Magnetic Resonance Imaging: Health Effects and Safety

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ABSTRACT

Magnetic Resonance Imaging (MRI) is one of the most rapidly advancing diagnostic imaging tools today. Hazards intrinsic to the MR environment must be understood, acknowledged and respected. MRI is safe, but if something goes wrong, it can go very wrong. MRI-related accidents do happen, however they were not reported in most countries, including Malaysia. There are several safety issues to be considered by the radiologists, clinicians, radiographers, nurses and medical physicists involving with MRI examinations. These include those related to the magnetic field, gradient magnetic fields, and radiofrequency (RF) magnetic fields. This paper reviews the health effects and current safety issues related to MRI environment for both the patients as well as the staff members. Injuries from MRI accidents are occurring more frequently now and there is an urgent need for MRI facilities to implement safety guidelines. We propose several safety recommendations for implementation by the MRI facilities and the health authority.

INTRODUCTION

Magnetic resonance imaging (MRI) is one of the most rapidly advancing imaging techniques available today. It is normally used to produce detailed sectional images of the body in any imaging plane. Compared to the x-ray based medical diagnostic techniques e.g. general radiography, positron emission tomography (PET) and computed tomography (CT), MRI does not employ ionising radiation but uses radiofrequency (RF) fields. Therefore, the modality is considered to have less health effects than the ionising radiation-based imaging modalities.

As a start, let’s review your knowledge of MRI health effects and safety. How would you answer the following questions?

1. What advice would you give to a medical doctor about scanning a pregnant woman?
2. Can a pregnant staff member enter the MRI scanning room?
3. What procedures would you advise if a patient suffers from cardiac arrest in the MRI scanning room?

If you are uncertain in answering these questions then you are advised to review your understanding of MRI health effects and safety. There are many excellent books and review papers on MRI health effects and safety [1-12].
HEALTH EFFECTS

The potential benefits of MRI are numerous. However, there are hazards intrinsic to the MR environment which must be understood, acknowledged and respected. In general, during MR diagnostic imaging and spectroscopy, patient being scanned and those individuals in the immediate vicinity of the equipment can be exposed to three types of magnetic fields simultaneously:

- The static (main) magnetic fields
- Time-varying magnetic field gradients
- Radiofrequency (RF) magnetic fields

The hazards caused by these fields can affect patients, staff and other persons within the magnetic field environment.

Several incidents involving MR have been reported in ECRI Health Device Alerts (HDA), U.S. Food and Drug Administration (FDA) Medical Device Reporting (MDR). Below are some examples from the database:

- “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 (2001)”

- “A patient with an implanted cardiac pacemaker died during or shortly after an MR exam. The coroner determined that the death was due to the interruption of the pacemaker by the MR system (1989)”

- “A patient with an implanted intracranial aneurysm clip died as a result of an attempt to scan her. The clip reportedly shifted when exposed to the magnetic field. The staff apparently had obtained information indicating that the material in this clip could be scanned safely (1992)”

- “A patient complained of double vision after an MR exam. The MR exam as well as an x-ray revealed the presence of metal near the patient's eye. The patient was sedated at the time of the exam and was not able to inform anyone of this condition (1993)”

- “A patient received blistered burns on the finger where a pulse oximeter was attached during MR scanning. A skin graft was required to treat the affected area (1995)”

MRI is safe, but if something goes wrong, it can go very wrong. MRI-related accidents do happen, however they were not reported in most countries, including Malaysia. Lack of uniform safety rules and negligence in screening of the patients and staff contribute towards this unfortunate situation. Anecdotal accounts abound, only the fatal accidents make it to the mass media and the professional journals.
Effects of Static Magnetic Field \((B_s)\)

The static or main magnetic field is used to align the nuclei in patient’s body. This powerful static magnetic field is always present even when the MR scanner is not imaging. The strengths of the static magnetic fields used in clinical and research MR systems for imaging and/or spectroscopy range from 0.012 T to more than 10 T compared to the 50 mT of the earth magnetic field. According to FDA, clinical basis for safety is for static magnetic field strength of up to 2 T. However, above this level, evidence of safety must be provided by the sponsor or device manufacturer prior to routine clinical use [1].

There are two major safety issues regarding the static magnetic fields used in MR: attraction of ferromagnetic material towards the magnet and biological changes.

