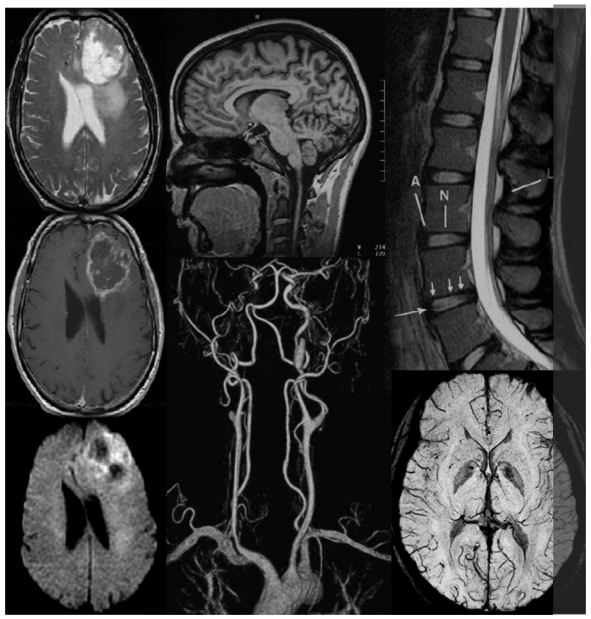
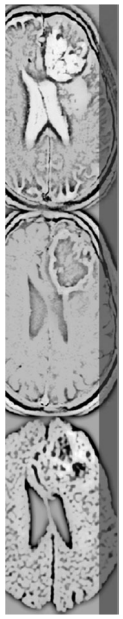


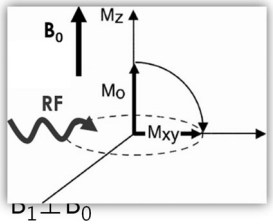
磁振影像學MRI
磁振假影與磁振安全

盧家鋒 副教授

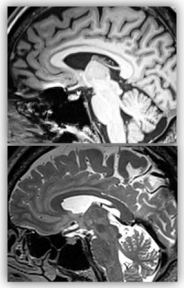
國立陽明交通大學
生物醫學影像暨放射科學系
alvin4016@nycu.edu.tw

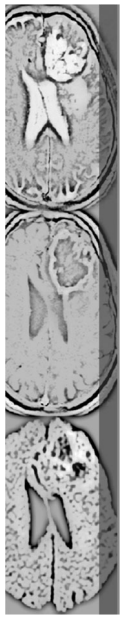


Procedure of MRI



- ☑ 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, 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

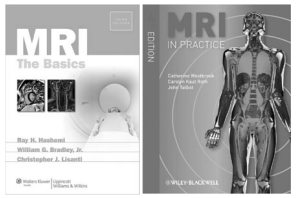




本週課程內容 http://cflu.lab.nycu.edu.tw

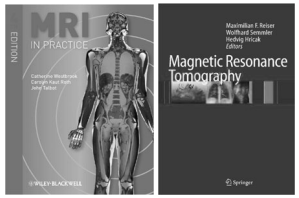
磁振假影

- **MRI The Basics (3rd edition)**
  - Chapter 18: Artifacts in MRI
- **MRI in Practice, (4th edition)**
  - Chapter 7: Artefacts and their compensation



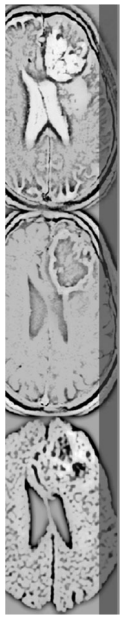
磁振安全

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



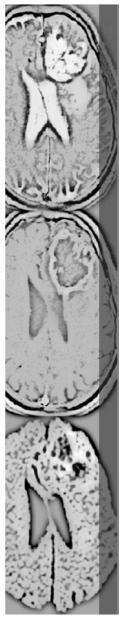
磁振假影

Artifacts in MRI



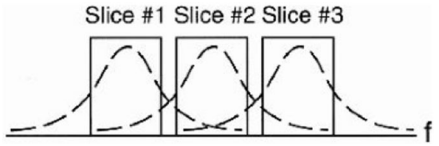
Hardware-related Artifacts

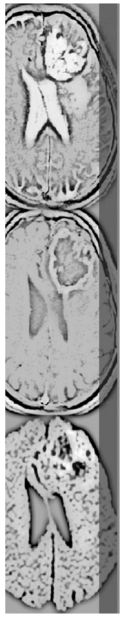
- **Radio frequency (RF)-related artifact**
  - Cross-talk
  - Zipper artifacts
- **External magnetic field artifacts**
  - Magnetic inhomogeneity
- **Gradient-related artifacts**
  - Eddy currents
  - Nonlinearity
  - Geometric distortion



