MR Basics

Module 5 Transcript

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MR Basics: Module 5 – Contrast Media

1. MR Basics – Contrast Media

Welcome to Module 5 of MR Basics – Contrast Media. This module was written by Jeannett Montes, M.P.A., R.T.(R)(CT)(MR).

2. License Agreement and Disclaimer

3. Objectives

After completing this module, you will be able to:

- Discuss proper screening and preparation of patients for contrast-enhanced magnetic resonance (MR) imaging examinations.
- Describe the use of MR contrast agents.
- List potential adverse effects of contrast agents.
- Explain the mechanism of action and effects of contrast media on images.
  Describe how to prepare contrast materials for injection.

4. History of Contrast

When MR pioneers first injected manganese salts into dogs in 1978, they found differences in magnetic relaxation times matching the concentration of manganese in the tissues. The first scan of a person using a paramagnetic contrast agent was performed in 1981, using an oral medium consisting of ferric chloride. The contrast agent was used to enhance the patent's gastrointestinal (GI) tract. Gadolinium-based agents were introduced a few years later to improve the specificity and sensitivity of many examinations.

5. Contrast-enhanced MR Imaging

Some magnetic resonance (MR) imaging examinations require contrast media enhancement to better highlight tissues or structures, such as blood vessels or arteries, or to differentiate a lesion from surrounding tissue. Contrast can be used to improve the diagnosis and evaluation of tumors, infections, metastases and neurological pathology. Look at these two images. Both are T1-weighted sagittal views of the same patient's brain. The image on the left is precontrast and the image on the right post-contrast T1 image. Notice how the pathology, in this case a meningioma, is hyperintense on the post-contrast image. These images illustrate the value of using contrast in MR imaging. Before we discuss the specifics of contrast agents in MR imaging, let's review the concept of magnetism.

6. Magnetism

Magnetism is a fundamental property of matter. All substances have some degree of magnetism related to their moving electrons, and MR imaging uses the magnetic susceptibility of a substance to create images. There are four principle degrees of magnetic susceptibility: diamagnetic, paramagnetic, superparamagnetic and ferromagnetic.

7. Diamagnetic Substances

Diamagnetic substances have no net magnetic moment because they have no unpaired orbital electrons. When exposed to a magnetic field, diamagnetic substances actually demonstrate a

negative magnetic susceptibility, which means they are repelled by the magnetic field. As a result, the magnetic field is reduced.

Examples of diamagnetic substances include silver, copper and mercury.

8. Paramagnetic Substances

Paramagnetic substances, on the other hand, have unpaired orbital electrons. When exposed to a magnetic field, paramagnetic substances demonstrate a small positive magnetic susceptibility of less than 1. When exposed to the magnetic field, paramagnetic substances are slightly attracted, increasing the field slightly. As a result, the magnetic field is greater.

Examples of paramagnetic substances include tungsten, platinum and gadolinium.

9. Superparamagnetic Substances

Superparamagnetic substances are individual elements that have ferromagnetic properties in bulk. They behave in the same way as paramagnetic substances, except that instead of each individual atom being independently influenced by an external magnetic field, the magnetic moment of the entire substance reacts to it. When exposed to the magnetic field, superparamagnetic substances are attracted to the magnetic field, demonstrating a magnetic susceptibility much stronger than paramagnetic substances.

An example of a superparamagnetic substance is an iron-containing contrast agent.

10. Ferromagnetic Substances

When exposed to a magnetic field, ferromagnetic substances demonstrate a positive magnetic susceptibility greater than 1. Ferromagnetic substances are highly attracted to the magnetic field and become permanently magnetized when exposed to the field. Once magnetized, these objects can become projectiles and very dangerous.

Ferromagnetic substances that have been exposed to a magnetic field retain their magnetism, even after the magnetic field is removed. This magnetic field can be much larger than the applied magnetic field.

Examples of ferromagnetic substances include iron, steel, nickel and cobalt.

11. Knowledge Check

Answer the following question.

12. Knowledge Check

Answer the following question.

13. Knowledge Check

Answer the following question.

14. MR Contrast Agents

The chemical properties of contrast media used in MR differ from contrast agents typically used for x-ray imaging. MR contrast agents contain paramagnetic or superparamagnetic metal ions that affect the MR signal properties of tissue.

Paramagnetic contrast media, also known as T1 enhancement agents, shorten T1 relaxation times of nearby hydrogen protons. The shorter T1 times increase signal intensity on T1-weighted images. Superparamagnetic contrast media, also called T2 enhancement agents, are used to shorten T2 decay times. Shorter T2 times reduce signal intensity on T2-weighted images.

15. Types of MR Contrast

The most common MR contrast media are paramagnetic agents, and the majority of these are gadolinium based. MR imaging also uses iron oxide-based agents, manganese-based contrast and tissue-specific agents. Let's discuss each of these in more detail.

16. Gadolinium-based Contrast

The first commercially available MR contrast agent was called gadolinium diethylenetriaminepentacetic acid (Gd-DPTA). Now known as gadopentetate dimeglumine, it was the precursor to several brands of gadolinium-based agents. Gadolinium is a rare-earth metal with significant paramagnetic properties. The metal's ion is chelated, or chemically bonded, with a chemical such as DPTA to reduce toxicity and to assist excretion by the kidneys.

Gadolinium-based contrast has specific characteristics that help enhance MR imaging. For example, extracellular gadolinium-based agents collect in tissues with more extracellular space to better demonstrate certain pathologies. In addition, gadolinium-based contrast media do not cross the blood-brain barrier, which is one reason they are used in MR imaging of the brain.

17. Gadolinium Mechanism of Action

The paramagnetic properties of gadolinium affect longitudinal (T1) and transverse (T2) relaxation times. Gadolinium chelates shorten T1 relaxation time in those tissues that absorb the contrast, making the tissues brighter. The chelates produce negative enhancement for T2 relaxation times, causing tissues with T2 weighting to appear darker. The effects depend on the type of contrast, dosage, distribution in the tissue, pulse sequence and magnetic field strength chosen for the examination.

18. Gadolinium Pharmacology

The enhancement agents used in MR imaging have different molecular structures than those of iodinated contrast agents and, as a result, affect patients and examinations differently. Select groups of patients who receive gadolinium-based contrast media can experience serious adverse events. MR technologists should be aware of the harmful effects associated with gadolinium and prepare for adverse events according to their institution's policies and procedures.