Devices made from ferromagnetic material such as surgical tools (e.g. aneurism clips scissors and haemostats) and certain components of implantable medical devices (e.g. prostheses, pacemakers and neuro-stimulators) will be attracted to the core of the main magnet and this effect is known as projectiles. Anyone or anything in the direct path of the object may be struck as the object moves toward the magnet. Individuals in or near the MR system could be seriously injured by the effect. In addition, the object, the MR system, or other equipment in the room could be damaged. For some sensitive devices such as physiological monitoring instruments and pacemaker, permanent damage may occur when exposed to certain level of magnetic fields. Furthermore, the implantable device such as pacemaker may experience a torque, which is sufficient to cause displacement in the body. Even devices such as sandbag that might appear safe have become projectile in the MR environment. This is because some sandbag contains ferromagnetic pallet to add weight to the bag without increasing its size.

The biological effects of static magnetic fields is one of the most controversial topics in the field of MR safety. It have been reported in several literature that several structures within humans are affected by the static magnetic fields such as the retina, pineal gland, and some cells in the parasal sinuses. However, the effects are not the same as harmful, or teratogenic/carcinogenic [2, 10]

Effects of Time-varying Magnetic Field \((dB/dt)\)

Time-varying magnetic field gradients in MR system functions to provide position dependent variation in magnetic field strength. The gradients are pulsed during and between RF excitation pulses. The faster the sequence of imaging or spectroscopy, the greater the gradient fields change rate.

The main safety concerns with the time-varying magnetic field gradients are biological effects and acoustic noise. Subjecting the human body to time-varying magnetic fields leads to induced electric fields and circulating currents in conductive tissues. At any particular location, the currents induced will be determined by the rate of change of the magnetic field and the local distribution of the body impedance, which is primarily resistive at frequencies below about 1 MHz.
At frequencies above 1 MHz, a reactive element begins to be significant and at frequencies above about 30 MHz, the wavelength begins to influence the electric field and current distribution. The time-varying field gradients employed in MR scanners are of relatively low frequency when compared, for example, to RF fields and microwaves.

Time-varying magnetic fields induce electric currents that could be sufficiently large in tissues to interfere with the normal function of nerve cells and muscle fibres. One example of this is the sensation of flashes of light, caused by induced electric currents stimulating the retina. However, this effect has not been shown to be harmful. A more serious response to electric currents flowing through the body is that of ventricular fibrillation.

As the gradient coils are switched on and off during image acquisition, a significant amount of acoustic noise will be generated in the bore of the magnet. This noise occurs during rapid alterations of currents within the gradient coils. These currents, in the presence of a strong magnetic field produce significant forces that act upon gradient coils and produce noise. The noise is manifested as loud tapping, knocking, or chirping sounds.

Change in the gradient output (rise time or amplitude) caused by modifying the MR imaging parameters will cause the level of gradient-induced acoustic noise to vary. This noise is enhanced by decreases in section thickness, field of view (FOV), repetition time, and echo time. Temporary hearing loss has been reported using conventional sequences. [3]

**Effects of Radiofrequency Fields**

Radiofrequency (RF) pulses are used in MR imaging for the excitation of the nuclei. RF fields may interact with both tissues and foreign bodies, such as metallic implants. During the imaging process, the majority of RF power is transformed into heat within the patient’s tissue. Absorption of energy from RF fields by tissues results in generation of heat due to resistive losses. This local heating will be dissipated by the tissues. This ohmic heating of tissue is greatest at the surface and minimal at the centre of the patient’s body.

The thermal characteristics of different organs and parts of organs are different. Limbs will dissipate thermal energy more rapidly than internal parts of the abdomen. The eyes are an example of an organ that have very little blood flow, therefore, takes time to dissipate thermal energy. The testes which is separated from the main volume of the body is regarded as heat sensitive.

A rise of 1°C is generally acceptable to a normal healthy body. The actual temperature rise at any time depends on the balance between the energy absorbed and the energy transferred from the region of the body concerned. The ambient temperature and humidity play a major role in the rate of dissipation. The lower the ambient temperature and the lower the humidity the greater the transfer.

The rate of RF deposition is represented in terms of specific absorption ratio (SAR) which is normally measure in W kg⁻¹. The SAR actually is the mass normalized rate at which RF power is coupled to biological tissues. For a given pulse sequence, the SAR is dependent
upon the radiation, amplitude, and number of RF pulses during each repetition time of the
sequence.

