MRI and Ultrasound: Hazards and Safety Awareness Training

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Children's Health Ireland

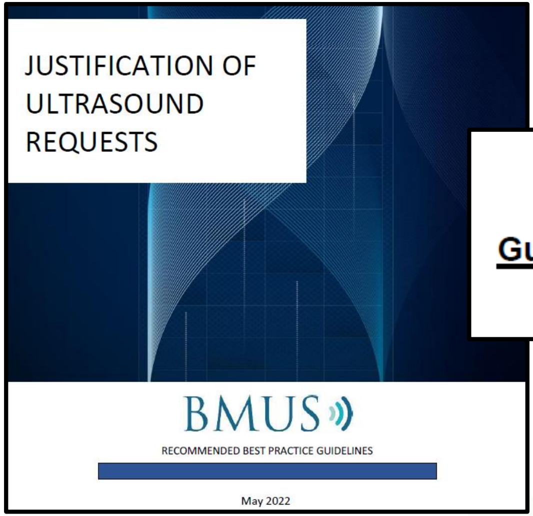
8th June 2023

Layout

- Ultrasound hazards and safety
- Intro to MRI
- 3 x magnetic fields used by MRI scanners
- Hazards associated with each of these magnetic fields
- Focus on implanted devices
- MRI safety guidelines, structure and policies

Intro to ultrasound safety

- Ultrasound is considered a low risk modality but it is not completely without hazards
- Guidelines for justification and safe use of medical ultrasound should be followed when referring patients for ultrasound imaging (**referrer**) and when performing the scan (**radiographer/ultrasonographer**)



The British Medical Ultrasound Society.

<u>Guidelines for the safe use of diagnostic ultrasound equipment</u>

Prepared by the Safety Group of the British Medical Ultrasound Society.

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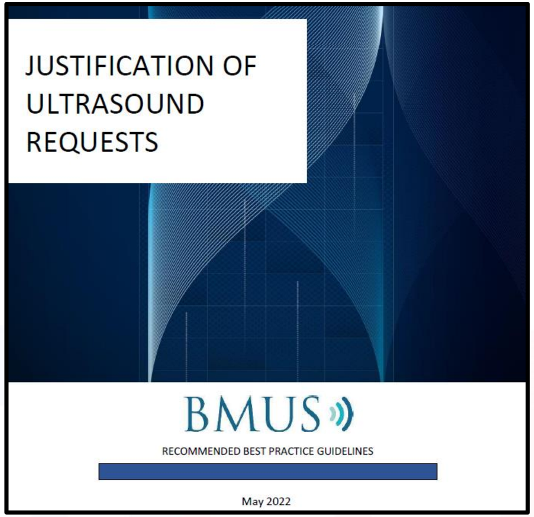
Justification principles

- Imaging requests should include a **specific clinical question(s)** to answer
- There must be sufficient information from the clinical history / physical examination / lab results to support the request
- There are patients for which US is not an appropriate first line test
- Radiology department may re-direct US requests to CT / MR if deemed more appropriate
- Requests that are inappropriate (i.e. don’t meet best-practice guidelines) will be returned with appropriate advice and guidance

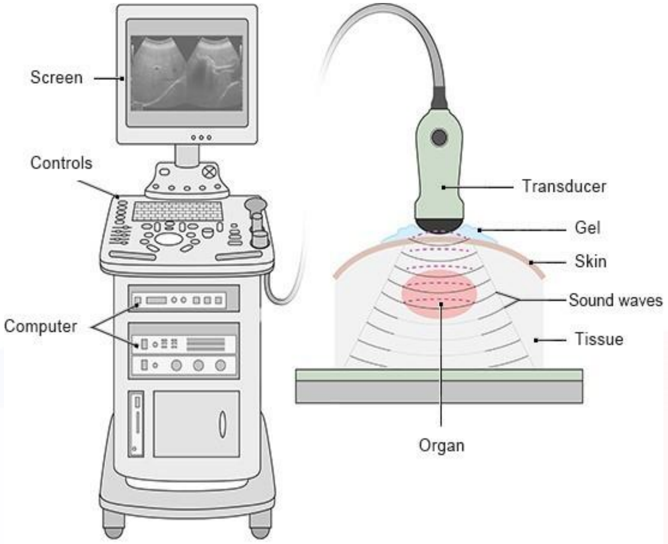


Key principles for safe use of ultrasound

- Medical ultrasound imaging should only be used for the purpose of medical diagnosis
- Ultrasound equipment should only be used by people who are fully trained it its safe and proper operation:
  - Understanding of potential **thermal and mechanical** bio-effects
  - Full awareness of equipment settings (safety and image quality)
  - Understanding of effects of machine settings on power levels
- Examination times should be kept as short as necessary to produce diagnostic quality images
- Output levels should be kept as low as is reasonably achievable (ALARA)
- Operator should aim to stay within BMUS recommended scan times (NB fo
- Scans in pregnancy should not be carried out solely for purpose of producir

Thermal effects

- Range of normal temperatures 36-38°C
  - Moderate temperature increases may arrest or retard cell division
  - Teratogenic effects above 40°C, enzymes denatured >45°
  - A diagnostic exposure with a maximum temperature rise of 1.5°C does not appear to present a risk if limited to under 30 min
- Particular risks in:
  - The eye, where blood supply is poor so heat cannot be easily dissipated
  - Neural cells
  - Bone/soft tissue interfaces
  - The developing embryo and foetus (particularly as bone becomes denser)
- In risky cases, exposure limits are defined
  - A threshold dose of 0.5 min exposure to a 4°C increase above normal temperature is considered hazardous to embryonic & foetal development
  - In later pregnancy, heated volume is small compared to size of foetus making biological effects difficult to predict (prudent to minimise output)



https://www.informedhealth.org/

Thermal Index (TI)

- TI is defined as the **ratio** of the emitted acoustic power to the power required to raise the temperature of tissue by 1°C.
- TI is intended to give a rough guide to the magnitude of the temperature rise that might be produced after a long exposure, although technically the TI is not a measure of the precise temperature rise.
- A larger TI value represents a higher heating potential and correspondingly a higher risk (eg, a TI of 2 means a higher risk than a TI of 1.5 but not as high a risk as a TI of 3).

