## MRI for Technologists

# Patient and Facility Safety in MRI

### PROGRAM INFORMATION

***MRI for Technologists*** is a training program designed to meet the needs of radiologic technologists entering or working in the field of magnetic resonance imaging (MRI). These units are designed to augment classroom instruction and on-site training for radiologic technology students and professionals planning to take the review board examinations, as well as to provide a review for those looking to refresh their knowledge base in MR imaging.


| | |
|---|---|
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*This material will be reviewed for continued accuracy and relevance. Please go to www.icpme.us for up-to-date information regarding current expiration dates.*

### OVERVIEW

The skill of the technologist is the single most important factor in obtaining good quality diagnostic images. A successful MRI examination is the culmination of many factors under the direct control of the technologist.

***MRI for Technologists: Patient and Facility Safety in MRI*** introduces the learner to best practices for ensuring the patient is safe and comfortable throughout the examination, the biological and physical hazards of MRI, and the MRI suite layout and safety procedures.

After completing this educational material, the reader will be able to:

- Identify patient safety hazards as they relate to the static magnetic field and transmitted radiofrequencies
- Identify patient contraindications to an MRI examination
- Describe procedures used to ensure patient comfort and safety during an MRI scan
- Describe the biological and physical hazards of MRI
- Explain the different zones in the MRI suite and the access restrictions for each
- Discuss environmental safety procedures in MRI

### EDUCATIONAL CREDIT

This program has been approved by the American Society of Radiologic Technologists (ASRT) for 1.0 hour ARRT Category A continuing education credit.

## HOW TO RECEIVE CREDIT

Estimated time to complete this activity is **1.0** hour. The posttest and evaluation are required to receive credit and must be completed online.

- In order to access the posttest and evaluation, enroll in the online course at www.icpme.us.
- Read the entire activity.
- Log in to your account at www.icpme.us to complete the posttest and evaluation, accessible through the course link in your account.
- A passing grade of at least 75% is required to be eligible to receive credit.
- You may take the test up to three times.
- Upon receipt of a passing grade, you will be able to print a certificate of credit from your online account.

## ACKNOWLEDGMENTS

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**Jeffrey J. Brown, MD, FACR, MBA**
Washington University School of Medicine
St. Louis, MO

**Alan H. Stolpen, MD, PhD**
University of Iowa Hospitals and Clinics
Iowa City, IA

**Thomas Schrack, BS, ARMRIT**
Fairfax Radiological Consultants
Northern Virginia Community College
Fairfax, VA

**Daniel R. Thedens, PhD**
University of Iowa
Iowa City, IA

For their contributions to this material, special thanks go to:

**Stephen Dashnaw, ARMRIT**
Columbia University, New York, NY

**Mark Flyer, MD**
Maimonides Medical Center, Brooklyn, NY

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# FDA Drug Safety Communication: FDA warns that gadolinium-based contrast agents (GBCAs) are retained in the body; requires new class warnings

https://www.fda.gov/Drugs/DrugSafety/ucm589213.htm Accessed June 14, 2018.

**05-16-2018 Update**

In addition to approving the updated prescribing information concerning the gadolinium retention safety issues described in the Drug Safety Communication below, FDA has also approved new patient Medication Guides for all GBCAs.

Health care professionals and patients can access the patient Medication Guides according to the GBCA drug name* on the Medication Guides webpage, or the latest prescribing information by searching in Drugs@FDA.

All MRI centers should provide a Medication Guide the first time an outpatient receives a GBCA injection or when the information is substantially changed. In general, hospital inpatients are not required to receive a Medication Guide unless the patient or caregiver requests it. A health care professional who determines that it is not in a patient's best interest to receive a Medication Guide because of significant concerns about its effects may direct that it not be provided to that patient; however, the Medication Guide should be provided to any patient who requests the information.†

*The brand names of the GBCAs can be found in Table 1 below.
†For more information on distribution of Medication Guides, see the Guidance Document, the Drug Info Rounds Video, or the Code of Federal Regulations at 21 CFR 208.26.

This is an update to the FDA Drug Safety Communication: FDA identifies no harmful effects to date with brain retention of gadolinium-based contrast agents for MRIs; review to continue issued on May 22, 2017.

**12-19-2017 Safety Announcement**

The U.S. Food and Drug Administration (FDA) is requiring a new class warning and other safety measures for all gadolinium-based contrast agents (GBCAs) for magnetic resonance imaging (MRI) concerning gadolinium remaining in patients' bodies, including the brain, for months to years after receiving these drugs. Gadolinium retention has not been directly linked to adverse health effects in patients with normal kidney function, and we have concluded that the benefit of all approved GBCAs continues to outweigh any potential risks.

However, after additional review and consultation with the Medical Imaging Drugs Advisory Committee, we are requiring several actions to alert health care professionals and patients about gadolinium retention after an MRI using a GBCA, and actions that can help minimize problems. These include requiring a new patient Medication Guide*, providing educational information that every patient will be asked to read before receiving a GBCA. We are also requiring manufacturers of GBCAs to conduct human and animal studies to further assess the safety of these contrast agents.

GBCAs are used with medical imaging devices called MRI scanners to examine the body for problems such as cancer, infections, or bleeding. GBCAs contain gadolinium, a heavy metal. These contrast agents are injected into a vein to improve visualization of internal organs, blood vessels, and tissues during an MRI, which helps health care professionals diagnose medical conditions. After being administered, GBCAs are mostly eliminated from the body through the kidneys. However, trace amounts of gadolinium may stay in the body long-term. Many GBCAs have been on the market for more than a decade.

**Health care professionals** should consider the retention characteristics of each agent when choosing a GBCA for patients who may be at higher risk for gadolinium retention (see Table 1 listing GBCAs). These patients include those requiring multiple lifetime doses, pregnant women, children, and patients with

inflammatory conditions. Minimize repeated GBCA imaging studies when possible, particularly closely spaced MRI studies. However, do not avoid or defer necessary GBCA MRI scans.

**Patients, parents, and caregivers** should carefully read the new patient Medication Guide* that will be given to you before receiving a GBCA. The Medication Guide explains the risks associated with GBCAs. Also tell your health care professional about all your medical conditions, including:

- If you are pregnant or think you might be pregnant
- The date of your last MRI with gadolinium and if you have had repeat scans with gadolinium
- If you have kidney problems

There are two types of GBCAs based on their chemical structures: linear and macrocyclic (see Table 1 below). Linear GBCAs result in more retention and retention for a longer time than macrocyclic GBCAs. Gadolinium levels remaining in the body are higher after administration of Omniscan (gadodiamide) or OptiMARK (gadoversetamide) than after Eovist (gadoxetate disodium), Magnevist (gadopentetate dimeglumine), or MultiHance (gadobenate dimeglumine). Gadolinium levels in the body are lowest after administration of Dotarem (gadoterate meglumine), Gadavist (gadobutrol), and ProHance (gadoteridol); the gadolinium levels are also similar across these agents.

*The Medication Guide will be posted once it is approved.

**Table 1. FDA-Approved GBCAs***

| Brand name | Generic name | Chemical Structure |
|---|---|---|
| Dotarem† | gadoterate meglumine | Macrocyclic |
| Eovist | gadoxetate disodium | Linear |
| Gadavist† | gadobutrol | Macrocyclic |
| Magnevist | gadopentetate dimeglumine | Linear |
| MultiHance | gadobenate dimeglumine | Linear |
| Omniscan‡ | gadodiamide | Linear |
| OptiMARK‡ | gadoversetamide | Linear |
| ProHance† | gadoteridol | Macrocyclic |

*Linear GBCAs result in more gadolinium retention in the body than macrocyclic GBCAs.
†Gadolinium levels remaining in the body are LOWEST and similar after use of these agents.
‡Gadolinium levels remaining in the body are HIGHEST after use of these agents.

To date, the only known adverse health effect related to gadolinium retention is a rare condition called nephrogenic systemic fibrosis (NSF) that occurs in a small subgroup of patients with pre-existing kidney failure. We have also received reports of adverse events involving multiple organ systems in patients with normal kidney function. A causal association between these adverse events and gadolinium retention could not be established.

We are continuing to assess the health effects of gadolinium retention in the body and will update the public when new information becomes available. We are requiring the following specific changes to the labeling of all GBCAs:

- A *Warning and Precaution*
- Changes related to gadolinium retention in the *Adverse Reactions, Pregnancy, Clinical Pharmacology*, and *Patient Instructions* sections

We urge patients and health care professionals to report side effects involving GBCAs or other medicines to the FDA MedWatch program.

# Patient and Facility Safety in MRI

**After completing this educational material, the reader will be able to:**

- **Identify patient safety hazards as they relate to the static magnetic field and transmitted radiofrequencies generated by an MRI system**
- **Identify patient contraindications to an MRI examination**
- **Describe procedures used to ensure patient comfort and safety during an MRI scan**
- **Describe the biological and physical hazards of MRI**
- **Explain the different zones in the MRI suite and the access restrictions for each**
- **Discuss environmental safety procedures in MRI**



## PATIENT SAFETY

At present, no adverse long-term effects of exposure to the magnetic fields and radiofrequency (RF) energy associated with MRI have been identified. Unlike CT and some other imaging modalities, MRI does not employ ionizing radiation. Nevertheless, there are important safety concerns for patients and technologists that must be addressed when considering whether a patient is a candidate for MRI, as well as patient safety considerations before, during, and after the examination.

### STATIC MAGNETIC FIELD

The Food and Drug Administration (FDA) considers the following static magnetic field strengths to pose no significant risk:[1]

- adults and children, up to 8.0 Tesla
- infants less than one month old, up to 4.0 Tesla

#### Magnetic Fields Below 2.0 Tesla

No long-term biological effects have been reported from exposure to static magnetic fields below 2.0 T. No cell growth or morphology changes have been seen, and no evidence of carcinogenesis has been found in any study.