19. Gadolinium-based Pharmacokinetics

After intravenous administration, water-soluble gadolinium chelates move into the intravascular space. In the case of gadopentetate dimeglumine, for example, the meglumine salt is completely dissociated from the gadopentetate dimeglumine complex. The chelates diffuse rapidly into the interstitial space.

In healthy patients, most of the gadopentetate (usually about 98 percent) is eliminated in the urine within 24 hours of injection. The exact half-life of the gadolinium chelate depends on its volume of distribution and the agent's glomerular filtration rate. In addition, the half-life is

longer in patients with renal impairment. MR technologists always should follow their facility's policy regarding the use of contrast in renal-impaired patients.

20. Blood Pool Agents

Blood pool agents remain confined to the intravascular space and are used for vascular imaging. This type of contrast remains in the blood for a longer period of time than other gadolinium-based agents, has a longer half-life in the kidneys (up to about 200 minutes) and is a macromolecular agent. These agents help extend the acquisition time for MR angiography images.

Blood pool contrast media are used in several applications, such as assessing myocardial viability, evaluating perfusion in ischemic areas, showing the extent of neovascularity in tumors and collecting information about capillary permeability.

21. Iron-oxide Contrast Agents

Iron-oxide contrast media are superparamagnetic agents. The agents are nano-sized particles of iron crystals that affect relaxation times. Two iron-oxide agents are available for clinical use: ferumoxide and ferucarbotran. Both of these agents are used for hepatic MR examinations. Ferumoxides have been available in the United States for several years; ferucarbotran is a newer agent that only is available currently in Europe and Japan.

Ferumoxide generally is administered as a slow IV infusion and used along with delayed-phase MR imaging, whereas ferucarbotran is administered as a rapid bolus and used with dynamic and delayed MR imaging.

22. Iron-oxide Mechanism of Action

Ferumoxide is used for liver imaging because it's processed through the liver rather than the kidneys as is the case with gadolinium. Iron-oxide contrast is taken up by Kupffer cells, which are part of the reticuloendothelial system. Found mostly in the liver, these cells are distributed uniformly, producing homogeneous contrast uptake and negative relaxation throughout the liver parenchyma on T1- or T2-weighted images. As a result, pathology such as small primary malignancies and metastases can be seen more easily against the dark hepatic parenchyma. Because the contrast remains in the liver a longer time, lesions have more time to enhance and fill. A few other products have been developed, but clinical trials were discontinued because of adverse findings. Oral iron oxide-based agents for imaging of the GI lumen have been proven safe and effective, but are not used much in the United States.

23. Manganese-based Agents

Manganese is the 12th most common element in the earth's crust and the 4th most widely used metal in the world. In the body, manganese enters the portal venous system from the GI tract, passing through the liver. About 98 percent of the absorbed manganese is cleared through the liver and later excreted into the bile. An example of a manganese-based contrast agent is mangafodipir trisodium.

24. Tissue-specific Contrast Agents

There are many tissue-specific contrast agents used in MR imaging, depending on the type of study and anatomy involved. An example of a tissue-specific agent is Secretin. Commercially available secretin is either porcine (pigs) secretin or a synthesized form of human secretin.

Secretin is a natural hormone produced by glands in the small intestine that acts to stimulate pancreatic secretions. IV administration of secretin induces the emission of fluid and bicarbonate by the exocrine pancreas. Ductal filling is increased and visualization of the pancreatic duct is improved. The use of secretin has helped to promote magnetic resonance cholangiopancreatography (MRCP) as an effective noninvasive imaging technique for patients who are suspected of having pancreatic or biliary tract disease.

25. Knowledge Check
Answer the following question.

26. Knowledge Check
Answer the following question.

27. Knowledge Check
Answer the following question.

28. Knowledge Check
Answer the following question.

29. Patient History
MR technologists can only administer a prescription MR contrast agent if there is an order from a licensed health care provider. Before the examination, the technologist gathers patient information relevant to the specific exam and contrast media administration. The technologist and radiologist use the medical history and information about past adverse contrast reactions to decide between a contrast and noncontrast study, the appropriate protocol and possible additional MR sequences. Obtaining a patient history helps the technologist prepare for potential contrast reactions, and choosing the correct exam provides the optimal diagnosis, safety and patient care.

Information obtained from the medical history also helps the technologist screen for contraindications to the MR exam, such as metal implants or medical devices. MR facilities should have established procedures and screening forms that patients must complete before undergoing examinations, but technologists can prevent accidents and adverse contrast reactions by carefully interviewing the patient.

30. Patient Prescreening
Prescreening a patient helps MR technologists and radiologists prepare for the MR examination and ensures the ordered examination and use of contrast are appropriate. Here are examples of questions that should be asked:

- Inquire whether the patient has had a previous MR examination. If so, ask when and where.
- Ask whether the patient has ever had a reaction to a contrast agent or to iodinated contrast media.
- Ask about prior medical imaging.
- Inquire whether the patient has a history of allergies or asthma.
- Inquire whether the patient has a history of significant cardiac disease.
- Ask the patient about any history of renal disease, including renal disease in first-degree relatives.

In addition to the prescreening questions, the technologist should explain the procedure and be prepared to answer any questions the patient may have about the technical aspects of the examination.

31. Prescreening for Gadolinium-based Contrast

Most patients tolerate gadolinium chelates well. In 2006, however, the U.S. Food and Drug Administration (FDA) issued an alert concerning the development of nephrogenic systemic fibrosis (NSF) in patients with moderate to end-stage renal disease following exposure to gadolinium-based contrast agents. Much still is unknown about the disease and the role gadolinium plays in causing it. The risk factors since have expanded to include patients with stages 3 through 5 chronic kidney disease and acute kidney injury. NSF will be discussed in more detail later in this module.

32. Glomerular Filtration Rate (GFR)

GFR (glomerular filtration rate) is equal to the total of the filtration rates of the functioning nephrons in the kidney. GFR is usually accepted as the best overall index of kidney function. A person's GFR can be estimated using the serum creatinine level and some or all of the following variables: gender, age, weight and race. In most healthy people, the normal GFR is 90 mL/min/1.73 m2 or higher. GFR and its change over time can be indicative of kidney disease and its severity.

33. Prescreening for Gadolinium-based Contrasts

New recommendations suggest patient assessment should begin with a medical history, but providers should not rely solely on this information. The patient's glomerular filtration rate (GFR) also should be tested no more than six weeks prior to administering contrast. Technologists should follow their facility's guidelines regarding laboratory testing and contrast media administration. Specific agents do not pose equal risk of NSF; contrast media most associated with NSF include gadodiamide, gadopentetate dimeglumine and gadoversetamide. Dosage also seems to affect risk.