RF-related artifacts: Cross talk

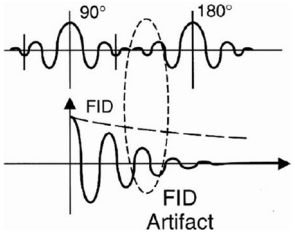
- An imperfect rectangle of the FT of the RF pulse
- Decrease TR due to saturation of protons by the RF for adjacent slices.
- T1 weighting ↑ and SNR ↓
- Remedy: interleaving, increase gap, rectangular wave

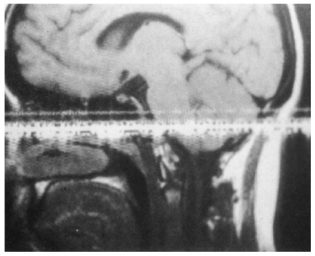




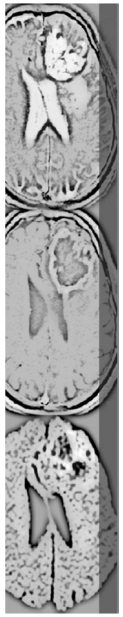
RF-related artifacts: Zipper artifacts

- Along the phase encoding axis at zero frequency
  - Cause 1, RF feed-through: excitation RF pulse → receiver coil
- Along the frequency-encoding axis without phase encoded
  - Cause 2, Stimulated echo: imperfect RF pulses of adjacent slices, imperfect 90°-180°-180° pulses
  - Cause 3, FID artifact: the overlapping of 180° RF pulse with the FID



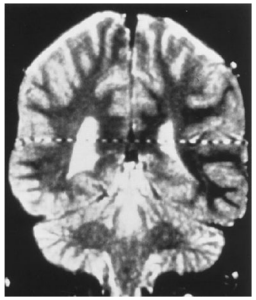


Central artifacts



RF-related artifacts: Zipper artifacts

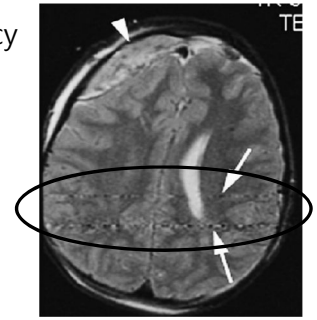
- Remedy to FID artifact:
  - Increase TE (increase the separation between FID and RF pulse)
  - Increase slice thickness (a wide RF BW narrows RF signal in the time domain)
- Remedy to stimulated echo:
  - Use spoiler gradients
  - Adjust the transmitter



Central artifacts

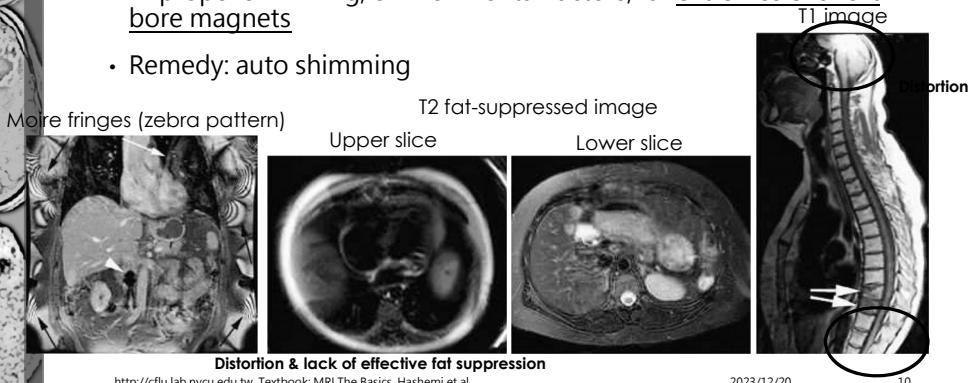
RF-related artifacts: Zipper artifacts

- Unwanted external RF noise (TV, radio station, electronic monitoring equipment)
- Occurs at the specific frequency
- Remedy: improve RF building, shut the door of MR room



External magnetic field artifacts

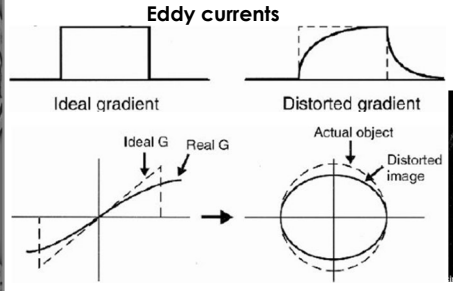
- Improper shimming, environmental factors, far <u>extremes of short bore magnets</u>
- Remedy: auto shimming



Distortion & lack of effective fat suppression

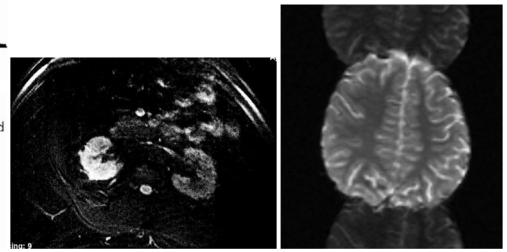
Gradient-related artifacts

- Eddy currents are generated when the gradients are rapidly switched on and off, resulting in a distortion in the gradient profile.



