



磁振影像學MRI

磁振安全

盧家鋒 教授

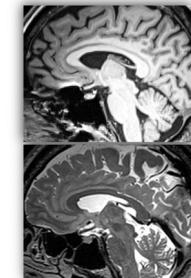
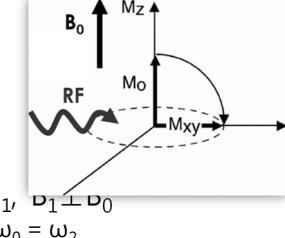
國立陽明交通大學
生物醫學影像暨放射科學系
alvin4016@nycu.edu.tw



Procedure of MRI

- Alignment (magnetization) B_0
- Precession $\omega_0 = \gamma B_0$
- Resonance (given B_1 by RF with ω_2) $\omega_1 = \gamma B_1$, $\omega_1 \perp \omega_0$
 - The most effective resonance is produced when $\omega_0 = \omega_2$
- MR signal (EMF, relaxation time)
- Imaging (Pulse sequencing: SE, GRE, EPI)
 - Tissue Contrast: Image weighting
 - Spatial localization: Slice selection & Spatial Encoding
 - Data space/K space
- Tissue Suppression Techniques
- Artifacts and Safety Issues in MRI

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



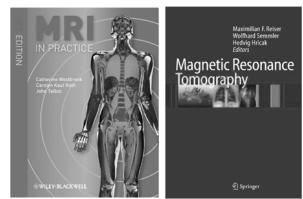
2025/12/7

2

本週課程內容 <http://cflu.lab.nycu.edu.tw>

- 磁振安全

- MRI in Practice, (4th edition)
 - Chapter 10: MRI safety
- Magnetic Resonance Tomography
 - Chapter 2.9: Risks and Safety Issues Related to MR Examinations



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

2025/12/7

3

磁振安全

MRI safety issues

To date, there have been no known long-term adverse biological effects associated with extended exposure to the magnetic fields used in MR imaging.

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

2025/12/7

4

Safety Issues

- **A high static magnetic field (B_0)**
 - Generating a macroscopic nuclear magnetization
- **Rapidly alternating magnetic gradient fields (Gx,Gy,Gz)**
 - Spatial encoding of the MR signal
- **RF electromagnetic fields (α)**
 - Excitation and preparation of the spin system

Ex: burns, device failures, contrast reactions and even death.

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

2025/12/7

5



Safety Regulations

- In 2001, a tragedy occurred when a 6-year-old child was killed by a ferromagnetic oxygen tank while in the MRI scanner.
 - **White Paper on MRI Safety** by American College of Radiology (ACR) in 2002. <https://www.ajronline.org/doi/pdf/10.2214/ajr.178.6.1781335>
- MRI Safety website by Dr. Frank Shellock
 - <http://www.mrisafety.com>
- Institute for Magnetic Resonance, Safety, and Education and Research
 - <http://www.imrser.org>

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

2025/12/7

6

Safety Regulations

- International Commission on Non-Ionizing Radiation Protection (ICNIRP)
 - <http://www.icnirp.de/index.html>
- International Electrotechnical Commission (IEC)
 - <http://www.iec.ch/index.htm>

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

2025/12/7

7



Operating Modes

- **Normal operating mode**
 - Routine MR examinations
- **Controlled operating mode (first-level controlled mode)**
 - Specific MR examinations
 - Discomfort or physiological stress to some patients may occur
 - Medical supervision for patients
- **Experimental operating mode (second-level controlled mode)**
 - Potential risks for patients and volunteers
 - Ethical approval and medical supervision

Operating mode	Normal	Controlled	Experimental
$B_0 \leq 2 \text{ T}$	$2 \text{ T} < B_0 \leq 4 \text{ T}$	$B_0 > 4 \text{ T}$	