A pulsed RF field can also induce a current in a coil made from loop of wire. The current
could cause localized heating of the wire which may cause patient’s skin burns. These burns
could be caused by heating of the loop or by conductive effects between loop and the
patient’s skin.

RF field may also cause athermal field-specific changes in biological systems that are
produced without increase elevation in temperature. However, these effects are not well
understood and have not been studied in association with the use of MR systems [4].

SAFETY RECOMMENDATIONS

Main Magnetic Fields

There is no adverse effects have been found from whole-body exposure up to 2 T and of the
extremities to 5 T. However for the patient scanned with static magnetic field greater than 2
T, the International Radiation Protection Association (IRPA) has suggested that the patients
should be monitored for symptoms referable to the nervous system [5].

Although no deleterious biologic effects from the static magnetic fields used in MRI have
been definitively associated with MRI’s static magnetic fields, there is no conclusive answer
yet for this effect. Researches are still continued in this area using various animal models and
at various magnetic field strengths.

In order to prevent accidents caused by projectile, all equipment brought into the scanning
room such as anaesthetic trolleys, wheelchairs, and patient trolleys, must be ensured to be
non-ferromagnetic. The installation of a metal detector which everybody has to pass through
before entering the MR suite is highly recommended [1].

Some examples of medical devices and materials that could be dangerous in MR environment
are as follow:

<table>
<thead>
<tr>
<th>Examples of devices that may contain ferromagnetic materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>· Aneurism Clips</td>
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<tr>
<td>· Biopsy Needles, markers, and devices</td>
</tr>
<tr>
<td>· Breast Tissues expanders and implants</td>
</tr>
<tr>
<td>· Bone and spinal fusion stimulators</td>
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<tr>
<td>· Cardiac pacemakers</td>
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<tr>
<td>· Cochlear implants</td>
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<tr>
<td></td>
</tr>
<tr>
<td>· Carotid artery vascular clamps</td>
</tr>
<tr>
<td>· ECG electrodes</td>
</tr>
<tr>
<td>· Hearing aids</td>
</tr>
<tr>
<td>· Heart valve prosthesis</td>
</tr>
<tr>
<td>· Dental implants, devices and materials</td>
</tr>
<tr>
<td>· Tattoos and permanent make-up</td>
</tr>
</tbody>
</table>

It is also advisable that all nursing, housekeeping, fire department, emergency and MR personnel be educated to the potential risks and hazards of the static magnetic field. Signs should be posted to prevent possible entry into the scan room with ferromagnetic objects. Constant education of everybody involved is also vital. It is essential that every individuals involve with MR have a thorough understanding of the possibility of danger of the powerful magnetic fields of MRI.

**Time-varying Magnetic Fields**

Clinical experience indicates that no adverse effects are to be expected when the rate of change of magnetic flux density does not exceed 6 T s\(^{-1}\). However, patients with changes in the electrocardiogram (ECG) indicative of abnormalities in conduction may particularly susceptible to exposure to magnetic fields. Therefore, an assessment of cardiac function should be made when exposures above 6 T s\(^{-1}\) are contemplated, and the patient’s cardiovascular function should be monitored during exposure above 6 T s\(^{-1}\). [5]

In order to reduce the acoustic noise caused by the gradient field, the use of earplugs of headphones, ear defenders, or other means of hearing protection is highly recommended.

A reduction of acoustic noise levels may also be achieved by decreasing the level of gradient pulsing in an imaging sequence.

Recent advances in digital signal processing technology allow efficient active noise control system. The system continuously sampling the sounds in the noise environment so that the gradient magnetic field-induced noise is attenuated. [3]

**Radiofrequency Fields**

In MR exposures up to 1 hour, the total body exposure should be limited to a total energy deposition of 120 W min kg\(^{-1}\) in order not to overload the thermoregulatory system. To avoid overheating of any local area, the product of time and local SAR should not exceed:

- 60 W min kg\(^{-1}\) averaged over the head, or
- 120 W min kg\(^{-1}\) averaged over the trunk, or
- 180 W min kg\(^{-1}\) averaged over extremities, provided that the instantaneous SAR does not exceed:
  - 4 W kg\(^{-1}\) averaged over the head, or
  - 8 W kg\(^{-1}\) averaged over the trunk, or
  - 12 W kg\(^{-1}\) averaged over extremities