nonlinearities

Nyquist N/2 ghost artifact on EPI images



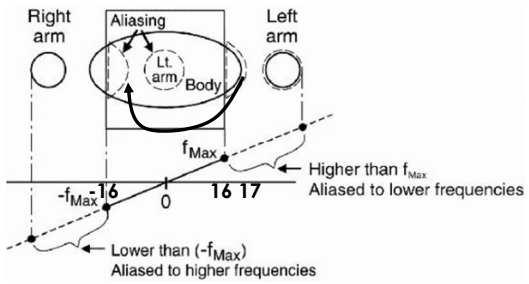
Geometry distortion

Software-related Artifacts

- Image processing artifact
  - Aliasing
  - Chemical shift
  - Truncation
  - Partial volume

Image processing Artifacts: aliasing

- Any frequency higher than the maximum frequency allowed by the gradient cannot be detected correctly.
- f(perceived)= f(true)-2f(max)



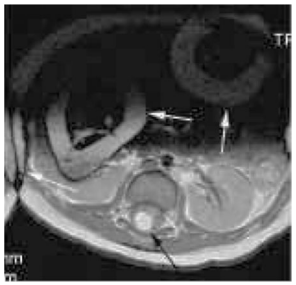
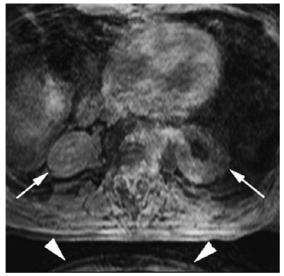


Image processing Artifacts: aliasing

- 2D imaging: along frequency-encoding or phase-encoding directions
- 3D imaging: in all three directions

Kidneys in lungs!

3D axial imaging



3D coronal imaging

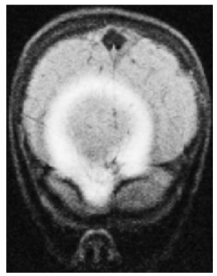


Image processing Artifacts: aliasing

- Remedy
  - Increase FOV (may reduce spatial resolution)
  - Use surface coils that only covers the area within FOV.
  - Frequency or phase oversampling ("No Phase Wrap")
  - Use saturation pulses to saturate the signals outside the FOV.

Image processing Artifacts: chemical shift

- The protons from different molecules precess at slightly different frequencies.
- The protons in H_2O precess slightly faster than those in fat (about 3.4 ppm).

- $\omega_0=\gamma B_0=(42.6\ MHz/T)(1.5T)=64\ MHz$
- $64\ MHz \times 3.4\ ppm = (64 \times 10^6\ Hz)(3.4 \times 10^{-6}) \approx 220\ Hz$
- $B_0 \uparrow$,chemical shift $\uparrow$

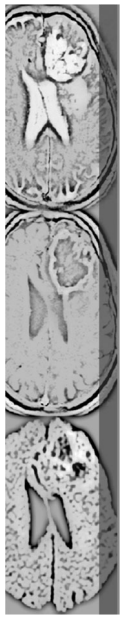


Image processing Artifacts: chemical shift

- BW = Nx/Ts = 256/(8 ms) = 32 kHz
- BW/pixel = 1/Ts = 125 Hz
- Pixel difference (H_2O/fat) = 220 Hz/ 125Hz = 1.76 pixels
- Fat protons are going to be misregistered from H_2O by about 2 pixels (in a 1.5 T magnet using a standard 32kHz bandwidth).
- $chemical\ shift(in\ mm) = \frac{3.5\times10^{-6}\gamma B_0 \times FOV}{BW}$

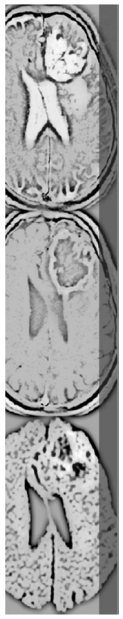
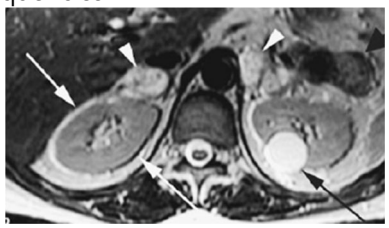
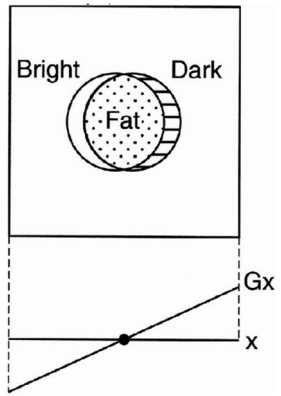


Image processing Artifacts: chemical shift

- Chemical shift artifact only occurs in the frequency-encoding direction.
  - A bright band toward the lower frequencies
  - A dark band toward the higher frequencies



