磁振影像原理與臨床研究應用

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課程內容介紹

Introduction of MRI course

課程內容

- **磁振成像原理（前8週）**
  - 射頻脈衝、組織對比、影像重建、脈衝波序、影像假影與安全…等
- **磁振影像技術與分析技術文獻討論**
  - 對比劑增強、功能性影像、擴散張量影像、血管攝影、常用分析方式…等
- **磁振影像於各系統應用**
  - 腦部與頸部、脊椎、骨骼肌肉與關節…等
- **磁振造影掃描與分析實作**
  - 陽明3T磁振造影參觀與掃描、上機實作結構性與功能性影像分析…等

參考書籍

- **基本原理與各系統應用**
  - MRI The Basics 2nd, Hashemi et al, 2004 by LWW
  - Magnetic Resonance Tomography, Reiser et al, 2008 by Springer
- **磁振血管攝影**
  - Magnetic Resonance Angiography: Principles and Applications, Carr et al, 2012 by Springer
  - Magnetic Resonance Angiography: Techniques, Indications and Practical Applications, Schneider et al, 2005 by Springer
- **磁振腦部解剖圖譜**
  - 7.0 Tesla MRI Brain Atlas, Zang-Hee Cho, 2010 by Springer

參考書籍

- **動態對比劑增強磁振影像**
  - Dynamic Contrast-Enhanced Magnetic Resonance Imaging in Oncology, Jackson et al, 2005 by Springer
- **腦部擴散張量磁振影像**
  - Diffusion-Weighted MR Imaging of the Brain, Moritani et al, 2005 by Springer
- **磁振影像脈衝波序**
  - Handbook of MRI Pulse Sequences, Bernstein et al, 2004 by Elsevier
- **其他**
  - MRI of the Upper Extremity, Lower Extremity
  - MRI of the Musculoskeletal System

評分標準

- **出席率（20%）**：但缺、曠課達學期課堂數三分之一以上者，總成績以不及格計算。
- **課堂討論（40%）**：在第9~14週每週課程中，針對修課學生於文獻討論時的參與度與理解程度評分。
- **期末報告（40%）**：在第17~18週，修課學生於課堂上口頭報告磁振影像的相關研究，鼓勵與自身研究相關內容為佳。評分標準為：報告架構10%、內容15%、口調與回答問題15%。

上課教材與錄影

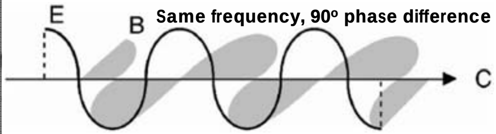
- 提供課後複習或其他未修課同學自修
- http://www.ym.edu.tw/~cflu 點選左欄課程教材連結本課程

磁振基本原理

Basic Principles of Magnetic Resonance
Nuclear magnetic resonance (NMR) ⇔ Magnetic resonance imaging (MRI)

Electromagnetic Waves

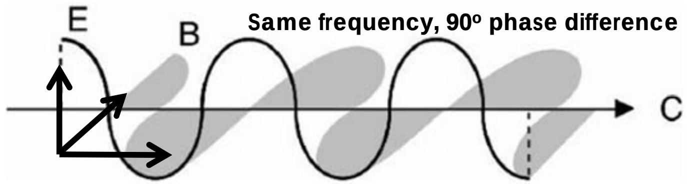
- All travel at the speed of light $c = 3 \times 10^8$ m/sec
- Maxwell's wave theory:
  - an electric field *E*
  - A magnetic field *B*



	Frequency (Hz)	Energy (eV)	Wavelengt
Gamma rays and X-rays	10^{24}	10^{10}	10^{-16}
	10^{23}	10^{9}	10^{-15}
	10^{22}	10^{8}	10^{-14}
	10^{21}	10^{7}	10^{-13}
	10^{20}	10^{6} (1 MeV)	10^{-12} (1 pn
	10^{19}	10^{5}	10^{-11}
	10^{18}	10^{4}	10^{-10}
Ultraviolet	10^{17}	10^{3} (1 keV)	10^{-9} (1 nm)
	10^{16}	10^{2}	10^{-8}
Visible light	10^{15}	10^{1}	10^{-7}
Infrared	10^{14}	10^{0} (1 eV)	10^{-6} (1 μ)
	10^{13}	10^{-1}	10^{-5}
Microwaves	10^{12} (1 GHz)	10^{-2}	10^{-4}
	10^{11}	10^{-3}	10^{-3} (1 mm
	10^{10}	10^{-4}	10^{-2} (1 cm)
	10^{9}	10^{-5}	10^{-1}
MRI	10^{8} (100 MHz)	10^{-6}	10^{0} (1 m)
	10^{7}	10^{-7}	10^{1}

