1. **MR Basics – Neuroimaging**

Welcome to Module 9 of MR Basics – Neuroimaging. This module was written by Kathryn Withers Latimer, B.S.R.S., R.T.(R)(CT)(MR), and Meredith Gammons, B.S., R.T.(R)(M)(CT)(MR)(BD).

2. **License Agreement and Disclaimer**

3. **Objectives**

   After completing this module, you will be able to:
   - Identify common anatomic structures and pathology of the central nervous system.
   - State positioning criteria for different areas of the body.
   - List the coils available for magnetic resonance (MR) imaging and their specific applications.
   - Describe considerations in designing an imaging protocol and how to apply protocols in specific situations.
   - Explain how to apply MR imaging parameters in the clinical setting.
   - Describe various imaging options typically used to optimize image quality.

4. **Advantages of MR Imaging**

   Magnetic resonance (MR) imaging uses a strong magnetic field and radiofrequency (RF) pulses to generate images that can display soft-tissue structures and disease processes in the brain and spinal cord, called the central nervous system (CNS). A distinct advantage of using MR for neuroimaging is that it provides astounding detail of the structures of the CNS in three orthogonal planes and oblique orientations. In this module, we will also review the process of patient interaction, safety screening and image acquisition. Before we continue, let’s review the relevant anatomy.

5. **Brain Anatomy**

   There are four major components of the adult brain: the cerebrum, cerebellum, diencephalon and brainstem.

6. **Brain Anatomy**

   The cerebrum is divided into right and left hemispheres by the falx cerebri. The right hemisphere is the center of feelings and emotions. It is the visual, intuitive area where art and music are processed. The more logical left side of the brain deals with black-and-white issues, such as math and language. The corpus callosum is a dense bundle of white matter fibers that connects the two hemispheres. Other white matter tracts that transmit electrical impulses throughout the brain are the internal and external capsules.

   Projection fibers relay information from the cerebral cortex through the brainstem downward into the cord. These fibers cross at the medulla. Therefore, if a patient has a stroke or injury on the left side of the brain, the right side of the body manifests symptoms.
The outer layer of the brain is the cerebral cortex. This area stores long-term memory and information. Comprised of gray matter, it also has a large vascular component. As you view this proton density image, you will notice that this vascular area appears brighter than the adjoining white matter tracts. The white matter has a lot of myelin and fat throughout its tissue, which has a darker more hypointense appearance. Medial to the white matter tracts is the basal ganglia.

8. **Lobes of the Brain**

   The frontal lobe is the inhibitory area of the brain that houses information about socially acceptable behavior. The parietal lobe stores tactile information, such as the recognition of objects that are sharp, soft, hot or cold. The posterior lobe of the cerebrum is the occipital lobe, where higher visual processing occurs. The bilateral temporal lobes maintain auditory and emotional information.

   A cluster of subcortical gray matter is called the basal ganglia. The main portions of the basal ganglia are the caudate nucleus, lentiform nucleus and the claustrum. The basal ganglia is one of the balance centers of the brain, where coordination and motor functions reside. The basal ganglia does not enhance on postcontrast images.

9. **Brain Anatomy**

   The diencephalon is a gray matter area that lies above the brainstem. It is composed of the thalamus, subthalamus, epithalamus and hypothalamus. The thalamus relays sensory information such as pain. The subthalamus is an area that helps control motor functions. The hypothalamus is responsible for maintaining normal body temperature and is part of the feeding and appetite center. Sexual drive and sleep patterns are affected by the hypothalamus. The epithalamus is the pineal gland and its stalk, the infundibulum. Part of the endocrine system, the pineal gland secretes melatonin, which regulates reproductive functions and night-day cycles.

10. **Brainstem**

    The brainstem is a relay station for incoming sensory information. Our internal alarm system is located within the reticular activation system of the brainstem. If this part of the brain senses danger while you’re sleeping, it awakens you to a keen level of awareness.

    There are three parts of the brainstem. The most superior portion of the brainstem is the midbrain. The anterior portion of the midbrain is composed of the cerebral peduncles, and the posterior section of the colliculi (corpora quadrigemina). The superior colliculus relays visual information and the inferior colliculus is an auditory pathway. The pons, which means “little belly” in Latin, is an area that bulges anteriorly and sends information between the midbrain and the medulla.