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

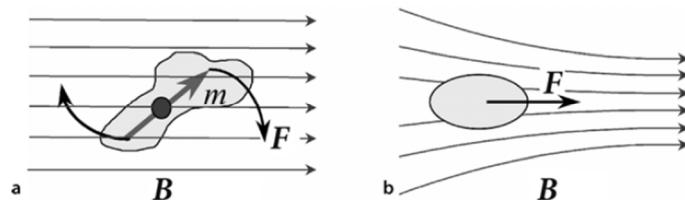
2025/12/7

8



Static Magnetic Fields Projectiles, devices and implants

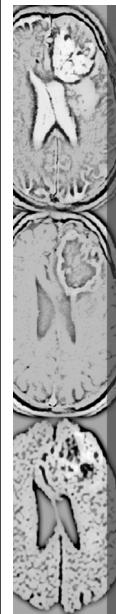
- Magneto-mechanical interactions
 - A uniform magnetic field: a magnetic moment experience a **mechanical torque** that align their magnetic moment parallel (or antiparallel) to the B .
 - A non-uniform magnetic field: paramagnetic and ferromagnetic materials become **dangerous projectiles**.



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

2025/12/7

9



Static Magnetic Fields



<http://www.impactednurse.com/?p=2927>



Quenching button (淬息)

How dangerous are magnetic items near an MRI magnet: <http://youtu.be/6BBx8BwLhgq>

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

2025/12/7

10



Quench

- Liquid helium is generally used as the cryogen with very low temperatures of 4 K (-269°C).
- In a scanner with a cryostat volume of 1500 liters, a spontaneous helium boil-off would liberate over 1,000,000 liters of gas.
- All systems should have **helium-venting equipment**, which removes the helium to the outside environment in the event of a quench.
- If this fails, helium will vent into the room and replace the oxygen. → **oxygen monitor!**

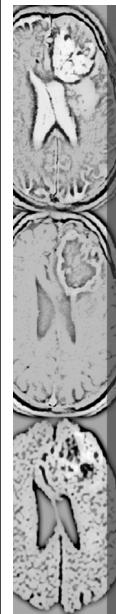


https://youtu.be/Q_sz106ijYg



2025/12/7

11



Quench

- If there is a quench pipe failure, an inwardly opening magnet room door may become sealed.
- Possible side effects from a sudden drop in oxygen level, reduced room temperature and dramatic increase in air pressure:
 - Asphyxia
 - Hypothermia
 - Ruptured eardrums



2025/12/7

12



Mumbai MRI death: Nair hospital radiologist arrested in connection to Rajesh Maru's death, released on bail

India PTI Feb 02, 2018

Comment 0 Share 0 Tweet

Mumbai: A radiologist of the Nair hospital was arrested in connection with the death of a man in a freak Magnetic Resonance Imaging (MRI) machine accident at the facility on 27 January, police said on Friday.



File image of Rajesh Maru. News18

Agripada police said Dr Siddhant Shah was arrested on Thursday after the family of the 32-year-old victim, Rajesh Maru, told them that the radiologist was also present when the accident occurred.

Shah was charged with dereliction of duty, police said, adding he was released on bail. Shah's was the fourth arrest in the case.

Earlier, police had arrested three hospital staffers — Dr Saurabh Lanjekar, ward boy Vitthal Chavan and attendant Sunita Surve — for negligence causing death.

Maru had accompanied a relative to the hospital for an MRI examination. When he entered the room carrying a liquid oxygen cylinder, the strong magnetic field got activated, pulling him violently towards the machine. The oxygen cylinder burst on impact and he died after inhaling copious quantities of the gas.

Metal objects are not allowed inside rooms having MRI machines.

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

2025/12/7

13

MRI Safety Issue

恐怖意外！核磁共振儀產生巨大磁力吸入氧氣瓶 砸中老翁胸口慘死

更新時間：2021/10/17 22:49

南韓傳出一起恐怖的醫療事故，一名老翁在醫院進行核磁共振攝影(MRI)時，疑因攝影室內一個金屬氣瓶沒固定好，被運轉中的核磁共振儀產生的強大磁力吸引，重砸被固定在機器上的老翁胸口，當場慘死。

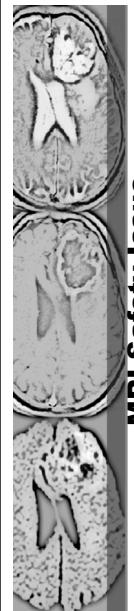
警方表示，該攝影室內並無設置監視器，缺乏現場影片佐證，現場工作人員表示，該氧氣鋼瓶被放置在距離核磁共振儀「幾步外」，機器開始運轉產生巨大磁力，鋼瓶就被吸入機器內，不幸砸中老翁胸口致命。

