MRI Safety

Magnetic Fields

Class III
MRI Safety

• When used properly is a very safe diagnostic procedure.
• On the other hand when not used properly becomes the only imaging modality that can kill a patient within seconds.
  – Projectile effect
  – Torque force
  – Burning
  – Cardiac fibrillation
  – Loud noises
  – Asphyxiation
  – Frostbite
  – Pressure
In 2002 the American College of Radiology (ACR) initially publish the "ACR Guidance Document on MR Safe Practices.

It is believed that less than 10% of the MRI related accidents are reported.
MR Safety

• The Food and Drug Administration (FDA) is one of the entities in charge of controlling and set guidelines for evaluating electromagnetic exposure risk for trials of clinical MRI.

• These elements are:
  – The main magnetic field (also known as primary magnet $B_0$)
  – Time varying magnetic field (magnetic field produce by the gradients)
  – Radio frequency fields (created by RF coils, known as secondary or $B_1$ fields)
Magnetic Forces

• Magnetic Forces:
  – Translational (Projectile)
  – Alignment (Torque)

• These forces of depend on several factors:
  – Strength of the magnet
  – Weight of the object
  – Magnetic susceptibility of the object
  – Proximity of the object to the magnet
Magnetic Forces

- Alignment Force (Torque)
Main Magnetic Field

• The FDA limit the static magnetic field strength of clinical imagers:
  – 4 T for babies and infants up to one month of age.
  – 8 T for children and adults.
Main Magnetic Field

• The primary concern with the static magnetic field is the possibility of potential biological effects.
  – Most studies done shows no effects on cell growth and morphology changes at field strength below 2T.
  – Data shows no evidence of leukemia or other carcinogenesis
  – Small electrical potentials have been observed in large blood vessels that flow perpendicular to the static magnetic field.
Static Field Below 2.0T

- Although no biological effects have been observed at field strength below 2T, reversible effects have been noted on ECGs at these field strength.

- An increase in the amplitude of the T wave can be noticed called:
  - Magneto-hemodynamic, or
  - Magneto hydrodynamic effect.
Static Field Above 2.0T

Some other reversible biological effects have been observed on humans exposed to 2T and above.

- Fatigue
- Headaches
- Hypotension
- Irritability
Fringe Field

- Hazards of fringe field are associated with the sitting of the magnet.

   It is recommended that general public limit the exposure of magnetic field strength of 5G.
Main Magnetic Field

• **Zone I**: include the hall ways and areas around the department it is not a restricted area.

• **Zone II**: include the patient waiting area, this area should be monitored for MR patients only.

• **Zone III (warm zone)**: include the MR department itself where only MR personnel is aloud and patients under the supervision of the MR personnel

• **Zone IV (hot zone)**: the scan room itself
Main Magnetic Field

MR system should be sited in a restricted area in which only authorized personnel are allowed.

MR Zones
- Zone I
- Zone II
- Zone III
- Zone IV
MR Zones

- Zone III and IV are restricted areas they should be locked at all times. General public should NOT have access to it.
• The 5 Gauss line is usually defined by a red arc in the 1.5T and differentiate by wood grain and red tape in the 3T.

• The 10 Gauss Yellow taped lines on the floor in Zone IV.
Main Magnetic Field

• It is recommended that the MR department should have limited access to the public in order to avoid accidents.

• Personnel related to MR can be classified in two categories:
  – MR Personnel
  – Non MR Personnel
Non MR Personnel

- **Non MR Personnel**: is the personnel that may be expose to an MR environment but has not been properly train or not trained at all in MR environment.
- This individuals must be supervised at all times by an MR level II, while in Zone III & IV
MR Personnel
Level I

- **MR Personnel**: is the personnel that had been trained to work or respond to an emergency in an MR environment. There are two levels of MR personnel.