T2 FSE



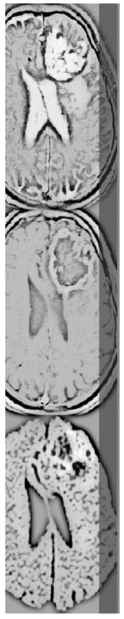
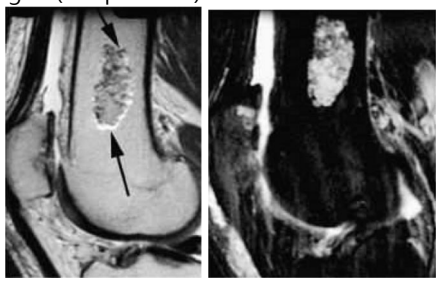
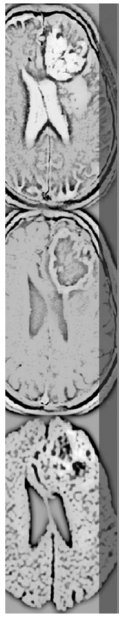


Image processing Artifacts: chemical shift

- Remedy:
  - Fat suppression
  - Increase pixel size by keeping FOV the same and decreasing Nx (spatial resolution ↓)
  - Lower the magnet's field strength (not practical)
  - Increase bandwidth (SNR ↓)
  - Use a long TE (less signal from fat)

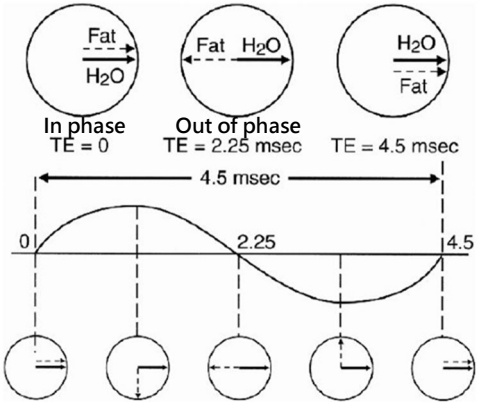


T2 with/without fat saturation



Chemical shift of the second kind

- 220 Hz at 1.5T:
- Fat and water are in phase every 4.5 msec.
- Only exist in GRE (without 180° rephasing pulse).
- Not only in the frequency-encoding direction



Chemical shift of the second kind

- Boundary effect (when out of phase)

In phase

Out of phase

Image processing Artifacts: Truncation

- Truncation artifacts (Gibbs Phenomenon)
- Occurs at high contrast interfaces
  - Skull/brain, spinal cord/CSF, meniscus/fluid in the knee
- Due to insufficient samples for the large signal changes
  - Mostly seen in the phase direction (because fewer samples are usually taken)
- Causes alternating bright and dark bands
  - Pseudo syrinx of the spinal cord
  - Pseudo tear of the knee meniscus

The K-space data is often under-sampled and truncated to shorten the scan time.

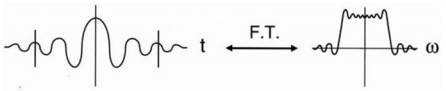
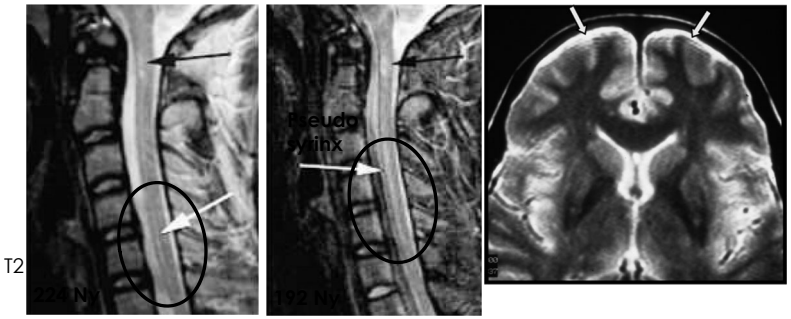


Image processing Artifacts: Truncation

- Remedy:
  - Decrease pixel size (increase phase encoding steps, reduce FOV)
  - Increase sampling time, increase sampling bandwidth

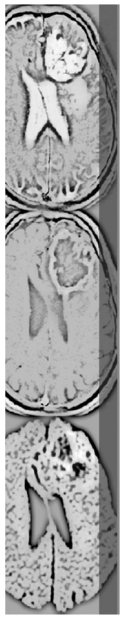


Fat-saturated T2

Image processing Artifacts: Partial volume

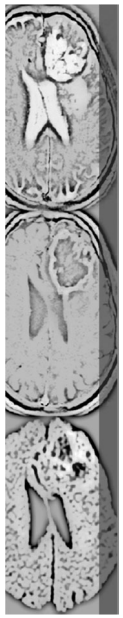
- Remedy: decrease the slice thickness

Axial FLAIR image



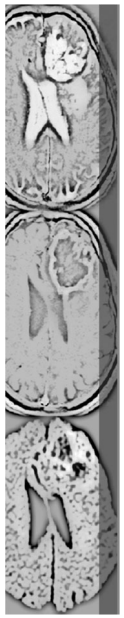
Subject-related Artifacts

- Motion artifacts
- Magnetic susceptibility artifacts
  - Diamagnetic, paramagnetic, ferromagnetic
  - Metal