目前警方仍在調查現場供詞的真實性，同時也在了解為何金屬氣瓶會被放置在攝影室內，盼能完整釐清責任。（於慶中／綜合外電報導）

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

2025/12/7

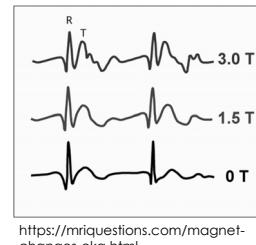
14



MRI Safety Issue

Static Magnetic Fields

- Magneto-hydromechanical (MHD) interactions
 - Static magnetic fields also exert **Lorentz forces** on moving ionic charge carriers giving rise to induced electric fields and currents.
 - At very high B , it can reduce the flow velocity and the flow profile of blood in large vessels.
 - **EKG T wave enhancement.**
 - Reduce the volume flow rate of blood in the human aorta by a maximum of 1.3, 4.9, and 10.4% at 5, 10, 15T, respectively.
- Magnetic effects on chemical reactions



<https://mr/questions.com/magnet-changes-ekg.html>

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

2025/12/7

15

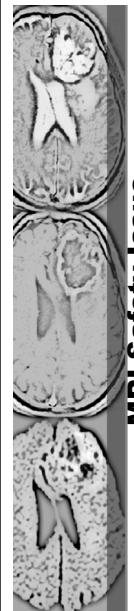
Static Magnetic Fields

- No magnetic effects on implantation, prenatal, and postnatal development were reported between 1 and 9.4T.
- Humans exposed to a maximum flux density of 8T did not yield clinically relevant changes.
 - Heart rate
 - Respiratory rate
 - Diastolic blood pressures
 - Finger pulse oxygenation levels
 - Core body temperature
 - Systolic blood pressure ↓

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

2025/12/7

16



MRI Safety Issue

Static Magnetic Fields

- Epidemiological studies are currently insufficient to draw any conclusions about potential health effects.
- From the evaluation of 1421 pregnancies of women working at clinical 1T MR facilities, no significant increased risks for...
 - Spontaneous abortions
 - Delivery before 39 weeks
 - Reduced birth weight
 - Male gender of the offspring

- More sensitive to magnetic fields in the first trimester of pregnancy
- Avoid the injection of Gd contrast agent
- $B_0 < 4T$ for fetus

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

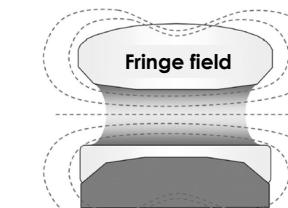
2025/12/7

17



Fringe Fields

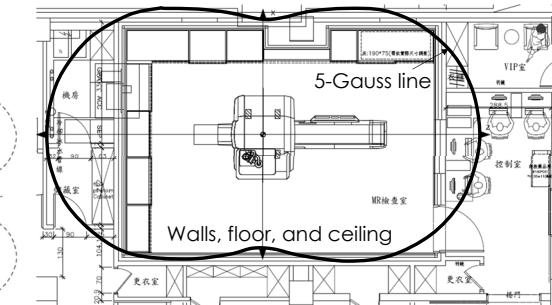
- **Passive (magnetic) shielding:** scanner room with galvanized steel plates
- **Active shielding:** additional solenoid electromagnets located around the outside of the main magnet coil.
- **5 Gauss line – safety zone** around 4 m from the center of 3T MRI scanner



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

2025/12/7

18



Terminology of MRI and Implants/Devices

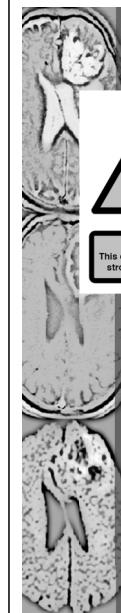
- Formerly,...
 - MR compatible
 - MR incompatible
- American Society for Testing and Materials (ASTM) International, 2005
 - **MR safe:** An item that poses no known hazards in all MRI environments.
 - **MR unsafe:** An item that is known to pose hazards in all MRI environments.
 - **MR conditional:** An item that has been demonstrated to pose no known hazards in a specified MRI environment with specified conditions of use.