Thermal Index
Easily interpreted as a TI of 2 means a temperature rise of 2°C

$$TI = \frac{W}{W_{deg}}$$

W: Current acoustic output power from the transducer during use

W_{deg}: Acoustic output power required to raise the temperature by 1°C anywhere in the beam using identical scanner settings

3 x TI values used in practice:

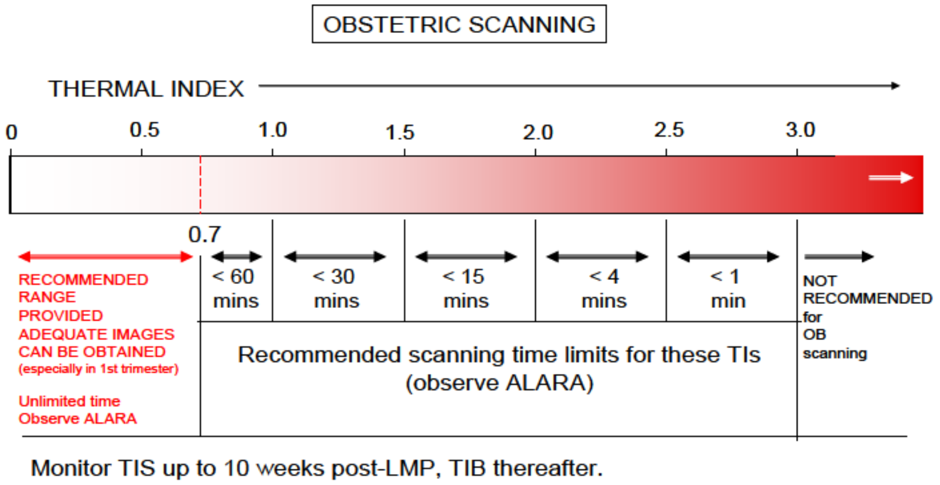
- TI soft tissue (TIS)
- TI bone (TIB)
- TI cranial bone (TIC)

What is the ultrasound beam impinging on?

Heating depends on ability of object to absorb ultrasound waves, more dense material tend to heat more (e.g. bone ~ 50 x soft tissue)

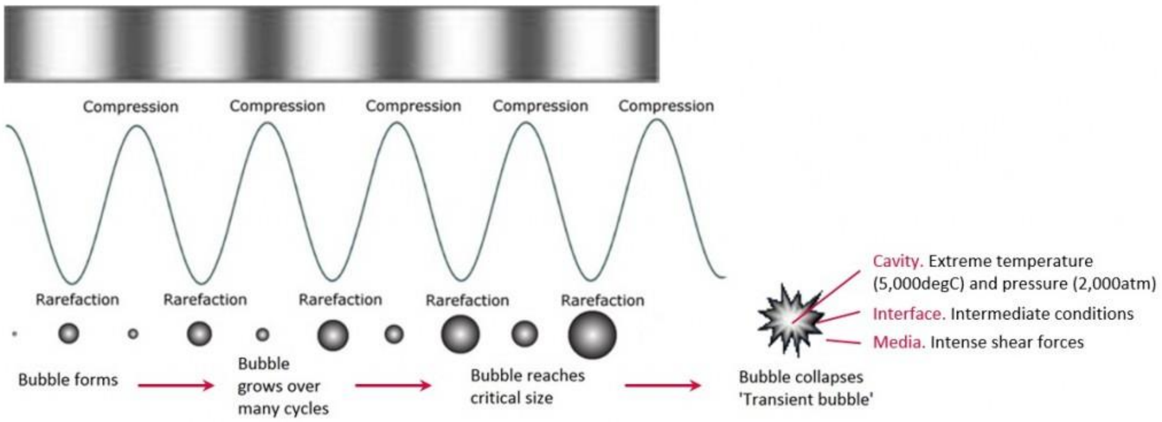
Thermal Index (TI)

- TI effectively allows scanning durations to be limited according to heating risk of the exam:



Mechanical effects

- Acoustic cavitation occurs when bubbles interact with acoustic energy (i.e. ultrasound waves)



- Oscillations/cavitation of the bubbles can generate mechanical waves in the tissue which may induce shear stresses on cells and tissues → **acoustic streaming**
- **Note:** Mechanical effects can be used constructively to treat e.g. malignant lesions → High intensity focused ultrasound (HIFU)

Mechanical Index (MI)

- MI indicates the probability of occurrence of inertial cavitation:

Mechanical index.
Based on a model that assumes the presence of bubble nuclei in tissue, which predicts that inertial cavitation is more likely at lower frequencies and higher values of peak rarefaction pressure.
MI < 0.7 indicates conditions for inertial cavitation probably do not exist.

$$MI = \frac{p_{r,0.3}}{\sqrt{f}}$$

Maximum value of derated** peak rarefaction pressure in the beam (MPa) -> Measured by recording p at a range of depths (p_r) and derating the values to find the maximum value of $p_{r,0.3}$

Centre frequency in the pulse (MHz)

**NB Normal measurements of acoustic pressure are made in water ("free-field"), which has almost no attenuation. To estimate pressure in soft tissue for the same ultrasound beam, values are "derated" by an amount dependent on tissue attenuation, normally 0.3 $dBcm^{-1}MHz^{-1}$.

Summary of TI and MI

- The Thermal Index (TI) and Mechanical Index (MI) were introduced to provide the operator with an indication of the potential for ultrasound induced bio-effects.
- TI provides an onscreen indication of the relative potential for a tissue temperature rise.
- MI provides an onscreen indication of the relative potential for ultrasound to induce an adverse bio effect by a non thermal mechanism such as cavitation

Summary of ultrasound hazards and safety

- Ultrasonographers (radiographers) employ an ALARA approach to diagnostic ultrasound to keep TI and MI as low as possible while acquiring diagnostic quality images
- Important for referrers to be aware of justification guidelines and to understand that ultrasound, although generally safe, is not a hazard-free modality
- But, as per the American Institute for Ultrasound in Medicine:

"the benefits to patients of the **prudent** use of diagnostic ultrasound outweigh the risks, **if any**, that may be present

MRI hazards and safety awareness

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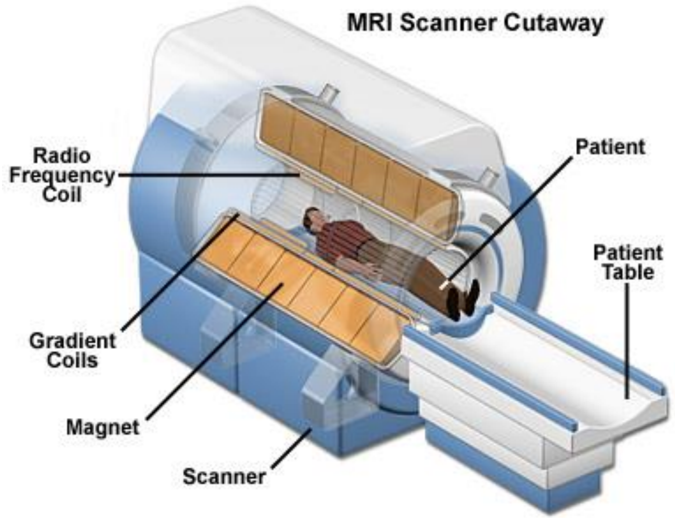
Three magnetic fields used by MRI scanners



- Main (static) magnetic field (**B_0**) of scanner produced by large current running continuously in superconducting coils (requirement for liquid helium)
- Radiofrequency (**RF**) field generated by RF coils, either volume coil built into scanner or local transmit coils (e.g. Tx/Rx head or knee coil)
- Magnetic field gradients (**dB/dt**) generated by gradient coils

Three magnetic fields used by MRI scanners

- **Static field** (main magnetic field of scanner, B_0) → Projectile and/or torque effect on ferromagnetic objects
  - Projectile force will cause metal objects to “fly” into the middle of the scanner at very high speeds
  - Torque force causes metal objects to align with the main magnetic field

Always on!!