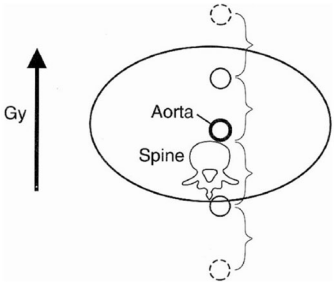
Subject-related Artifacts: Motion

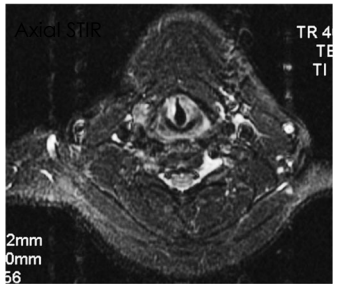
- Random movements, periodic motion (pulsating flow in vessels)
- We only get motion artifacts in the phase-encoding direction (the sampling time for frequency-encoding is short).

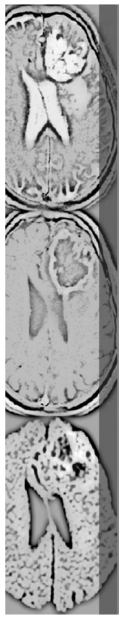


Periodic Motion

- Ghost artifacts of the vessels are equally separated along phase-encoding direction.
- $\boldsymbol{separation\ (SEP\ in\ pixels)} = \frac{\boldsymbol{TR \times Ny \times NEX}}{\boldsymbol{T(motion)}} = \frac{\boldsymbol{acquisition\ time}}{\boldsymbol{T(motion)}}$



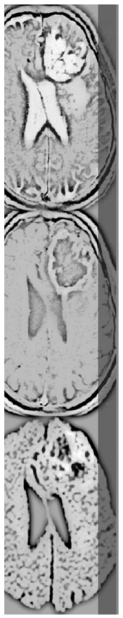




Motion artifacts

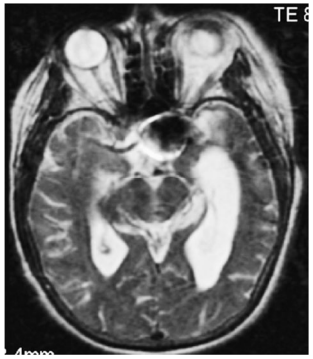
- Remedy for Periodic motion
  - Spatial presaturation pulses to saturate inflowing protons
  - Increase separation between ghosts
  - Swap phase and frequency (only change the direction of artifacts)
  - Use cardiac/respiration gating
  - Use flow compensation
- Remedy for random motion
  - Patient instruction: **don't move!**
  - Fast scanning techniques
  - Sedation

Random eye movements

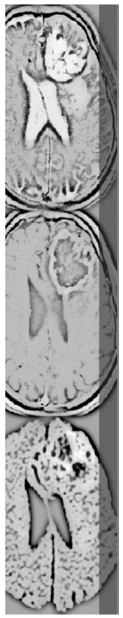


Magnetic susceptibility artifacts

aneurysm clip



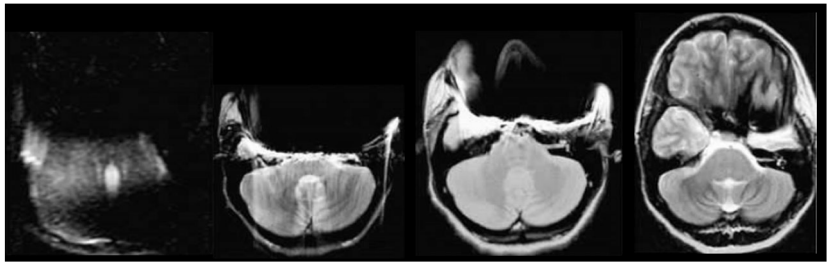
Metallic foreign body



Magnetic susceptibility artifacts

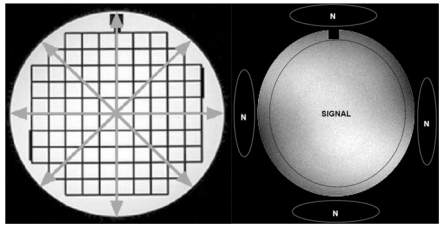
- A patient with dental braces

EPI B0 CSE T2 CSE PD FSE T2



- **請完整練習此部分國考題，很多臨床假影影像實例！**
- **請務必閱讀ACR MRI phantom (11 slices)補充教材！**

< 補充資料 >
ACR phantom overview.pdf
ACR phantom guidance.pdf
ACR 官網連結

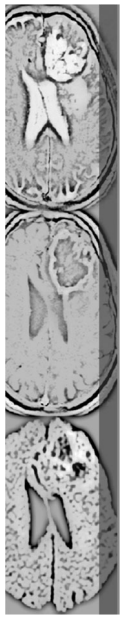


- Geometric Distortion
- Spatial Resolution
- Slice thickness and position
- Interslice Gap
- Estimate of Image Bandwidth
- Low Contrast Detectability
- Image Uniformity
- Signal-to-Noise Ratio (SNR)
- Physical and Electronic Slice Offset
- Landmark