Electromagnetic Waves

- The angular frequency $\omega=2\pi f$, f is linear frequency
- We are interested in the magnetic field rather than the electric field
  - Electric field generates heat



Radio frequency (RF) pulse

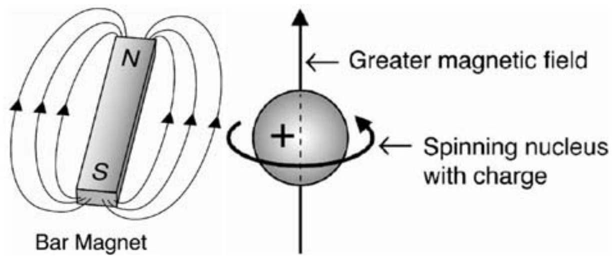
- The electromagnetic pulse used in MRI to get a signal is called an RF pulse.

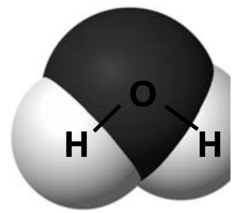
	Frequency (Hz = Hertz)	Energy (eV = electron volts)	Wave Length (m = meters)
X-ray	1.7-3.6 × 10^{18} Hz	30-150 KeV	80-400 pm
Visible light (violet)	7.5 × 10^{14} Hz	3.1 eV	400 nm
Visible light (red)	4.3 × 10^{14} Hz	1.8 eV	700 nm
MRI	3-100 MHz	20-200 meV	6-60 m

AM radio frequency	0.54-1.6 MHz (540-1600 kHz)
TV (Channel 2)	Slightly over 64 MHz
FM radio frequency	88.8-108.8 MHz
RF used in MRI	3-100 MHz

Spins and electromagnetic field

- Felix Bloch (Standard University, Nobel prize in 1946)
  - A spinning charged particle (such as the **hydrogen nucleus**) creates an electromagnetic field.





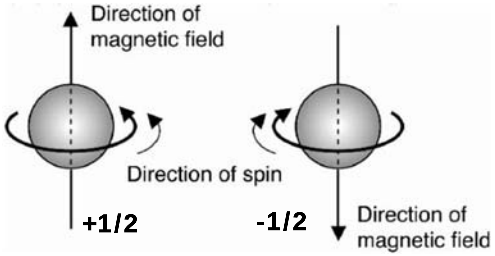
Spin quantum number (S)

- The hydrogen nucleus (a proton) has a spin quantum number

  $S\,(^1H) = 1/2$

- The number of energy states of a nucleus

  # of energy states = 2S+1 (for ^1H = 2)



Magnetic dipole moment (MDM)

- An MDM is found in any nucleus with an odd number of protons, neutrons, or both.
- MDM is the signal source of MRI.

		Spin Quantum Number (S)	Gyromagnetic Ratio (MHz/T)
1P0N	^1H	1/2	42.6
9P1N	^{19}F	1/2	40.0
11P12N	^{23}Na	3/2	11.3
6P7N	^{13}C	1/2	10.7
8P9N	^{17}O	5/2	5.8

Hydrogen Nucleus (^1H)

- We use hydrogen for imaging because of…
  - its abundance (about 60~70% of body is water)
  - its high MR sensitivity (high gyromagnetic ratio, γ = 42.58 MHz/T)

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S ≠ 0, can be MR signal source

Magnetic Susceptibility, χ

- χ is the measure of magnetizability of a substance.
- The χ is defined as the ratio of the induced magnetic field (M) to the applied magnetic field H:

  $$M = \chi H \ \text{ or } \ \chi = M/H.$$

- The *magnetic induction field* or *magnetic flux density*, B, is the net magnetic field effect caused by an external magnetic field H:

  $$B = \mu H = (1+\chi)H = H + M.$$

  μ represents the *magnetic permeability*.

Magnetic Substances

- **Diamagnetic**
  - No unpaired orbital electrons
  - Under an external B_0, a weak M is induced in the opposite direction to B_0 ($\chi<0$ and $\mu<1$).
  - Most tissues in body are diamagnetic.
- **Paramagnetic**
  - Unpaired orbital electrons
  - M is in the same direction as B_0 ($\chi>0$ and $\mu>1$).
  - Become demagnetized once the B_0 has been turn off.
  - Dipole-dipole (proton-proton and proton-electron) interactions cause T1 shortening (bright signal on T1-weighted images)
  - Breakdown products of hemoglobin: deoxyhemoglobin, methemoglobin, hemosiderin (superparamagnetic),
  - gadolinium (Gd) – contrast agent

Magnetic Substances

- **Ferromagnetic**
  - Become permanently magnetized even after the magnetic field has been turned off (χ>>0 and μ>>1).
  - Iron (Fe), cobalt (Co), and nickel (Ni)
  - Aneurysm clips and shrapnel

Bulk Water is Diamagnetic ?!