- **Radiofrequency (RF) field** → energy deposited in patient during scan
  - Whole body and localised tissue heating
  - Heating around wires, devices and metal implants within body

On during scan only

- **Magnetic field gradients (dB/dt)** → used for spatial localisation during scan
  - Acoustic noise as gradients are rapidly switched on and off
  - Nerve stimulation
  - Heating / vibration of implanted devices

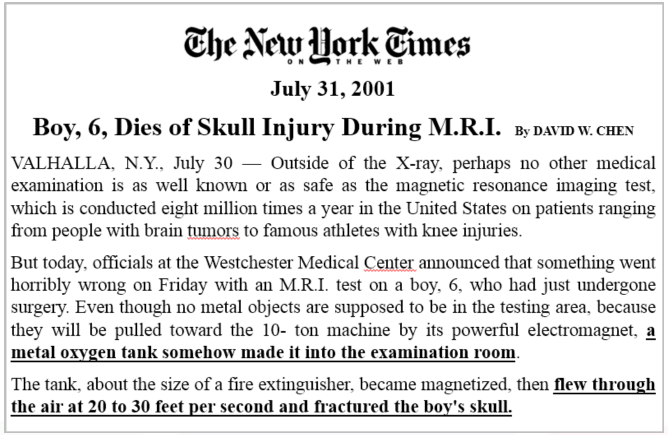
On during scan only

Static Field – Projectile Effect

- **Any metal object** brought into the MR environment can become a potential projectile
- The harm done by a metal object in this environment **CANNOT** be over-emphasised
- Paper clips or hair pins can reach a velocity of >60kmph
- Larger objects will generate more momentum and can have disastrous consequences (e.g. oxygen cylinder)

Static Field – Projectile Effect

- Begins July 27th of each year to honour the memory of Michael Colombini.
- Killed in 2001 when medical staff brought an oxygen cylinder into the scan room while he was having a brain scan.



The New York Times ON THE WEB

July 31, 2001

Boy, 6, Dies of Skull Injury During M.R.I. By DAVID W. CHEN

VALHALLA, N.Y., July 30 — Outside of the X-ray, perhaps no other medical examination is as well known or as safe as the magnetic resonance imaging test, which is conducted eight million times a year in the United States on patients ranging from people with brain tumors to famous athletes with knee injuries.

But today, officials at the Westchester Medical Center announced that something went horribly wrong on Friday with an M.R.I. test on a boy, 6, who had just undergone surgery. Even though no metal objects are supposed to be in the testing area, because they will be pulled toward the 10- ton machine by its powerful electromagnet, **a metal oxygen tank somehow made it into the examination room**.

The tank, about the size of a fire extinguisher, became magnetized, then **flew through the air at 20 to 30 feet per second and fractured the boy's skull.**

Employees of the Westchester Medical Center in Valhalla, N.Y., gather outside after learning of the deadly MRI incident. (ABCNEWS.com)

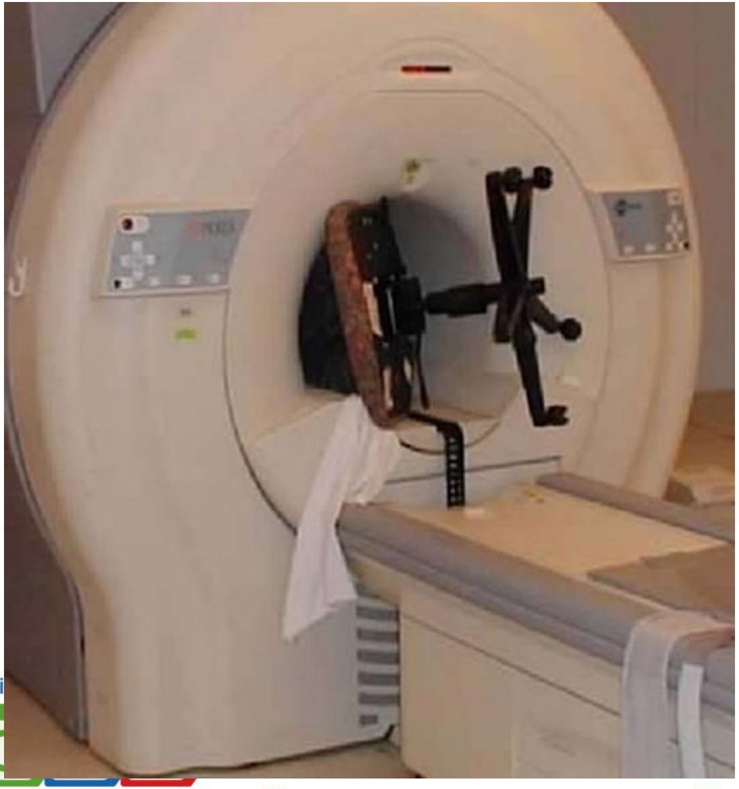
Hospital Nightmare

Boy, 6, Killed in Freak MRI Accident

abcNEWS

July 31 — A 6-year-old boy died after undergoing an MRI exam at a New York-area hospital when the machine's powerful magnetic field jerked a metal oxygen tank across the room, crushing the child's head.

Static Field – Projectile Effect



Static Field – Projectile Effect

THE STRAITS TIMES

ST SINGAPORE POLITICS

ASIA › East Asia SE Asia

ASIA

Man dies aft
Mumbai hos

At the same time, Maru, who was holding the oxygen cylinder with his left hand, his fingers wrapped around the cylinder's nozzle, stepped through the door into Zone IV.

The next instant, Maru, still holding the cylinder, flew off his feet "like a missile" and slammed into the gantry of the machine a few feet away.

The cylinder's nob snapped, and with his upper body lodged halfway inside the machine's circular hollow, Maru inhaled a rush of oxygen. Pneumothorax — a condition in which air (or other gas) fills the space between the lungs and chest wall, and the lungs collapse — followed.

Happened in 2018!