磁振安全

MRI safety issues

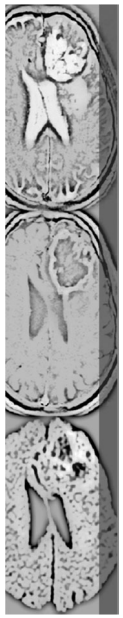
To date, there have been no known long-term adverse biological effects associated with extended exposure to the magnetic fields used in MR imaging.



Safety Issues

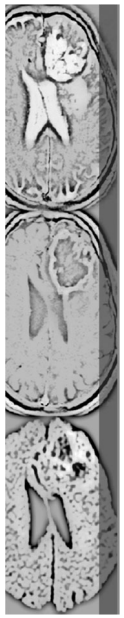
- **A high static magnetic field (B_0)**
  - Generating a macroscopic nuclear magnetization
- **Rapidly alternating magnetic gradient fields (Gx,Gy,Gz)**
  - Spatial encoding of the MR signal
- **RF electromagnetic fields (α)**
  - Excitation and preparation of the spin system

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



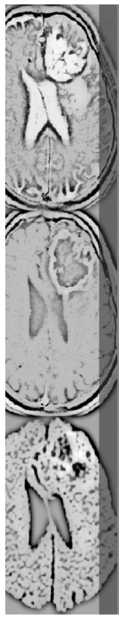
Safety Regulations

- 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



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



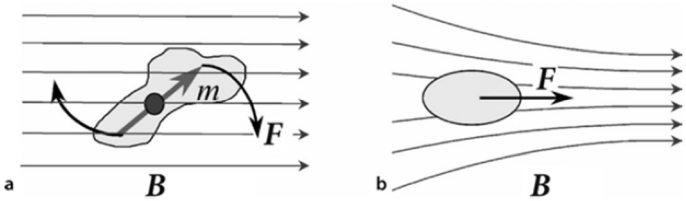
Operating Modes

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

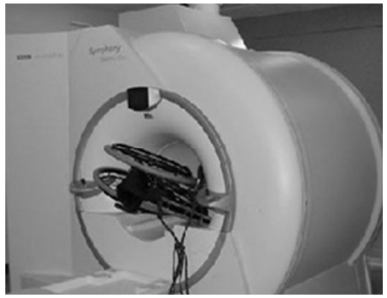
- Normal operating mode
  - Routine MR examinations
- Controlled operating mode **(first-level controlled mode)**
  - Specific MR examinations
  - Discomfort or physiological stress to some patients may occur
  - Medical supervision for patients
- Experimental operating mode **(second-level controlled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

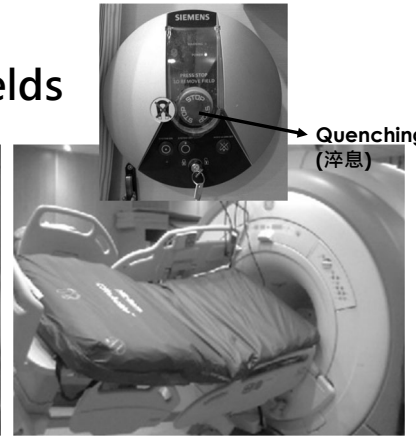
Static Magnetic Fields **Projectiles, devices and implants**

- 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**.



Static Magnetic Fields





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

How dangerous are magnetic items near an MRI magnet: http://youtu.be/6BBx8BwLhqg

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

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

MRI Safety Issue

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

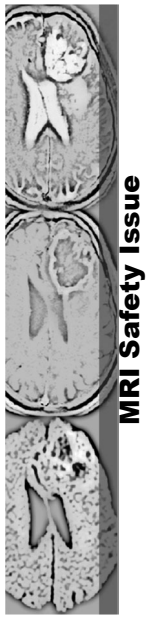
Agripada police said Dr Siddhant Shah was arrested on Thursday after the family of the 32-year-old victim, Rajesh Maru, told them that the radiologist was also present when the accident occurred.

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.



