Lesson 319: Management of the Patient for Magnetic Resonance Imaging

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Read this article, reflect on the information presented, then go online and complete the lesson post-test and course evaluation before the termination date below. (CME credit is not valid past this date.) You must achieve a score of 80% or better to earn CME credit.

TIME TO COMPLETE ACTIVITY: 2 hours
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Professional Gaps

The American Society of Anesthesiologists (ASA) has issued new practice parameters for the care of patients undergoing magnetic resonance imaging (MRI). While most anesthesiologists may already be familiar with patient management in this area, they may not be aware of the most recent information and references provided by the parent society.

Learning Objectives

At the completion of the activity, the reader will be able to:

1. Describe the basic principles of the MRI
2. Understand the indications and risks associated with contrast materials
3. Appreciate the flexibility required for off-site anesthetic care
4. List items that may be safely taken into an MRI unit
5. Describe the need for special education about the MRI suite
6. Recognize the hazards of a quench
7. Be aware of the complications that may arise in the MRI
8. Determine each of the zones within the MRI suite
9. Incorporate the recent advisories from the ASA
10. Differentiate between practice parameters and standards

Case

An 82-year-old woman awoke with difficulty in speech and a marked weakness of her left arm. She had been in fairly good health and took hydrochlorothiazide and amlodipine for hypertension, which was controlled around 155/95 mm Hg. She had type 2 diabetes, with an average daily blood glucose level of 160 mg/dL. She managed her activities of daily living mainly by herself. Her son came by when he received repeated calls from her, but she was not able to speak. She was taken to the hospital, but by
then the weakness and aphasia had resolved and she had only a severe headache. She was scheduled for an emergent MRI study.

Introduction

Magnetic resonance imaging (MRI) or nuclear NMRI, is a radiologic technique used to visualize internal structures and functions. It provides 2- and 3-dimensional views of body tissue and structure. Globally, there are about 250,000 scanners performing more than 20 million MRI scans annually. MRI provides greater contrast between the different soft tissues of the body than computed tomography (CT), making it especially useful in diagnosing musculoskeletal disorders. Unlike CT, it uses no ionizing radiation, but rather a powerful magnetic field to align the nuclear magnetization of hydrogen atoms in water in the body. Radiofrequency (RF) fields are used to alter the alignment of this magnetization, causing the hydrogen nuclei to produce a rotating magnetic field detectable by a scanner.

Challenges for health care workers in the MRI unit are related not only to the remote location but also to unfamiliarity with the unique complexities and hazards of the area. Because of these difficulties, hospitals, departments, and organizations including the Joint Commission have focused on definitions and education.

MRI Technology

MRI is relatively new. The theory behind the technique was published by Paul C. Lauterbur in 1973. 1 The first study performed on a human took place on July 3, 1977.2 By comparison, the first human x-ray image was taken in 1895. Early on, the technique was referred to as NMRI. Subsequently, “nuclear” was associated in the public mind with ionizing radiation exposure and thus was dropped.

The human body is composed mainly of water molecules, each containing 2 hydrogen nuclei or protons. In the magnetic field of the scanner, these protons align with the direction of the field. A second RF electromagnetic field is then briefly turned on, causing the protons to absorb energy. When this field is turned off, the protons release the energy at an RF that can be detected by the scanner. The position of protons in the tissues can be determined by applying additional magnetic fields during the scan, which allows an image of the body to be constructed. These images are created by turning gradient coils on and off, creating the knocking sounds heard during the scan.