If the pre-examination assessment shows that the patient is at high risk for NSF or other contrast reaction, the referring physician and radiologist can consider alternative imaging examinations that do not require a gadolinium-based agent.

34. Contraindications

In general, patients who have stages 4 or 5 chronic kidney disease should not receive gadolinium-based contrast agents. If gadolinium contrast is absolutely necessary, radiologists and MR technologists should avoid administering the agents considered most likely to cause reactions, and avoid higher or repeated doses. Patients and referring physicians should be thoroughly informed of all risks and benefits of contrast-enhanced examinations.

35. ACR Recommendations

The American College of Radiology (ACR) states that patients with stages 1 and 2 kidney disease can safely receive gadolinium contrast. Those with stage 3 chronic kidney disease should be evaluated in light of the patient's estimated GFR and a risk-benefit analysis of the use of contrast and the proposed examination. Practitioners should follow their institution's policies and procedures regarding use of the lowest possible dose of contrast. Patients who have stage 3 chronic kidney disease and higher estimated glomerular filtration rates (typically near 30 mL)

may require the same sort of precautions as patients who have stage 4 and 5 kidney disease. Pediatric patients should be prescreened following the same guidelines and institutional policies as adults.

36. Patient Preparation

Some facilities instruct a patient to have nothing by mouth (NPO) at least two to three hours before a contrast-enhanced examination. This requirement is a precaution against the patient experiencing nausea after the injection and aspirating while in the supine position. MR technologists should always follow their facility's policies and procedures regarding all patient preparation.

37. Contrast Preparation

Before drawing up the IV contrast, the MR technologist must verify the patient's weight and condition and the type of examination ordered. In addition, the technologist must know the amount of contrast and rate of administration as specified by the radiologist and institutional policies. The expiration date on the vial should be checked before administration, and the vial should not be discarded until the patient has left the facility. The lot number, amount administered, type of contrast and expiration date should be documented in the patient's record.

Technologists should wash their hands regularly, follow universal precautions and use personal protective equipment according to institutional policies and procedures.

38. Contrast Administration

The standard procedure for IV preparation can vary from one institution to another, but generally includes explaining contrast administration to the patient, discussing contrast reactions and precautions, obtaining written or verbal consent and completing IV setup. The MR technologist is responsible for maintaining his or her knowledge and skills and understanding institutional policies and procedures.

Technologists should always keep these key factors in mind:

- Exercise precaution with at-risk patients, such as those with diabetes, sickle cell disease, asthma and renal insufficiency with or without hepatic impairment.
- Follow facility policies and procedures regarding patients who are pregnant or breast-feeding.
- Be aware that contrast media reactions can be serious, life-threatening or fatal and appear as anaphylactic or cardiovascular responses.
- Obtain the patient's GFR, calculated contrast dose and rate of administration.

For MR accreditation purposes, the ACR approves administration of contrast agents by certified or licensed technologists or radiologic nurses under the direction of a radiologist or the radiologist's physician designee and in line with institutional and state regulations.

39. Universal Precautions

Technologists should follow universal precautions and facility infection control procedures when administering IV contrast to minimize the risk of infection. Infection control practices include regular hand washing and the use of gloves at all times when performing venipuncture.

Technologists also must be aware whether a patient is allergic to latex and other environmental factors, food, medication or chemicals before starting an IV.

40. Blood Vessels

Let's briefly cover some blood vessel anatomy that's important to know when performing venipuncture. The tunica intima, or innermost layer, is very thin and is made up of endothelial cells. The tunica media, or middle layer, is composed of muscle cells and varies in width depending on the size of the vessel. This layer is larger in arteries than in veins. The outer layer of a vessel is the tunica externa or tunica adventitia. This layer also is relatively thin and is made up of connective tissues, such as collagenous and elastic fibers. Contrast media should only be injected into a vein and not an artery.

41. IV Administration Sites

The most common IV injection sites for MR contrast media are the veins in the antecubital fossa of the forearm. The three main veins in this area are the basilic, cephalic and median cubital. The basilic vein is located on the medial, or ulna, side of the fossa; the cephalic vein is found on the lateral, or radius, side; and the median cubital vein runs diagonally across the middle of the forearm. The basilic and cephalic veins are preferred injection sites because they are larger, more accessible and better able to withstand the pressure of power injection. A vein in the nondominant arm might be chosen so that any adverse reaction will not affect the dominant arm.

42. Contrast Administration

There are two ways to administer IV contrast. The first is to hand bolus the contrast using a butterfly needle just prior to scanning contrast-enhanced sequences. The second is through a catheter which is inserted prior to the examination. The catheter method is most commonly used when contrast will be administered by a power injector.

43. Power Injector Administration

Contrast media also may be administered using a power injector. When using a power injector, the MR technologist must make sure the vein is accessed appropriately and that all air is out of the extension tubing. After the IV is started, it should be hand flushed with saline before connecting to the injector to prevent extravasation, or leakage into the surrounding tissues.

Typical injection rates vary depending on the examination ordered, institutional policies and condition of the patient. For example, if a small vein is used for venipuncture because a larger vein is unavailable, the rate of contrast administration should be slowed. In addition, tissue characteristics determine contrast uptake in the anatomy. In the case of breast MR, for example, the wash-in and washout of contrast may show the differences between a benign or malignant lesion.

44. Standard IV Procedural Steps

All IV equipment should be prepared and nearby before beginning the IV injection. The MR technologist should wear clean gloves on both hands. To begin, a tourniquet is tied four inches above the chosen venipuncture site on the patient's arm. The technologist wipes the injection site with a sterilizing skin cleanser in a circular motion.

45. Standard IV Procedural Steps

The technologist then inserts the needle or catheter into the vein at a 15- to 30-degree angle with the bevel up. A blood flash should be observed, which indicates the insertion was successful. When using a catheter, the technologist threads the plastic sheath into the vein, removes the needle, secures the catheter into place and then attaches a saline flush. For a butterfly needle, the technologist should tape the needle down and connect the saline syringe to the tubing.

In both cases, the technologist should be certain to flush the line before and after injecting the contrast medium. Flushing the tubing before injection removes all air from the line and improves patency. In some cases such as scanning radiation oncology patients, the IV access is not removed following the study. To maintain the integrity of the IV access and prevent clotting, heparin is used to flush the line. However, studies have shown that heparin does not extend catheter access any longer than saline.