Static Field – Projectile Effect

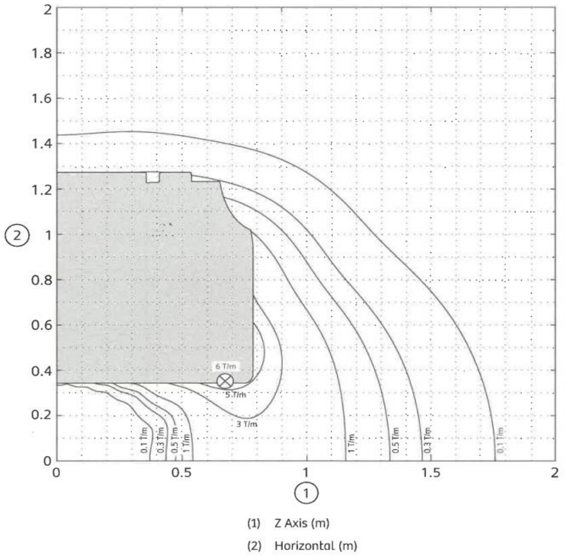
- Nurse and radiographer brought patient into magnet room on an **MR Unsafe** gurney
- Patient thrown off, struck MRI scanner
- Nurse pinned by gurney, reported to have suffered broken femur and fractured pelvis

Happened in 2023!

Static Field – Projectile Effect

Projectile video played here

Static Field – Projectile Effect



Fringe field spatial gradient:

- Units are T/m → "gradient" or change in static magnetic field strength over space
- **NB:** Not the same as time varying gradients used for spatial localisation! (compare order of magnitude, T/m compared to mT/m for imaging gradients)
- Gradient is present due to main field B_0 → always there!

$$F_m = \left(\frac{\chi V}{\mu_0}\right) B_0 \nabla B_0$$

Projectile force — Static field — Spatial gradient!

Static Field – Projectile Effect

MR Radiographers, Anesthetists and other Medical Personnel

- Scissors, Hemostats
- Scalpels, Syringes, Needles
- Stethoscopes
- Oxygen Cylinders
- Gurneys, Wheelchairs
- Clipboards, Metal Pens

Technical Services Personnel, Cleaning Personnel

- Dustpans
- Buckets
- Buffers
- Vacuum Cleaners
- Tools
- Tool Kits

Static Field – Projectile Effect

- All staff working in the MR unit should be aware of the potential danger posed by ferromagnetic objects
- All pockets should be emptied
- All watches, keys, phones, etc. should be removed

Radiofrequency (RF) heating effect

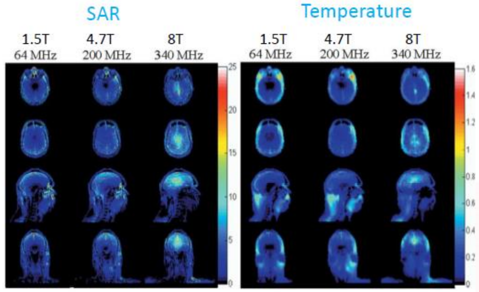
- RF energy (64MHz at 1.5T, 128MHz at 3T) used to excite signal in patient (*Resonance*)
- Power deposited in patient (Watts per kg of tissue)
- Patient heats up over duration of scan but body is usually very good at heat dissipation
- Also work within strict limits that restrict scanning if necessary

But…

- Not all patients can dissipate heat effectively

And…

- SAR hotspots occur (worse at 3T than 1.5T) and heating can be very localised around metal objects (wires, skin-skin contact, ECG dots, pulse oximeters, etc)



Radiofrequency (RF) heating effect

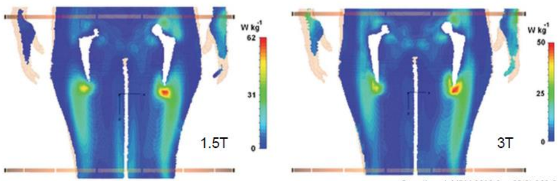
- SAR (specific absorption rate) is a regulated parameter, monitored by the scanner

- IEC limits:

	Whole Body	Head
Normal mode	2 W/kg	3.2 W/kg
1^{st} level controlled mode	4 W/kg	3.2 W/kg
2^{nd} level controlled mode	> 4 W/kg	> 3.2 W/kg

- Temperature rise: NORMAL MODE < 0.5^0C, 1^{st} CONTROLLED MODE < 1^0C, 2^{nd} CONTROLLED MODE >1^0C <2^0C (whole body average values – localised heating may be worse, especially near implants, but also due to SAR hotspots)

- Example around Co-Cr-Mo hip prostheses



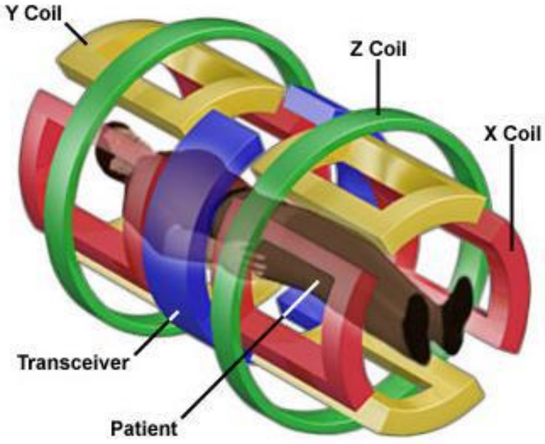
Powell et al. MRM 2012 Sep;68(3):960-8

- Temperature rises of 9 °C reported at tip of Co-Cr hip implant *in vitro*

Muranaka et al. Nihon Hoshasen Gijutsu Gakkai Zasshi. 2010 Jul 20;66(7):725-33

Magnetic field gradient effects

- Switching gradient magnetic fields on and off causes acoustic noise and potentially harmful electric fields within the patient
- Temporary shift in hearing threshold (damage to ear) if noise protection is inadequate
- PNS (peripheral nerve stimulation)
- Potential heating and vibration of external and implanted devices



Magnetic field gradient effects

- Some sequences can generate sound pressures as high as 130dB
- 3T scanners are generally noisier than 1.5T
- Painful and may cause temporary or permanent hearing loss
- Distress can lead to patient motion → degraded image quality
- US: should not exceed 115dB for 15mins exposure, 105dB for 60mins, peak noise should not exceed 140bB
- UK limits are ~5dB lower
- Ear protection must be provided and should reduce exposure levels in MRI to below 99dB

https://mriquestions.com/acoustic-noise.html

Cryogen Risk (liquid helium)