An MRI study requires a strong and uniform magnetic field. The field strength of the magnet is measured in teslas, the standard unit of magnetic flux density. While the majority of systems operate at 1.5 T, commercial systems are available between 0.2 and 7 T. The measure of 1 T is equivalent to 1 weber (Wb)/m². Reduced to base units in the International System of Units, 1 T represents 1 kg/s²/A. A smaller unit of flux density called the gauss is often used. There are 10,000 G in 1 T. The strongest fields encountered from permanent magnets are from Halbach spheres, which can be over 4.5 T. The strongest field trapped in a laboratory superconductor, as of 2014, is 17.6 T. The record magnetic field was produced by scientists at the Los Alamos National Laboratory campus of the National High Magnetic Field Laboratory, which was a 100-T nondestructive magnetic field.3,4

Most clinical magnets are superconducting, which requires liquid helium. Lower field strengths can be achieved with permanent magnets, which are often used in “open” MRI scanners for claustrophobic patients.
Abnormal tissue such as tears, areas of destruction, excessive buildup, and ischemic insults can be detected because the protons in different tissues return to their equilibrium state at different rates. By changing the parameters on the scanner, this effect creates contrast between different types of body tissue. Image contrast is thus determined by differences in the strength of the MR signal recovered from different locations within the sample, which depends on the relative density of excited nuclei (the water protons), differences in relaxation times ($T_1$, $T_2$, and $T_2^*$) of those nuclei after the pulse sequence, and some other parameters used in specialized MR scans. Contrast in most MR images is actually a mixture of all these effects, but careful design of the imaging pulse sequence allows one contrast mechanism to be emphasized while the others are minimized.

**The MRI Suite**

The MRI suite is usually freestanding or at some distance from the operating room, which is the more conventional comfort zone for the anesthesiologist. Equipment and monitors in this area must be adaptable to the MRI suite. All devices must meet 3 criteria:

1. They must function normally at the site.
2. They must present no danger to the patient or personnel.
3. They must not affect successful completion of the procedure or imaging.

For most locations, these goals can be met by selecting commercially available portable monitoring devices. Nonferromagnetic equipment must be used. Only certain metals such as iron, nickel, and cobalt are magnetic. Items made of nonmagnetic aluminum, titanium, copper, silver, and gold are safe as far as missile dangers are concerned, and are among the materials used to make MRI-compatible intravenous (IV) poles, fixation devices, and nonmagnetic anesthesia machines. If susceptible metal items such as infusion pumps for IV lines must be brought into the MRI suite, those objects should be secured before the patient enters the magnet bore. Biomedical engineers with expertise in MRI should be consulted before installation or use of any electronic devices.

**MRI: Adverse Events**

Although the technology is generally safe, several complications may arise during procedures in the MRI suite. The Manufacturer and User Facility Device database, a branch of the FDA, reports on all adverse events related to devices. Some of the types of injury than can occur and have occurred are:

- missile or projectile injury when ferromagnetic objects (pens, oxygen canisters, wheelchairs) are pulled into the scanner at rapid speed;
- injury caused when ferromagnetic objects are dislodged, such as aneurysm clips, pins in joints, and drug infusion devices;
- burns from objects that may heat up, such as wires for external and internally implanted devices, surgical staples, pulse oximeters, tattoos (from iron oxide pigment), or from the body touching the inside of the scanner;
- equipment or devices that malfunction because of the magnetic field, including battery-powered laryngoscopes, infusion pumps, and monitors. Some programmed pumps may perform erratically, including pacemakers and implantable defibrillators;
- complications that arise if the patient is sedated and the health care worker is not close enough to be able to adequately monitor;
- hearing difficulties that may increase from the knocking sounds made by the scanner;
• administration of contrast materials, especially gadolinium, to patients that may precipitate kidney failure;
• adverse events that may be associated with failure to adequately handle and store cryogen or due to inadvertent release at superconducting MRI sites; and
• failure, often by ancillary hospital staff, to realize that the scanner should never be turned off. For example, a vacuum cleaner may be sucked into the scanner.