Temporary effects of the static magnetic field have been observed at levels below 2.0 T in some patients on electrocardiogram (EKG). Blood is a conductive fluid, and its motion through the magnetic field can cause noticeable increases in the amplitude of the T-wave, an effect that grows in proportion to the magnetic field. This phenomenon primarily affects cardiac gating, causing the scanner to attempt synchronization of the acquisition with the T-wave, rather than with the R-wave as expected. The T-wave amplitude

changes are completely reversed when the patient is removed from the magnet. No serious or permanent cardiovascular effects have been noted in patients as a result of static magnetic fields.

### Magnetic Fields Above 2.0 Tesla

At higher field strengths, some transient effects on patients have been noted. These include headache, nausea, vertigo, tingling in the extremities, visual disturbances, and pain in dental fillings. These unpleasant effects can be minimized by the technologist advising the patient to move slowly while in the presence of the main magnetic field; all symptoms cease once the patient is removed from the magnetic field.

## RADIOFREQUENCY FIELDS

RF fields are used to generate the signal for creating an image during an MR examination. RF fields are applied during many different phases of the imaging cycle. The RF energy is generated by RF-transmitting coils surrounding the patient, such as the body coil or a head or extremity coil covering a particular portion of the body. Potential effects of the RF fields include tissue heating (described in terms of specific absorption rate) and induced electrical currents.

### Specific Absorption Rate (SAR)

The SAR measures energy deposition in units of watts per kilogram (W/kg). During the MRI scan the body absorbs RF energy, which results in tissue heating. The major risk associated with excessive RF exposure is that the patient may not be able to dissipate the excess heat.

Measurement of SAR is complex because it relies upon many variables. Some of these variables include the induced electrical fields, pulse amplitudes and how efficiently the gradients can turn on and off (often referred to as a gradient duty cycle), patient tissue density, conductivity, and body size and weight. Providing an accurate patient weight to the MR system is very important to correctly calculate the SAR. The scanner uses the known pulse sequence parameters and patient weight to estimate SAR for a given examination. Further, certain areas of the body—such as the orbits and the testicles—have very little ability to dissipate heat as compared to the rest of the body. Some patients may have a compromised ability to regulate body temperature and may need to be excluded from MRI to avoid tissue heating risks, but this is extremely rare.

When calculating SAR, limits are set conservatively to eliminate risk of significant tissue heating. Exposures to high SAR values (when excessive RF energy is used) have shown no serious adverse effects in several studies. Rapid imaging sequences such as fast spin-echo (FSE) use larger amounts of RF energy. As more experience is gained using these scanning methods, it is possible that manufacturers will be able to decrease RF energy and thus the SAR. This would allow an increase in the number of acquired slices in a given TR period. All current MR systems use built-in, comprehensive, software-driven protections that immediately calculate SAR based on all the sequence parameters entered and the patient's weight. For example, sequences like FSE and other high RF sequences are usually slice-limited, meaning that as RF usage increases the number of slices that may be acquired in
each repetition time (TR) period decreases.

The current FDA guidelines for maximum SAR exposure are shown in Table 1. These guidelines were released in 2003.[1]

| Specific Absorption Rate (SAR) | Site Dose Time (min) equal to or greater than: | SAR (W/kg) |
|---|---|---|
| whole body | averaged over 15 | 4 |
| head | averaged over 10 | 3 |
| head or torso | per gram of tissue 5 | 8 |
| extremities | per gram of tissue 5 | 12 |

**Table 1. FDA guidelines for maximum SAR exposure.**[1]



SAR is of less concern at lower field strengths, but it may be an important limitation at higher field strengths because RF energy deposition rises as the square of the magnetic field strength. Simply put, as field strength increases, more RF energy is needed to flip protons 90° into the transverse plane for imaging. For example, the same pulse sequence performed at 3.0 T will generate SAR values four times larger than when performed at 1.5 T. Accordingly, the technologist may need to adjust some protocols to lower SAR levels by increasing TR, reducing the number of echoes, or reducing the number of slices.

## Induced Electrical Currents

In examinations that incorporate surface coils or EKG monitoring, special precautions must be taken. Any conductive material—such as the cable for a surface coil or the EKG leads—must be prevented from forming a conductive loop with itself or with the patient. Such a conducting loop may cause a great deal of heating during RF pulsing and can lead to clothing or tissue burns. Though rare, second and third degree burns have been reported. A malfunctioning surface coil may also become coupled with the transmitting coil and generate considerable heat. All conducting materials should be electrically and thermally insulated and routinely checked for proper operation. The technologist must check with specific MR manufacturer's instructions for proper cabling use to ensure patient safety.

## Gradient Magnetic Field

Understanding gradient magnetic fields is an important aspect of patient comfort. The gradient magnetic fields can change polarity very quickly, potentially inducing current in peripheral nerves. Gradient magnetic fields are generated by a set of three pairs of gradient coils (one for each principal direction: X, Y, and Z). The coil pairs create a magnetic field additional to that arising from the main (or permanent) magnet. A gradient coil functions by varying the magnetic field strength along a coordinate; one gradient coil increases the main magnetic field on one end of the magnet while decreasing the total magnetic field at the other end. The magnitude of these gradient-induced field charges is much smaller than that of the main magnetic field. The gradient fields are pulsed on and off throughout the examination to create the spatial information needed to acquire an image. Because the gradient fields are rapidly changing, or time varying, they can induce noticeable effects by causing small currents in body tissues that act as conductors, such

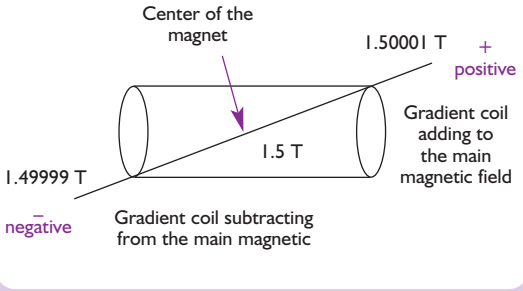



**Figure 1 illustrates how a gradient coil alters the main magnetic field along a coordinate.**

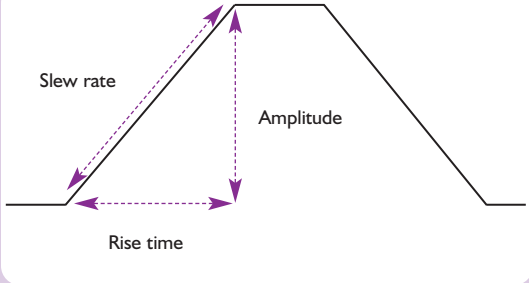



**Figure 2 illustrates the gradient amplitude and the rise time needed to achieve that amplitude. The slew rate is a function of amplitude and rise time.**

as nerves, blood vessels, and muscles. Figure 1 illustrates how a gradient coil alters the main magnetic field along the magnet dimension. It is important for the technologist to understand that gradient coils alter the magnetic field not only in the X, Y, and Z directions, but in varying degrees of obliquity as well.

The maximum gradient amplitude is measured in milliTesla per meter (mT/m) and on modern MRI systems is typically in the range of 20–40 mT/m. There is also a rise time that measures how long it takes to go from zero gradient amplitude to the maximum, as illustrated in Figure 2. The measurement of the rate of change of the magnetic field ($B_0$) at a given position is expressed as dB/dt, where the change in field per unit time dB equals the change in the $B_0$ and dt equals the change in ramp time. Because the magnetic field changes with distance from the center of the bore, areas of the body further from the center experience a higher rate of change than areas near the center. The distance from the center of the magnet, the gradient field amplitude, the shape of the pulse, and the rate at which the gradient is pulsed on and off all contribute to the value of dB/dt. Pulse sequences that use rapid strong gradient changes, such as echo-planar imaging (EPI), are most likely to generate high dB/dt values.

Faraday's Law states that a stationary conductor in a rapidly changing magnetic field will have an electrical current induced in that conductor. MR systems with high gradient performance and slew rate have the potential to meet the criteria to induce currents in the body. Rapidly changing magnetic fields and the induced current can cause a wide range of effects on the patient; these include stimulation of peripheral nerves or muscle cells, resulting in tingling sensations or muscle contractions, and visual sensations such as light flashes. Peripheral nerve stimulation (PNS) is a function of dB/dt and the gradient ramp time. While rise time is the measurement of the time required for a gradient to go from zero to its peak amplitude, ramp time is the time for the gradient to go from peak negative value to peak positive value. While the FDA does not consider PNS to be a patient safety concern, it can be a patient comfort issue. PNS effects are more likely to occur in tissues that are farther from the center of the magnet since the gradient coils generate larger magnetic fields as the distance from the magnet center increases. Additionally, the induced electrical currents can potentially cause cardiac electrical stimulation

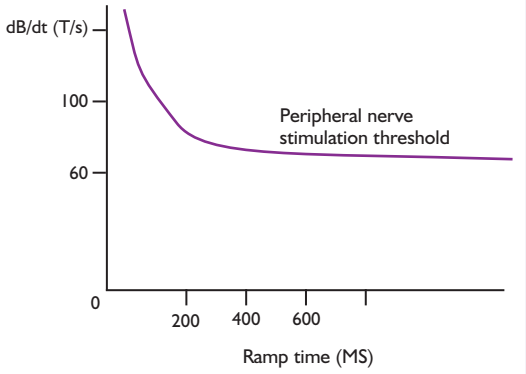



**Figure 3. The Reilly curve defines the point at which 50% of a population will experience peripheral nerve stimulation during MRI imaging.**

and arrhythmias. The 2003 FDA guidelines state that there is not a significant risk involved if the change in the rate of gradient switching of the magnetic fields is not sufficient to cause discomfort or painful nerve stimulation. All MR systems in the United States have their dB/dt levels governed by the FDA based on the Reilly Curve. The Reilly Curve indicates where 50% of a given population can expect to feel peripheral nerve stimulation due to dB/dt. The FDA stipulates that all MR scanners in the United States must operate at no more than 66% of the Reilly Curve[1] (see Figure 3).

## Acoustic Noise

Acoustic noise is generated by the gradients. The current passing through the gradient coils causes the coils to vibrate and produce the noise. The volume of noise depends on the system construction, the main magnetic field strength, and the gradient pulses used during the scan. At high amplitudes, there is a potential for temporary or permanent hearing loss; patient use of earplugs or headphones is very important to prevent these possibilities. FDA guidelines require that noise levels be kept below a peak sound pressure level of 140 dB and an average level of 99 dB (with hearing protection in place) to prevent hearing loss.