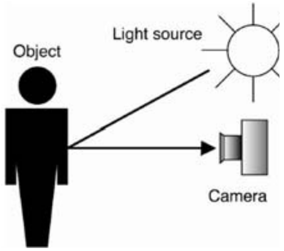
- The individual protons in a water molecule exhibit a magnetic moment (nuclear paramagnetism), but bulk (free) water is diamagnetic.
- NMR depends on nuclei (protons and neutrons), whereas bulk magnetism depends on electrons.

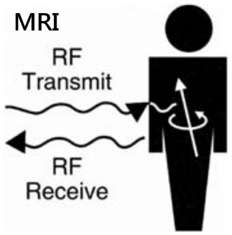
磁振造影原理

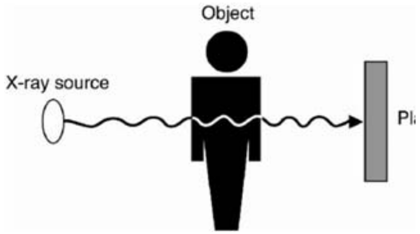
Basic Principles of MRI

Concepts/Types of Imaging

- Reflection
  - Photography, ultrasound
- Penetration
  - X-ray
- Emission
  - PET, SPECT, MRI

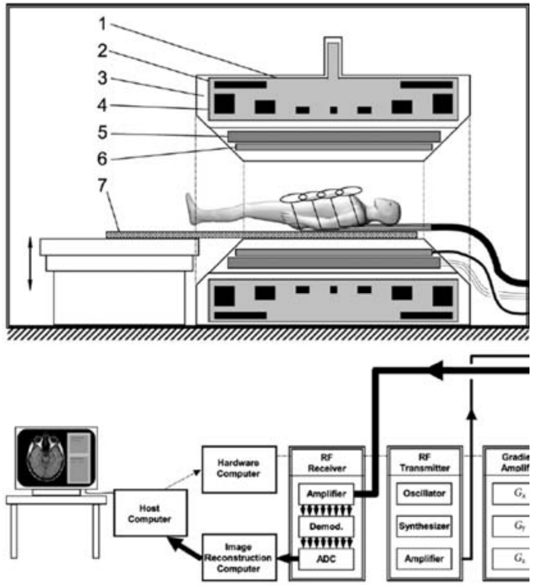






MRI System

- Superconducting magnet (in a cryotank)
- Gradient coil/ RF coil

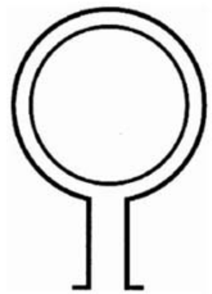


External B_0 Magnetic Field

- On the order of 1 Tesla (1T) = 10000 Gauss (0.5 Gauss for earth's magnetic field)
- Required magnetic uniformity is less than 5 ppm (parts per million), which can be achieved by shimming and shielding.
- Types of Magnets
  - Permanent magnets (for open MRI scanners), always stay on
  - Resistive magnets (for low field MRI), can be turned on/off
  - Superconducting magnets (the most common today)
    - operate near absolute zero temperature (-270^{o}C)
    - generate a high B_0 without generating significant heat
    - require cryogens (liquid helium), very expensive !!

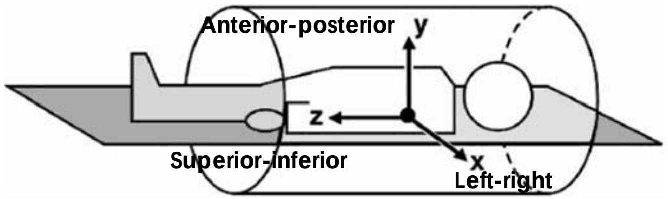
Coils

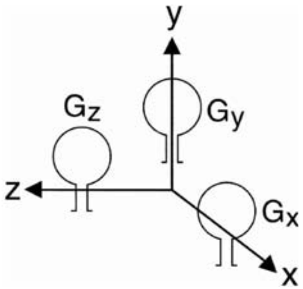
- Gradient coils
  - Shim coil – increase B_0 homogeneities
  - Imaging gradient coil – intentional perturbation for spatial encoding
- Transmit and/or receive RF coils
  - Linear phase or quadrature (receive or transmit)
  - Surface or volume (Helmholtz or solenoid)
  - Single or phased-array