To protect poorly perfused tissues such as the eye, the tissues should not be exposed to a local SAR of more than 10 W kg\(^{-1}\), average over 0.01 kg for more than 10 min.
For exposures of infants, pregnant women, or persons with cardio-circulatory and/or cerebral vascular impairment, a reduction of these values by a factor of two is recommended. For an RF-emitting surface coil, the average should be taken over the volume affected by the coil. [5]

When utilizing surface coils, the operator must be careful to prevent any electrically conductive material (i.e. cable of surface coil) form a "conductive loop" with itself or with the patient. Tissue or clothing could potentially be ignited by uninsulated cables. Coupling of a transmitting coil to a receive coil may also cause severe thermal injury. [4]

ANSWERS TO THE QUESTIONS POSED

1. What advice would you give to a medical doctor about scanning a pregnant woman?

If it is avoidable, don't scan her in the first trimester. This is precautionary advice only. There is no good evidence that the mammalian embryo or foetus suffers any detrimental effect when subjected to static magnetic fields of the MR scanner. There is some equivocal data that suggest that the developing chick embryo is sensitive to prolonged exposure to weak gradient magnetic fields.

There is still the acoustic noise question. The development of hearing in the foetus occurs after 24 weeks and the noise of the scans might pose risk to the development of the hearing of the child. The mother's heart sounds are actually very loud already for the foetus because there is very good propagation of sound from the heart to the womb.

These guidelines are currently being reviewed by the MR community.

2. Can a pregnant staff member enter the MRI scanning room?

Yes. But they should be given the option to stay out of the inner Controlled Area during the first trimester. It is considered prudent to exclude all pregnant women from the scanning room containing the magnet (Inner Controlled Area) during the first three months of pregnancy. These guidelines are currently being reviewed by the MR community.

3. What procedure would you advise if a patient suffers from cardiac arrest in the MRI scanning room?

Begin resuscitation, call the resuscitation team and get the patient out of the inner controlled area as soon as possible.

The resuscitation equipment used in the event of cardiac arrest can be extremely dangerous in an MR environment, and should never be taken into the scanning room. In the event of a cardiac arrest, resuscitation should begin immediately, but priority then moves to getting the patient out of the scan room so that resuscitation can occur without risk of further disaster due to unscreened medical personnel or equipment entering the scanning room. An MR
compatible patient trolley should be kept in the scanning room to enable swift evacuation of the patient.

OUR RECOMMENDATIONS

- Several incidents and accidents had already occurred in Malaysia, however these were not documented and reported to the Ministry of Health. A standardised system of incident and accident reporting should be formulated and implemented.

- The authority must establish MRI safety guidelines for all MRI centres. Written procedures for screening of patients must be available, read and understood by all authorised persons. An example of MR procedure screening form for patients is given in Appendix 1 [11]

- MRI facilities should have their own set of Local Rules, which must be read by all staff (both medical and supporting personnel) who have access to the department. These guidelines are department-specific information about the controlled areas, the designated Responsible Person, and Authorised Personnel. These should be reviewed and audited periodically. An example of Local Rules is shown in Appendix 2 [10].

- Identify a safety officer responsible for ensuring that procedures are in effect and enforced to ensure safety in the MR environment.

- An easily recognised and standardised warning sign is very important in the MRI environment. However, the information shown on the most signs is out-of-date, erroneous, or not displayed prominently enough. Appendix 3 shows two examples of the new proposed signs. [13]

  \[\text{We must not be complacent!} \]
  \[\text{Develop a safety culture in MRI.} \]

REFERENCES


Proceedings of the International Conference on Non-Ionizing Radiation at UNITEN (ICNIR2003)
Electromagnetic Fields and Our Health
20th – 22nd October 2003


Documents of the NRPB 2 (1).


Article excerpted from www.mrisafety.com with permission from Frank G. Shellock, Ph.D.


Article excerpted from Diagnostic Imaging.com with permission of Frank G. Shellock, Ph.D.