Implanted metals, such as hip prostheses and Harrington rods, are made of stainless steel, which is only weakly magnetic. Information about the presence of such devices in a patient should be obtained and appropriate consultation sought with radiologists and orthopedists regarding safety. Issues with these objects usually involve image degradation rather than danger to the patient. Metals do not need to be missiles to be dangerous to the patient. Dangers from wires in epidural or pulmonary artery catheters relate to RF fields and the risk for burns, which are the most common complications. Although at one point the American College of Radiology recommended that implanted cardiac pacemakers and implantable cardiovertor/defibrillators should be considered a relative contraindication for MRI, several studies have examined the use of MRI-compatible pacemakers during MRI studies.\textsuperscript{7-9} Medtronic has FDA approval for its Advisa MRI and Revo MRI SureScan pacing systems to allow for access to MR scans. A complete SureScan pacing system, including an Advisa MRI SureScan IPG and a Revo MRI SureScan IPG and 2 CapSureFix MRI SureScan leads, is required for use in the MRI environment.

Other electronic implants, especially vagal nerve stimulators and cochlear implants, have various contraindications, depending on scanner technology, implant properties, scanning protocols, and the anatomy imaged. Improved designs to further minimize the risks that MR scans pose to medical device operation are constantly being developed. One such development is a nanocoating for implants to screen them from RF waves. In addition, patients who may have shrapnel of bullet material lodged in their bodies are generally not candidates for MRI.

**Site Classification**

A classification system for implants and ancillary clinical devices was developed in 2006 by ASTM International – the American Society for Testing and Materials, an international standards organization that publishes voluntary consensus technical standards. The standard for implants and ancillary clinical devices is supported by the US Food and Drug Administration.

Three signs are recognized. (See Figure.) Depending on the device, the appropriate sign should be affixed. The classification applies to all manner of items, appliances and equipment intended for use in the MR environment.
FIGURE: ASTM International signage for device compatibility during MRI

<table>
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<tr>
<th>SIGN</th>
<th>DEFINITION</th>
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| ![MR Safe](image1) | **MR Safe**  
The device or implant is completely non-magnetic, non-electrically conductive, and non-RF reactive, eliminating all of the primary potential complications during an MRI procedure. |
| ![MR Conditional](image2) | **MR Conditional**  
The device or implant may contain magnetic, electrically conductive or RF-reactive components that is safe for operations in proximity to the MRI, provided the conditions for safe operation are defined and observed (such as 'tested safe to 1.5 teslas' or 'safe in magnetic fields below 500 gauss in strength'). |
| ![MR Unsafe](image3) | **MR Unsafe**  
This category is reserved for objects that are significantly ferromagnetic and pose a clear and direct threat to persons and equipment within the magnet room. |

**Cryogens and Emergency Shut Down**

Most MRI scanners use cryogenic liquids to enable the superconducting capabilities of the electromagnetic coils inside. Although the cryogenic liquids most frequently used are nontoxic, their physical properties present specific hazards. An emergency shutdown of a superconducting electromagnet, an operation known as *quenching*, involves the rapid boiling of liquid helium from the device. If the rapidly expanding helium cannot be dissipated through an external vent, sometimes referred to as a *quench pipe*, the gas may be released into the scanner room where it may displace oxygen and create a risk for asphyxiation. Liquid helium, the most commonly used cryogen in MRI, undergoes near-explosive expansion as it changes from a liquid to a gaseous state. Rooms built in support of superconducting MRI equipment should have pressure-relief mechanisms and an exhaust fan, in addition to the required quench pipe.

A quench results in rapid loss of all cryogens in the magnet, and recommissioning the magnet is extremely expensive and time-consuming. Spontaneous quenches are uncommon but may be triggered by equipment malfunction, improper cryogen fill technique, contaminants inside the
cryostat, or extreme magnetic or vibrational disturbances.

