



磁振影像學MRI 射頻脈衝與設備

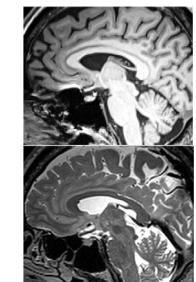
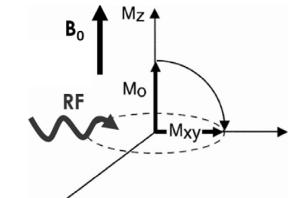
盧家鋒 教授

國立陽明交通大學
生物醫學影像暨放射科學系
alvin4016@nycu.edu.tw



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, electromotive force)
- Imaging (Pulse sequencing)
 - Image Contrast: Relaxation time
 - Spatial localization: Spatial Encoding



<http://cflu.lab.nycu.edu.tw>. Textbook: MRI The Basics, Hashemi et al.

2025/9/8

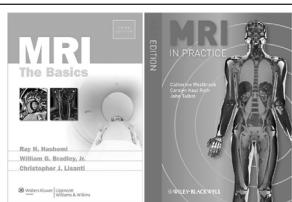
2



本週課程內容 <http://cflu.lab.nycu.edu.tw>

- 射頻脈衝
- 射頻線圈

- MRI The Basics (3rd edition)
 - Chapter 3: Radio Frequency Pulse
- MRI in Practice, (4th edition)
 - Chapter 9: Instrumentation and equipment



<http://cflu.lab.nycu.edu.tw>. Textbook: MRI The Basics, Hashemi et al.

2025/9/8

3

射頻脈衝

Radio Frequency (RF) Pulse

<http://cflu.lab.nycu.edu.tw>. Textbook: MRI The Basics, Hashemi et al.

2025/9/8

4



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 oscillate or precess about z axis) to generate a readable signal.

<http://cflu.lab.nycu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

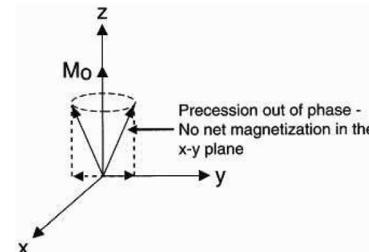
2025/9/8

5

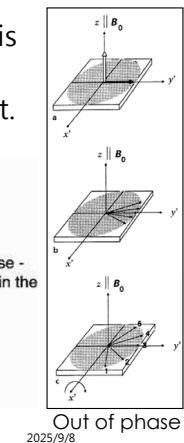


Magnetization Vector M_0

- The individual spins are precessing along z-axis and "out of phase" with each other.
- The x and y components cancel each other out.



<http://cflu.lab.nycu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

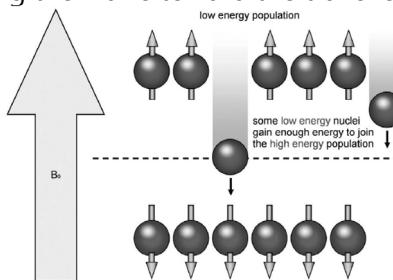


2025/9/8 6



Radio Frequency Pulse

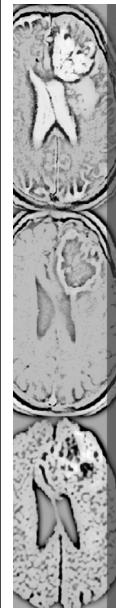
- Create phase coherence
- Flip some of the spins from a low-energy state to a high-energy state
- Transfer the NMV along the Z axis toward the transverse X-Y plane.



<http://cflu.lab.nycu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

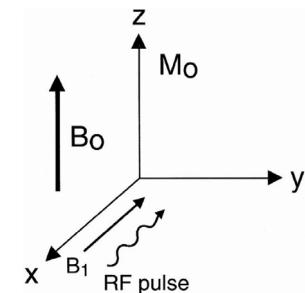
2025/9/8

7



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 $B_1 \ll B_0$
then $\omega_1 \ll \omega_0$

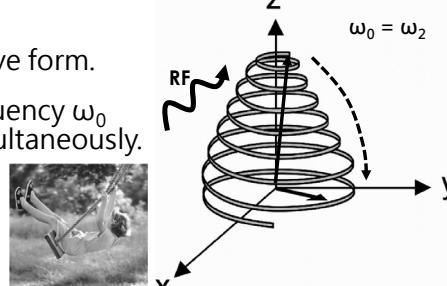


<http://cflu.lab.nycu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

2025/9/8 8

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. \rightarrow spiral motion (nutation)



<http://cflu.lab.nycu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

2025/9/8

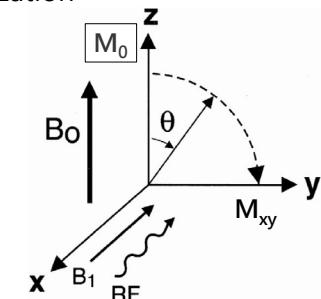
9

Resonance $\omega_0 = \omega_2$

- The B_1 field also causes a spiral downward motion of the protons \rightarrow flipping
- By introducing the B_1 , the spinning protons will then be in phase \rightarrow creates transverse magnetization
- 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 ratio of protons