46. Standard IV Procedural Steps

After removing the needle, the technologist applies gentle pressure to the insertion site using gauze. The light pressure helps reduce the chance or severity of a hematoma. Tape or a self-adhesive wrap can be placed over the gauze to maintain pressure and stop bleeding. The tape or wrap should remain in place for approximately 20 minutes.

47. Adverse Reactions

The technologist must be aware of adverse consequences of the injection and contrast administration. These effects might include local events limited to the venipuncture site or severe systemic events, such as anaphylactic reactions. MR technologists should have a good knowledge of contrast reactions to provide safe patient care in an efficient manner.

48. Local Injection-related Complications

Bruising and hematomas are the most common local complications resulting from venipuncture. These effects are more frequent in women than in men. Hematoma occurs when the cannula of the needle punctures the vein and blood leaks into the surrounding tissues. The uncontrolled bleeding under the skin forms a hard swelling of infiltrate blood.

Infection is another common injection-related complication. If the injection site is not properly disinfected, harmful bacteria can enter the bloodstream causing potential problems.

49. Other Injection-related Complications

Other injection-related complications include extravasation, infiltration and thrombus. Extravasation of contrast into subcutaneous tissue is a risk associated with IV administration of any contrast media. The effects on the patient can vary, but small amounts of contrast can cause pain, minor swelling and erythema in the region of the extravasation. Compartment syndrome is a serious complication in which the extravasation involves large amounts of contrast.

Infiltration is the accidental administration of contrast to surrounding tissues instead of directly into the vein. A thrombus is a small clot that can develop at the distal end of the catheter. Thrombi also can form as a result of phlebitis. Flushing should not be used to resolve a thrombus.

Gadolinium is considered much less toxic to subcutaneous tissues and skin than iodinated contrast media.

50. Reactions to Gadolinium

In addition to injection-related events, patients can have immediate reactions to gadolinium-based contrast, and patients with compromised kidney function are at risk for NSF. Although the incidence of reactions to gadolinium is low, MR technologists should be aware that reactions can be mild, moderate or severe. About six acute adverse reactions occur per 10,000 injections, and only one event in 40,000 injections is likely severe.

51. Mild Reactions to Gadolinium

Allergic reactions to gadolinium are unusual and generally mild. The patient might experience a rash or hives; bronchospasm and anaphylactic shock are even less common at less than 1 percent of cases. Mild acute reactions to gadolinium include nausea, vomiting, coldness, warmth or pain at the injection site, headache, dizziness or itching. The MR technologist should notify the radiologist and document the physiological reaction in the patient's record.

52. Moderate-to-Severe Reactions

Moderate-to-severe reactions to gadolinium-based contrast are even more unusual than mild reactions. The risk of an acute adverse event is eight times higher in patients who have had previous reactions to a gadolinium-based medium. These reactions are more likely to occur in people who have asthma, allergies to food or medications or previous reactions to iodinated contrast media. Symptoms of moderate reactions are similar to those for other contrast-related allergic reactions: nasal stuffiness, swelling of the eyes or face, tachycardia or bradycardia, hypertension, bronchospasm, dyspnea and laryngeal edema. The radiologist should be notified in the event of a moderate reaction, and it should be documented in the patient's chart.

53. Moderate-to-Severe Reactions

Symptoms of severe reaction include serious respiratory distress, convulsions, arrhythmia, unresponsiveness, cardiopulmonary arrest and progressive angioedema. MR technologists must be aware that these events can occur at any time, even though they are rare. Technologists should recognize the signs and symptoms of all levels of contrast reactions and continuously monitor the patient. Because reactions can range from mild anxiety to sudden cardiopulmonary arrest, technologists should be prepared to follow emergency procedures or implement advanced cardiac life support according to facility policies and procedures.

54. Nephrogenic Systemic Fibrosis

NSF, which was first identified in 1997, is a disease involving fibrosis of the skin and internal organs. It occurs in patients with compromised kidney function who have had gadolinium-based contrast-enhanced imaging studies. Not all patients with severe kidney disease develop NSF from these contrast agents; however, some agents appear more likely to cause NSF than others. One of the most important points to remember about NSF is that the exact mechanisms of the disease and its relation to gadolinium chelates are not completely understood. As a result, MR technologists should remain up-to-date on clinical studies and facility policies and procedures regarding gadolinium-based contrast administration.

55. Nephrogenic Systemic Fibrosis

Symptoms of NSF generally appear within a few days of contrast administration, but might not be seen for up to six months. Some patients have reported signs of NSF years after exposure to gadolinium. Symptoms usually begin as fibrosis of the skin and connective tissues. As the skin thickens, it inhibits flexion and extension of the joints. Some patients experience joint contracture and eventually need wheelchairs for mobility or assistance with daily living activities. The fibrosis can spread to other organs and cause severe morbidity or death. Some patients may experience slight improvement, stabilization or remission of symptoms. There is no definitive treatment for NSF.

56. Nephrogenic Systemic Fibrosis

MR technologists can take several steps to help prevent NSF. The FDA requires facilities to screen all patients receiving gadolinium for renal dysfunction by completing an appropriate patient history or by measuring glomerular filtration rates. Before proceeding with contrast administration, MR technologists should follow ACR recommendations and institutional policies regarding proper patient screening and laboratory testing.

MR technologists should carefully follow facility protocols and package labeling to ensure the proper dosage is not exceeded when administering gadolinium-based contrast agents. Technologists should make sure patients have sufficient time to eliminate gadolinium-based contrast from one examination before undergoing another contrast-enhanced exam.

Overall, incidence of NSF has been greatly reduced because of increased attention and care taken by providers and manufacturers. To date, newer agents appear safer than older gadolinium-based products.

57. Reactions to Blood-pool Agents

About one-fourth of patients receiving blood-pool agents report adverse side effects, although most have been mild to moderate. The most common effects are a sensation of tingling, burning, pricking or numbness (paresthesia); widening of the blood vessels (vasodilation); and an altered sense of taste.

58. Reactions to Iron-oxide Agents

Iron-oxide contrast agents can cause back, groin or leg pain in a small number of patients. They also can cause nausea, vomiting, hypotension and diarrhea, and anaphylactic-like reactions. People with hypersensitivity to iron should not receive iron-based agents, and those with autoimmune diseases are at higher risk of reaction.

59. Reactions to Manganese Agents

Manganese contrast agents can have a higher incidence of adverse effects, most notably discomfort at injection site, nausea and headache.

60. Reactions to Secretin

Secretin still is under study, with some users of the pancreatic agent reporting no adverse events that caused difficulty with the examinations. Others have reported that secretin injection can worsen pancreatic disease symptoms if administered within three weeks of an acute episode of pancreatitis. Nausea and vomiting have been reported after bolus injection of secretin, but the effects can be minimized by slower administration.

