Key concepts of MRI safety - What radiologists need to know and understand

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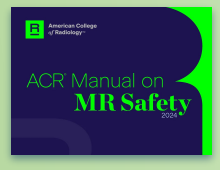
Objectives

To enhance radiologists' awareness and understanding on key principles of MRI safety

Materials and methods

To discuss key MRI safety concepts on the 4-zone principle, MR personnel types, and risks of the main magnetic fields—Static field (B0), radiofrequency pulse (B1), and time-varying gradient field (dB/dt)—as outlined in **2024 ACR Manual on MR Safety**.



ACR 4-zone principles

The ACR 4-zone principle reduces MRI injury risk by assigning Zones I–IV, each with **progressively stricter safety protocols**. This zoning should be integrated into all MRI facility designs, including intraoperative MRI.

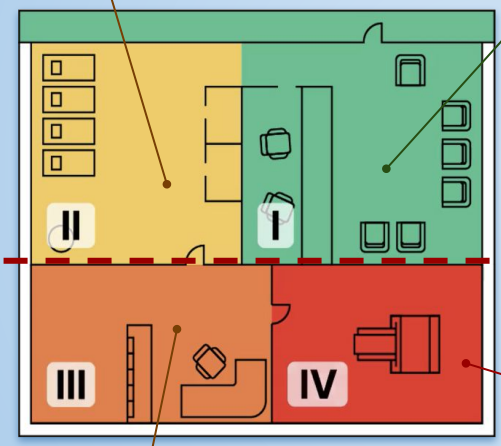
Zone II

Buffer area between public and restricted area (Patient **screening and changing** area)

Patients are under general supervision from MRI personnel

Zone I

Uncontrolled area freely accessible to general public (∵ **No magnetic field hazard**)



Strictly controlled area restricted to MRI personnel and screened patients only

Use of identifier e.g. badges to differentiate MR / non-MR personnel e.g. Intraoperative MRI (IoMRI)

Zone III

Strictly controlled area that is **immediately adjacent to MRI scanner room**

(∵ Potential magnetic field hazards for unscreened patients and untrained staff)

Zone IV

Contains the **strongest magnetic field** with illuminated warning sign "**The magnet is always on**"

Use of **ferromagnetic detection systems (FMD)** for final screening before entering zone IV

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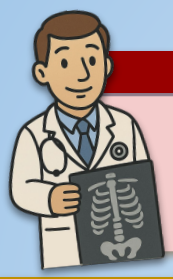
MRI personelle

ACR recommends clear definition of roles of MR personnel as following:



MR medical director (MRMD)

A licensed **radiologist** with appropriate MR safety training responsible for overseeing **overall MR facility operational safety policies and procedures**

MR safety expert (MRSE)

A **MR physicist** responsible for working with MRMD and MRSO for **technical- and physics-related issues**

MR safety officer

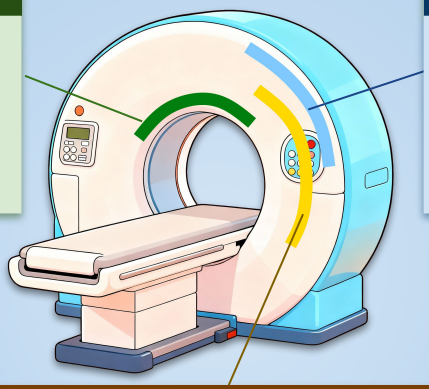
A **MR technologist** responsible for working with MRMD and MRSE in implementation of **day-to-day practice of a comprehensive MR safety program**

Overview of 3 magnetic fields of MRI machine

Radiofrequency pulse (B1)

For transmitting excitation RF pulse of **various flip angles** and receive MR signal

(∴ **Closest to patient** for best SNR)



Static magnetic field (B0)

e.g. 1.5T or 3T

Superconducting coils within cryostat which is **more peripherally located**

Time-varying gradient field (dB/dt)

Three pairs of coils with opposing current to produce a predictable linear gradient magnetic field for localization of MRI signals, **rapid reversal in directions** in certain sequences (e.g. GRE sequences)

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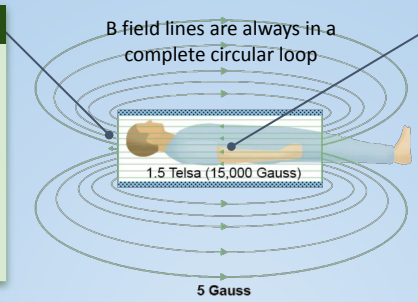
Risks related to magnetic forces from static magnetic field (B0)