## Metal Objects and Devices

Special consideration must be given to performing MRI on patients with ferromagnetic implants and other types of metal objects and/or embedded foreign bodies. In certain cases, such patients should not be scanned using MRI because of the potential risk for severe injury.

The primary risk is that a ferromagnetic object may move or become dislodged because of interactions with the magnetic fields. In the presence of a strong magnetic field, some ferromagnetic implants will react with significant force or torque and be deflected. If dislodged, they can move in unpredictable ways and cause internal damage. Nonferrous implants may show less movement due to magnetic fields, or none at all, but there is still a risk that they will heat up from the applied RF fields and cause damage to surrounding tissues. Always obtain a list of all implants and their tested degree of MR safety from the MRI system manufacturer and also from the manufacturer of the specific implant. Another good resource for this type of information is the website **http://www.mrisafety.com**.

Embedded metal objects are also a cause of significant image artifacts. While not a direct safety risk, artifacts can result in an unusable study or cause inaccurate interpretation of the image. The appearance and severity of the artifact will depend on the pulse sequence and parameters used. See additional educational material in the *MRI for Technologists* series for a full discussion on artifacts and how to eliminate or minimize them.

### Sources

The presence of metal in the patient's body may be well known as a result of previous medical treatment, or it may be completely unexpected.

Implantation of metal and other devices as part of medical treatment must be determined before MR examination as many devices and implants must not be permitted anywhere near the strong magnetic field. Specific knowledge or documentation about any implants (such as part and serial numbers) is often required before making a decision to proceed with MR examination, as there may be no other way to firmly establish the safety of embedded devices. Categories of medical devices and their implications for MRI are discussed in the following section.

Automobile accidents, military combat, and other traumas are all means by which metal fragments may enter the body. Pellets, bullets, and shrapnel have varying metallic content (some of which may be ferromagnetic) and may also be contaminated with other ferromagnetic materials. Patients who have been involved in metalworking also have a heightened risk during MRI because small but significant embedded metal fragments may be present. Fragments located around the eyes are particularly dangerous. All patients suspected to have potential embedded ferromagnetic material require an individual assessment to decide if it is safe to perform MRI, with consideration given to the size, shape, location, and composition of the objects. A detailed medical history is needed, and x-ray examination may be warranted to evaluate such patients for suitability for an MR procedure.

## DEVICES AND CONSIDERATIONS

Several categories of medical devices that may be contraindications to MRI are described below. In all cases, a detailed description of the specific device (including type, name, serial number, lot number, and date inserted, if possible) should be acquired to determine its compatibility with MRI based on the manufacturer's information or other safety manuals.

Additionally, the technologist must consider that many of these devices have been tested only at field strengths up to 1.5 T. MRI imaging at 3.0 T is becoming more common; however, the safety of some devices at 3.0 T may not be established yet. Additional caution is needed when assessing patients for scanning at 3.0 T and higher fields.

**Aneurysm clips.** Some intracranial aneurysm clips are known to be ferromagnetic. MRI may cause movement of these clips, damaging blood vessels and leading to hemorrhage. Nonferromagnetic aneurysm clips are proven to be safe, but the composition of any clip must be established before scanning.

**Pacemakers.** Pacemakers have always been considered an absolute contraindication for MRI. However, with the advent of newly approved MR-compatible pacemakers, their contraindication is no longer considered absolute. The risks associated with non-MR compatible pacemakers include movement of the device, damage to the switches, current inducement in the leads, and changes to the mode or programming. Any of these effects potentially have catastrophic results for the patient. Even MR-compatible pacemakers require a high degree of care and monitoring during the exam, often with a cardiologist present. Regardless of the

type of pacemaker—compatible or non-compatible—patients with pacemakers require special attention before proceeding with the MR exam.

**Heart valves.** Many heart valve prostheses available commercially have been tested for MRI safety. Most show slight deflection during MRI, but the effect is small compared to the regular forces from the heart itself. Patients with approved heart valves may safely undergo MRI. For these and other types of implants, there may be an advised waiting period after implantation to permit the device to stabilize before scanning.

**Orthopedic implants.** Most orthopedic implants and devices are nonferromagnetic and have been tested for MRI safety. Patients with such implants may undergo MRI. However, the presence of some devices can yield imaging artifacts that make obtaining diagnostic imaging studies around the implant difficult.

**Electronic devices.** Most implanted electronic devices are contraindicated for MR imaging by the FDA. These devices include, but are not limited to, neurostimulators, bone growth stimulators, internal defibrillators, and cochlear implants. However, some patients with implanted electronic devices can be imaged with MR under certain circumstances; for example, some deep-brain stimulators are considered safe to scan. MR head imaging for these patients typically is permitted using a transmit/receive only coil and at field strengths no greater than 1.5 T. Also, some programmable intracranial shunts can be imaged using proper precautions. **Always check with the manufacturer of the device before proceeding with imaging.**

## PRECAUTIONS

The most important and effective measure to assure safety and quality of MR examinations is a thorough and diligently applied screening procedure. The majority of adverse incidents in MRI have resulted from inadequate screening and access control. Adhering to comprehensive screening and safety procedures is crucial. See Table 2 for a list of internal patient hazards.

### Screening

Initial patient screening before an MRI examination generally takes place at the time of scheduling. The screening should be performed by someone familiar with MR safety issues and potential hazards, including the determination of any devices or embedded objects that prevent MRI from being performed safely, and whether pregnancy or disabilities are a concern. If there is a question about being able to complete the examination, the patient should not be scheduled until all concerns have been addressed.

A more comprehensive screening, including written forms for documentation, should be undertaken just before the examination. This information should be reviewed with the patient along with any other questions or concerns that may arise. Sample screening forms are shown in Figures 4 and 5.

For patients who are comatose or unresponsive, the screening should be performed in consultation with whoever is most qualified to answer the relevant questions. This could include a family member, guardian, or a physician with a thorough knowledge of the patient's medical history. Additional care is needed to identify possible implants or embedded metals in unresponsive patients. In cases where the absence or presence of metal or other foreign bodies cannot be firmly

| Absolute Contraindications (do not study) | Relative Contraindications (study if nonferromagnetic) |
|---|---|
| • Non-MR compatible pacemakers/pacemaker wires<br>• Automatic internal defibrillators<br>• Biostimulators (neural, bone growth)<br>• Implanted infusion pumps<br>• Cochlear implants/internal hearing aids<br>• Metallic orbital foreign body<br>• Tissue expanders<br>• Ocular prosthesis<br>• Non-MR compatible neurostimulators<br>• Bone growth stimulators<br>• Implantable drug infusion pumps | • Aneurysm clips<br>• Heart valve prosthesis<br>• Middle ear prosthesis<br>• Penile prosthesis<br>• Shrapnel/foreign bodies<br><br>**Safe to Study (may produce artifacts)**<br>• Surgical hemostasis clips<br>• Orthopedic prostheses, pins, rods, plates<br>• Dental fillings, orthodontic braces<br>• Intrauterine devices (IUDs), contraceptive diaphragms |

Table 2. **Classification of internal patient hazards.**[2]

established, a standard head and/or chest x-ray of the patient may be recommended before MRI to rule out the presence of implants that are particularly hazardous during an MR examination, such as pacemakers or aneurysm clips.

## Absolute Contraindications

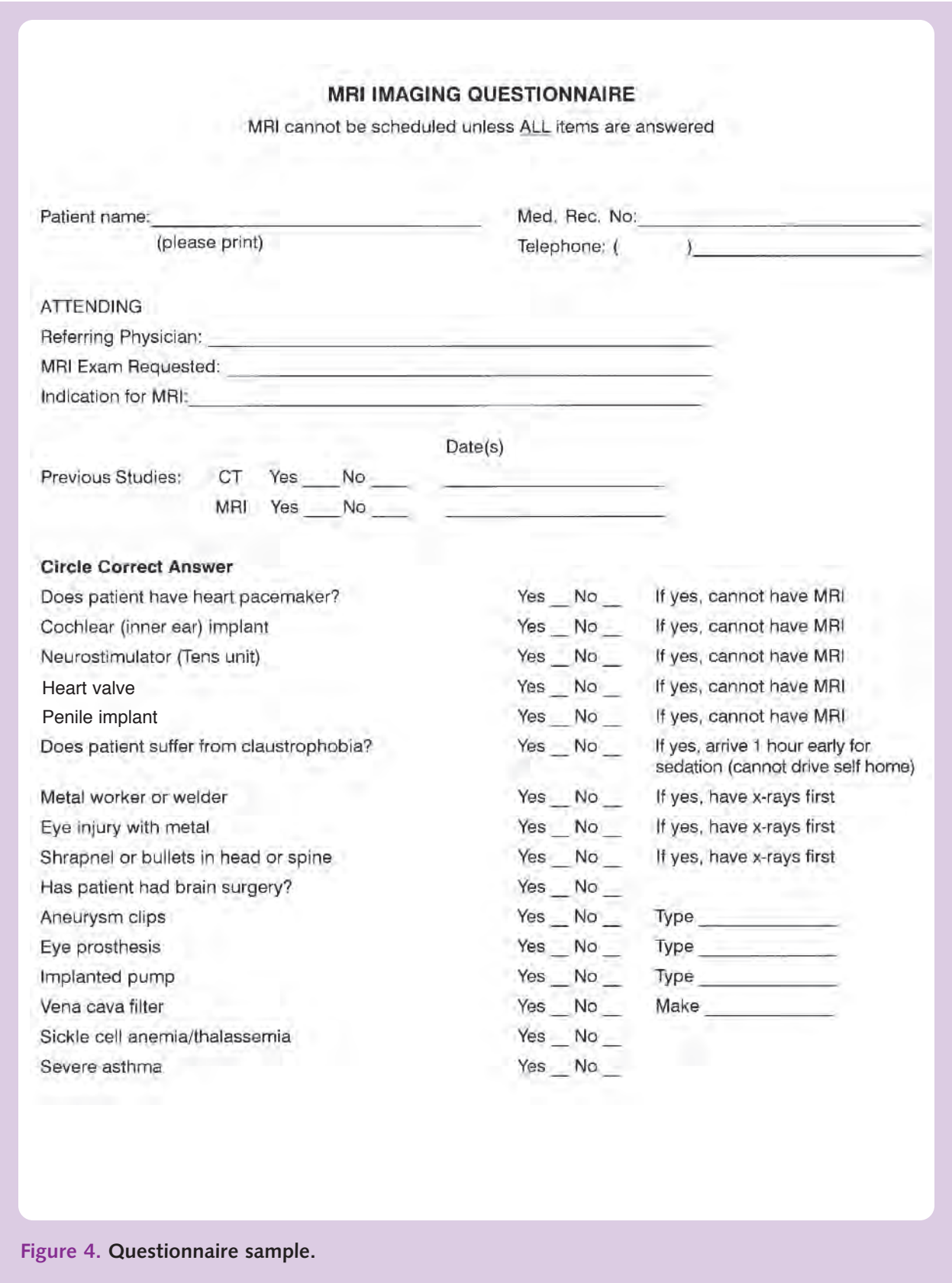
Each patient must be evaluated individually before MR imaging. However, the following devices and conditions are considered to be absolute contraindications for MRI in any patient:

- Non-MR compatible pacemakers
- Permanent pacemaker leads
- Defibrillators
- Biostimulators
- Cochlear implants
- Internal hearing aids
- Infusion pumps
- Metallic orbital foreign bodies
- Tissue expanders
- Ocular prostheses
- Bone growth stimulators

## Possible Contraindications

The devices and conditions in this list may or may not be contraindications to MRI, but further evaluation is needed to establish that the examination can be safely performed.

- MR-compatible pacemakers
- Deep-brain stimulators
- Intravascular devices
- Heart valves
- Penile implants
- Otologic implants
- Ocular implants
- Orthopedic implants
- Surgical or vascular clips
- Halo vests
- Dental devices and implants
- Bullets or shrapnel



**MRI IMAGING QUESTIONNAIRE**

MRI cannot be scheduled unless ALL items are answered

Patient name:_____ Med. Rec. No:_____
(please print) Telephone: ( )_____

ATTENDING
Referring Physician: _____
MRI Exam Requested: _____
Indication for MRI:_____

| | | | Date(s) |
|---|---|---|---|
| Previous Studies: | CT | Yes ___ No ___ | _____ |
| | MRI | Yes ___ No ___ | _____ |

**Circle Correct Answer**

| | | |
|---|---|---|
| Does patient have heart pacemaker? | Yes __ No __ | If yes, cannot have MRI |
| Cochlear (inner ear) implant | Yes __ No __ | If yes, cannot have MRI |
| Neurostimulator (Tens unit) | Yes __ No __ | If yes, cannot have MRI |
| Heart valve | Yes __ No __ | If yes, cannot have MRI |
| Penile implant | Yes __ No __ | If yes, cannot have MRI |
| Does patient suffer from claustrophobia? | Yes __ No __ | If yes, arrive 1 hour early for sedation (cannot drive self home) |
| Metal worker or welder | Yes __ No __ | If yes, have x-rays first |
| Eye injury with metal | Yes __ No __ | If yes, have x-rays first |
| Shrapnel or bullets in head or spine | Yes __ No __ | If yes, have x-rays first |
| Has patient had brain surgery? | Yes __ No __ | |
| Aneurysm clips | Yes __ No __ | Type _____ |
| Eye prosthesis | Yes __ No __ | Type _____ |
| Implanted pump | Yes __ No __ | Type _____ |
| Vena cava filter | Yes __ No __ | Make _____ |
| Sickle cell anemia/thalassemia | Yes __ No __ | |
| Severe asthma | Yes __ No __ | |

**Figure 4. Questionnaire sample.**

**MAGNETIC RESONANCE IMAGING**
**PATIENT INFORMATION**

**DEPARTMENT OF RADIOLOGY**

INFORMATION OBTAINED BY:

**PLEASE COMPLETE AND SIGN:**

| TODAY'S DATE | PATIENT NAME | BIRTHDATE | WEIGHT | AGE |
|---|---|---|---|---|
| | | | | |

*The following are*
***ABSOLUTE CONTRAINDICATIONS***
*for MR Imaging:* Mark YES or NO

CARDIAC PACEMAKER/AICD ☐ YES ☐ NO
BRAIN (Aneurysm) CLIPS ☐ YES ☐ NO
COCHLEAR (Ear) IMPLANTS ☐ YES ☐ NO

1. *Have you had brain surgery?*
   ☐ YES ☐ NO
   Date:
2. *Have you had heart surgery?*
   ☐ YES ☐ NO
   Date and Type of Surgery:
3. *Have you had any surgery?*
   ☐ YES ☐ NO
   Date and Type of Surgery
4. *Have you had any previous MR or CT studies?*
   ☐ YES ☐ NO
   Date and Type:
5. *Have you had a piece of metal removed from your eyes?*
   ☐ YES ☐ NO
6. *Do you have allergies/kidney disease/ sickle cell anemia?*
   ☐ YES ☐ NO

*The following items may be hazardous or may interfere with the MRI exam.*

*Please mark YES or NO*

| YES | NO | | DATE OF SURGERY |
|---|---|---|---|
| ☐ | ☐ | Internal defibrillator | |
| ☐ | ☐ | Aortic clips | |
| ☐ | ☐ | Carotid clips | |
| ☐ | ☐ | Neurostimulators | |
| ☐ | ☐ | Heart valve | |
| ☐ | ☐ | Insulin pump | |
| ☐ | ☐ | Shunts or stents | |
| ☐ | ☐ | Joint replacements/Bone pins/ Metal rods/Metal plates | |
| ☐ | ☐ | Harrington rod | |
| ☐ | ☐ | Coils, filters | |
| ☐ | ☐ | Retinal Tac Implant | |
| ☐ | ☐ | Wire mesh | |
| ☐ | ☐ | IUD | |
| ☐ | ☐ | Shrapnel/Metal injuries | |
| ☐ | ☐ | Transdermal patches | |

*PLEASE REMOVE:*
- Hearing aids
- Watches
- Hairpins/Barrettes
- Keys
- Pens/Pencils
- Wallets/Credit cards

*Are you or MAY you be pregnant?**
☐ YES* ☐ NO

* *The FDA has indicated that the safety of MR imaging on the fetus has not been established or proved. You may want to discuss this matter with your referring physician.*

*Have you had any tattoos/body parts pierced?*
☐ YES ☐ NO

THE TECHNOLOGIST WILL HAVE YOU CHANGE INTO A GOWN IF APPROPRIATE

Please describe your symptoms and how long they have been present:

Were the symptoms caused by an injury? If so, please describe:

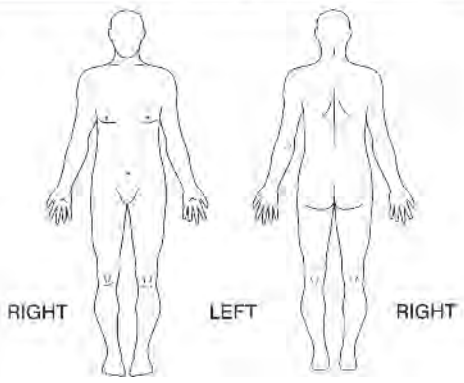



**Figure 5. Questionnaire sample.**

There are different opinions regarding the safety of some of these devices for imaging; but in all cases, specific information regarding the device and its safety profile must be acquired from the manufacturer. This applies to the actual device, as well as to the location and history of its implantation. Patients with any of the devices listed above who undergo MRI scanning should be closely monitored for any sensations or reactions to the scan that might indicate the device has either moved or heated up during the procedure.

### Other devices

Patients may have a variety of other devices and implanted objects that pose no risk for MRI, but which can produce image artifacts that result in a poor quality study. Examples include orthopedic prostheses, pins, rods, and plates; dental fillings or braces; surgical hemostasis clips (it is recommended to wait several weeks after surgery to perform MRI to allow the clips to stabilize); intrauterine devices and other contraceptive implants.

The above lists are not complete or comprehensive. The most up-to-date information should be acquired directly from the manufacturer of any particular device. An extensive list of medical and surgical devices and their safety profiles is available at the website **www.mrisafety.com**.

## PREGNANCY

There has been only limited scientific study of the effects of MR imaging on the fetus during pregnancy. No study to date has identified any negative consequences. Nevertheless, the potential risks and benefits of MR imaging should be carefully weighed in the case of pregnant patients. Recent FDA guidelines suggest avoiding MRI in the first trimester of pregnancy. After that time, the need to scan a pregnant patient should be considered against the availability and safety of other diagnostic procedures; it is worth noting that MRI may be more appropriate than x-ray exposure in some instances. In particular, if other nonionizing forms of imaging are inadequate and the only other options involve ionizing radiation such as x-ray or CT, an MRI examination may be the best choice for a pregnant patient.

### Use of Gadolinium Chelates in Pregnancy

There have several papers regarding the use and safety of gadolinium chelates in pregnancy.[3-6] Gadolinium chelate contrast agents all cross the placenta and accumulate in the fetal bladder, where they are excreted into the amniotic fluid and then swallowed by the fetus. It is generally felt that gadolinium chelates should be used in pregnancy only if the expected benefit far outweighs the risk. Studies have found that less than 0.04% of administered gadopentetate dimeglumine is excreted into human breast milk. This amount of contrast ingested by the infant translates to 0.0004% of the total dose given to the mother and less than 0.4% (4 10,000ths) of what is permitted for a two-year-old child.

There is a theoretical risk of allergenic reaction in the infant, but thus far it remains only theoretical. There have been no reported instances of toxic reactions to any infant breastfeeding after the mother has been administered a GBCA. Therefore, the guidelines from the ACR and FDA are that it is safe for the child of a breastfeeding mother to ingest the small amount of contrast present in breast milk. However, if the mother remains concerned about contrast material passing through breast milk, it is recommended that the mother practice a "pump and dump" of breast milk for 24 hours following injection.[7,8]

## PREPARATION AND MONITORING

In preparation to enter the MR magnet room, patients must be instructed to remove all objects containing metal. Examples include watches, jewelry, body piercing ornaments, hairpins, hair clips, glasses, dentures, and hearing aids (wedding rings are typically allowed to remain on the patient as they are not ferromagnetic, and thus have no torque). Some items of clothing may also need to be removed, such as items with metal buckles, snaps, clips, or eyelets (shoes, for example). Credit cards and any other card or object containing a magnetic recording strip should be left outside the magnet room as the information on the recording strip is erased in the presence of even a modest magnetic field. Coins and keys should also be left outside, along with any other potentially ferromagnetic items like pens, paper or binder clips, pocket knives, or ID badges.