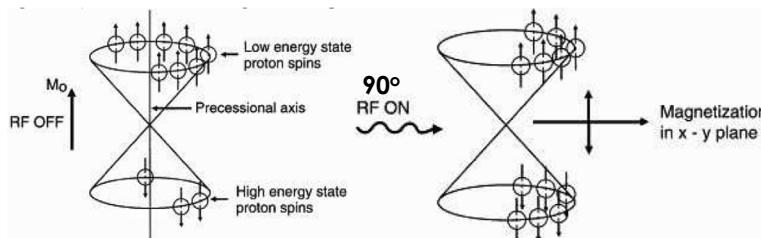
<http://cflu.lab.nycu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

2025/9/8

10

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
- $\rightarrow M_{xy} = M_0$
- $\tau_{\pi/2} = (\pi/2)/(\gamma B_1)$



<http://cflu.lab.nycu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

2025/9/8

11

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



<http://cflu.lab.nycu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

2025/9/8

12



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.

<http://cflu.lab.nycu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

2025/9/8

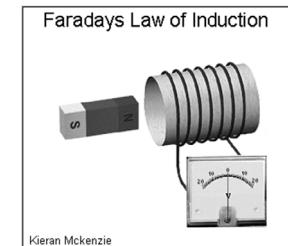
13



Receiver coils

- Faraday's law of induction
- $\frac{dB}{dt} = \frac{dv}{dt}$

where, dB is the changing magnetic field (oscillating magnetic field)
 dt is the changing time
 dv is the changing voltage (MR signal)



2025/9/8

14



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 .

<http://cflu.lab.nycu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

2025/9/8

15

射頻線圈

RF Coils

<http://cflu.lab.nycu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

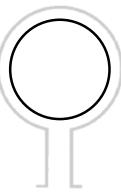
2025/9/8

16

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

A loop of wire



<http://cflu.lab.nycu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.



Solenoid coil

Helmholtz coil

2025/9/8

17

RF Coils

- A transmitter (Tx) coil transmits an RF pulse
- A receiver (Rx) coil receives an RF pulse
- A transceiver (T/R) coil can transmit/receive RF pulses

- Types of coils
 - Body coils: both transmitters and receivers, a part of magnet. **Takes most RF transmit missions.**
 - Head coils: receivers or transceivers, a helmet-like device
 - Surface coils: just receivers, imaging joints/body

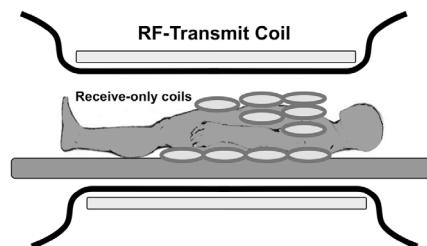
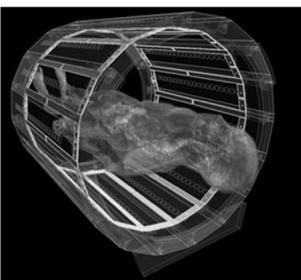


2025/9/8

18

Primary RF transceiver

- The closest component to the magnet bore in a closed-bore MRI.
- Known as the body coil.
- Can be used with local receiver.



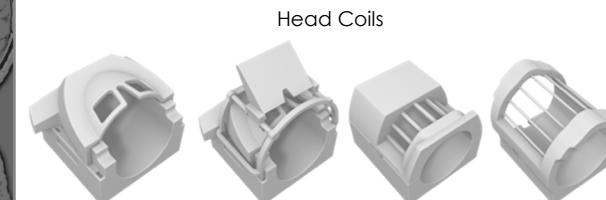
<http://cflu.lab.nycu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

2025/9/8

19

Head Coils

- Saddle shape, or birdcage type configuration.
- Can be multichannel coil (which are generally receivers only)



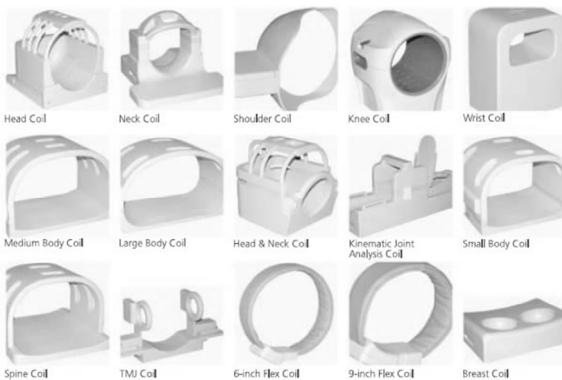
<http://cflu.lab.nycu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.