  - **Level one MR personnel**: is the one that is trained in an MR environment to protect themselves or anybody else in an MR environment such as environmental services, fire fighters, administration, security officers.
MR Personnel Level II

- Level two MR personnel: is the one fully train in MR environment such as MR technologist, medical director, physicists
- Magnetic Resonance Safety Officer (MRSO) is a level two train staff (MR Technologist)
Patients Dress

• Patient should be encouraged to wear hospital gowns.
  – Purse, wallet, money clip, credit cards, cards with magnetic strips
  – Any article of clothing that has a metal zipper, buttons, snaps, hooks, underwire, or metal threads
  – Electronic devices such as cell phones
  – Hearing aids
  – Metal jewelry, watches
  – Pens, paper clips, keys, coins
  – Hair barrettes, hairpins
  – Shoes, belt buckles, safety pins
Projectiles

- The MRI system has a powerful magnetic field that attracts iron-containing objects, which are also known as ferromagnetic objects.
- The MRI magnet may cause these ferromagnetic objects to move suddenly with great force.
- The MRI magnet is always turned on, even when the machine is not scanning.
- The MRI magnet is so strong that it will pull heavy items, such as, oxygen cylinders, beds, and stretchers into the scanner.
Projectiles

• These objects can become powerful projectiles and can cause serious injury or death.
• Patients and others have been killed in this way

https://youtu.be/7g5UVrOt2CI
Projectiles

• All ferromagnetic objects are removed and not taken into the MRI system area because they can become a flying, moving, dangerous object that can pose a risk for anyone caught in it’s flight path.

• Some ferromagnetic objects are:
  • oxygen tanks
  • Ferromagnetic IV poles
  • cardiac monitors

https://www.youtube.com/watch?v=6BBx8BwLhqg
Other Related Accidents
MRI Equipment

- Equipment that is not ferromagnetic can be brought into the MRI.
- Special non-ferrous material must be used for items such as screwdrivers, fire extinguishers, floor cleaning tools, and IV poles.
- MRI-safe tools are specially labeled.
- Always check with the MRI staff if in doubt.
Medical Equipment

• There are specific criteria by which ancillary devices are deemed MR compatible. They include:

  – FDA approval
  – Manufacturer declaration
  – Prior testing

• Is probably prudent to trust no-one and test each device yourself before risking patient safety.
Electronic Equipment

Most of the electronic equipment should operate at the 10 G line to avoid the main magnetic field to interfere with the equipment functionality.
Wheelchairs
MR Stretchers
Oxygen Tanks

- MR Compatible
Gradient Magnetic field

- The gradient magnetic field most known as **Time Varying Magnetic Field** is produce by the rapid change of the magnetic field produced by the three sets of gradient coils (Gx, Gy, Gz).
- The TVMF indices electrical fields on the patient.
Gradient Magnetic field

- The FDA considers the limit exposure to the TVMF to:

  MR procedures using rates of change (dB/dt) sufficient to produce sever discomfort of painful nerve stimulation.
Gradient Magnetic field

- The best means to address the discomfort of peripheral nerve stimulation is to instruct subjects not to clasp their hands together (nor cross their feet) during scanning because this causes a conductive loop that may potentiate dB/dt effects.
- Subjects should also be instructed to report any tingling, muscle twitching, or painful sensations that might occur during scanning.”
Time Varying Magnetic Field

- The induce current produce by the TMVF is greater in the peripheral tissues as the amplitude of the gradient is higher away from the magnetic isocentre.
Time Varying Magnetic Field

- Gradient switching
  - Higher slew rates increase possibility of current induction

- In MR, there is concern with three particular tissues because they act as conductors:
  - Nerves
  - Blood vessels
  - And muscles
Time Varying Magnetic Field

• Biological effects can be manifest in:
  – Peripheral Nerve stimulation:
    • Vision
      – Stimulated the retinal phosphenes
      – Vision of flashing lights and starts
    • Cutaneus sensations
    • Involuntary muscle contractions
    • Cardiac arrhythmias
  – Acoustic noise
Acoustic Noise

• During an MRI exam, various types of acoustic noises are produced.

• These sounds may cause problems for patient and technologist including:
  – Difficulties in communicating with the patient
  – Scaring the patient
  – Temporary and permanent hearing loss

• The acoustic noise is measure on dB/dt. The FDA limits the acoustic noise to a maximum of 140 dB/dt.
Acoustic Noise

- The easiest way of minimizing noise problems during an MR exam is to encourage the routine use of earplugs by all patients.

- Another alternative is to use MR compatible headphones.
Imaging Factor Affect TVMF

- Sequence type
  - SE Vs. GRE
- Slice Thickness
  - Thinner Vs. Thicker
- Image Matrix
  - High Vs. Low
- Slice Position
  - Straight Vs. Oblique
Radio Frequency Fields

• Exposure to radio frequency occurs during MR examination as the hydrogen nuclei are subject to an oscillating magnetic field.