**Contrast agents**

Contrast agents may be added to improve imaging. Most agents used in MRI are selected for their specific magnetic properties. Commonly, a gadolinium compound is given. Gadolinium-enhanced tissues and fluids appear extremely bright on $T_1$-weighted images, providing high sensitivity for detection of vascular tissues (eg, tumors) and allowing assessment of brain perfusion (eg, in stroke). Concerns have been raised regarding the toxicity of gadolinium-based contrast agents and their effect on impaired kidney function. A recent review indicated that an acute adverse reaction to contrast administration occurred in 0.12% of cases. Most reactions were considered mild (43 of 45). Although gadolinium agents have proved useful for patients with renal impairment, in patients with severe renal failure requiring dialysis there is a risk for a rare but serious illness, nephrogenic systemic fibrosis, which may be linked to the use of certain gadolinium-containing agents, most frequently gadodiamide.

**Practice Advisory**

Recently, the American Society of Anesthesiologists (ASA) published an updated practice advisory with 146 references on anesthetic care for MRI. As the ASA notes, practice advisories are systematically developed reports that are intended to assist decision making in patient care. They provide a synthesis and analysis of expert opinion, clinically feasible data, open-forum commentary, and consensus surveys. They are not intended as standards, guidelines, or absolute requirements. Implementation does not guarantee specific outcomes. They may be modified or rejected according to clinical needs. The new statement differs from previous ones by providing updated evidence from the literature, and acknowledges that the FDA has approved an MRI-conditional implantable cardiac pacing generator and lead system. Specific anesthetic drug choices are not addressed, and the advisory does not apply to patients receiving only anxiolytic agents.

Zone definitions identify 4 areas. Zone I includes all areas that are freely accessible to the public. The area is outside of the MRI environment and is the area through which patients and others can access the MR site. Zone II represents the interface between the publicly uncontrolled zone and the strictly controlled Zone III. Patients in this area are under the supervision of MRI personnel and are not free to move around. History and physical examination may be conducted here. Zone III is the region where free access by unscreened non-MRI personnel or ferromagnetic equipment may result in serious injury. Access is restricted, and access to regions within it is controlled. Zone IV is located within Zone III and is synonymous with the MRI scanner itself.

Advisories are offered in 6 main categories:

1. **Education**

MRI safety education includes MRI hazards and limitations of monitoring and long-term health hazards. The evidence to evaluate the effects of education on magnet hazards or long-term health hazards remains insufficient. One study found no significant difference in relative risk between pregnant and nonpregnant workers for early delivery, low birth weight, or spontaneous abortion. Awareness of
potential health hazards such as high decibel levels should be addressed. General safety education and specific education on the unique features of the scanners within specific institutions are essential, including how to respond to emergency situations with integrated protocols and identification of MRI-compatible items. Collaboration with radiologists, technologists, and physicists within individual institutions is necessary to develop safety training programs.

2. **Screening of anesthetic care providers and ancillary support personnel**

The MRI medical director or designated technologist is responsible for access to Zones III and IV to prevent incursion of ferromagnetic materials, although the literature is silent as to whether screening of anesthetic personnel’s functions improves safety. Nevertheless, all panel members agreed that anesthesiologists should work in collaboration with the MRI director or designee to ensure that all anesthesia team personnel entering Zone III have been screened for the presence of ferromagnetic materials, foreign bodies, or implanted devices.

3. **Patient screening**

Risks related to patients include age (heart rate fluctuations in neonates and the elderly) and health-related risks from implanted or applied foreign bodies, such as eyeliners, tattoos, intraocular fragments, pierced jewelry, arterial stents, aneurysm clips, dental work, and spinal fusion stimulators, all of which may heat up in a magnetic field, causing burns. Health-related risks include the need for intensive care, impaired respiratory function (obstructive sleep apnea), changes in level of sedation, hemodynamic instability, and other comorbidities. Exposure of iron filings to the magnetic field may cause hemorrhage. All experts agreed that communication between the anesthesiologist, patient, radiologist, technologist, and possibly referring physician and pain specialist is essential, and a plan for managing patients with implanted devices must be in place. Gadolinium should not be administered to patients with acute or severe renal insufficiency because of the elevated risk for nephrogenic systemic fibrosis. Equipment should not interfere with image acquisition or quality. Cardiac monitor leads have been shown to interfere with an MR scan, and fire or burns have occurred near or beneath cardiac electrodes, and around looping of temperature and pulse oximetry cables. Several reports have noted image artifacts in patients with neurostimulators, implantable pumps, and cochlear implants. Communication between all parties is essential. Generally, MRI should not be performed in patients with implantable devices unless the study is considered essential when a plan should be developed to manage the case. Anesthesiologists should work with their institutions to properly identify and label anesthesia-related equipment according to convention. The ASA’s advisory believes that cardiac pacemakers are generally contraindicated for MRI, although the FDA has approved the use of pacemakers and leads as MRI conditional for certain patients and selected scans. Subsequent development and clinical application will be addressed by the ASA in future revisions. The presence of implanted devices should be noted and MRI safety determined.