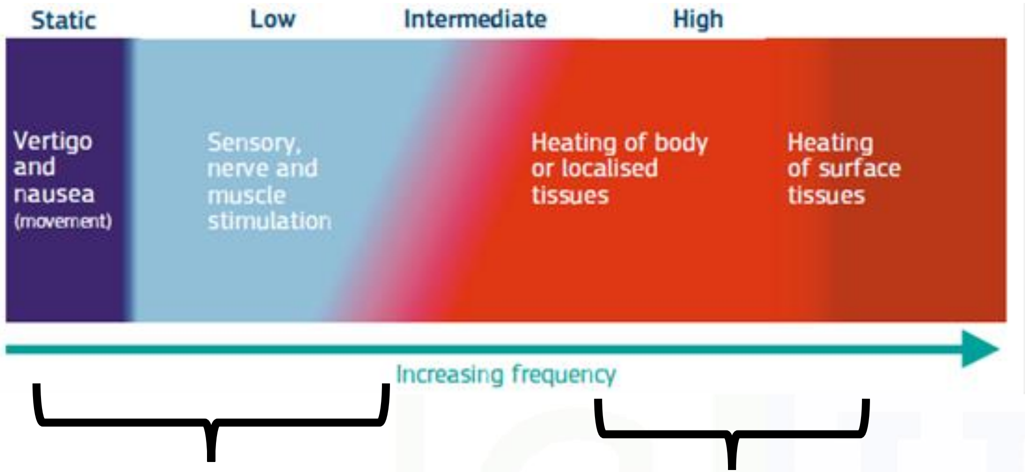
- If helium compressor "life support of scanner" is interrupted and not re-established quickly, pressure and temperature will increase within the scanner until a critical point is reached → "**Helium Quench**" → all helium released through quench pipe (**some good examples on YouTube**)
- Helium quenches can also happen **spontaneously** and may even be **deliberately initiated** by MRI staff (e.g. emergency situation in order to remove magnetic field, push "quench button", field takes ~4 mins to dissipate)
- If quench pipe functions properly, all helium is vented outside building
- But, there is always a risk of helium leaking into the MRI scanner room and displacing room air
- For this reason we continuously monitor O_2 concentration in the scan room

(O2 signal is linked to emergency extract system)

Staff Exposure to magnetic fields

Statutory Instrument 337 of 2016

- Primary aim is to ensure, in so far as is possible, that staff do not experience effects from exposure to electromagnetic fields.

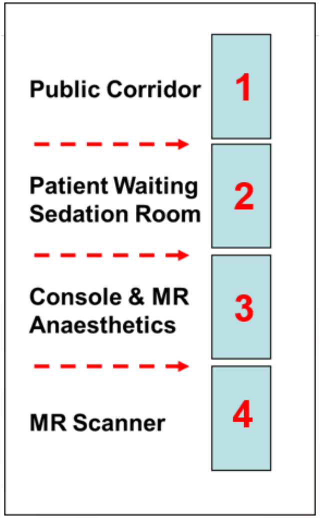


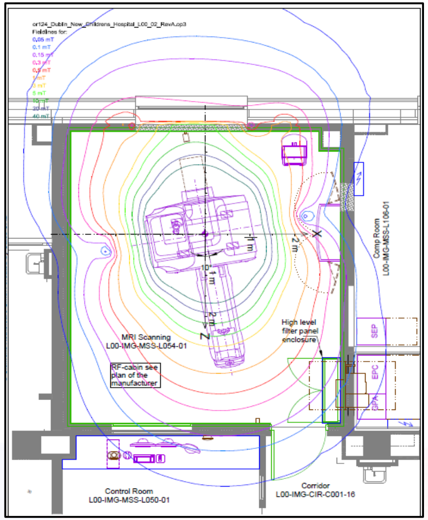
STAFF
(effects are minor and transient)

PATIENTS

How do we set up MRI departments to minimise risks?

- Establish 4 x safety zones (**as per ACR guidelines**)
- Demarcation of 5G line (**changing to 9G following latest version of IEC-60601-2-33**)
- RF cage to contain RF from scanner and prevent external RF from interfering with acquisition
- Training of staff and definition of access levels to MRI (**level 1 and level 2 as per ACR**)
- Labelling of equipment as MR Safe, MR Conditional and MR Unsafe





MR SAFE MR CONDITIONAL MR UNSAFE

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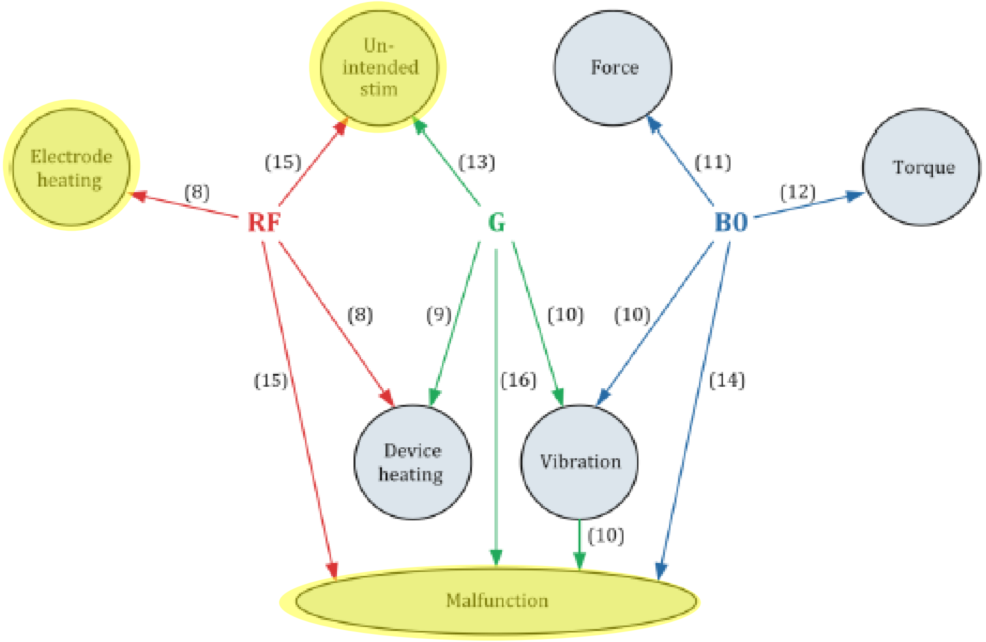
Focus on implanted devices…

Three magnetic fields used by MRI scanners



- Diagram represents relationship between MR output fields and hazards
- Includes active implanted medical devices (AIMDs) – anything with a power source / battery

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Figure adapted from ISO/TS 10974-2018. Assessment of the safety of MRI for patients with an active implantable medical device

MRI labelling of implants – Passive

MR Unlabelled

ASTM F2503 – 20 (IEC 62570)

MRI labelling of implants - Active

MR CONDITIONAL

'an item with demonstrated safety in the MR environment within defined conditions. At a minimum, address the conditions of the static magnetic field, the switched gradient magnetic field and the radiofrequency fields. Additional conditions, including specific configurations of the item, may be required.'