It is also advisable to remove makeup and eyeliner, since many cosmetics contain metallic elements that may result in skin irritation and image artifacts. Permanent makeup or tattoos can also cause irritation or heating and, depending on the content of the pigment, may also cause image artifacts.

Finally, patients should be continually monitored throughout the scan. At a minimum, this includes verbally asking patients if they are experiencing any discomfort or other reactions during the scan. For certain types of patients or scans, monitoring of vital signs—such as heart and respiratory rates—may be required as well. High-risk patients (eg, comatose, critically ill, or sedated subjects) may need more extensive monitoring with MRI-compatible nonferromagnetic monitoring systems, taking care to properly position the devices so that no conducting loops are created. Further observation after the scan may also be necessary for patients in high-risk categories.

## PATIENT COMFORT

MRI is a routine procedure for the technologist, but for the patient undergoing a scan it can be a unique and stressful experience. Patient comfort is an important component in acquiring a high-quality study, and the role of the technologist in communicating with patients to prepare them for a positive examination experience should not be underestimated. The technologist must be prepared to deal with a spectrum of patient reactions, from mild anxiety to serious claustrophobia and emotional distress.

### Positioning and Noise

An MRI examination requires the patient to lie still for considerable lengths of time in an unfamiliar and noisy environment. To assure acquisition of a high-quality study, it is essential that the patient be made as comfortable as possible for the duration of the scan. A high level of comfort helps improve the tolerance and cooperation of the patient and minimizes patient motion that can corrupt images. Pillows, blankets, and pads all help enhance patient comfort, along with proper placement of coils to avoid heating. Communicating with patients between each series of scans to inquire about their comfort level can help reassure them and maintain a reasonable level of ease to assure a quality study.

The noise of the scanner can be disturbing to the patient once the examination has begun. Earplugs or headphones (possibly with music provided) should always be used for both safety and comfort purposes.

## The Importance of Technologist-Patient Communication

One of the most influential factors in assuring a good quality study is the technologist taking time to thoroughly explain the examination to the patient before positioning the patient on the scanner table. Though no formal study is known to exist, it can be logically argued that most compromised examinations are the result of patient anxiety. Patients presenting for an MRI may be nervous about the procedure before they arrive in the MR suite. They are anxious about the health issue that prompted the examination, and they may be apprehensive about the procedure itself if they have never experienced an MR scan. However, a few minutes of careful instruction provided by the technologist can significantly reduce the patient's trepidation.

### Before the examination

Be sure to verify the patient's identification by name and birthdate and also ID bracelet if an inpatient. Signed consent may be required if the patient is given intravenous contrast, receives a joint injection, or undergoes a biopsy procedure.

At some point before the examination begins the technologist should take a few minutes to sit down with the patient to thoroughly explain the entire procedure. Information that should be discussed includes:

- The very basics of how MR works (example: "Strong magnetic fields and radio waves are used to detect signals coming from the area that we are scanning.")
- The fact that the MR procedure is very safe; ie, no radiation, no adverse effects, no long term effects have been shown
- The importance of lying very still
- The noise and "knocking" sound of the scanner, and how long it will last
- The expected length of the entire examination
- Assuring patients that they will be in constant two-way communication with the technologist

Taking a few minutes to give the patient clear information and instruction will save a great deal of time for the technologist by reducing repeated series and patient "call-backs" to be scanned again. If patients feel rushed their anxiety level increases, resulting in more nervous movements that can cause the need to repeat an imaging series because of motion artifact. The technologist should try to make patients feel secure and comforted by talking to them about the examination procedure; often patients can be made to feel more assured and at ease simply by having the technologist listen to their concerns.

### During the examination

Communication with the patient during the actual examination is also extremely important. A typical MR examination can consist of four to six series of imaging sequences. After each imaging series it is recommended that the technologist ask patients if they are doing okay, or if they are having any problems during the procedure. Moreover, the technologist should give patients adequate time to reply completely before starting the next series of images. If the patient senses the technologist is rushed, it will add to the patient's anxiety level. A calm, reassuring voice from the technologist soothes the patient in many cases. Before actually starting any imaging series the technologist should inform the patient that it is about to begin and advise how long it will take. For example,

> "OK, Mr. Smith, I'm glad you are doing well. We are going to start the next series of pictures now and it will last about three minutes."

The patient communication skills of the technologist are just as important to ensuring a high-quality MR examination as the selection of the physical scanner parameters.

### Claustrophobia and Confinement

Patients may often feel an uncomfortable sense of confinement or claustrophobia while in the bore of the magnet, even if they have never been prone to these sensations in the past. Although it was thought that the introduction of both open bore and short conventional bore systems would help lessen these complications in recent years, the national average of patients unable to complete an MRI examination due to claustrophobia has remained fairly constant at 1–4%, even after the introduction of the new technologies.[9] Fear of confinement is often present and can be magnified by the underlying anxiety of what medical problems the test may reveal. Again, discussion before the scan about what will happen during the procedure and communication during the scan can go a long way to moderate the patient's anxieties.

Patients who are severely claustrophobic or have anxiety attacks during MRI scanning may need to be sedated if other means of reducing distress are not effective; for such patients, sedation may be the only means available to complete an examination. The appropriateness of sedation must be carefully considered. If sedation is necessary, the timing of administration, the possibility of an adverse reaction, and recovery time after the procedure must be taken into account. The patient may also need transportation after receiving medication.

## SUMMARY

While MRI examinations are routine procedures, thorough screening and safety procedures are an absolute necessity. Up-to-date information on medical histories and device safety are of great importance to minimize the possibility of adverse events in an MRI examination. Consideration of patient comfort and concerns during all steps of the examination can also help to assure high-quality diagnostic studies.

Patient safety is the most important responsibility of the technologist throughout the examination process. The second most important responsibility of the technologist is to obtain highly diagnostic images in the fastest possible time. Patient anxiety is arguably the greatest factor in the patient's ability to remain motionless for the entire scan process, facilitating diagnostic images. The technologist's communication skills before and during the examination can be very effective in calming the patient. Taking a few minutes to explain the exam, reassuring patients and calming their fears, and communicating clearly and calmly during the examination helps patients relax and feel that they are in the hands of a technologist that is an expert in the field.

# FACILITY SAFETY

Patient safety considerations are of paramount importance in the MRI environment. Healthcare personnel entering the MRI suite are affected by the same safety considerations as the patient, but they must also be very aware of additional hazards and safety precautions when working within the magnetic field. Any person working in or around the MRI facility must be educated about the potential risks relating to the safety of medical devices, tools, and other equipment, or be escorted by trained MRI personnel. It is the responsibility of the technologist and all healthcare personnel in the MRI suite to ensure that safety procedures are well planned and described, fully implemented, and strictly adhered to in order to prevent serious accidents, injury, and even death. Thankfully, personal injury is rare in MRI facilities if proper safety protocol is observed.



## PHYSICAL HAZARDS

For the MR technologist, the physical hazards associated with the MRI environment can be separated into two categories:

- Magnet failure (rapid quenching)
- Magnetic force (projectile objects)

First, there are safety considerations in the case of a failure of the magnet itself. In this material we discuss superconducting magnets, where cryogens such as liquid helium and liquid nitrogen may be present. Second, there are hazards associated with the force that the high magnetic field exerts on other objects that are ferromagnetic. The primary risk is that such objects will become projectiles and fly towards the magnet.

### Quenching

The main hazard associated with a high field *superconducting* magnet is the occurrence of a sudden, unexpected quench of the magnet. A quench is the sudden boiling off of the cryogenic liquid (liquid helium), which occurs if the superconductivity of the main magnet is lost. If the system is no longer superconducting, the magnet windings—the cabling wrapped many times around the magnet in a circular pattern used to generate the main magnetic field—where the current is flowing and generating the magnetic field will begin to experience resistance and will give off heat as a result. This heat causes the cryogens to boil off, rapidly converting all of the liquid helium to gas. The magnetic field will also be completely lost.

The structure that contains the magnet and the cryogens is called the cryostat, which is insulated from the surrounding environment as much as possible to reduce heating of the cryogens.

The conversion of liquid helium to gaseous helium involves a tremendous volume change. All superconducting magnets are installed with a ducting and ventilation system (such as a quench pipe) designed to rapidly remove gas from the room. However, in an accidental quench the conversion to gas happens almost instantaneously, and in such a situation the ventilation systems may prove inadequate to remove the gas fast enough, or may even fail.

The primary risk of any magnet quench is oxygen depletion in the room. The helium gas may displace most or all of the oxygen in the room, causing oxygen levels to drop below levels that can sustain life, producing the danger of asphyxiation. If the ventilation

system fails, additional hazards may result from a pressure increase in the room, such as the magnet room door being forced shut by the immense in-room pressure, as well as rapid cooling of the room as the cold helium gas fills it. The loss of the magnetic field is not a significant risk associated with a quench.

Superconducting magnets usually have a way to initiate a controlled quench to shut down the magnetic field slowly, allowing the ventilation system to effectively remove the helium gas produced. This is a very serious operation and should be considered only as an extraordinary remedy in the case of a medical emergency endangering a patient's life. Refer to the magnet manufacturer's guidelines for instruction on how to quench the magnet in a controlled manner during an emergency.

## Ferromagnetic Objects

The most significant hazards associated with the large magnetic field of the MRI system are posed by ferromagnetic objects brought within the range of the magnet. The risks to patients with implanted devices or embedded metal in the body are discussed earlier in this material.