4. **Preparation**

Preparation should consist of determining and implementing individualized anesthetic plans and optimal positioning of equipment and personnel. Although the literature is insufficient to determine whether active preparation and pre-MRI planning reduces the frequency of adverse events, anecdotal reports exist of major complications due to misinformation and lack of communication. Thus, there is general agreement that the anesthesiologist with support personnel should prepare a plan for providing appropriate anesthetic care. The anesthesiologist should select a position for optimal patient
observation, as the line of sight within the bore varies depending on the facility. Communication with other health care workers, especially radiology personnel, is essential to understand individual requirements and to demarcate safe locations for movable equipment in relation to the gauss lines. A plan to secure emergency help should be in place.

5. **Patient management during MRI**

MRI-safe or MRI-conditional monitors, remote monitoring, and compliance with ASA standards must be evident. The use of MRI-compatible monitoring equipment has been shown to result in no RF interference, interruptions in scanning, or artifacts. Remote monitoring can be performed safely and effectively. Monitoring should be done in a manner consistent with the ASA’s *Standards for Basic Anesthetic Monitoring*. Light levels of anesthesia as well as moderate sedation or even general anesthesia are appropriate, but may result in motion artifacts or respiratory compromise. As the study is painless, lighter levels of sedation are preferred. Monitoring should be done in a manner consistent with that used in other areas of the institution under similar depths of narcosis. Automated apnea monitoring may decrease risks during moderate and deep sedation. Equipment should mirror that found in the operating room. In the absence of an MRI-compatible anesthetic machine, inhalational anesthetics can be administered from a machine in Zone III via an elongated circuit through a wave guide. If total IV anesthesia is used, it should be administered by using MRI-safe or MRI-conditional pumps in Zone IV, traditional pumps in Zone III with IV tubing through a wave guide, or periodic bolus injections in Zone III or IV.

The literature is insufficient to assess the management of airway problems and whether endotracheal intubation or the use of a supraglottic airway improves outcome. The consensus is that an airway plan must be made in advance. Complex airway management should be completed outside the MRI suite. Alternative airway devices should be available.

Emergencies in the MRI suite include medical (cardiac arrest) and environmental (quench, fire, projectiles) types. Remote locations of scanners may delay response of support personnel. If an emergency occurs while the patient is in the scanner, he/she should be removed immediately, help should be summoned, and the patient transported to a previously designated safe area outside of Zone IV, where all resuscitation equipment should be stored (defibrillator, code cart, etc). Preassigned fire management tasks should be performed in accordance with the ASA’s *Practice Advisory for the Prevention and Management of Operating Room Fires*. In case of projectile emergencies, team members should perform their institution’s protocol. The patient should be removed from Zone IV and the scan discontinued. A quench occurs when a superconducting magnet turns resistive and catastrophically releases all of the stored energy as heat, boiling off the stored cryogens as gas. A controlled quench may be necessary to remove the patient from the bore. The most common cause of a quench is an intentional shutdown of the magnet for a life-threatening emergency such as a large projectile missile drawn into the scanner. It may also be unintentional, and if not properly vented, could result in complete dissipation of oxygen, risking hypoxia to the patient and others in the immediate area. Also, high pressure from escaping gases may make it impossible to open the door into Zone IV. The institution should have a protocol in place to respond to this occurrence, which generally includes removing the patient from the scanner and administering oxygen. Static magnetic fields may persist after a quench, and the usual precautions should apply when entering the scan area.
6. **Postprocedure care**

The anesthesiologist should collaborate with the radiologist and other staff in postanesthetic care. All patients receiving sedation or anesthesia should have access to postanesthetic care consistent with that provided in other areas of the institution. Written discharge instructions should be provided.