MR UNSAFE

'an item which poses unacceptable risks to the patient, medical staff or other persons within the MR environment.'

Static field – Force (projectile effect)

Neuroradiology

Richard P. Kluczník, MD • David A. Carrier, MD • Ron Pyka, MD • Regis W. Haid, MD

Placement of a Ferromagnetic Intracerebral Aneurysm Clip in a Magnetic Field with a Fatal Outcome[1]

Unfortunately there are many more examples of similar incidents (and near misses) occurring in MRI scanners in the literature

Static field – Torque

Original Investigation

Adverse Events and Discomfort During Magnetic Resonance Imaging in Cochlear Implant Recipients

Bo Gyung Kim, MD, PhD; Jin Won Kim, MD; Jeong Jin Park, MD; Sung Huhn Kim, MD, PhD;
Hee Nam Kim, MD, PhD; Jae Young Choi, MD, PhD

Invited Commentary page 52

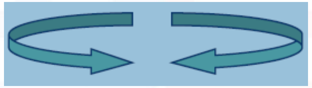
IMPORTANCE Patients with cochlear implants (CIs) should be fully informed before undergoing magnetic resonance imaging (MRI) about the possibility of discomfort or pain. Prior to an MRI scan, patients need to fully understand not only the potential complications but also the potential discomfort that they may experience during the scan.

CONCLUSIONS AND RELEVANCE Even with protective head bandages, 1.5-T MRI in patients with CIs led to a variety of adverse events, including discomfort or pain and displacement of the internal magnet. Therefore, sedation and careful head positioning may be appropriate for some patients with CIs who undergo MRI, and these patients should be carefully monitored to decrease the likelihood of such adverse effects.

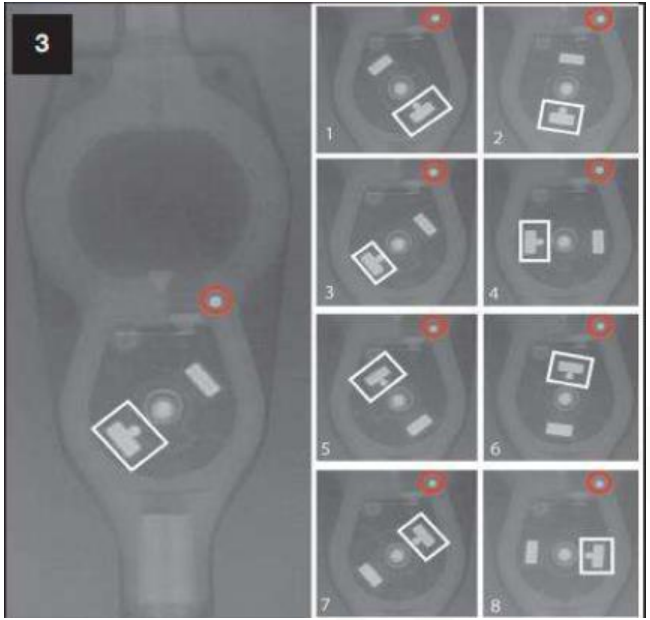
Artifacts induced by the CI internal magnet compromised the diagnosis of ipsilateral brain lesions under 1.5-T MRI. Auditory performance in the CI recipients who had major events was unaffected.

CONCLUSIONS AND RELEVANCE Even with protective head bandages, 1.5-T MRI in patients with CIs led to a variety of adverse events, including discomfort or pain and displacement of the internal magnet. Therefore, sedation and careful head positioning may be appropriate for some patients with CIs who undergo MRI, and these patients should be carefully monitored to decrease the likelihood of such adverse effects.

Torque effect – internal magnet wants to align with the external magnetic field

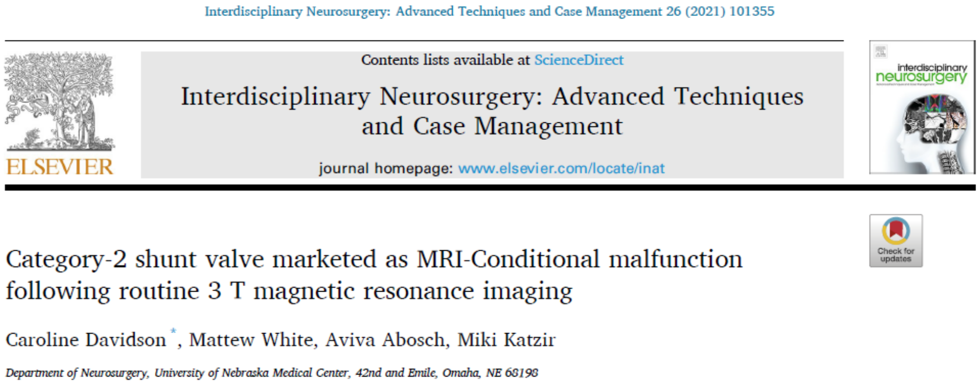


Static field – device malfunction



- **Codman Certas Plus** programmable shunt marketed as MRI conditional with effectively 0% risk of MRI scan changing the valve setting
- But, manufacturers still recommend checking post-scan in the MR conditions
- Is this just the manufacturer "covering themselves" or is there a tangible risk the valve setting may change??

Static field – device malfunction



Interdisciplinary Neurosurgery: Advanced Techniques and Case Management 26 (2021) 101355

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journal homepage: www.elsevier.com/locate/inat

ELSEVIER

Category-2 shunt valve marketed as MRI-Conditional malfunction following routine 3 T magnetic resonance imaging

Caroline Davidson*, Mattew White, Aviva Abosch, Miki Katzir

Department of Neurosurgery, University of Nebraska Medical Center, 42nd and Emile, Omaha, NE 68198

- Day after scan, patient (35 year old female) experienced epileptic seizures
- Shunt could not be interrogated or reprogrammed by external programmer
- CT scan revealed valve setting had changed from setting of 4 to 7 → over-draining CSF
- Emergency surgical replacement of shunt performed

Similar effects can occur in cardiac implanted electronic devices (CEIDs) and other “active implants” → Static field of MRI scanner affecting device performance post-scan

Radiofrequency field (RF) – electrode heating

Permanent Neurological Deficit Related to Magnetic Resonance Imaging in a Patient with Implanted Deep Brain Stimulation Electrodes for Parkinson's Disease: Case Report

OBJECTIVE AND IMPORTANCE: Deep brain stimulation (DBS) is an accepted treatment for patients with Parkinson's disease refractory to medication. The efficacy of this therapy has led to increasing numbers of patients receiving DBS implants. Importantly, physicians caring for patients with implantable neurostimulators must be aware of treatment guidelines for these patients, including the use of therapeutic ultrasound, diathermy, and imaging studies such as magnetic resonance imaging (MRI).