• Most of the RF power used in MRI is transformed to heat and absorbed by the patients tissues.
Radio Frequency Fields

- Similar to a microwave oven, RF pulses generate heat within the patient’s body and, if not regulated, could cause extensive heating and possible tissue damage.
Radio Frequency Fields

• The excess energy may penetrate the surface of the body and become absorbed by the tissue. The excess energy is dissipated in the form of heat.

• RF heating of tissues is greatest at the skin surface or periphery.

• RF energy has the potential to harm the patient directly if overexposed to energy by raising the patient’s core body temperature.
RF Concerns

• The FDA has a restriction to ensure that too much RF energy is not transmitted into the patient’s body.

• The restriction is called specific absorption rate (SAR).

• SAR is measured in units of watts per kilogram (W/Kg) and regulates the amount of RF energy allowed per kilogram of patient body weight.
Patient Weight

- The SAR is calculated based on the patient weight.
- For SAR measurements to be accurate it is extremely important to enter the correct patient weight and height.
RF Concerns

• All MR system manufactures have SAR limitations for each pulse sequence.

• The FDA allows the manufacturer to either maintain the SAR level less than or equal to a very low value of 4 W/Kg for the whole body, or ensure that any given pulse sequence does not elevate the patient’s temperature by more than 1°C.

• At rest, the approximate basal metabolic rate for humans is 1 w/kg.
Ultra-High Field

• There are several safety considerations associated with field strength higher than 1.5T:
  – Increase in the RF power (SAR)
Magnetic Field Strength

• There are some negative outcomes by going to higher magnetic field strength
  – More artifacts will appear on the image (chemical shift, and motion)
  – Lack of research on implanted devices (Safety)
  – The RF needed to flip the magnetization vector NMV has a higher frequency resulting in a increase of the SAR.

1.0 T

1.5 T

3.0 T
RF Effects

- Areas of concern
  - Eyes
  - Testis
# RF Concerns

<table>
<thead>
<tr>
<th>Area</th>
<th>Dose</th>
<th>Time (minutes)</th>
<th>SAR (Watts/KG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole Body</td>
<td>Averaged over</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>Head</td>
<td>Averaged over</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>Head or Torso</td>
<td>Per gram of tissue</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Extremities</td>
<td>Per gram of tissue</td>
<td>5</td>
<td>12</td>
</tr>
</tbody>
</table>
RF Concerns

- In addition RF energy can harm the patient by coupling energy into coils and cables, causing a burn to the patient’s skin.
Wires in the Magnet

- When electrical conductive material are required within the bore of the magnet:
  - Place thermal insulation between the patient and electrical conductor
  - Keep the electrical conductor from direct contact with the patient
  - Position the leads or wires away from the inner walls of the MRI scanner
MR Equipment

• Equipment used in MRI, such as ECG leads and surface coils, magnet board, should therefore be used with extremely caution.
Patient Position

- It is important to ensure the patient’s tissues do not form large conductive loops.
- Patients should be instructed not to cross their arms or legs in the MRI scanner.
- The use of pads between the surface of the coils and the patient’s skin should be reinforced.
- Large patients must be also insulated from the bore of the magnet by using pads.
Skin Burns

• Other devices to have in consideration are:
  – Metal intradermal patches
  – Metallic leads/probes

• The risk of burn increases with the magnetic field
Skin Burns

- Permanent tattoos in any body part can cause severe skin burn to the patient.
- It is important to take this into consideration, especially if they are recent.
- Special attention to permanent eyeliner when scanning the head.
MRI System Conditions

• For optimum operation of the MR system and patient safety overheat, the ambient temperature should be between 65° and 75°F.

• The relative humidity should remain between 50% and 70%.
Imaging Options SAR

• Coil Type
  – RF Transmitter

• Sequence Combination
  – FSE
  – GRE

• SAR Level
  – Normal Mode
  – First Level
  – Second Level
RF Transmitter-Receiver

Receive-Only Head Coil
(Body Coil Transmits RF)

Transmit-Receive
Head Coil
Sequence Type

- SE
- FSE
- GRE
SAR Level

- Normal Mode
  - Calculate the actual SAR levels
- First Level
- Second Level
  - Permits to scan at higher levels of SAR on the patient (needs closer monitoring from technologist). Some implanted devices are not allowed to be scanned at First or Second level.
Febrile Patients

• Patients having high fever (Specially pediatric patients) should wait to have their MRI done.
• If MRI is an emergency medication can be used to reduce fever.
• RF deposition might increase temperature more and the patient will start to have seizure in the MR Unit.