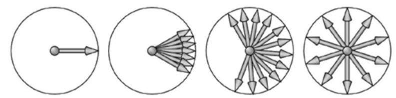


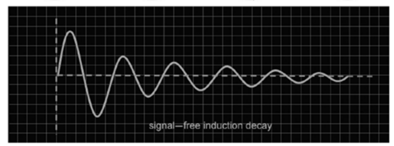
The frequency of the received signal is also ω_0.



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.
- $M_{xy}(t)=M_0e^{-t/T2^*}(\cos\omega_0 t)$



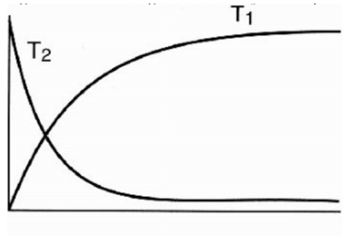


組織鬆弛時間

Tissue Relaxation Time

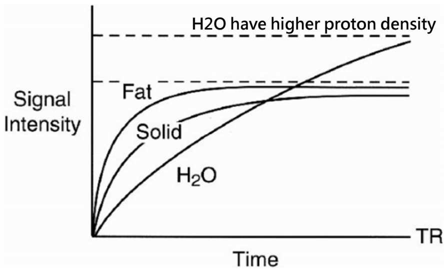
T1 and T2

- T1 is defined as the time when 63% of the longitudinal magnetization has recovered (with 3*T1=95% recovery).
- T2 is defined as the time when 63% of the transverse magnetization has decayed (with 3*T2=95% decay).

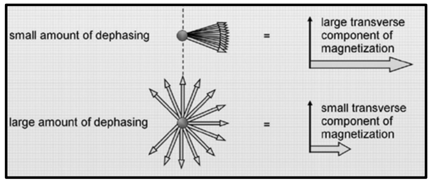


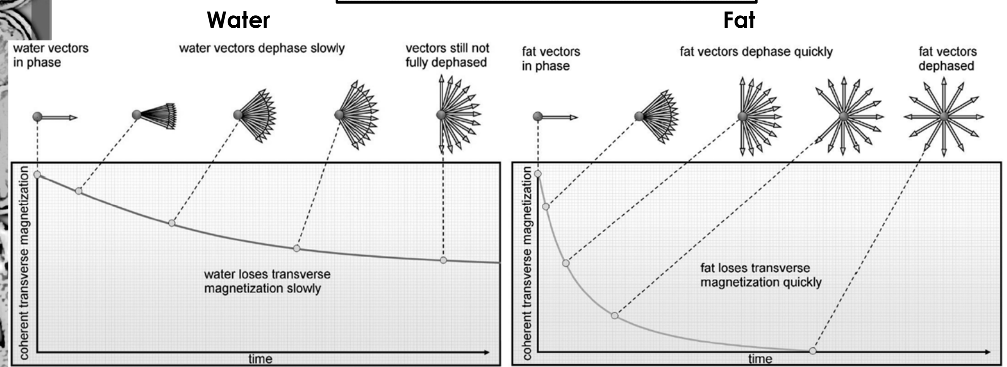
T1 and T2 Characteristics

- T1 (longer T1, slower M_z recovery)
  - **H_2O > Solid tissue > Fat**
- T2 (longer T2, slower M_{xy} decay)
  - **H_2O > Fat > Solid tissue**

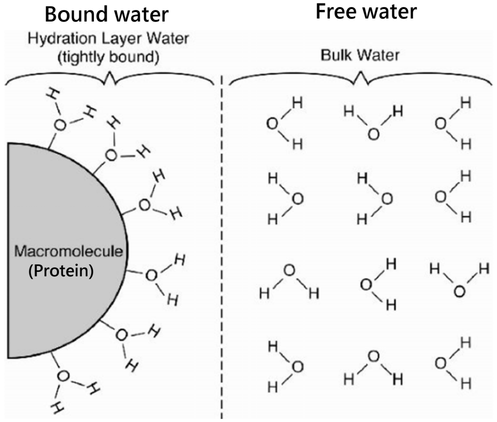


T2 Water vs. Fat





Water



T1: 10~100 ms
T2: 5~10 ms

T1: 2000~3000 ms
T2: 1000~2000 ms

Although the hydration layer water has much shorter T1 than bulk water, it also has shorter T2 (fast signal decay).

T1 and T2 Characteristics: Brain Tissues

- T1 (longer T1, slower M_z recovery)
  - **Cerebrospinal fluid (CSF) > Gray matter (GM) > White matter (WM)**
- T2 (longer T2, slower M_{xy} decay)
  - **CSF > GM > WM**

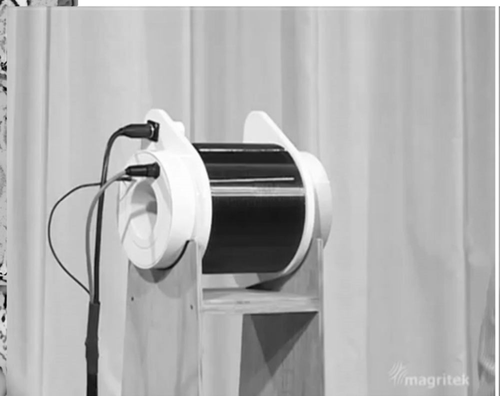
Table 6-1 T1, T2, and Proton Density of Brain Tissues at 1.5 T*

	T1 (msec)	T2 (msec)	N(H)
White matter	510	67	0.61
Gray matter	760	77	0.69
Edema	900	126	0.86
CSF	2650	180	1.00

*Stark and Bradley, p. 44.

Video Demonstration magritek-youtube channel

Video 4 3:23 FID & Larmor frequency

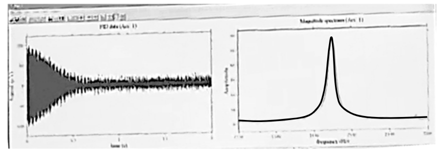


Video 5 2:50/3:43 B0 inhomogeneity → T2*

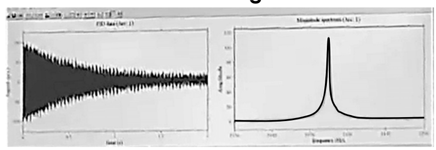
Video Demonstration magritek-youtube channel

Video 5 4:30 shimming → T2

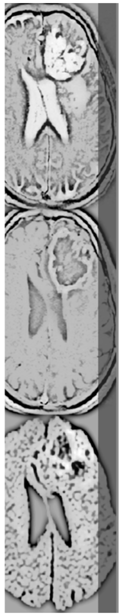
without shimming → T2*



with shimming → T2



time frequency



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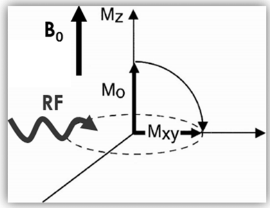

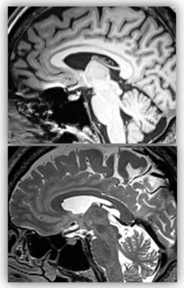

THE END

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