Gradient Coils

- Intentional perturbation (in a linear fashion) in B0 to decipher spatial information from the received signal
  - The slice-select gradient
  - The phase-encoding gradient
  - The frequency-encoding or readout gradient





RF Coils

- A transmitter coil transmits an RF pulse
- A receiver coil receives an RF pulse
- Types of coils
  - Body coils: both transmitters and receivers, a part of magnet
  - Head coils: both transmitters and receivers, a helmet-like device
  - Surface coils: just receivers, imaging joints
- Quadrature-phased array coils
  - Multiple elements of coils, larger FOV and better SNR

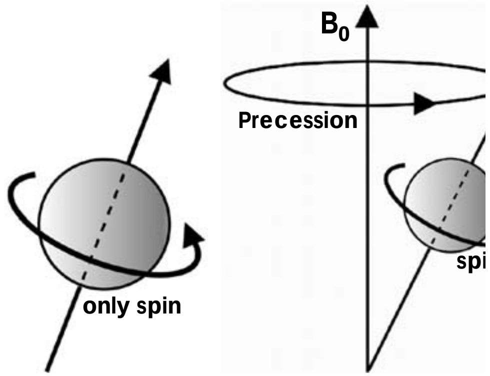
Precession

- With B_0, the proton not only spins about its own axis, but also precesses about the axis of the B_0.
- Each proton spins much faster about its own axis than it rotates around the axis of the B_0.
- Larmor equation (frequency)

  $\omega = \gamma B_0$

  γ is gyromagnetic ratio (MHz/T)

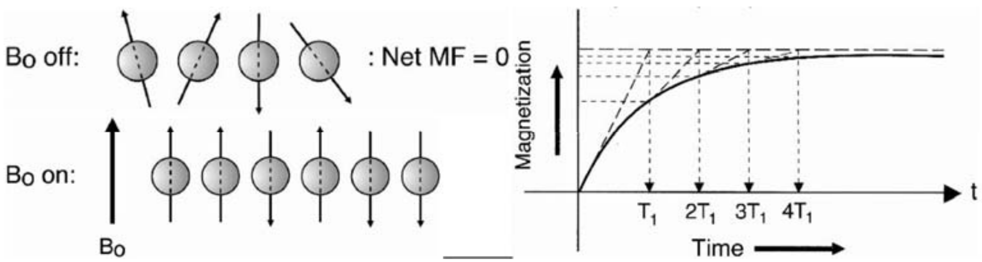
> For B0 from 1.5T → 3T
> ω = 42.6 x 1.5T = 63.9 MHz
> = 42.6 x 3.0T = 127.8 MHz
> The RF range for MRI !!



Magnetic Dipole Moment

- With B_0, protons line up and approximately half point north and half point south
- About one in a million more protons point in the direction of B_0.
- Over time, more spins line up, creating stronger net magnetization.

Magritek videos on youtube (6:33)!!

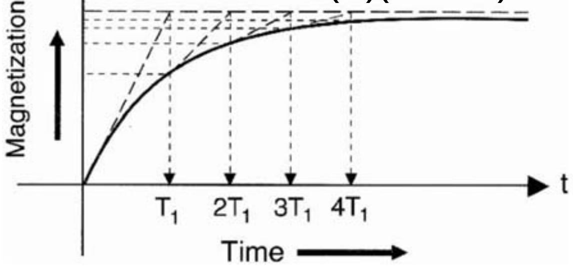


T1 Relaxation

- T1 relaxation differs from
  - The kind of tissue we are imaging
  - The strength of external magnetic field
- $\downarrow B_0 \rightarrow \downarrow T_1$

N(H) is the proton (spin) density

$$M \propto N(H)(1-e^{-t/T_1})$$

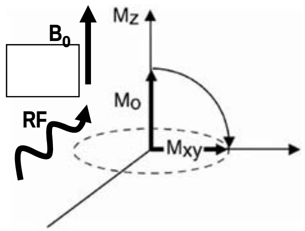


Longer T_1 at Higher Field B_0

- 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.

Magritek videos on youtube (4:12)!!

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
  - T_1 (recovery rate of M along B_0),
  - T_2 (decay rate of transverse M),
  - T2* (consider both T2 and B_0 inhomogeneities)
- The most effective resonance is produced when $\omega_0 = \omega_2$

THE END

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