    Beneath the pons, the medulla oblongata is a conducting pathway for the ascending and descending nerve tracts. These fiber tracts bridge the cerebrum and the spinal cord. The medulla is a center for breathing, swallowing and coughing reflexes. If a tumor invades this area, it causes serious neurological deficits.

    The cerebellum is located in the posterior cranial fossa. The cerebellum, often called the “little brain,” coordinates skeletal muscles and the maintenance of normal muscle tone and
equilibrium. There are two cerebellar lobes separated by the folds of the falx cerebelli and connected in specific areas by the vermis.

11. **Meningeal layers**
The delicate brain is protected by three meningeal layers. The strong, durable outer layer has two parts and is known as the dura mater. The meningeal arteries and the dural sinuses lie between the two layers of dura mater. The arachnoid membrane is a delicate, spider-like layer beneath the dura mater. The area under the arachnoid is called the subarachnoid space. CSF circulates around the brain and spinal cord in the subarachnoid space, providing buoyancy and protection for the delicate structures.

The layer nearest the cerebral cortex is the pia mater. It is a highly vascular structure that adheres to the folds of the brain. The brain is compressed within the skull in such a way that it has gyri which generate upward and shallow grooves, called the sulci. Deep grooves within some of the sulci are called fissures. Fissures are folds of brain tissue, and the falx is composed of dura mater, which lies on top of the cerebral folds.

12. **Brain Anatomy**
The ventricular system transports CSF throughout the central nervous system. The system includes two lateral ventricles, a third ventricle and a fourth ventricle. The foramen of Monro connects the lateral ventricles to the third ventricle. The cerebral aqueduct (aqueduct of Sylvius) connects the third ventricle to the fourth ventricle. At the level of the fourth ventricle, the foramen of Luschka moves CSF laterally and the foramen of Monro brings CSF downward through the central canal within the spinal cord. CSF moves around the spinal cord and back into the dural sinuses, where it is absorbed in the superior sagittal sinus. A network of blood vessels called the choroid plexus is located within the ventricles. The choroid plexus is responsible for daily production of CSF. If an area along the CSF pathway is blocked for any reason, the ventricles become enlarged, a condition known as hydrocephalus.

13. **Knowledge Check**
Answer the following question.

14. **Knowledge Check**
Answer the following question.

15. **Knowledge Check**
Answer the following question.

16. **Knowledge Check**
Answer the following question.

17. **The Developing Brain**
The images on this slide show the brain of an infant. The myelin of an infant is not well developed until the age of 2 years. Brain tissue in this image is isointense, meaning there is not much contrast between the gray and white matter. If a radiologist wants to better define this area, an inversion recovery sequence is helpful.

18. **The Aging Brain**
As the aging brain begins to atrophy, CSF becomes more prominent between the brain and skull and the cerebral ventricles enlarge. Small blood vessels are positioned in the meninges, forming perivascular spaces within the CSF track. These Virchow-Robin spaces may be large, contain CSF and appear bright within the white matter tracts on T2-weighted images. This is a normal variant.

19. **Clinical Indications**
   Let’s take a closer look at some of the clinical indications for MR neuroimaging.

20. **Developmental Brain Anomalies**
   Agenesis occurs when an anatomical structure fails to develop in utero; dysgenesis is when a structure develops abnormally. Either of these conditions may result in a variety of abnormalities, including Dandy-Walker syndrome and Chiari malformations. Dandy-Walker syndrome is a congenital brain malformation in which the fourth ventricle is enlarged, causing extreme accumulation of CSF in the posterior fossa area of the brain.

21. **Case Study**
   Look at the image. This particular patient has agenesis of the corpus callosum and a Dandy Walker cyst, which is a cystic malformation of the fourth ventricle of the brain resulting from hydrocephalus. The dark anterior area is a signal void from the braces that the patient had on her teeth.

22. **Case Study**
   These two images illustrate the difference between the normal corpus callosum on the left compared with agenesis of the corpus callosum, which is on the right.

23. **Chiari Malformation**
   A Chiari malformation occurs when the posterior part of the skull is narrower than normal. The abnormality causes part of the cerebellar tonsil and brainstem to herniate downward past its normal position. The malformation also may block the flow of CSF, causing headaches, hydrocephalus or problems with balance. There are four types of Chiari malformations.