2025/9/8

20

Coil Shapes



medical.neusoft.com
http://cflu.lab.nycu.edu.tw, Textbook: MRI The Basics, Hashemi et al.

2025/9/8

21

Volume coils

- Generally used to accommodate a "volume" of tissue
 - Body coil (saddle configuration)
 - Birdcage coil (head coils)
 - Solenoid coils (tube shaped)



Higher magnetic homogeneity

http://cflu.lab.nycu.edu.tw, Textbook: MRI The Basics, Hashemi et al.

2025/9/8

22

Surface (or local) coils

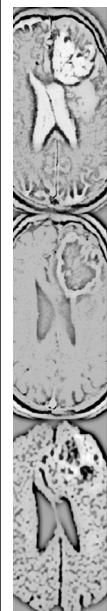
- Generally placed on the surface
 - linear coils (simple surface coil or local coil configuration)
 - quadrature coils (with coils (or electronics) configured perpendicular)
 - Helmholtz pair (two coils combined with B1 fields in the same direction)
 - Maxwell pair (two coils combined with B1 fields in the opposite direction)
 - phased array (multiple coils elements and multiple receivers)
 - Parallel array (multiple elements, multiple receivers for parallel imaging).

Higher signal-to-noise ratio (SNR)

http://cflu.lab.nycu.edu.tw, Textbook: MRI The Basics, Hashemi et al.

2025/9/8

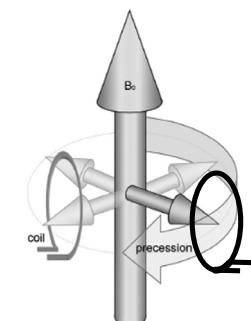
23



Body receiver (Flex coil)



Birdcage coil



http://cflu.lab.nycu.edu.tw, Textbook: MRI The Basics, Hashemi et al.

2025/9/8

24

Linear vs. Quadrature Polarized

- Linear polarized (LP)
- Quadrature (Circular) polarized (CP)
 - Has higher SNR!



Array Coils - Phased and Parallel

- Array coil systems are collections of small surface coils.
- Small-diameter surface coils near the patient have high sensitivity but limited anatomical coverage.
- By combining multiple small coils into large arrays → high signal-to-noise and large fields of view.

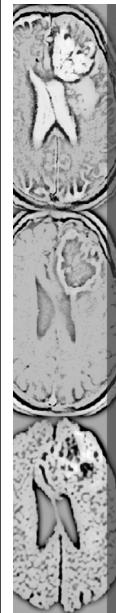


<http://cflu.lab.nycu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

<http://mri-q.com/array-coils.html>

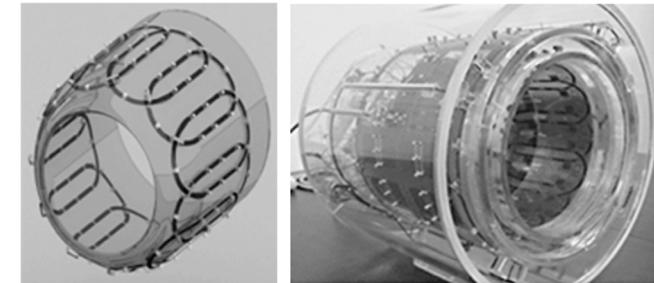
2025/9/8

25



Quadrature-phased array coils

- Multiple elements of coils, larger FOV and better SNR



http://nri.gachon.ac.kr/b_07_e.html

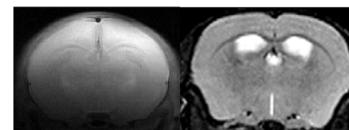
2025/9/8

26



Advantages of coil types

Can increase/achieve...



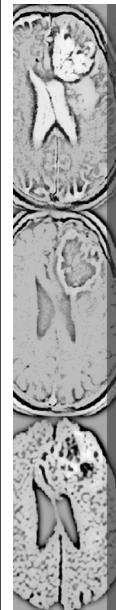
	Array coils	Volume coils
SNR	higher	higher
Magnetic homogeneity	--	higher
FOV	larger	--

- Generally speaking, the smaller the coil the better the SNR and the more coils used the better the SNR.
- The smaller the coil the smaller chance to produce aliasing artifacts.

<http://cflu.lab.nycu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

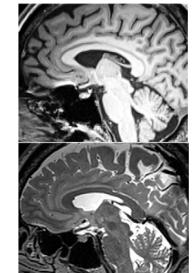
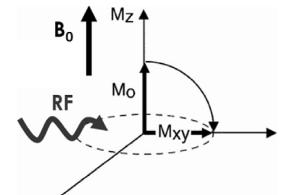
2025/9/8

27



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, electromotive force)
- Imaging (Pulse sequencing)
 - Image Contrast: Relaxation time
 - Spatial localization: Spatial Encoding



<http://cflu.lab.nycu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

2025/9/8

28

THE END

alvin4016@nycu.edu.tw