61. Knowledge Check
Answer the following question.

62. Knowledge Check
Answer the following question.

63. MR Contrast Applications
The ability of gadolinium-based agents to enhance T1 and T2 relaxation is clinically useful in many MR examinations and most organ systems. Contrast agents help radiologists differentiate benign from malignant primary tumors, diagnose metastases, assess infectious and inflammatory processes and evaluate vascular anatomy and pathology. To do so, the contrast media either distribute selectively within a specific tissue type after administration or decrease relaxation time for the targeted tissue vs. other tissues.

64. MR Contrast Applications
These two images are both axial views of the same patient's foot. On the right image the area of infection is highlighted due to the injection of contrast.

65. Extracellular Contrast Agents
Extracellular contrast agents, such as gadopentetate, don't target specific tissues. Rather, tissues with more extracellular space, such as tumors and abcesses, collect more of the extracellular agent and enhance on MR images.

Extracellular gadolinium-based contrast is indicated for MR examinations of adults and pediatric patients (age 2 years and older) to enhance lesions with abnormal vascularity in the brain, head and neck, spine and associated tissues. Contrast can enhance malignant and certain inflammatory lesions.

66. Magnetic Resonance Angiography (MRA)
Magnetic resonance angiography (MRA) with contrast allows in-plane vessel imaging and shorter acquisition times. Injecting the appropriate amount of contrast shortens T1 relaxation time for arterial blood and causes the blood to enhance on MRA images. Injection dose and rates are calculated based on arterial gadolinium concentration being proportional to the rate of IV injection and inversely proportional to the patient's cardiac output. MR technologists should follow manufacturer and facility policies and procedures, under a radiologist's direction, regarding dosage and injection rate for MRA contrast.

67. MRA Scans
Technologists should acquire the scans as quickly as possible. An advantage of the shortened acquisition times is that an entire 3-D MRA data set or multiple sets often can be acquired in a single patient breath-hold. Timing of the bolus injection is particularly critical in MRA. For scans lasting less than 40 seconds, mistiming the injection by a mere 10 or 15 seconds can produce a nondiagnostic study due to lack of contrast. Several techniques can help solve this dilemma, including running a test bolus with saline, automatically synchronizing the acquisition with the appearance of the contrast in the sample region and collecting sequential rapid 3-D image sets at the precise time the contrast enhances the area of interest.

68. MRA Renal Scan

Looking at the image on this slide, you'll notice that the injected contrast highlights the arterial flow. On a renal MRA image, some of the contrast also can be seen going into the kidneys or other organs if delayed imaging is requested.

69. Other Cardiovascular Applications

Blood pool agents collect in the intravascular spaces and are used to image smaller blood vessels and tissue perfusion. The agents permit first-pass, arterial-phase imaging of vascular or pulmonary anatomy and monitoring of vascular interventions. Detecting smaller, distal pulmonary arteries without having to inject higher amounts of iodinated contrast is a potential benefit of blood pool agents for MRA over conventional angiography.

Acquiring MRA and MR venography (MRV) images of the deep veins of the patient's pelvis and thighs following pulmonary artery imaging can more thoroughly evaluate possible thromboembolic disease.

70. Breath-hold and Cardiac Gating

Pulmonary imaging can be complicated with older MR scanners and if breath-hold techniques are required. Breath-holds require technologists to adjust imaging time and contrast administration to the individual patient. Newer MR imaging equipment uses cardiac gating or trigger techniques that eliminate the need for breath-holds.

There are two types of cardiac gating: electrocardiogram and peripheral gating. Electrocardiogram uses electrodes and lead wires positioned on the patient's chest. Peripheral gating uses a sensor placed on the patient's finger. In both of these techniques the electrical signal of the heart is used to prompt each pulse sequence therefore reducing artifact due to pulsatile flow and motion from the heart.

71. Breath-hold Image

This image is a coronal view of the abdomen using the breath-hold technique. Although this technique is commonly used it can be difficult for some patients to hold their breath because of age or condition. If circumstances prevent the use of a breath-hold technique, the technologist should seek an alternative to acquire the necessary scan such as reducing the scan time.

72. Cardiac Gating Images

These axial and sagittal images of the heart were acquired using cardiac gating. Cardiac gating allows MR data to be collected according to a patient's cardiac cycle. This technique minimizes and/or reduces motion artifact from pulsations of the heart. Acquiring diagnostic cardiac images was not possible until the advent of electrocardiogram and peripheral gating.

73. Hepatic Applications

Several contrast agents approved specifically for liver imaging enhance signal intensity on T1-weighted images. Gadoxetate disodium helps detect or characterize focal liver lesions, particularly small lesions. Like extracellular agents, gadoxetate disodium enhances in the dynamic arterial phase. Using a delayed hepatocyte phase improves sensitivity for detecting smaller lesions such as metastases.

74. Hepatic Imaging

Eovist contrast was used to acquire this 20-minute delay coronal liver image.

75. Superparamagnetic Contrast Media

Superparamagnetic contrast media shorten T2 decay times, reducing signal intensity on T2-weighted images. Gadobenate dimeglumine is used in dynamic postcontrast imaging and delayed-phase imaging of the liver. The delayed-phase imaging helps distinguish lesions with functioning hepatocytes from those that have no functioning hepatocytes, such as focal nodular hyperplasia.

76. Iron-oxide Agents

Iron-oxide agents are used to increase the contrast between normal liver parenchyma with high concentration of Kupffer cells and lesions that lack Kupffer cells, such as metastases, focal nodular hyperplasia and regenerative nodules. The agent usually is administered slowly in a diluted solution and scanning begins after the agent has diffused. T2 and T2* sequences maximize contrast enhancement with iron-oxide agents and imaging can occur up to 3.5 hours after contrast administration.

The liver and GI tract also can be imaged using extracellular gadolinium agents and phased-array 3-D imaging, or according to specific indications and facility protocols and procedures.

77. MRCP Sequences

Pancreatic imaging with secretin begins with acquisition of precontrast images, including thick-slab MR cholangiopancreatography (MRCP) sequences. After the region of interest is located, saline-diluted secretin is slowly injected, usually over a period of about one minute. The technologist might acquire MRCP thick-slab images every minute for 10 to 15 minutes, followed by postcontrast images. Technologists should follow their facility's specific protocol.