In summary, the advisory emphasizes education about MRI, collaboration between specialties, and availability of MRI-compatible equipment. As difficult as it may be, standards as they pertain in the operating room should be maintained in this remote location. Collaboration with other specialties and preparation of protocols and plans are emphasized.

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**Management of the Case**

The patient was restless and complaining of a headache and arthritic pains in her hips. The procedure was explained to her and she was instructed about the importance to lay still. She denied having any implants when asked. She noted that she was claustrophobic and doubted she would be able to tolerate the study. She was overweight at 220 lbs and stated that she snored quite loudly although she had never had a sleep study. She was edentulous. After careful review and discussion, it was decided that general anesthesia, using propofol followed by desflurane and intubation was the preferred technique. The patient agreed. All MRI compatible equipment was obtained and checked out. The study lasted for 45 minutes and revealed a small area of infarct along the distribution of the middle cerebral artery. The patient was awakened, extubated and transferred to the post anesthetic care unit. She was admitted overnight for further evaluation by the neurology service.
REFERENCES

13. Visit www.mssm.procampus.net today for instant online processing of your CME post-test and evaluation form. There is a registration fee of $15 for this non-industry-supported activity. For assistance with technical problems, including questions about navigating the Web site, call toll-free customer service at (888) 345-6788 or send an e-mail to Customer.Support@ProCEO.com. For inquiries about course content only, send an e-mail to ram.roth@mssm.edu. Ram Roth, MD, is director of PreAnesthetic Assessment Online and assistant professor of anesthesiology at The Icahn School of Medicine at Mount Sinai, New York, NY.

Post-test

1. MRI scans:
   a. are performed on 5 million people worldwide annually
   b. provide 2 dimensional views of body tissues
   c. allow greater contrast between the soft tissues of the body than CT
   d. all of the above

2. The knocking sound heard during a scan is caused by:
   a. release of energy from protons
   b. the turning on and off of gradient coils
   c. application of radiofrequency electromagnetic fields
   d. addition of extra magnetic fields

3. Ferromagnetic metals include:
   a. iron, aluminum and gold
   b. iron, silver and titanium
   c. iron, nickel and cobalt
   d. iron, silver and steel

4. During MRI wires from spine cord stimulators may:
   a. cause burns
   b. result in tissue damage from movement of the wire
   c. have little or no effect on the image
   d. immediately become detached

5. The most common complication in MRI is:
   a. cardiac arrest from pacemaker failure
   b. insulin overdose from pump failure
   c. burns
   d. projectile injury
6. **Cryogenic liquids:**
   a. are usually toxic
   b. enable the superconducting capabilities of electromagnetic coils
   c. are not released in a controlled quench
   d. do not explode

7. **Regarding the zones in the MRI suite:**
   a. free access is restricted in Zone 1
   b. zone 2 is part of Zone 3
   c. screening is required prior to entering zone 4
   d. relatives of patients can enter any zone especially after the MR unit is turned off

8. **Patient equipment-related risks include:**
   a. tattoos
   b. cochlear implants
   c. neurostimulators
   d. all of the above

9. **An absolute contraindication for MRI is:**
   a. presence of a pacemaker
   b. an uncooperative patient
   c. no availability of a noncompatible anesthesia machine
   d. none of the above

10. **A quench:**
    a. should be done at the end of each day
    b. should be done once a week for general maintenance
    c. may be necessary to remove a patient from the bore
    d. releases stored energy slowly in a controlled fashion