CLINICAL PRESENTATION: We describe a case of serious, permanent neurological injury secondary to a radiofrequency lesion produced by heating of a DBS electrode associated with MRI of the lumbar spine in a patient with Parkinson's disease.

INTERVENTION: MRI may be performed safely in patients with DBS devices only by following the specific guidelines of the manufacturer. The generalization of these conditions to other neurostimulation system positioning schemes, other scanners, and other imaging scenarios can lead to significant patient injuries.

CONCLUSION: To prevent catastrophic incidents, the manufacturer's guidelines should be followed carefully because they are known to result in the safe performance of MRI examinations of patients with neurostimulation systems used for DBS.

KEY WORDS: Deep brain stimulation, Magnetic resonance imaging, Neurostimulation, Parkinson's disease

Neurosurgery 57:1063, 2005 DOI: 10.1227/01.NEU.0000180810.16964.3E www.neurosurgery-online.com

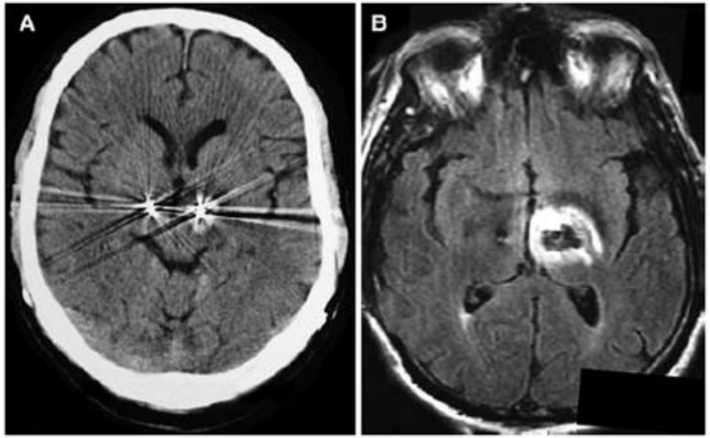


FIGURE 1. A, *computed tomographic scan performed immediately after the lumbar spine MRI scan revealed evidence of a hemorrhage surrounding the left DBS electrode.* B, *T2-weighted MRI scan of the brain showing edema around the left DBS electrode.*

Radiofrequency field (RF) – implanted device heating

- Max temperature rise occurs at ends of conductor when length is **approximately** equal to half the wavelength, λ
- $\lambda \propto 1/\sqrt{\varepsilon_r}$, where ε_r is the relativity electrical permittivity (also known as the dielectric constant)

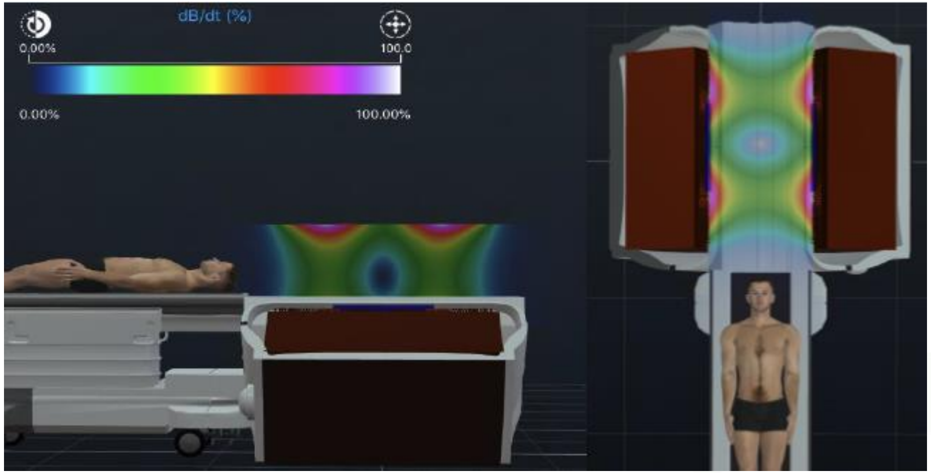
	Air (ε_r = 1)	**Representative value for tissue (ε_r = 81)**
64 MHz	$\lambda/2$= 235 cm	$\lambda/2$ = 26 cm
128 MHz	$\lambda/2$= 118 cm	$\lambda/2$ = 13 cm

ASTM F2182

- Weak dependence of λ with tissue conductivity, σ
- Variation of ε_r and σ with different tissue types and RF freq
- Additionally effects of implant geometry and any insulation material

Summary – dimensions of implanted device determine how much heating occurs at each field strength

Imaging gradients (dB/dt)



mriquestions.com

- dB/dt is the rate of change of the gradient magnetic field
- The diagram shows where maximum dB/dt values occur within the bore
- Electrical currents are induced in metallic devices and these are largest when:
  - The device is located at a dB/dt "hot spot"
  - The device has a large conducting surface
  - The device has a planar surface that is perpendicular to dB/dt

dB/dt is what matters most for device testing but manufacturers of devices nearly always quote gradient slew rate (T/m/s) → look-up tables required to convert

Imaging gradients (dB/dt) – device malfunction

SHORT COMMUNICATION

doi:10.1093/europace/eup162
Online publish-ahead-of-print 25 June 2009

Unexpected asystole during 3T magnetic resonance imaging of a pacemaker-dependent patient with a 'modern' pacemaker

J. Rod Gimbel*

- Patient with non-MR conditional pacemaker undergoing head MRI at 3T using Tx/Rx head coil
- Prescan checks all ok, device set to non-sensing mode prior to scan
- Immediately on starting the scan, asystole (or "flatline") ensued – scan aborted and pacing resumed
- Rule out B_0 and RF (why??) → gradient-induced malfunction?

How do we manage risks associated with implants?

- Implant manufacturers
  - ASTM (American Society for Testing and Materials) device testing → rigorous tests for response to devices to the 3 x magnetic fields
  - Establish MR conditional limits
  - Issue updates and safety alerts if/when a change is required based on reported incidents
- MRI scanner manufacturers
  - MR Equipment Output Conditioning → MR operator must be able to specify output limits of the MR scanner in line with the MR conditional labelling implanted devices
  - MR scanner "About function" and manual must specify location of max spatical gradient, max gradient amplitude, max slew rate, RF transmit profile, etc

What about us (i.e. the MR referrers, radiographers, radiologists, physicists)?

Referrer training, CPD, international best-practice, strict adherence to policies, etc.

Staff with implanted devices

All **staff** with implanted cardiac pacemakers, auto-defibrillators, diaphragmatic pacemakers, or any other electro-mechanically activated device upon which personnel are dependent are **precluded** from the MR Scanner Room unless otherwise advised (risk / benefit analysis required)

All staff should complete a **MRI screening form** if they are required to enter the MRI scanner room. Any update in health status / information provided on the form should be revealed to MRI staff straight away to allow a risk/benefit analysis to be performed.