Any ferromagnetic object is considered to be a risk in the MRI environment. The strength of the magnetic field created by an imaging system is so great that it can pull objects towards the system very suddenly and with great force and increasing velocity. The object becomes a projectile and will strike with great force anything in its path towards the magnet. This is true of any ferromagnetic object, regardless of its size. A few examples include pens, keys, tools, patient oxygen tanks, monitoring equipment, and wheelchairs.

Figures 6 and 7 show photos from an incident described in detail by Chaljub et al.[10] In this incident, maintenance was performed on an MRI-compatible anesthesia machine outside of the scan room. After completing the maintenance work, the service person replaced the nitrous oxide tank on the anesthesia machine with a non–MR-compatible ferrous tank. The anesthesia system was then moved back into the scan room. The service person discovered the error and went into the scan room to disconnect the tank, and attempted to carry it out of the room. The force of the magnet pulled the tank from his grasp and sent it flying into the MRI scanner, which sustained considerable damage. At the time, a patient and technologist were in the room preparing for an examination and were narrowly missed by the flying tank, which could have killed them had they been struck. While these types of incidents are rare, they demonstrate the danger and destructive

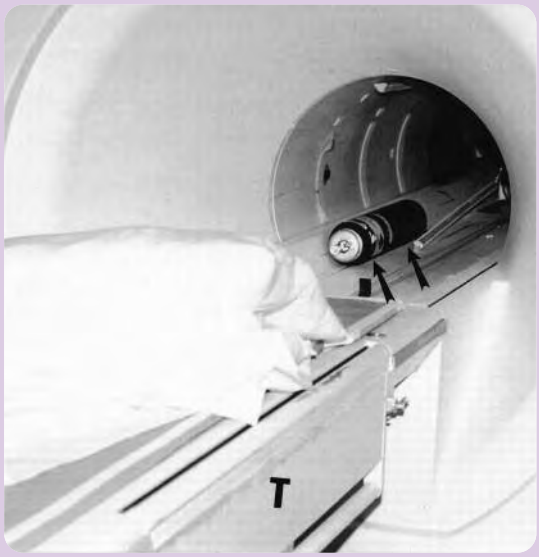



**Figure 6. A portable ferromagnetic anesthesia tank that was pulled into the magnet. Although nobody was injured, the magnet sustained $50,000 of damage and a loss of one week's operating time.[4]**

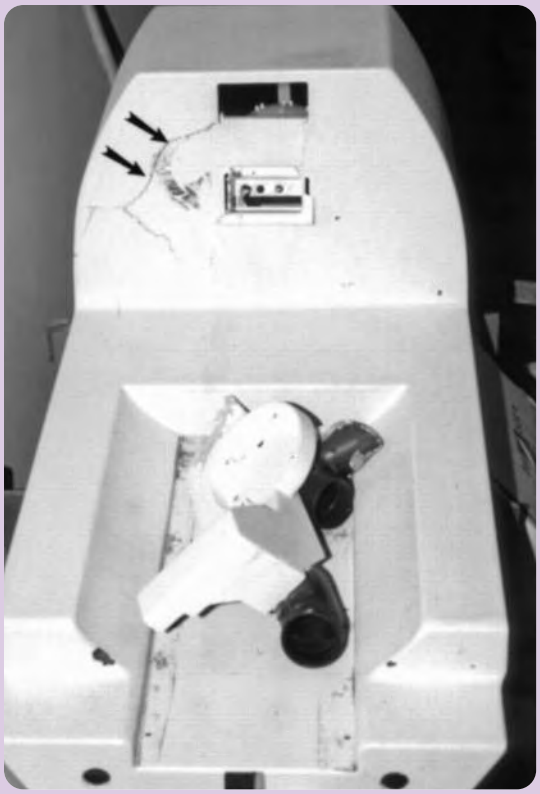


**Figure 7. Damage from the anesthesia tank included dislodgement of the head coil carriage and surface coil connection from the automated stepping table. Marks from the tank can also be seen (arrows).[4]**

potential that are always present in the environment of the MRI magnet. Virtually all such accidents result from a lapse in safety monitoring or procedures.

All potentially ferromagnetic objects must be screened and/or removed before entering the vicinity of the MRI machine. Small objects such as wrenches, screwdrivers, and scissors are risky because of their small size; they can easily be grabbed by the magnetic field and propelled at high velocity into the magnet. Large objects, such as wheelchairs, IV poles, gas tanks, or carts pose even greater risks. The force of the magnet is enough to lift even very heavy objects, which have greater destructive potential. In either case, it may be impossible to remove the object from the magnet without shutting down the MRI system (an expensive and time-consuming procedure for superconducting magnets) or further damaging the system.

Because MRI has become a common examination and is used even for seriously ill patients requiring monitoring, virtually all of the equipment listed above is available in nonferromagnetic form. However, it is always vital to verify that nonmagnetic equipment and tools are in use before entering the scan room.

## ROOM DESIGN

One aspect of MRI safety that is often overlooked is the design of the MRI suite, which can play a critical role in significantly reducing the incidence of patient accidents. In too many institutions the location of the magnet room, the magnet room door, the operator's console, waiting area, and changing areas is designed with convenience in mind rather than safety. For example, a large East Coast facility spent a considerable amount of money on renovations to install two 1.5 T MRI systems. When complete, the magnet room doors of both systems opened into a high-traffic hallway. It was not until after months of use and a near-disastrous incident involving a patient lost in the maze of hallways that the patient safety risk became apparent. Eventually, the facility decided to renovate the suite yet again to make it safer.

Most experts agree that at least 3 to 4 degrees of separation (usually referred to as zones) are needed between the magnet room and any area accessible to the general public. This system of controlled access to the differ-

ent zones prevents accidental walk-ins in the scanning area. The system also provides at least three opportunities to screen not only the patient to be scanned, but also anyone accompanying the patient, such as a family member or medical personnel unfamiliar with the MRI suite.

The American College of Radiology (ACR) has developed a set of guidelines to serve as a basis for an individual institution's safety policies and procedures.[11] A hallmark of the ACR recommendations is its precise definition of the zones within the MRI facility, which control access to the various areas of the MRI suite. A typical MRI suite floor plan is shown in Figure 8.

The basic zone definitions and the access restrictions imposed on each one are described below.

- **Zone I.** This zone is defined as any area that is freely accessible to the general public. This zone should lie outside of the MRI suite but lead to its entrance.
- **Zone II.** This zone serves as the buffer between the public Zone I and the more restricted areas of the MRI suite. Zone II

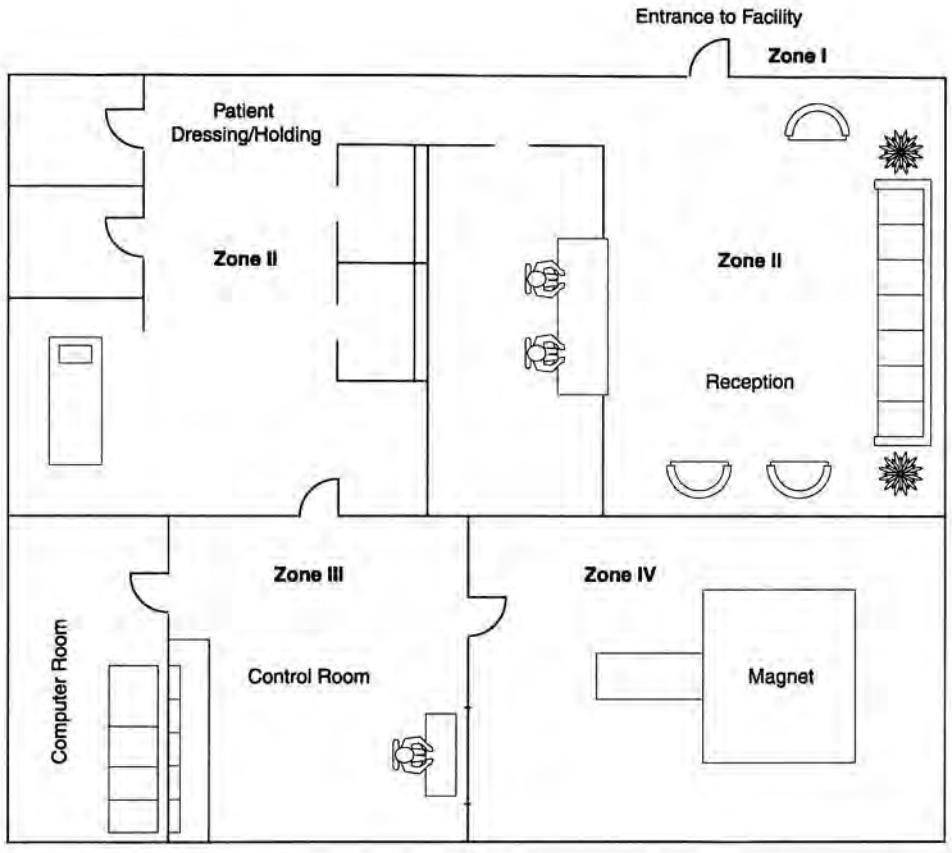



**Figure 8. A sample floor plan illustrating site access restriction considerations.[5]**

includes the reception and waiting areas, where patients and families can complete pre-examination forms and screening questionnaires. This area is within the MRI facility and is overseen by MRI personnel.

- **Zone III.** Access to Zone III is restricted to trained MRI personnel and other individuals and equipment that have been fully screened. Hazards associated with ferromagnetic objects and unscreened persons (such as those with pacemakers) are encountered in this zone. The MRI personnel associated with Zone III are charged with maintaining the supervision and safety of this area. Ideally, this zone should be physically restricted by the use of locked doors or other limited access methods. If the 5 Gauss line for any MRI system extends into this zone, it should be clearly marked and the potential hazards presented as patients with non-MRI compatible pacemakers and ICDs could be adversely affected, even at low field strengths. Recall that Gauss is a unit of magnetic field strength: 1 Tesla = 10,000 Gauss. The 5 Gauss line varies, depending on magnet strength, and can extend into Zone III, the MRI control room.