   A Chiari I is the most common type, it occurs when the cerebellar tonsil extrudes below the foramen magnum. A Chiari II is also referred to as an Arnold Chiari. This condition occurs when both the cerebellar tonsil and the brainstem are pushed below the line of the foramen magnum. In both type I and type II, a build up of CSF may cause headaches. Patients with Chiari II often have a syrinx, also called syringomyelia, which is an accumulation of CSF within the central canal of the cord. This syrinx may cause pain, numbness or burning. Spina bifida or a tethered cord also may be present.

   Even though type III is uncommon, it is the most serious type of Chiari malformation. The cerebellum and brainstem protrude outside the skull into a sac, or “cele,” called an encephalocele. These infants typically do not live very long. A Chiari IV is uncommon and involves an underdeveloped cerebellum.

24. **Knowledge Check**
   Complete the following activity.
25. Knowledge Check Review

26. Brain Inflammation
Inflammation of the brain is referred to as encephalitis. Inflammation generally appears hypointense on T2-weighted images; radiologists check the brain for symmetry because mass effect also may be present. A distinguishing characteristic of herpes simplex encephalitis is bilateral inflammation of the temporal lobes, which is shown by the image on the left. Even though patients are treated with large doses of antibiotics, the inflammation may persist and result in abscesses. Meningitis indicates inflammation of the meninges. Look at the image on the right. Notice the thin layer of enhancement in the meninges following the injection of gadolinium-based contrast.

27. Multiple Sclerosis
Multiple sclerosis, or MS, is a common white matter disease that affects the myelin in the brain. There is no known etiology. Plaques are found around the ventricles or periventricular area of the brain. Symptoms of MS include slurred speech, confusion, numbness of the face and fatigue. A classic symptom of MS exacerbation is optic neuritis, an inflammation of the optic nerve.

Lesions are isointense on T1-weighted images and hypointense on T2-weighted images. Steroid therapy may mask an exacerbation on the scan. When plaques are found in the cord, patients often manifest numbness, weakness, foot drop or burning in the extremities; bladder or bowel functions also may be affected.

28. Knowledge Check
Answer the following question.

29. Neoplasia
The term “neoplasia” means new growth. New formation of tissue may be benign or malignant, primary or metastatic. Brain tumors are classified as intracranial or extracranial. Gliomas are cancerous tumors found only within the brain or spinal cord. They are graded 1 to 4; the highest grade, glioblastoma multiforme, is the most aggressive. A glioma that transverses both hemispheres of the brain is a butterfly glioma.

Meningiomas are benign tumors that grow from or on the meninges; therefore, their location is on top of the brain tissue. Since they do not grow within brain tissue, they are classified as extracranial tumors. They are isointense on precontrast T1 images, and hypointense on T1-weighted post contrast images. Acoustic neuromas are benign, slow-growing tumors located on the seventh and eighth cranial nerves. They also are considered extracranial tumors because of their location in the petrous ridge.

30. Vascular Disease
Vascular diseases, such as arteriovenous malformations, aneurysms (AVM) and vascular stenoses, are seen clearly on MR images. An arteriovenous malformation is a congenital condition consisting of a cluster of arteries and veins. Without capillary beds, the normal flow of blood becomes disrupted. This condition may be found in the brain or spinal cord. Depending on the location of the AVM, patients may have headaches, seizures, pain in the spine or extremities and gait disturbances.
31. **Aneurysm**
   An aneurysm occurs when an arterial wall weakens and fills with an abnormal amount of blood. Both of these images display patients with aneurysms. The image on the left is a large aneurysm and the image on the right is a smaller “berry aneurysm.” Both aneurysms are located within the circle of Willis. Patients with aneurysms are at risk for rupture that results in stroke or death.

32. **Knowledge Check**
   Answer the following question.

33. **Stroke**
   A stroke occurs when there is a sudden disruption of blood flow to the brain, resulting in damage to brain tissue. The two major types of strokes are ischemic and hemorrhagic. Nearly 80 to 90 percent of strokes are considered ischemic and are caused when stenosis, a thrombus or an embolism blocks the arteries. A smaller number of strokes are classified as hemorrhagic, the consequence of blood vessel leakage or rupture.