Entrance of magnetic bore

Strongest dB/dz but less B0 compared to isocenter

(Greatest change in magnetic flux density per unit distance)



Isocenter

Strongest B0 but minimal dB/dz

(Most homogeneous B0 where body part to be imaged is placed for image production)

Translational force

Violent attraction of **ferromagnetic items** towards scanner (aka. projectile effect)

Proportional to spatial gradient of B0 (dB/dz)
(i.e. **Strongest near entrance** of magnetic bore but BUT weakest at isocenter of magnetic bore)

Rotational force

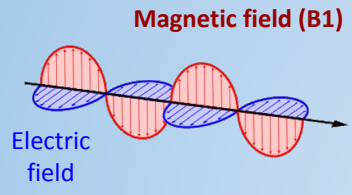
Torque of ferromagnetic object to twist and align along main B0 field direction

Proportional to square of B0 field strength
(i.e. **Strongest at isocenter** of magnetic bore)

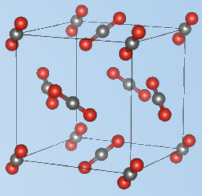
- Apply **ACR 4-zone principle** to ensure proper screening and supervision
- Use of **ferromagnetic detectors** to screen for ferromagnetic objects
- Check the MR safety condition of body implants, including **orientation** of patients (e.g. cochlear implant)

Risks related to radiofrequency pulse (B1)

Generalised body heating from energy deposited to the body concerns of two major parameters



NMV flips for variable angles (**Larger flip angle, more energy gained**)



Energy transferred to lattice i.e. molecular vibration by **T1 relaxation**

B1+ root mean square (RMS) - MRI system dependent -

B1+: The portion of oscillating B1 field of RF pulse that excites spin system by **resonance** (B1- has no contribution)

RMS: Time-varying and requires RMS to represent the average value (Simple mean is zero)

Inversion recovery
Flip angle 180°>90°

Turbo spin echo
Use of 180° refocusing pulses

Less flip angle or increase TR = Less body heating

Specific absorption rate (SAR) - Also patient dependent -

RF power absorbed per unit body weight (W/kg) which depends on: **B1+ RMS, operating mode** and **body weight**

Normal operating mode is generally safe for all patients (e.g. including those with implants)

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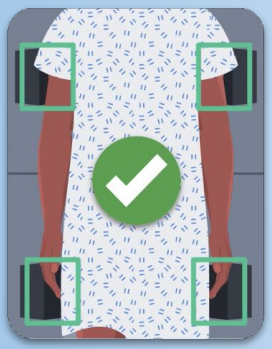
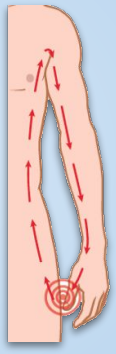
Risks related to radiofrequency pulse (B1)

Focal burns are due to electrical current generated by alternating B1 field at body parts in 2 main scenarios:



Body parts directly touching bore wall

Can be prevented by placing air-containing padding with adequate thickness



Conducting loops

Body contact is prevented by padding and ensure no looping of ECG leads

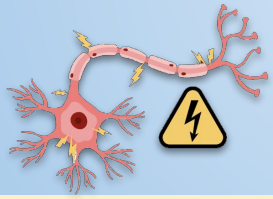
Risks related to time-varying gradient magnetic field (dB/dt)

Two major risks due to **varying direction of current flow** in gradient coils:

Peripheral nerve stimulation

Ranges from tingling sensation to some involuntary muscle contraction
=> Both will **affect image quality**

Can be minimized by adjusting scan parameters based on **rheobase and chronaxie value**



Can reach noise level of concert and chainsaw

Acoustic noise

Opposing current flow in gradient coils oscillate due to opposite Lorentz force acting on it under B0

Hearing protection is mandatory as many MR sequences have >85dB which can cause permanent hearing impairment

Conclusion

A thorough understanding of MRI safety principles is increasingly vital for radiologists, given the rising use of high-field 3T MRI, the growth of MRI-guided interventions such as MR lymphangiography, and the expansion of MRI facilities, including intraoperative MRI in the New Territories West Cluster.

References

1. American College of Radiology. (2024). ACR Manual on MR Safety (Version 2024). https://www.acr.org/Clinical-Resources/Clinical-Tools-and-Reference/radiology-safety/mr-safety
2. Metasens, MRI safety - Top 10 MRI Suite planning principles for architects and planners