- **Zone IV.** This zone encompasses the MRI scan room. Zone IV should be marked with the necessary warnings and cautions pertaining to the magnetic field, and the entrances should always be observable by MRI personnel. When emergency intervention such as resuscitation is required, basic lifesaving cardiopulmonary resuscitation (CPR) should be initiated as the patient is removed to a safe area outside Zone IV where full medical interventions can then be safely performed. Even in such emergency circumstances, full site access restrictions to Zones III and IV should be maintained for the safety of all involved.

## Personnel

Any person entering Zone III, whether a patient or healthcare provider, should be screened by MRI personnel before entering the zone. All persons entering the scan room (Zone IV) must remove any metallic personal belongings, such as jewelry (including watches), pagers, cell phones, and body piercings. The only exceptions are wedding and engagement rings, which are nonferromagnetic and are almost universally permitted. Because of the variable sensitivity and inability to differentiate between ferromagnetic and nonferromagnetic objects, metal detectors are not useful as screening devices in the MRI setting. Particular attention must be paid to anyone (patient or otherwise) who has a pacemaker, autodefibrillator, or other electromechanical device. Such persons should never enter the magnet room (Zone IV) and must always be kept outside the 5 Gauss line, even if the line extends outside the scan room.

Pregnant healthcare workers are permitted to work in the MRI environment, including the scan room, throughout all stages of pregnancy. Performance of all duties related to patient positioning, operation of the scanner, injecting contrast media, and emergency response into the scanner is allowed. Though no adverse effects have ever been shown, it is recommended that pregnant personnel not be present in the magnet bore or the scan room during an actual MRI data acquisition.

Access to the facility by emergency personnel, such as firefighters and security officers, must be planned for and accommodated. If possible, an MRI-trained member of the facility should be on-site when a fire alarm or other emergency call originates from the MRI facility, to prevent uncontrolled access to the unsafe areas of Zones III and IV. MRI-compatible fire-extinguishing equipment should be

stored and used in these areas, and incompatible equipment must not be brought in. In circumstances where emergency personnel must enter with incompatible equipment (such as axes, crowbars, defibrillators, or air canisters), a controlled quench of the magnet should be considered. Proper verification that the magnetic field has actually been eliminated or reduced to a sufficient degree for safe entry before allowing access is required.

### Equipment

Screening the devices and equipment brought into the scanning areas of Zones III and IV is just as important as screening and educating healthcare providers.

As the first step in testing for compatibility, a strong hand-held magnet should be available to perform basic testing on devices and equipment to see if it is MR compatible. Such a magnet can even be used to test some patients' superficially located internal devices and implants to determine if they are attracted by the magnet.

Devices made of metal or containing metal parts that are portable and/or not implanted should be verified in writing that they are nonferromagnetic and safe for the MRI environment before entering the Zone III area. It should never be assumed that a device is compatible unless there is written verification. Devices that must be so verified include oxygen cylinders, fire extinguishers, and aneurysm clips, to name the most common. Always err on the side of safety. Unless an object is verified as safe, always assume that it is ferrous and will exhibit a force toward the magnet. Any unknown equipment should be checked with a hand-held magnet. Further, safety information published for a given device should specify the field strength and gradients for which it was tested; it cannot be assumed that devices tested at 1.5 T are also safe at 3.0 T.

Exceptions may be made for some ferromagnetic equipment to be brought into Zone III if it is necessary for the care of the patient. In these cases, direct supervision by trained MRI personnel should be maintained at all times. Such devices must be located and monitored so that they cannot enter the scan room and accidentally get too close to the static magnetic field.

## ENVIRONMENTAL SAFETY

To ensure the safety of the MRI environment and eliminate or minimize the risks associated with the strong magnetic fields, an imaging site must have comprehensive and rigorous safety procedures in place. Additionally, consideration must be given to emergency conditions, such as fire, and the impact of the MRI system on emergency personnel and equipment, as well as to how those factors affect the system.

## SUMMARY

Comprehensive policies and procedures are necessary to ensure the safety of all personnel who come into contact with the MRI facility, including patients, staff, and emergency responders. All persons in the MRI environment must be familiar with and enforce screening procedures and zone restrictions in order to prevent accidents that could lead to serious injury or damage to the MR equipment.

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*Updated June 14, 2018*


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**Figures**

1, 2 Thomas Schrack, BS, ARMRIT
3 Courtesy of David Weber, PhD
4, 5 Courtesy of Maimonides Medical Center, Brooklyn, NY
6, 7 Chaljub G, Kramer LA, Johnson RF III, et al. Projectile cylinder accidents resulting from the presence of ferromagnetic nitrous oxide or oxygen tanks in the MR suite. AJR. 2001 Jul;177(1):27-30.
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# ABBREVIATIONS OF TERMS

| | |
|---|---|
| **ADC** | apparent diffusion coefficients |
| **AUC** | area under the curve |
| **$B_1$** | the RF transmission field |
| **$B_0$** | the main magnetic field |
| **bFFE** | balanced fast field echo |
| **BOLD** | blood oxygen level dependent |
| **cm** | centimeter |
| **CNS** | central nervous system |
| **CSF** | cerebrospinal fluid |
| **CT** | computed tomography |
| **CTL** | cervical-thoracic-lumbar |
| **dB/dt** | time-varying B fields (gradient-altered $B_0$) |
| **dB** | change in the main magnetic field ($B_0$) –OR– decibel |
| **dBA** | decibel attenuation |
| **DSC** | dynamic susceptibility contrast |
| **DTI** | diffusion tensor imaging |
| **eADC** | exponential ADC map |
| **EKG** | electrocardiogram |
| **EPI** | echo-planar imaging |
| **FLAIR** | fluid attenuated inversion recovery |
| ***f*MRI** | functional magnetic resonance imaging |
| **FNH** | focal nodular hyperplasia |
| **FS** | fat suppressed |
| **FSE** | fast spin-echo |
| **FOV** | field of view |
| **G** | Gauss |
| **g-factor** | geometry factor |
| **GRE** | gradient echo |
| **Hz** | hertz |
| **IR** | inversion recovery |
| **IV** | intravenous |
| **kHz** | kiloHertz (1,000 hertz) |
| **KVO** | keep vein open |
| **mHz** | megaHertz (1,000,000 hertz) |
| **min** | minute(s) |
| **MinIP** | minimum intensity projection |
| **MIP** | maximum intensity projection |
| **mm** | millimeter |
| **mmol/kg** | millimole per kilogram |
| **mOsm/kg** | milliosmoles per kilogram |
| **mOsm/L** | milliosmoles per Liter |
| **MPR** | multiplanar reconstruction |
| **MRI** | magnetic resonance imaging |
| **MRA** | magnetic resonance angiography |
| **MRCP** | magnetic resonance cholangiopancreatagraphy |
| **MRS** | magnetic resonance spectroscopy |
| **MRV** | magnetic resonance venography |
| **mT** | milliTesla |
| **mT/m** | milliTesla per meter |
| **mT/m/s** | milliTesla per meter per second |
| **MTT** | mean transit time |
| **NAA** | N-acetyl aspartate |
| **NEX** | number of excitations (also NSA) |
| **nm** | nanometer |
| **NSA** | number of signal averages (also NEX) |
| **OCP** | o-cresolpthalein complexone technique |
| **Osm/kg** | osmoles per kilogram |
| **PACS** | picture archiving communication system |
| **PNS** | peripheral nerve stimulation |
| **$r_1$** | $T_1$ recovery |
| **$r_2$** | $T_2$ decay |
| **RBW** | receive bandwidth |
| **rCBV** | relative cerebral blood volume |

| | |
|---|---|
| **RES** | reticuloendothelial system |
| **RF** | radiofrequency |
| **ROI** | region of interest |
| **SAR** | specific absorption rate |
| **SE** | spin-echo |
| **SNR** | signal-to-noise ratio |
| **SPGR** | spoiled gradient echo |
| **SPIO** | superparamagnetic iron oxide |
| **SSFP** | steady state free precession |
| **STIR** | short tau inversion recovery |
| **T** | Tesla |
| **T1** | time for 63% of a tissue's longitudinal magnetization to recovery |
| **T2** | time for 63% of a tissue's transverse magnetization to decay |
| **TE** | echo time |
| **T/m/s** | tesla per meter per second |
| **TOF** | time of flight |
| **TR** | time to recovery –OR– repetition time |
| **TSE** | turbo spin-echo (Siemens Medical Systems term for fast spin-echo) |
| **UAE** | uterine artery embolization |
| **USPIO** | ultrasmall superparamagnetic iron oxide |
| **W/kg** | watts/kilogram |

# GLOSSARY

**absolute zero**
the theoretical point at which all molecular motion stops, measured as $0^0$ Kelvin

**aliasing**
a common artifact caused when the FOV selected is smaller than the area of tissue excited; also known as "wrap-around"

**algorithm**[1]
a step-by-step method of solving a problem or making decisions, as in making a diagnosis. An established mechanical procedure for solving certain mathematical problems

**artifact**[1]
in radiology, a substance or structure not naturally present in living tissue, but of which an authentic image appears in a radiograph

**BOLD (blood oxygen level dependent) imaging**
an imaging technique based on the EPI pulse sequence in which the patient is given mental tasks to perform while undergoing MR examination. Increases in blood flow to affected areas of the brain are postprocessed into functional maps indicating brain activity.

**bore**
the tubular portion of the magnet in which the patient is placed

**contraindication**
an absolute reason or cause not to proceed with a diagnostic examination or procedure. In MRI it is typically a patient condition, such as an embedded cardiac non-MR compatible pacemaker, that prohibits the patient from undergoing MR examination.