78. MRCP Scans

Both of these images are MRCP scans acquired using thick slabs. The image on the left demonstrates gallbladder stones. The image on the right shows the carcinoma within the biliary tree.

79. Oral Contrast for Abdomen

Oral contrast media enhance the bowel by decreasing the signal on T1- and T2-weighted images. These agents have not been well accepted for MR imaging because most MR examinations of the abdomen focus on specific organs and use contrast agents or protocols specific to those organs. In addition, the contrast agents are of limited use. Some facilities use "off-the-shelf" substances such as a dietary fiber supplement to mark the bowel. To help improve the quality of MRCPs by reducing high signal from the gastrointestinal tract some facilities are using pineapple juice as a negative oral contrast. Pineapple juice shortens the T2 relaxation time which decreases the T2 signal. An alternative is blueberry juice which reduces T2 and T2* recovery times. It acts as a negative oral contrast on T2 weighted images and a positive oral contrast on T1 weighted images. With both of these juices the patient should consume 400 milliliters 15 to 20 minutes prior to the exam.

80. Imaging Lymph Nodes

Ultrasmall superparamagnetic iron-oxide (SPIO) particles are specific to the reticuloendothelial system and accumulate in lymph nodes. Lymph node imaging with ultrasmall SPIO particles normally is performed 24 hours after injection of the particles. Normal lymph nodes take up the

SPIO particles and appear dark on T2-weighted images; the appearance of malignant nodes does not change.

81. Abdominal Images

This abdominal image shows aortic enhancement in the arterial phase. Abdominal contrast-enhanced MR images usually are acquired as the patient holds his or her breath during contrast injection.

82. Intracranial Images

These images are of the same patient. The image on the left is pre-contrast. On the right image, note the enhancement of the left inner auditory canal (IAC), demonstrating an acoustic neuroma.

83. MRA Imaging with Contrast

This MRA image of the carotids demonstrates the use of contrast in MRA imaging. Contrast is nearly always used in carotid MRA imaging.

84. MR Arthrograms

In most MR procedures that use contrast agents, the contrast is injected directly into a patient's vein; however when performing an MR arthrogram, a small dose of contrast diluted by saline is injected under fluoroscopic guidance into the joint. An MR arthrogram can be performed on any joint, but this technique is used most often on shoulders, wrists and hips. After the injection the patient is immediately taken to the MR suite for the scan. The scan must be performed within 20 minutes of the injection to ensure that contrast is still visible within the joint space. An MR shoulder arthrogram is commonly used to diagnose a slap lesion or tear, which could be missed on an MR of the shoulder without contrast. A slap lesion or tear occurs in the superior portion of the labrum. This injury commonly occurs in athletes who repeatedly throw overhand. Each site has its own policies and procedures regarding arthrograms.

85. New Contrast Agents

New classes of MR contrast agents are in continuous development. Chemical exchange saturation transfer (CEST) agents and paramagnetic CEST (PARACEST) agents differ from relaxation contrast agents because they can be "turned on and off." This characteristic allows MR technologists to acquire enhanced and unenhanced images at the same time and could enable smaller enhancement effects to be measured. In addition, the agents may be customized so that a patient can receive a mixed agent that targets more than one tissue per exam.

86. Reporting Serious Adverse Events

The FDA MedWatch program is a mechanism to voluntarily report serious adverse events associated with the use of FDA-regulated drugs. Serious adverse events include those that cause a patient's death, life-threatening situations, hospitalization, disability or permanent damage to the patient, a congenital anomaly or birth defect, or an event that may require medical or surgical intervention to prevent further harm to the patient. There are several ways to report an event, including online or by telephone, fax or mail.

The MedWatch program played a role in alerting MR providers to the risk of NSF and gadolinium administration. The FDA included reports submitted through the program when it evaluated the safety of gadolinium-based agents and issued safety warnings.

The FDA stresses that the Health Insurance Portability and Accountability Act (HIPAA) Privacy Rule does not prevent reporting adverse events and other information related to the safety of FDA-regulated products. However, technologists should follow their facility's policies and procedures regarding reporting.

87. Conclusion

This concludes Module 5 of MR Basics – Contrast Media. Having completed this module, you should now be able to:

- Discuss proper screening and preparation of patients for contrast-enhanced magnetic resonance (MR) imaging examinations.
- Describe the use of MR contrast agents.
- List potential adverse effects of contrast agents.
- Explain the mechanism of action and effects of contrast media on images.
- Describe how to prepare contrast materials for injection.

88. Bibliography

89. Bibliography

90. Bibliography

91. Acknowledgements

92. Development Team

93. Module Completion

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MR Parameters
Actions and Associated Trade-offs

In MR imaging, there are no hard-and-fast rules. MR technologists choose a pulse sequence based on the area of interest, the condition of the patient and other clinical factors or protocols. For the new MR technologist, this aspect can be very frustrating, but in reality it is what makes the modality interesting and challenging. All MR technologists must be well-versed in the ramifications of various choices. The benefits and limitations of these choices are called "trade-offs." This chart summarizes MR parameters and their associated trade-offs.

MR Parameters
Actions and Associated Trade-offs

Parameter	Action	Benefit	Limitation
TR	Increase	Increased SNR	Increased scan time
		Increased number of slices	Decreased T1 weighting
TR	Decrease	Decreased scan time	Decreased SNR
		Increased T1 weighting	Decreased number of slices
TE	Increase	Increased T2 weighting	Decreased SNR
TE	Decrease	Increased SNR	Decreased T2 weighting
NSA/NEX	Increase	Increased SNR	Direct proportional increase in scan time
NSA/NEX	Decrease	Direct proportional decrease in scan time	Decreased SNR
			Decreased signal averaging
Slice thickness	Increase	Increased SNR	Decreased spatial resolution
		Increased coverage of anatomy	Increased partial volume averaging
Slice thickness	Decrease	Increased spatial resolution	Decreased SNR
		Decreased partial volume averaging	Decreased coverage of anatomy
FOV	Increase	Increased SNR	Decreased spatial resolution
		Increased coverage of anatomy	Decreased chance of aliasing
FOV	Decrease	Increased spatial resolution	Decreased SNR
		Increased chance of aliasing	Decreased coverage of anatomy
Matrix	Increase	Increased spatial resolution	Increased scan time
			Decreased SNR if pixel is small
Matrix	Decrease	Decreased scan time	Decreased spatial resolution
		Increased SNR if pixel is large	
Receive bandwidth	Increase	Decreased chemical shift	Decreased spatial resolution
		Decreased minimum TE	
Receive bandwidth	Decrease	Increased SNR	Increased chemical shift
			Increased minimum TE
Large coil	-	Increased area of received signal	Decreased SNR
			Increased aliasing if using small FOV
			Increased chance of artifacts
Small coil	-	Increased SNR	Decreased area of received signal
		Decreased chance of artifacts	
		Decreased aliasing if using small FOV	

FOV = field of view; NSA/NEX = number of signal averages/number of excitations; TE = echo time; TR = repetition time; SNR = signal-to-noise ratio.

