PATIENT CARE
AND
MRI SAFETY

Module Seven
Biological Considerations

• There are no reported adverse biological effects of extended exposure to MRI.
• However, several inconsequential and reversible effects of electromagnetism can be observed.
Static Magnetic Fields

• Many factors cause a risk when performing MRI on patients with ferromagnetic materials in their body:
  – strength of the static and gradient fields
  – degree of magnetism of the object
  – the mass of the object
  – the geometry of the object
  – the location and orientation of the object
  – the length of time the object has been in
Static Fields Below 2 T

• At fields below 2 T reversible abnormalities have been noted on ECGs.
• An increase in the amplitude of the T-wave due to the magnetohydrodynamic effect.
• When a conductive fluid, such as blood, moves across a magnetic field it results in the system triggering off the T-wave rather than the R-wave.
Heating

• Studies showed that patient exposed to field strengths of 1.5 T:

• 60 minutes - 0.1°C increase in body temperature

• 20 minutes - 0.03°C increase in body temperature
Static Fields above 2.0 T

• Some reversible biological effects observed at 2.0 T and above:
  – fatigue
  – headaches
  – hypotension
  – accounts of irritability
Static Fields above 2.0 T

• Some reversible biological effects observed at 2.0 T and above.
  – The effects of magnetic interaction energy and cell orientation.
  – Certain molecules (such as DNA) and cellular subunits (such as sickled red cells) have magnetic properties that vary with direction.

• FDA has cleared static magnetic field strengths up to 8 Tesla for clinical use in humans as “non-significant risk”.
Screening

- Metallic foreign materials within a patient must be identified before MR imaging.
  - Motion or displacement of these objects may result in injury to the patient.
  - We rely principally on clinical history.
MR Safe

- An item that poses no known hazards resulting from exposure to any MR environment. MR Safe items are comprised of materials that are electrically nonconductive, nonmetallic and nonmagnetic.

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.

• Conditional 1 - 8
MR Unsafe

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

• MR Unsafe 1 & 2

Implanted Devices

- Electrically
- Magnetically
- Mechanically activated and
- Electrically conductive implanted devices
  - Certain implanted devices are not safe for MR imaging.
  - The function of such implants is impaired by the magnetic field, therefore patients with such devices should not be examined with MR.
Equipment

- A wide variety of MR-compatible monitoring devices are available.
- MR-compatible anesthesia machines and respirators are also available.
- An important point is that electronic monitoring devices are no substitute for direct monitoring.
Gradient Magnetic Field (Time-Varying)

- There is concern with nerves, blood vessels, and muscles that act as conductors in the body.

- Faraday’s Law of Induction
  - states that changing magnetic fields induce electrical currents in any conducting medium.
Gradient Magnetic Field (Time-varying)

- Induced currents are proportional to:
  - the material’s conductivity
  - the rate of change of the magnetic field and
  - the radius of the inductive loop.

- This effect is determined by factors such as:
  - pulse duration
  - wave shape
  - repetition pattern
  - the distribution of the current in the body
Biological Effects

• Vary with current amplitude range from:
  – reversible alterations in vision,
  – to irreversible effects of cardiac fibrillation,
  – to alterations in the biochemistry of cells and fracture union.
  – Visual effects may occur when retinal phosphenes are stimulated by induction from TVMF.
Acoustic Noise

• As current is passed through the gradient coils acoustic noise is created.
• Although within recommended safety guidelines, it can cause some reversible and irreversible effects.
• Communication interference, transient and possible permanent hearing loss.
• Earplugs are an acceptable prevention and should be used regularly.
Radiofrequency Fields (RF)

- Exposure to radiofrequency occurs as the hydrogen nuclei are subjected to an oscillating magnetic field.
- As the energy levels of frequencies used is relatively low, the predominant biological effect of RF irradiation absorption is the potential heating of tissue.
Specific Absorption Rate (SAR)

- MR systems cannot measure RF exposure, therefore it is necessary to measure the RF absorption.
- This is manifested as tissue heating and the patient’s ability to dissipate excess heat.
- Energy dissipation can be described in terms of Specific Absorption Rate (SAR).
Specific Absorption Rate (SAR)

• SAR, expressed in Watts/kg, is a quantity that depends on:
  – induced electric field
  – pulse duty cycle
  – tissue density
  – conductivity
  – patient size
  – SAR is used to calculate expected increase in body temperature during an examination.
Specific Absorption Rate (SAR)

- In the US the recommended SAR level for imaging is:
  - 4 W/kg for the whole body

- The SAR limit levels should never be exceeded.
RF Antennae Effects

• Radio frequency fields can be responsible for significant burn hazards due to electrical currents that are produced in conductive loops.

• Coupling of a transmitting coil to a receive coil may also cause severe thermal injury.
Pregnant Patients

- There are no known biological effects of MRI on fetuses. There are mechanisms that could potentially cause adverse effects.
  - Cell undergoing division, during the first trimester of pregnancy, are more susceptible.
  - FDA requires labeling of MR systems to indicate the safety of MR when used to image the fetus and infant.
  - However official guidelines have not been set.
Pregnant Patients

• In general, it has been suggested that any examination of pregnant patients should be delayed until after the first trimester.

• Then a written consent form should be signed by the patient before the exam.
Pregnant Employees

• MRI facilities must establish individual guidelines for pregnant employees in the magnetic resonance environment.