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

2025/12/7

19

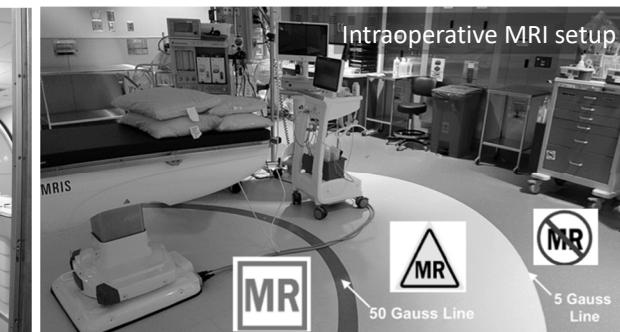


Warning
This equipment generates
strong magnetic fields

No Entry
for those wearing active
implanted medical devices



5 Gauss line



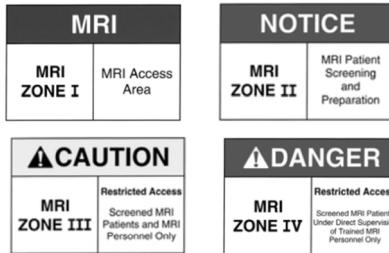
<http://cflu.lab.nycu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

2025/12/7

20

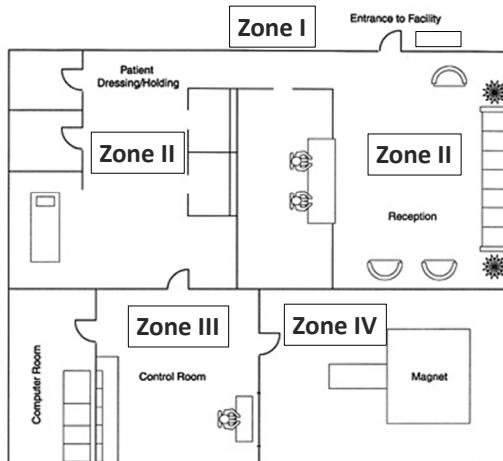


ACR Safety Zones



<https://mriquestions.com/acr-safety-zones.html>

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



2025/12/7

21



Time-Varying Magnetic Gradient Fields

- TVMF effects include
 - peripheral nerve stimulation
 - magneto-phosphenes
 - acoustic noise

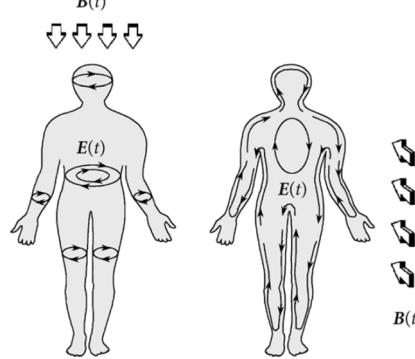
<http://cflu.lab.nycu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

2025/12/7 22



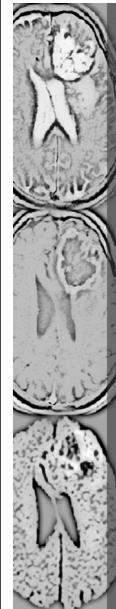
Time-Varying Magnetic Gradient Fields

- Faraday's law: a time-varying magnetic field (TVMF) $B(t)$ induces an electric field $E(t)$
- $E(t) = -\frac{r}{2} \cdot \frac{dB_z(t)}{dt}$
- r : the radius of loop
- $j(t) = \sigma E(t)$
- $j(t)$: Eddy currents
- σ : the electric conductivity



2025/12/7

23



Time-Varying Magnetic Gradient Fields

- The induced currents can influence cellular properties involve interactions at the level of the cell membrane.
- The primary concern is cardiac fibrillation (life threaten)
- The practical concern is the peripheral nerve stimulation (mild cutaneous sensations and involuntary muscle contractions)
- The FDA limit for gradient fields used to be 6 T/s for all gradients; limit axial gradient fields to 20 mT/m/s and gradient rise time to 120 μ s.

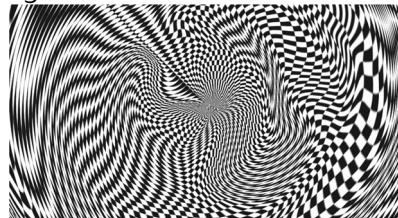
<http://cflu.lab.nycu.edu.tw>, Textbook: MRI The Basics, Hashemi et al.