Some Useful Websites

American College of Radiology (ACR)
http://www.acr.org

The Emergency Care Research Institute (ECRI)
http://www.ecri.org

Food and Drug Administration (FDA)
http://www.fda.gov

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Proceedings of the International Conference on Non-Ionizing Radiation at UNITEN (ICNIR2003)
Electromagnetic Fields and Our Health
20th – 22nd October 2003

Institute for Magnetic Resonance Safety, Education, and Research (IMRSER)
www.imrser.org

International Commission on Non-Ionizing Radiation Protection (ICNIRP)
http://www.icnirp.de

MRI Safety
http://www.mrisafety.com
# Appendix 1

## MR Procedure Screening Form for Patients [11]

<table>
<thead>
<tr>
<th>MAGNETIC RESONANCE (MR) PROCEDURE SCREENING FORM FOR PATIENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date / / /</td>
</tr>
<tr>
<td>Name</td>
</tr>
<tr>
<td>Last name</td>
</tr>
<tr>
<td>Date of Birth / / /</td>
</tr>
<tr>
<td>Address</td>
</tr>
<tr>
<td>State</td>
</tr>
<tr>
<td>Reason for MRI and/or Symptoms</td>
</tr>
<tr>
<td>Referring Physician</td>
</tr>
</tbody>
</table>

1. Have you had prior surgery or an operation (e.g., arthroscopy, endoscopy, etc.) of any kind? ☐ No ☐ Yes
   If yes, please indicate the date and type of surgery:
   Date / / / Type of surgery

2. Have you had a prior diagnostic imaging study or examination (MRI, CT, Ultrasound, X-ray, etc.)? ☐ No ☐ Yes
   If yes, please list:
   Date / / Facility
   MRI
   CT/CAT Scan
   X-Ray
   Ultrasound
   Nuclear Medicine
   Other

3. Have you experienced any problem related to a previous MRI examination or MR procedure? ☐ No ☐ Yes
   If yes, please describe:

4. Have you had an injury to the eye involving a metallic object or fragment (e.g., metallic slivers, shavings, foreign body, etc.)? ☐ No ☐ Yes
   If yes, please describe:

5. Have you ever been injured by a metallic object or foreign body (e.g., BB, bullet, shrapnel, etc.)? ☐ No ☐ Yes
   If yes, please describe:

6. Are you currently taking or have you recently taken any medication or drug? ☐ No ☐ Yes
   If yes, please list:

7. Are you allergic to any medication? ☐ No ☐ Yes
   If yes, please list:

8. Do you have a history of asthma, allergic reaction, respiratory disease, or reaction to a contrast medium or dye used for an MRI, CT, or X-ray examination? ☐ No ☐ Yes

9. Do you have anemia or any disease(s) that affects your blood, a history of renal (kidney) disease, or seizures? ☐ No ☐ Yes
   If yes, please describe:

For female patients:

10. Date of last menstrual period: / / / Post menopausal? ☐ No ☐ Yes

11. Are you pregnant or experiencing a late menstrual period? ☐ No ☐ Yes

12. Are you taking oral contraceptives or receiving hormonal treatment? ☐ No ☐ Yes

13. Are you taking any type of fertility medication or having fertility treatments? ☐ No ☐ Yes
   If yes, please describe:

14. Are you currently breast feeding? ☐ No ☐ Yes

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WARNING: Certain implants, devices, or objects may be hazardous to you and/or may interfere with the MR procedure (i.e., MRI, MR angiography, functional MRI, MR spectroscopy). Do not enter the MR system room or MR environment if you have any question or concern regarding an implant, device, or object. Consult the MRI Technologist or Radiologist BEFORE entering the MR system room. The MR system magnet is ALWAYS on.

Please indicate if you have any of the following:

☐ Yes ☐ No Aneurysm clip(s)
☐ Yes ☐ No Cardiac pacemaker
☐ Yes ☐ No Implanted cardioverter defibrillator (ICD)
☐ Yes ☐ No Electronic implant or device
☐ Yes ☐ No Magnetically-activated implant or device
☐ Yes ☐ No Neurostimulation system
☐ Yes ☐ No Spinal cord stimulator
☐ Yes ☐ No Internal electrodes or wires
☐ Yes ☐ No Bone growth/bone fusion stimulator
☐ Yes ☐ No Cochlear, otoologic, or other ear implant
☐ Yes ☐ No Insulin or other infusion pump
☐ Yes ☐ No Implanted drug infusion device
☐ Yes ☐ No Any type of prosthesis (eye, penile, etc.)
☐ Yes ☐ No Heart valve prosthesis
☐ Yes ☐ No Eyelid spring or wire
☐ Yes ☐ No Artificial or prothetic limb
☐ Yes ☐ No Metallic stent, filter, or coil
☐ Yes ☐ No Shunt (spinal or intracranial)
☐ Yes ☐ No Vascular access port and/or catheter
☐ Yes ☐ No Radiation seeds or implants
☐ Yes ☐ No Swan-Ganz or thermomodulation catheter
☐ Yes ☐ No Medication patch (Nicotine, Nitroglycerine)
☐ Yes ☐ No Any metallic fragment or foreign body
☐ Yes ☐ No Wire mesh implant
☐ Yes ☐ No Tissue expander (e.g., breast)
☐ Yes ☐ No Surgical staples, clips, or metallic sutures
☐ Yes ☐ No Joint replacement (hip, knee, etc.)
☐ Yes ☐ No Bone joint pin, screw, nail, wire, plate, etc.
☐ Yes ☐ No IUD, diaphragm, or pessary
☐ Yes ☐ No Dentures or partial plates
☐ Yes ☐ No Tattoo or permanent makeup
☐ Yes ☐ No Body piercing jewelry
☐ Yes ☐ No Hearing aid

(Remove before entering MR system room)

☐ Yes ☐ No Other implant
☐ Yes ☐ No Breathing problem or motion disorder
☐ Yes ☐ No Claustrophobia

Please mark on the figure(s) below the location of any implant or metal inside of or on your body.

IMPORTANT INSTRUCTIONS

Before entering the MR environment or MR system room, you must remove all metallic objects including hearing aids, dentures, partial plates, keys, beeper, cell phone, eyeglasses, hair pins, barrettes, jewelry, body piercing jewelry, watch, safety pins, paperclips, money clip, credit cards, bank cards, metallic strip cards, coins, pens, pocket knife, nail clipper, tools, clothing with metal fasteners, & clothing with metallic threads.

Please consult the MRI Technologist or Radiologist if you have any question or concern BEFORE you enter the MR system room.

NOTE: You may be advised or required to wear earplugs or other hearing protection during the MR procedure to prevent possible problems or hazards related to acoustic noise.

I attest that the above information is correct to the best of my knowledge. I read and understand the contents of this form and had the opportunity to ask questions regarding the information on this form and regarding the MR procedure that I am about to undergo.

Signature of Person Completing Form: ____________________________ Date __________ / __________ / __________

Form Completed By: ☐ Patient ☐ Relative ☐ Nurse ____________________________ Print name ____________________________ Relationship to patient ____________________________

Form Information Reviewed By: ____________________________ Print name ____________________________ Signature ____________________________

☐ MRI Technologist ☐ Nurse ☐ Radiologist ☐ Other ____________________________

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MAGNETIC RESONANCE (MR) ENVIRONMENT SCREENING FORM FOR INDIVIDUALS*

The MR system has a very strong magnetic field that may be hazardous to individuals entering the MR environment or MR system room if they have certain metallic, electronic, magnetic, or mechanical implants, devices, or objects. Therefore, all individuals are required to fill out this form BEFORE entering the MR environment or MR system room. **Be advised, the MR system magnet is ALWAYS on.**

*NOTE: If you are a patient preparing to undergo an MR examination, you are required to fill out a different form.

<table>
<thead>
<tr>
<th>Date (month/day/year)</th>
<th>Name (Last Name, First Name, Middle Initial)</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Address</td>
<td>Telephone (home) (______)</td>
<td></td>
</tr>
<tr>
<td>City</td>
<td>Telephone (work) (______)</td>
<td></td>
</tr>
<tr>
<td>State</td>
<td>Zip Code</td>
<td></td>
</tr>
</tbody>
</table>

1. Have you had prior surgery or an operation (e.g., arthroscopy, endoscopy, etc.) of any kind? □ No □ Yes
   If yes, please indicate date and type of surgery: Date / / Type of surgery __________________________

2. Have you had an injury to the eye involving a metallic object (e.g., metallic slivers, foreign body)? □ No □ Yes
   If yes, please describe: ____________________________________________________________

3. Have you ever been injured by a metallic object or foreign body (e.g., BB, bullet, shrapnel, etc.)? □ No □ Yes
   If yes, please describe: ____________________________________________________________