Optimizing Image Quality

In MR imaging, the technologist can manipulate a parameter to enhance image quality. However, these actions have consequences and will alter other aspects of the image. This table summarizes how changing a parameter affects other aspects of a scan.

Optimizing Image Quality		
Desired outcome	**Adjusted Parameter**	**Consequences**
Maximize SNR	Increase NEX	Increased scan time
	Decrease matrix	Decreased scan time
		Decreased spatial resolution
	Increase slice thickness	Decreased spatial resolution
	Decrease bandwidth	Increased minimum TE
		Increased chemical shift
	Increase FOV	Decreased spatial resolution
	Increase TR	Decreased T1 weighting
		Increased number of slices
	Decrease TE	Decreased T2 weighting
Minimize scan time	Decrease TR	Increased T1 weighting
		Decreased SNR
		Decreased number of slices
	Increase phase encodings	Decreased spatial resolution
		Increased SNR
	Decrease NSA/NEX	Increased SNR
		Increased motion artifacts
	Decrease slice number in volume averaging	Decreased SNR
Maximize spatial resolution (assumes a square FOV)	Decrease slice thickness	Decreased SNR
	Increase matrix	Decreased SNR
		Increased scan time
	Decrease FOV	Decreased SNR

FOV = field of view; NSA/NEX = number of signal averages/number of excitations; TE = echo time; TR = repetition time; SNR = signal-to-noise ratio.

MRI Fundamentals Glossary

B_0 — (pronounced "B zero") symbol used to represent the static main magnetic field of the magnetic resonance (MR) imaging system; the strength of the magnetic field is expressed in units of tesla (T).

B_1 — symbol used to represent the radiofrequency (RF) field in the MR system; the RF coils, or transmitter coils, at the Larmor frequency produce the B_1 field.

b-value — summarizes the influence of the gradients in diffusion-weighted imaging; the higher the b-value the stronger the diffusion weighting.

Chemical shift — phenomenon caused by protons resonating at different frequencies in a magnetic environment.

Coherence — the process of maintaining a constant relationship between the rotations of hydrogen protons; loss of phase coherence of the nuclear spins results in a decrease in transverse magnetization and decrease in MR signal.

Coil — single or multiple loops of wire that produce a magnetic field when current flows through them, or that detect a changing magnetic field by voltage induced in the wire.

Dephasing — after a radiofrequency (RF) pulse is applied, phase differences appear between precessing spins; the resulting decay in spin-spin interaction occurs in the transverse plane.

Diamagnetic — a substance that has a magnetic susceptibility of less than 0 because it has no unpaired orbital electrons; examples include silver, copper and mercury.

Dielectric effect — the result of radiofrequency (RF) wavelengths shortening inside the body at higher field strengths.

Duty cycle — interval during the repetition time (TR) that the gradient is permitted to be at maximum amplitude.

Echo spacing — time period from the middle of one echo to the middle of the next echo.

Echo time (TE) — time in milliseconds between the 90-degree pulse and the peak of the echo signal; TE is the primary factor controlling T2 relaxation.

Eddy current — electric current induced in a conductor when that conductor is exposed to a changing magnetic field.

Equilibrium — state of balance that exists between two opposing forces or divergent forms of influence.

Ernst angle — the flip angle for a particular spin that provides maximum signal in the least amount of time when the signal is averaged over many transients.

Excitation pulse — a brief radiofrequency (RF) pulse that distorts the equilibrium of the spins in the magnetic field; the RF pulse transfers energy to the spinning nuclei, placing the nuclei in a higher energy state; the MR scanner then collects the signal from the excited nuclei.

Extrinsic parameters — parameters that can be manipulated; extrinsic parameters include repetition time (TR), echo time (TE), inversion time and flip angle.

Faraday law of induction —if a receiver coil or any conductive loop is placed in the area of a moving magnetic field, voltage is induced in the receiver coil; this moving magnetic field voltage is the MR signal.

Ferromagnetic — a substance that demonstrates a positive magnetic susceptibility greater than 1; these substances are highly attracted to a magnetic field and retain their magnetism even after the magnetic field is removed; examples include iron, steel, nickel and cobalt.

Field of view (FOV) — area of the anatomy being imaged; increasing the field of view decreases echo space and resolution.

Fourier transform — algorithm used to convert raw scan data from waveform to digital form.

Free induction decay (FID) — signal induced by radiofrequency (RF) excitation of nuclear spins that decrease exponentially because of T2 relaxation.

Flip angle —the angle to which the net magnetization is rotated or tipped relative to the main magnetic field direction when a radiofrequency (RF) excitation pulse is applied at the Larmor frequency; MR imaging frequently uses 90-degree and 180-degree flip angles.

Frequency — the number of repetitions of a process over a unit of time (eg, hertz).

Gauss (G) — a unit measuring magnetic field strength; 1 tesla = 10,000 gauss.

Gradient — a linear slope of magnetic field strength across the scanning volume in a particular direction; gradients change the magnetic field along the slope by adding or subtracting magnetic field strength.

Gradient amplitude — the strength of the gradient.

Gradient rise time — the time it takes for gradients to reach their maximum strengths or amplitudes; gradient rise time is measured in millitesla per meter (mT/m) or gauss per centimeter (G/cm).

Gyromagnetic ratio — ratio of the magnetic moment (field strength) to the angular moment (frequency); the gyromagnetic ratio of hydrogen is a constant and can vary slightly. The MR Basics series uses a gyromagnetic ratio for hydrogen of 42.58 megahertz per tesla (MHz/T).

Homogeneity — a magnetic field is homogeneous when it has the same field strength across the entire field; homogeneity is an important criterion for image quality.

Hertz — standard unit of frequency equal to one cycle per second; the larger unit megahertz (MHz) = 1,000,000 Hz.

Image contrast — difference in signal strength between tissues; contrast is affected by pulse sequences and other factors chosen by the MR technologist.

Intrinsic parameter — imaging parameter that cannot be changed; intrinsic parameters include T1 relaxation, T2 relaxation and proton density.

k-space — area that serves as the mathematical repository for the Fourier transform; in general scan time is the amount of time needed to fill k-space.