2025/12/7

24

Magneto-phosphenes

- On occasion, patients will note unusual visual disturbances during MR scanning.
- Visual effects may occur when retinal phosphates are stimulated by induction from TVMF.
- stars in one's eyes or presents as light flashes



2025/12/7

25

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

Acoustic Noise

- As current is passed through the gradient coils during image acquisition, a significant amount of acoustic noise is created.
- ACR recommends:
 - all patients, volunteers, family members, and healthcare workers (essentially anyone who intends to enter the scan room during image acquisition or during scanning) should be offered and encouraged to use hearing protection prior to undergoing any imaging in the MR scanners.



ear plugs



MR-compatible head phones

2025/12/7

26

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

Radiofrequency Electromagnetic Fields

- Main bioeffects of RF irradiation:
 - Heating of tissues
 - Thermal injuries (burn hazards)

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

2025/12/7

27

Radiofrequency Electromagnetic Fields

- Specific absorption rate (SAR, in W/kg)
$$SAR \propto (\sigma \cdot A^2 \cdot B_0^2 \cdot \alpha^2 \cdot \frac{tp}{TR}) / 2\rho$$
 - σ : electrical conductivity of tissue (metal objects are highly conductive)
 - A: body cross-sectional area (body size)
 - B_0 : Strength of magnetic field
 - α : flip angle of RF pulse
 - tp/TR: The ratio of the pulse duration tp and the TR of the sequence, the duty cycle
 - ρ : body mass.
- Patient's weight must be correctly input to ensure the SAR does not exceed the permitted levels.

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

2025/12/7

28



Radiofrequency Electromagnetic Fields

- In case of a continuous RF exposure, the temperature rise even in poorly perfused tissues is less than 0.5°C for each W/kg of power dissipated.
- Thermoregulatory adjustments:
 - Reduced metabolic heat production
 - Vasodilatation
 - Increased heart rate
- Heat loss mechanisms
 - Sweat
 - Dynamic range of blood flow rates

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

2025/12/7

29



Radiofrequency Electromagnetic Fields

- Exposure of resting humans for 20-30 min to RF fields producing a whole-body SAR of up to 4 W/kg results in a body temperature increase between 0.1 and 0.6°C .

Operating mode	Rise of body core temperature ($^{\circ}\text{C}$)	Spatially localized temperature limits		
		Head ($^{\circ}\text{C}$) (or 3.2W/kg)	Trunk ($^{\circ}\text{C}$) (or 8W/kg)	Extremities ($^{\circ}\text{C}$) (or 12W/kg)
Normal	0.5 (or 2W/kg)	38	39	40
Controlled	1 (or 4W/kg)	38	39	40
Experimental	> 1 (or >4W/kg)	> 38	> 39	> 40

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

2025/12/7

30

Hospitals warn patients: Your Lululemon yoga pants could burn you during MRIs

Published: May 12, 2018 9:24 a.m. ET



One 11-year-old girl took an MRI wearing an athleisure top and ended up with second-degree burns

Aa 天線效應
(Antenna effect)

Many clothing companies, like, lululemon  athletica, are now using metallic fibers in exercise, spandex, and stretch clothing. These fibers can burn you if worn in the MRI scanner. If you have on clothing, even undergarments, that could potentially have these fibers, please notify the technologist. We will provide you with clothing to wear. We care about your safety!



Radiofrequency Electromagnetic Fields

- Prevent the focal skin-to-skin contacts



Current-induced third-degree burns

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

2025/12/7

32



Safety Tips

If you are in any doubt about their safety, do not send them into the scan room.

- Carefully screen the patient and anyone else accompanying the patient into the scan room.
 - surgical histories and procedures
 - metal injuries
 - Pacemakers
 - contraindicated implants
- Remove all following things, and wear an examination gown
 - credit cards, loose metal items, keys, jewelry, body piercing (any body part can be pierced).
 - bras and belts (even non-ferrous and outside the imaging field)
- Tattoos can heat up during image acquisition. A cool wet cloth placed over the tattoo acts as a good heat dissipater.
- Let patients use the earplugs correctly!

THE END

alvin4016@nycu.edu.tw