MRI Safety Issue

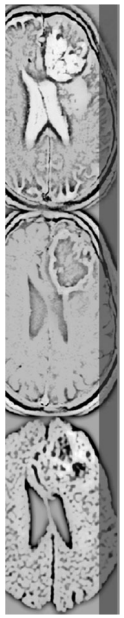
恐怖意外！核磁共振儀產生巨大磁力吸入氧氣瓶　砸中老翁胸口慘死

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氧瓶沒固定好，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。

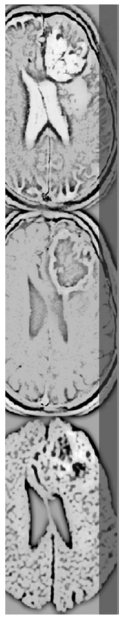
目前警方仍在調查現場供詞的真實性，同時也在了解為何金屬氧瓶會被放置在攝影室內，盼能完整釐清責任。（於慶中／綜合外電報導）



Static Magnetic Fields

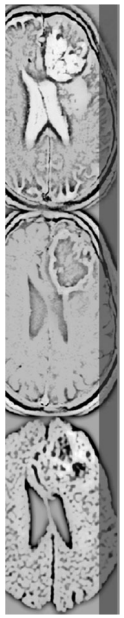
- Magneto-hydromechanical (MHD) interactions
  - Static magnetic fields also exert **Lorentz forces** on moving ionic charge carriers giving rise to induced electric fields and currents.
  - At very high B, it can reduce the flow velocity and the flow profile of blood in large vessels.
  - **EKG T wave 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://mriquestions.com/magnet-changes-ekg.html



Static Magnetic Fields

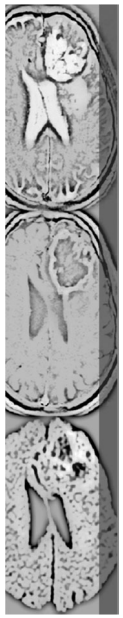
- No magnetic effects on implantation, prenatal, and postnatal development were reported between 1 and 9.4T.
- Humans exposed to a maximum flux density of 8T did not yield clinically relevant changes.
  - Heart rate
  - Respiratory rate
  - Diastolic blood pressures
  - Finger pulse oxygenation levels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



Static Magnetic Fields

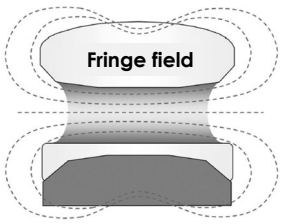
- Epidemiological studies is at present not sufficient to draw any conclusions about potential health effects.
- From evaluation of 1421 pregnancies of women working at clinical 1T MR facilities, no significant increased risks for…
  - spontaneous abortions
  - Delivery before 39 weeks
  - Reduced birth weight
  - Male gender of the offspring

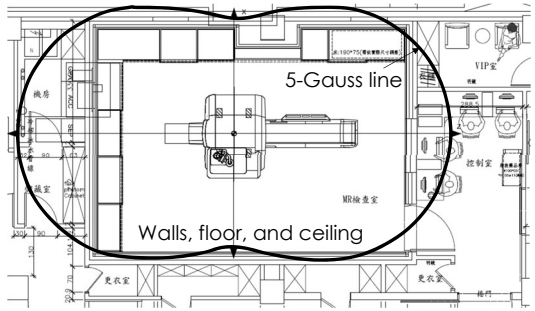
- More sensitive to magnetic fields in the first trimester of pregnancy
- Avoid the injection of Gd contrast agent
- B_0 < 4T for fetus

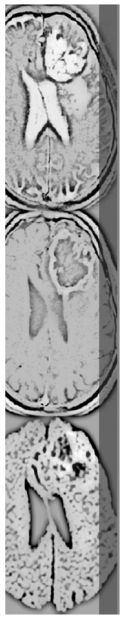


Fringe Fields

- **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







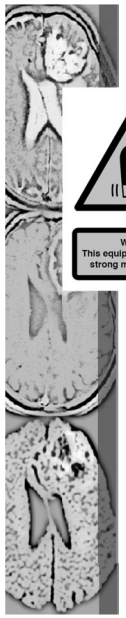
Terminology of MRI and Implants/Devices

- 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.