4. Are you pregnant or suspect that you are pregnant? □ No □ Yes

**WARNING:** Certain implants, devices, or objects may be hazardous to you in the MR environment or MR system room. **Do not enter the MR environment or MR system room if you have any question or concern regarding an implant, device, or object.**

### Important Instructions

Remove all metallic objects before entering the MR environment or MR system room including hearing aids, deceased, cell phone, keys, eyeglasses, hair pins, barrettes, jewelry (including body piercing jewelry), watch, safety pins, paper clips, money clip, credit cards, bank cards, magnetic strip cards, coins, peas, pocket knife, nail clipper, steel-toed boots/shoes, and tools. Loose metallic objects are especially prohibited in the MR system room and MR environment.

Please consult the MRI Technologist or Radiologist if you have any question or concern BEFORE you enter the MR system room.

I attest that the above information is correct to the best of my knowledge. I have read and understand the entire contents of this form and have had the opportunity to ask questions regarding the information on this form.

Signature of Person Completing Form: __________________________ Date / /

Form Information Reviewed By: __________________________ Signature

□ MRI Technologist □ Radiologist □ Other __________________________

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Appendix 2

Basic Local Rules for Magnetic Resonance [From Martin and Sutton, Ref. 10]

In view of the demanding electromagnetic environment associated with MR equipment, such equipment should be located within a designated controlled area where free access is provided only to authorized staff.

- It is recommended that the 0.5 mT contour is entirely within the controlled area.
- Access to the controlled area should be through self-closing and self-locking doors.
- All unauthorized persons must be medically screened and warned of potential hazards (projectile effect, malfunctioning of some devices in the presence of a magnetic field), before entering the controlled area.
- Unauthorized persons include:
  - support staff (engineering staff, nurses, portering staff, cleaning staff, emergency services staff) who should be aware of the potential hazards and should be appropriately trained
  - patients
  - volunteers for research projects who should be fully informed and have given consent
  - the general public (visitors, patients’ relations or friends).
- Patients, volunteers, and the general public must be supervised by authorized staff at all times within the controlled area.
- Persons fitted with a heart pacemaker must not enter the controlled area.
- It is also convenient to define an inner controlled area containing the 3 mT contour.
- All persons entering this area should remove items such as watches, credit cards, and all ferromagnetic objects from their clothing and deposit them outside the area before entering.
- No ferromagnetic object (tools, gas cylinders, trolleys, etc.) must be allowed in this inner area.
- Persons with any metallic implant should be forbidden to enter the inner controlled area until the implant has been declared safe by a suitably qualified person.
- Persons with intracranial aneurism clips or intraorbital metallic implants should not enter the inner controlled area.
- Persons with metallic implants such as artificial joints, surgical clips, or prosthetic cardiac valves need not be excluded from MR procedures but care must be taken and the procedure terminated if discomfort or heating is experienced. A large database regarding MR compatibility and safety of implants has been compiled.
- It is prudent to exclude women in the first trimester of pregnancy from the inner controlled area.

Procedures for dealing with emergency situations such as cardiac arrest should be defined. Resuscitation equipment must not be taken into the inner controlled area and support staff must be fully informed of such procedures. Care should be taken in attaching physiological monitoring equipment to the patient. High-impedance leads should be used and displays/recorders should be outside the 3 mT contour. Loops of cables should be avoided since these can lead to overheating and local burning. Adverse incidents arising from the use of MR equipment should be reported to the Medical Devices Agency.
Appendix 3

New MR safety warning sign designed to help control access to the MR environment. This sign should be placed on the door to the MR system room. [13]

![DANGER! Restricted Access](image)

**STRONG MAGNETIC FIELD**
The Magnet is Always On!

- **NO CARDIAC PACEMAKERS OR IMPLANTABLE CARDIOVERTER DEFIBRILLATORS (ICDs)**
  Persons with certain metallic, electronic, magnetic, or mechanical implants, devices, or objects may not enter this area. Serious injury may result.
  Do not enter this area if you have any question regarding an implant, device, or object. Consult the MRI Technologist or Radiologist.

- **NO LOOSE METAL OBJECTS**
  Objects made from ferrous materials must not be taken into this area. Serious injury or property damage may result. Electronic objects such as hearing aids, cell phones, and beepers may also be damaged.