**contrast**
differences in signal intensity between two adjacent areas on an MR image

**cryogen**
super-cooled liquid gas used to cool a given material to near absolute zero, thus becoming superconductive; in MR, liquid helium

**cryostat**
the vessel in which the magnet is immersed in liquid helium

**diffusion imaging**
an imaging technique usually based on the EPI pulse sequence; it is used to indicate the amount of water absorption across a brain cell membrane

**duty cycle**
the amount of time (stated in percentage) that an MR system gradients can be "active" before they must be turned off in order to cool; most MR manufacturers report a duty cycle of 100%, indicating the gradients can run at full power continuously

**echo planar imaging (EPI)**
a very fast pulse sequence characterized by rapid oscillation of the frequency encoding gradient to create an echo train; EPI fills k-space quickly

**echo spacing**
the time from the peak of one echo in an echo train to the next

**echo train**
the series of echoes created by a FSE or EPI pulse sequence

**electromagnetic spectrum**
continuous series of different types of electromagnetic radiation, ordered according to wave-length of frequency

**fast spin-echo (FSE)**
a rapid pulse sequence characterized by a series of $180^0$ RF echo pulses used to create numerous echoes within a single TR, thus filling k-space more quickly

**fat suppression**
any of the methods used to reduce signal from fat on an MR image

**ferromagnetic**
materials that react to a magnetic force; all iron and some stainless steel are ferromagnetic

**field of view (FOV)**
an area of tissue or anatomy to be imaged in an MRI scan

**fluid attenuated inversion recovery (FLAIR)**
inversion recovery-based pulse sequence that utilizes a relative long TI in order to suppress signal from a long T2 tissue while maintaining heavy T2-weighting throughout the rest of the image

**flip angle**
the rotation of the amount of RF energy used to excite some portion of protons in the longitudinal plane into the transverse plane

**frequency**
cycles per unit time; usually measured as cycles per second, or hertz (Hz)

**frequency encoding**
generation of frequency differences along a particular direction of a tissue slice for use in spatial localization of MR signal

**fringe field**
the extended magnetic field generated by an MRI magnet system that is outside the magnet bore, or scan area. The fringe field decreases in strength as the distance from the magnet increases

**functional MRI (*f*MRI)**
any of the imaging techniques that demonstrate function of anatomical structure; examples include spectroscopy, dynamic liver imaging, cardiac imaging, and BOLD imaging

**Gauss**[1]
[Karl Friedrich *Gauss,* Geman mathematician and physicist, 1777-1855] the cgs unit of magnetic flux density, equal to $10^{-4}$ tesla. Symbol, G

**gradient (magnetic field)**
a magnetic field that changes in strength along a given direction

**gradient amplitude**
the degree to which a gradient field can vary from zero to the peak maximum point; typically measured in milliTesla/meter (mT/m)

**gradient coil**
one of six coils (3 pair) placed in the three orthogonal planes (denoted X,Y, and Z) that generate small magnetic fields along the plane of the main magnetic field; it is used for slice selection, phase and frequency encoding

**gradient echo**
pulse sequence characterized usually by a $<90^0$ RF excitation pulse and an echo generated by gradient reversal instead of a $180^0$ RF echo pulse

**gradient moment nulling**
a method to reduce flow artifact in which one, or all three, pair of gradients are pulsed to dephase and rephase spins that flow along the axis of that gradient

**homogeneity**
the uniformity of any field; in MRI it is the uniformity of the $B_0$ field

**inhomogeneity**
absence of homogeneity or uniformity; inhomogeneity in a magnetic field may occur as one area of the field deviates from the average magnetic field strength

**inversion recovery**
pulse sequence characterized by an initial $180^0$ RF inversion pulse

**k-space**
the domain in which the information from each phase-encoding step is placed during a pulse sequence. Each "filled in" line of k-space corresponds to each phase-encoding step; once the required amount of k-space is filled, image reconstruction can begin

**Larmor frequency**
the frequency at which magnetic resonance is produced in a sample of hydrogen nuclei, or other types of nuclei used in MRI

**ligand**[1]
a molecule that donates or accepts a pair of electrons to form a coordinate covalent bond with the central metal atom of a coordination complex

**magnetic moment**
the net magnetic properties of an object or particle (such as a magnetic dipole)

**magnetic shielding**
metal surrounding an MR magnet used to contain the main magnetic field fringe field within acceptable limits; magnetic shielding can be passive (steel lined walls) or active (built into the system)

**magnetic susceptibility**
the degree to which a tissue can become magnetized

**maximum intensity projection (MIP)**
a ray tracing algorithm where a ray goes through a designated imaging block or volume. Signal intensity is designated based on nearness to the observer

**motion artifact**
an artifact or signal not naturally present in living tissue, but which appears on MRI film due to movement of muscle or fluid or motion of any body part

**multiplanar reconstruction (MPR)**
two-dimensional views of a single voxel thickness of vascular structures reconstructed from three-dimensional or multi-slice images

**magnetic resonance angiography (MRA)**[1]
a form of magnetic resonance imaging used to study blood vessels and blood flow, particularly for detection of abnormalities in the arteries and veins throughout the body

**magnetic resonance imaging (MRI)**
a method of visualizing soft tissues of the body by applying an external magnetic field that makes it possible to distinguish between hydrogen atoms in different environments

**magnetic resonance spectroscopy (MRS)**
MR examination in which the data collected are not reconstructed into an image, but into a spectrum of signals based on metabolite presence within the tissue being examined; a type of *f*MRI

**nanometer (nm)**[1]
a unit of linear measure equal to one-billionth of a meter, $10^{9}$ meter

**number of excitations (NEX)**
the number of cycles of completed k-space filling; also known as number of signal averages (NSA)

**number of signal averages (NSA)**
see number of excitations

**paramagnetic**
a substance with magnetic properties that may significantly reduce T1 and T2 relaxation times in MRI

**perfusion imaging**
an imaging technique based on the EPI pulse sequence; gadolinium contrast is used to indicate the amount of blood perfusion across a brain cell membrane

**peripheral nerve stimulation (PNS)**
activation of a peripheral nerve fiber(s) caused by rapidly switching gradient fields; PNS is not a patient safety concern but a potential patient comfort concern

**phase**
particular stage or point of advancement in a cycle

**phased array coil**
a type of surface coil composed of several coils and receivers that are linked together. The signals from each of the coils and receivers are subsequently united to form an image with good SNR.

**phase encoding**
generation of phase differences along a particular direction of a tissue slice for use in spatial localization of MR signal

**pixel**
picture element; the smallest discrete part of a digital image display

**pulse sequence**
a series of events for exciting protons and detecting signals during the MR examination; every pulse sequence includes slice excitation, echo generation, and phase and frequency encoding

**quench**
sudden and massive expansion of liquid helium into gaseous helium due to an increase of heat from a loss of superconductivity of the magnet

**R-R interval**
the period of time between each R-wave; one cardiac cycle

**R-wave**[1]
the initial upward deflection of the QRS complex, following the Q-wave in the normal electrocardiogram

**radiofrequency (RF)**[1]
the range of frequencies of electromagnetic radiation between 10 kilohertz and 100 gigahertz that is used for radio communication

**ramp time**
the minimum time required for a gradient field to go from its peak maximum point to its peak minimum point; measured in microseconds

**ramp up/ ramp down**
the controlled process of bringing the magnet to maximum field or reducing the magnet from its maximum field

**receive bandwidth (RBW)**
the range of frequencies collected during the frequency encoding portion of the pulse sequence

**region of interest (ROI)**
a specific defined area, ie, fluid or a portion of an organ or tumor, where a relative signal intensity measurement can be obtained

**RF shielding**
metal used to prevent stray RF frequencies from entering the magnet room during an MR exam, typically made of copper

**rise time**
the minimum time required for a gradient field to go from zero to its required maximum; measured in microseconds

**resonance**
state of a system through which energy may be transferred to another system with the same preferred or resonant frequency; characterized by absorption and dissipation of energy through resonant oscillation

**saturation**
lack of signal due to overexcitation of protons

**signal-to-noise ratio (SNR)**
amount of true signal relative to the amount of random background signal (noise) on an image

**slew rate**
describes overall gradient performance as a function of gradient amplitude and gradient rise time. Slew rate is derived by dividing the amplitude by the rise time and typically is described in units of T/m/sec.

**specific absorption rate (SAR)**
the FDA-regulated amount of RF heat energy that a patient can absorb during an MRI exam, measured in Watts/kilogram

**spin-echo**
basic pulse sequence of MR imaging using a $90^0$ RF excitation pulse and a $180^0$ RF echo pulse

**static magnetic field**
the large main magnet field generated by the magnet to place the protons into the longitudinal plane prior to the MRI pulse sequence; also known as the $B_0$ field

**short tau inversion recovery (STIR)**
inversion recovery-based pulse sequence that utilizes a relatively short TI time in order to obtain heavy fat suppression; the TI is selected based on T1 recovery time of fat

**superconductivity**
the state where all molecular motion becomes so restricted, due to a lack of heat, that electricity can flow through a conductor without resistance. Materials such as a magnet coil become superconductive after being immersed in liquid helium and reaching a temperature of $4^0$ Kelvin

**surface coil**
specialized antenna for transmitting and/or receiving RF energy to or from the patient during a pulse sequence

**T1**
the amount of time for 63% of a tissue's protons to recover to longitudinal magnetization

**T1-weighting**
generation of MR images under conditions that highlight differences in T1 between tissues

**T2**
the amount of time for 63% of a tissue's protons to decay in the transverse plane

**T2-weighting**
generation of MR images under conditions that highlight differences in T2 between tissues

**Tesla**[1]
the SI unit of magnetic flux density, calculated as webers per square meter. It replaces the gauss.

**time to echo (TE)**
the amount of time selected by the technologist to allow for T2 decay of excited protons; also the amount of time from the beginning of initial slice excitation pulse and the generated echo signal

**time-of-flight imaging (TOF)**
gradient echo-based pulse sequence that uses flow-related enhancement to greatly increase the contrast between flowing blood and stationary tissue; performed in either a 2D or 3D acquisition, the images are postprocessed into a maximum intensity pixel projection (MIP) to display like an MR angiogram

**time to inversion (TI)**
the time allowed from the initial 180 degree excitation pulse until the 90 degree pulse in an inversion recovery pulse sequence; TI determines the amount of T1 recovery time for a given tissue

**torque**[1]
a rotatory force causing a part of a structure to twist about an axis

**time to recovery (TR)**
the amount of time selected by the technologist to allow for T1 recovery of the excited protons; also the time from the beginning of one pulse sequence to the beginning of the next

**trigger window**
the time delay before each R-wave

**vector**
mathematical quantity representing both magnitude and direction, symbolized by an arrow

**voxel**
a three-dimensional volume of tissue corresponding to a pixel on an MR image, a "volume element"

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