Larmor frequency — rate at which the nuclear spins precess around the direction of the magnetic field; the rate depends on the type of nuclei and the strength of the magnetic field. The Larmor equation states that the precessional frequency (ω) of the nuclear magnetic moment is directly proportional to the product of the magnetic field strength (B_0) and the gyromagnetic ratio (γ) of hydrogen; stated mathematically, the equation reads $\omega = \gamma B_0$. The gyromagnetic ratio of hydrogen is a constant and may vary based on the MR technologist's training. The MR Basics series uses a gyromagnetic ratio for hydrogen of 42.58 megahertz per tesla (MHz/T).

Lattice — magnetic environment where the nuclei exchange energy during longitudinal relaxation.

Longitudinal magnetization — portion of the magnetization vector in the direction of the z-axis, that is, along the main magnetic field; after excitation by a radiofrequency (RF) pulse, longitudinal magnetization returns to equilibrium within a characteristic time constant T1.

Longitudinal relaxation — Return to equilibrium of longitudinal magnetization after excitation; longitudinal relaxation is due to the energy exchange between the spins and surrounding lattice, also called spin-lattice relaxation.

Longitudinal relaxation time — tissue-specific time constant that describes the return of longitudinal magnetization to equilibrium; after the time period of T1, longitudinal magnetization increases to approximately 63 percent of its end value; a tissue parameter that determines contrast**.**

Magnetic field — space surrounding a magnet (or a conductor with current flowing through it) that has special characteristics; every magnetic field exercises a force on magnetizable parts aligned along a primary axis (magnetic north or south pole). The effect and direction of this force is symbolized by magnetic field lines.

Magnetic field strength — strength of the magnetic field force on magnetizable parts. In physics, the effect is called magnetic induction; in MR, it is referred to as magnetic field strength.

Magnetic isocenter — point in the center of the magnet where x, y and z equal 0.

Magnetic moment — a measure of magnitude and direction of an object's magnetic properties that causes the object to align with the B_0 field and create its own field.

Magnetization vector — the integration of all the individual nuclear magnetic moments that have a positive magnetization value at equilibrium vs. those in a random state.

Magnetism — fundamental property of all matter related to moving electrons.

Magnetic resonance — absorption or emission of electromagnetic energy by atomic nuclei in a static magnetic field after excitation by electromagnetic radiofrequency (RF) radiation at a resonance frequency.

Magnetic susceptibility — degree of magnetism that exists within any substance or the ability of a material to become magnetized. There are four types of magnetic susceptibility: diamagnetic, paramagnetic, superparamagnetic and ferromagnetic.

MR conditional — label given to a piece of equipment or medical device that is considered to be MR safe.

MR signal — electromagnetic signal in the RF range; the signal is produced by the precession of transverse magnetization created by a variable voltage in a receiver coil.

Net magnetization vector — the sum of the magnetic moments of unpaired nuclei after pairs of low-energy and high-energy nuclei cancel each other out.

NEX — see number of excitations.

NSA — see number of signals averaged.

Number of excitations (NEX) — number of times the image is sampled, also referred to as number of signals averaged (NSA).

Number of signals averaged (NSA) —number of times the image is sampled, also referred to as number of excitations (NEX).

Paramagnetic — a substance with a magnetic susceptibility between 0 and 1 because it has unpaired orbital electrons; examples include tungsten, platinum and gadolinium.

Phase coherence —the degree to which precessing nuclear spins are synchronous.

Precession — the motion of net magnetization as is it “wobbles” around the main magnetic field of the MR scanner; precession measurement is the signal produced by the wobbling protons.

Precessional frequency calculation — equation stating that the Larmor frequency (ω) is equal to the product of the gyromagnetic ratio of hydrogen (γ) and the strength of magnet (B_0), or $\omega = \gamma B_0$.

Proton — positively charged particle located in the nucleus of an atom.

Pulse sequence diagram — In MR, a 4-line diagram representing all pulse sequences used for a scan. The first line represents the timing of the radiofrequency (RF) pulse. The second line (Gz) represents a gradient pulse used for slice selection. The third line (Gy) represents a gradient pulse used for phase encoding. The fourth line (Gx) represents a gradient pulse used for frequency encoding.

Radiofrequency (RF) — frequency required to excite hydrogen nuclei to resonate; MR uses frequencies in the megahertz (MHz) range.

Relaxation — dynamic, physical process in which a system returns from a state of imbalance to equilibrium; MR imaging consists of two types of relaxation: longitudinal and transverse.

Repetition time (TR) — time period between the beginning of a pulse sequence and the beginning of the succeeding, identical pulse sequence.

Resonance — exchange of energy between two systems at a specific frequency; resonance occurs when an object is exposed to a precessional frequency the same as its own.

Resonance frequency — frequency at which resonance occurs; the frequency for the radiofrequency (RF) pulse matches the Larmor frequency.

Rewinder gradient — a gradient that rephases and creates a coherent gradient echo.

RF coils — coils or antennas used in MR to transmit radiofrequency (RF) pulses or receive RF signals.

Saturation — when the same amount of nuclear spins are aligned against and with the magnetic field.

Shimming — the process of creating a uniform, or homogeneous, magnetic field.

Slew rate — the strength of the gradient over distance; slew rate is calculated by dividing the gradient amplitude by the gradient rise time.

Specific absorption rate (SAR) — a measure of radiofrequency (RF) energy absorbed by the body and expressed in watts per kilogram (W/kg); SAR characterizes the increased heating of tissue due to RF exposure.

Spin — the property exhibited by atomic nuclei that contain either an odd number of protons or neutrons, or both.

Superparamagnetic — a substance that has ferromagnetic properties in bulk; similar to paramagnetic substances except each individual atom is independently influenced by an external magnetic field. An example of a superparamagnetic substance is an iron-containing contrast agent.

TE — see echo time.

Tesla — a measure of magnetic field strength of the MR scanner; 1 tesla = 10,000 gauss.

TR — see repetition time.

Transverse magnetization — when the application of a radiofrequency (RF) pulse causes the net magnetization vector to flip into the transverse plane; the magnetization vector as measured in the x-y plane.

Transverse relaxation — decay of transverse magnetization through the loss of phase coherence between precessing spins due to spin exchange; also known as spin-spin relaxation.

Transverse relaxation time — tissue-specific time constant that describes the decay of transverse magnetization in an ideal, homogeneous magnetic field; after the time T2, transverse magnetization loses 63 percent of its original value; a tissue parameter that determines contrast**.**