MRI safety guidelines, structure and policies…

Sláinte Leanaí Éireann

CHI

Children's Health Ireland

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Why do incidents and near misses still occur in MRI?

Lack of sufficient:

- safety policies, procedures, risk assessments
- training / understanding of the risks (**MRI staff, referrers and association groups**)
- clear designation of MR safety roles
- MRI safety structure in hospital / organisation
- proper inspection, servicing and maintenance of MR equipment

Documentation, Training, Testing

Polices and Procedures

- MRI safety procedures (local rules)
- Implant policies (active / non-active)
- MRI access policy
- Training policy (multiple levels of training →…)
- MRI risk assessments (acoustic noise, cryogens, heating, fire, projectiles, pregnancy, contrast agents, staff EMF, etc

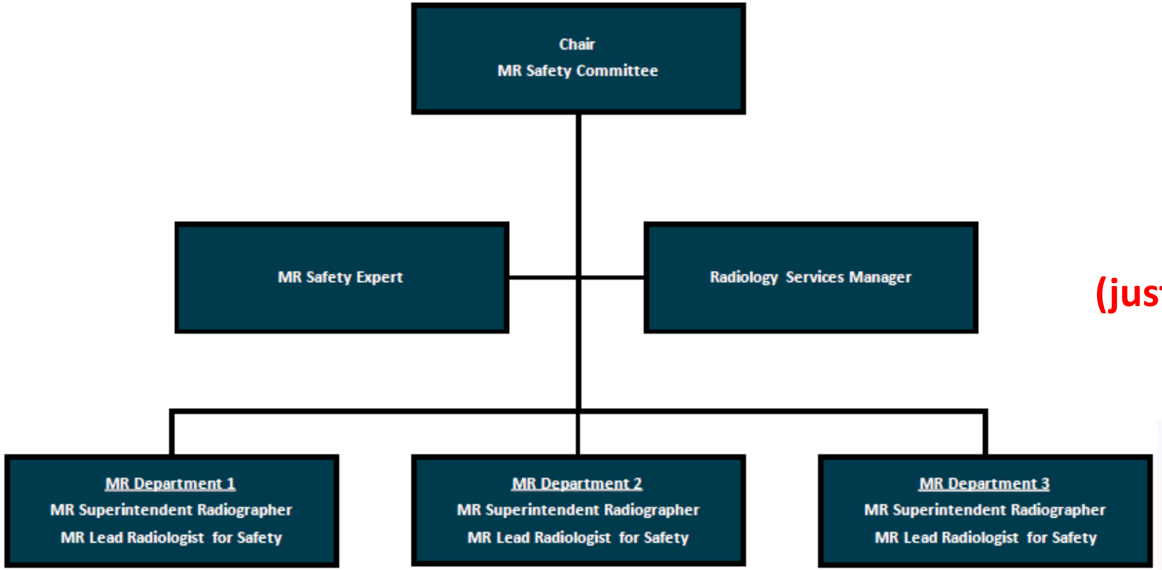
Training

- Basic MRI safety training (minimum requirement for access to MRI)
- Implant safety training (radiographers, radiologists, referrers)
- Scanner specific training (e.g. how to manage SAR limits, scanning within conditional limits of implants, etc)

Scanner QA / testing / optimisation

- Daily check
- Weekly (RF coils)
- Annual (full scanner check, allocate time!)
- Validation and implementation of new techniques (e.g. AI/deep-learning methods)

Safety structure and allocation of roles

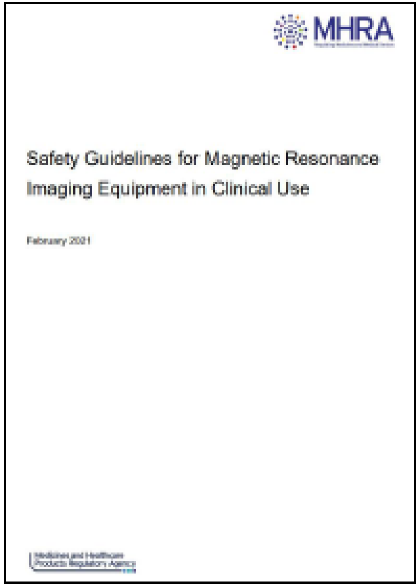


(just an example…)

MR Safety Committee should feed up to hospital risk management, may form part of Radiation Safety Committee, Non-Ionising Radiation Safety Committee, etc)

Guidelines and Publications

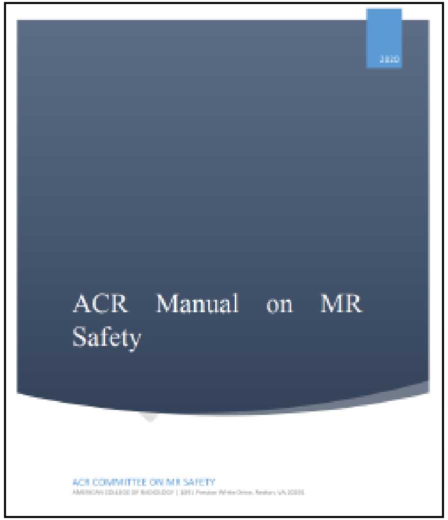
- Just to mention a couple…


MHRA

Safety Guidelines for Magnetic Resonance Imaging Equipment in Clinical Use

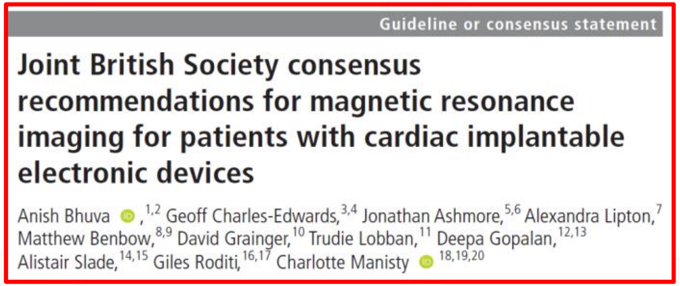
February 2021

Medicines and Healthcare Products Regulatory Agency


2020

ACR Manual on MR Safety

ACR COMMITTEE ON MR SAFETY


Guideline or consensus statement

Joint British Society consensus recommendations for magnetic resonance imaging for patients with cardiac implantable electronic devices

Anish Bhuva,[1,2] Geoff Charles-Edwards,[3,4] Jonathan Ashmore,[5,6] Alexandra Lipton,[7] Matthew Benbow,[8,9] David Grainger,[10] Trudie Lobban,[11] Deepa Gopalan,[12,13] Alistair Slade,[14,15] Giles Roditi,[16,17] Charlotte Manisty [18,19,20]