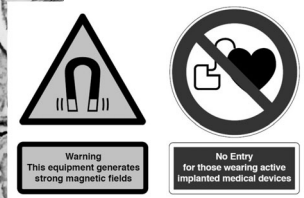
MR safe

MR conditional

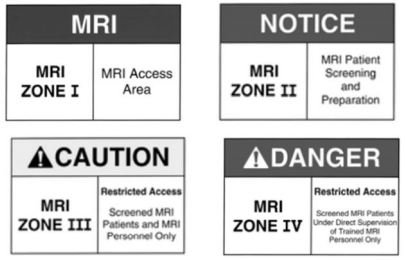
MR unsafe

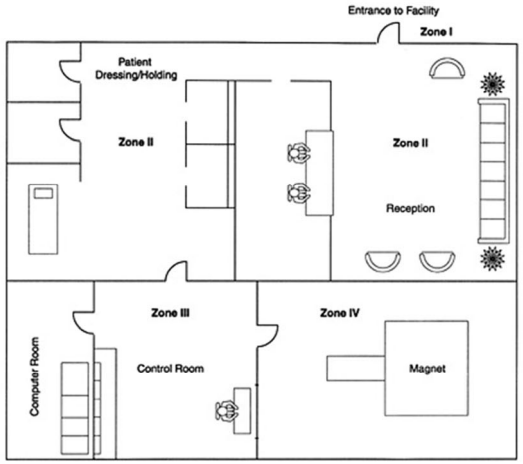


5 Gauss line



ACR Safety Zones





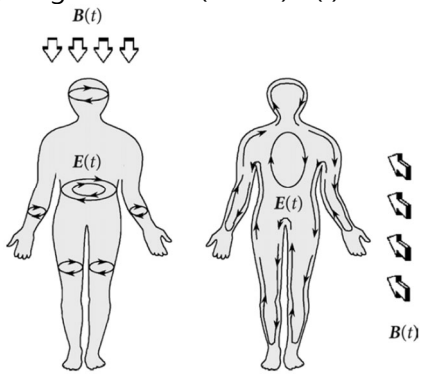
https://mriquestions.com/acr-safety-zones.html

Time-Varying Magnetic Gradient Fields

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

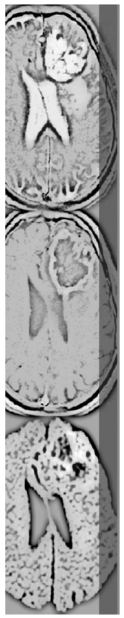
Time-Varying Magnetic Gradient Fields

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



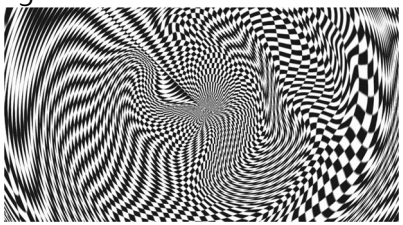
Time-Varying Magnetic Gradient Fields

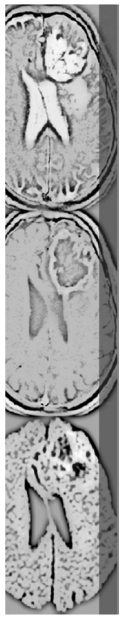
- The induced currents can influence cellular properties involve interactions at the level of the cell membrane.
- The primary concern is cardiac fibrillation (life threaten)
- The practical concern is the peripheral nerve stimulation (mild cutaneous sensations and involuntary muscle contractions)
- 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 μs.



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





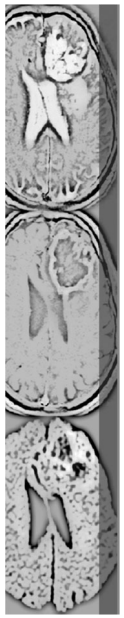
Acoustic Noise

- 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

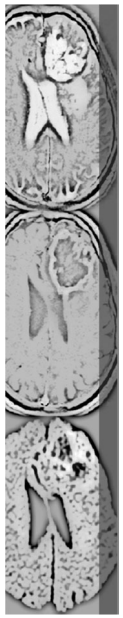
MR-compatible head phones

- MRI generates 110~120 dB of noise.
- Simple foam earplugs can attenuate the acoustic noise by 10 dB to 20 dB.



Radiofrequency Electromagnetic Fields

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

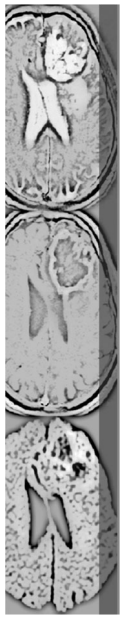


Radiofrequency Electromagnetic Fields

- Thermal effects due to tissue heating are of importance.
- Specific absorption rate (SAR, in W/kg)

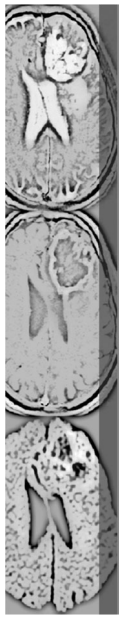
$$SAR \propto B_0^2 \cdot \alpha^2 \cdot \frac{tp}{TR} \cdot Ns$$

  - 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
  - N_S: the number of slices in a TR.
- Patient's weight must be correctly input to ensure the SAR does not exceed the permitted levels.



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



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 (°C)	Spatially localized temperature limits		
		Head (°C) (or 3.2W/kg)	Trunk (°C) (or 8W/kg)	Extremities (°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

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

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

17

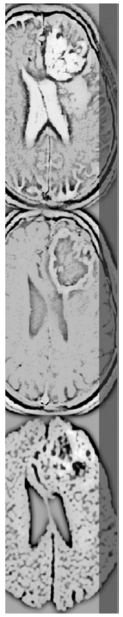
Aa

天線效應
(Antenna effect)

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

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.

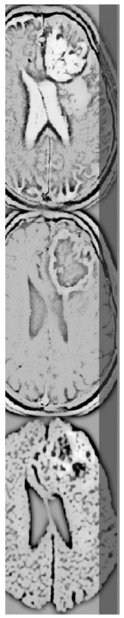
We care about your safety!



Radiofrequency Electromagnetic Fields

- Prevent the focal skin-to-skin contacts

Current-induced third-degree burns



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

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