• The majority have determined that pregnant employees can safely enter the scan room and leave while the RF and gradient fields are employed.
Implants and Prostheses

• Metallic implants pose serious effects which include:
  – torque
  – heating
  – artifact on MR images.

• Before imaging a patient, any surgical procedures the patient has undergone prior to the MR examination, must be identified.
Torque and Heating

• Some metallic implants have shown considerable torque when placed in the presence of a magnetic field.

• Heating experiments have not shown excessive temperature increases in implants.
Aneurysm Clips

• Some of the aneurysm clips tested displayed ferromagnetic qualities.
• Clip motion may damage the vessel, resulting in hemorrhage, ischemia, or death.
• It is recommended that the type of clip is emphatically non-ferrous and be identified before scanning.
Hemostatic Vascular Clips
Heart Valves

• Hemostatic Vascular Clips
  – Should be evaluated ex-vivo prior to the exam although none of the clips evaluated showed deflection.

• Heart Valves
  – Tests showed negligible deflection to the magnetic field. The deflection is minimal compared with normal pulsitile cardiac motion.
  – Although considered MR safe, careful screening for valve type is advised.
Intra-vascular Coils, Filters and Stents

• These devices usually become imbedded in the vessel wall after several weeks and are unlikely to become dislodged.
• Therefore it is considered MR safe to perform MR imaging provided a reasonable period of time has elapsed after implantation.
Otologic Implants

• Cochlear implants are attracted to magnetic fields and are magnetically and electronically activated.
  – They are mostly MR unsafe to MR exams.

• Many Otologic Implants are MR Safe or MR Conditional
Intra-ocular Ferrous Foreign Bodies

• It is not uncommon for metal workers to have metal fragments or slivers located in and around the eye.

• A study demonstrated that metal fragments as small as 0.1x0.1x0.1mm can be detected on radiograph and is sufficient enough to determine the risk to a patient.
Surgical Clips

• Abdominal surgical clips are generally MR safe because they become anchored by fibrous tissue.

• They can however produce artifact in proportion to their size and can distort the image.
Halo Vests and other Devices

• Halo vests pose several risk factors which include:
  – deflection and subsequent dislodging of the halo, heating due to RF absorption
  – electrical current induction within the halo rings
  – electrical arching
  – severe artifact consequences.
  – Non-ferrous and non-conductive halo vests which are MR compatible are commercially available
Claustrophobia

• It is a **condition** that commonly affects patients, not a contraindication.
  – RF heating, gradient noise, and the confines of the magnet itself, add to the reaction.

• Reduce the incidence of claustrophobia.
  – Controllable air movement within the bore, good patient contact and education should help to reduce the reactions.
  – Open Architecture.
Gadolinium

- A rare earth metal or ‘heavy metal’
- Toxic if not chelated.
- Ionic and Nonionic
- Shorten both T1 and T2 relaxation times
Current Applications

• Gadolinium has proven invaluable in imaging the central nervous system because of its ability to pass through breakdowns in the blood-brain barrier (BBB).
Current Applications

• tumor pre- and post surgery
• lesions with abnormal vascularity
• pre- and post-radiotherapy
• infection, infarction, inflammation
• liver (hemangiomas); renals
• post-traumatic lesions
• post-operation lumbar disc
• MR Angiography
• Previous Surgery
• History of Cancer
Contraindications

- Hematological disorders such as:
  - hemolytic anemia
  - sickle cell anemia
  - Pregnancy
  - Compromised renal function
  - GFR < 30
  - Acute Kidney Injury (AKI)
Contrast Reactions

• mild transitory headache
• nausea
• vomiting
• hypotension gastro-intestinal upset
• rash
• deaths have been reported.
Elimination of Gadolinium

- Approximately 80% of gadolinium is excreted by the kidneys in three hours.
- 95.5% eliminated primarily in urine within 24 hours
- 98% is recovered by feces and urine in one week.
Nephrogenic Systemic Fibrosis

• NSF is a disease that has been linked to gadolinium-based MRI contrast administration.

• FDA as of September 2010, has issued new policy regarding all gadolinium MRI agents updated in 2013 (ACR Guidance Document for Safe MR Practice: 2013)

• The revised labeling is specific to certain manufacturers however there are guidelines for all agents.
NSF – Black Box Warning

• The first black box warning was issued in 2007 to address the growing concern about the devastating disease.
• The warning requires screening of the patient prior to administration of any MR contrast agent.
• The warning also comes with utilization restrictions.
NSF

• According to FDA warnings these agents are not to be administered to patients with chronic, severe kidney disease (defined by a glomerular filtration rate (GFR) of less than 30 mL/min/1.73m$^2$) or acute kidney injury.

• Patients are to be screened for acute kidney injury and other conditions that may reduce kidney function.
NSF

• The FDA now requires specific patient screening and kidney function tests for patients at risk for NSF before being administered a gadolinium with MRI.

• The requirements include avoiding administration for patients at risk, specifically those who would have problem eliminating the drugs...
NSF

• ...unless the diagnostic information from the contrast-enhanced MRI is essential and not available with non-enhanced MRI or other imaging modalities.

• Users are instructed to screen patients for acute kidney injury and other conditions that may reduce renal function.

• A GFR test is required for at risk patients.