34. **Stroke Symptoms**
   Stroke symptoms lasting less than one hour represent a transient ischemic attack (TIA). When there is a lack of oxygen or nutrients to the brain, cells may begin to die within minutes. If a patient becomes aware of stroke symptoms, such as slurred speech, confusion or numbness in the extremities and seeks medical attention within a three-hour window, he or she may be given the clot-busting drug tissue plasminogen activator (tPA). Experimental research is investigating the use of the saliva from vampire bats to treat stroke. The substance, called desmoteplase, has been shown to destroy fibrin produced during blood coagulation. If successful, this drug could extend the critical window from three to nine hours after onset of stroke. These drugs are used to preserve as much viable neural tissue as possible.

35. **Spinal Anatomy**
   The spine is a bony structure that supports the weight of the body and protects the spinal cord. The most superior portion of the spine is the cervical spine, which consists of seven cervical vertebral bodies. The top vertebra, the atlas, has a unique shape, resembling a ring of bone; the second vertebral body, the axis, has a segment called the dens that extends upward through the atlas. This configuration allows the head and neck to move in a variety of directions. The posterior segment of the cervical spinous processes from C3 through C6 may be split. This is normal and is called a bifid process.

   There are 12 thoracic or dorsal spine vertebrae. The ribs articulate with the vertebral body at the costovertebral joints. Most patients have five lumbar vertebrae, although some may have four or six vertebrae.

36. **Spinal Cord Anatomy**
   The spinal cord descends from the cranial-cervical junction to the level of T12 through L1 or L2. The end of the cord is the conus medullaris. At the end of the conus, nerve root bundles traverse downward within the thecal sac. Because its appearance resembles a horse’s tail, this area is called the “cauda equina.” The cord is anchored to the sacrum and coccyx by a strand of meninges called the filum terminale. In the brain, the gray matter is located on the outer surface, and the white matter is within the brain. This arrangement is reversed in the spinal cord: The white matter is on the outside, and the gray matter is on the inside.
37. **Lumbar Spine**
   Look at the two images on this slide. The sagittal T1 image on the left displays anatomic structures, whereas the sagittal T2 image on the right best displays any pathologic processes, hydration of the discs and the cord surrounded by CSF. Notice the position of the end of the cord at the level of T12-L1 and the nerve endings (the cauda equina).

38. **Vertebral Anatomy**
   Intervertebral disks lie between the vertebral bodies; the disks act as shock absorbers for the spine. The strong outer layer of the disk is the annulus fibrosus, and the inner gelatinous layer is the nucleus pulposus. The disks may begin to lose some of their fluid as people age, causing the disks to lose strength and resiliency. Lifting heavy weights, lifestyle and poor body mechanics can also cause the annulus to break down. The progression of disk problems is an initial bulge, then a tear and eventually an area where the annulus may completely break down, allowing the nucleus pulposus to herniate onto a delicate nerve root. This may cause severe pain, burning or numbness. When the nucleus completely herniates onto a nerve, the condition is referred to as a herniated nuclear pulposus (HNP).

   Degenerative disk disease (DDD) also can result in the loss of appropriate disk height. This may lead to a narrowing of the nerve pathways, producing nerve impingement, inflammation and pain. Degenerative disk disease can lead to a condition in which the bones in the spine press against each other.

   Several longitudinal ligaments stabilize the spine. As the name indicates, the most anterior ligament is known as the anterior longitudinal ligament. The ligament immediately posterior to the vertebral bodies is the posterior longitudinal ligament, and the most posterior ligament is the supraspinal ligament.

39. **Knowledge Check**
   Answer the following question.

40. **Congenital Spinal Deformity**
   The three major patterns of congenital spinal deformity are hyperlordosis, kyphosis and scoliosis. Spinal stenosis generally is the result of aging, but it also may be a congenital disorder. Some patients are born with an abnormally narrow spinal canal, and the disorder is generally progressive. Small-disk herniations may cause more symptoms in patients with narrow spinal canals than in patients with large-disk herniation within wider spinal canals. Symptoms of spinal stenosis depend on the nerves that are being compressed. Narrowing in the cervical area may produce pain or numbness in the upper extremities, whereas narrowing in the lumbar region creates pain or numbness in the lower extremities.

41. **Spina Bifida**
   Another congenital abnormality is a spina bifida. This condition occurs when the vertebra of a fetus does not develop completely and it allows part of the spinal cord and surrounding nerve roots to protrude outside of the spinal canal into a soft tissue pouch called a myelomeningocele. This condition is most often found in the lumbar area. New surgery has been successfully performed to repair this condition while the baby is in utero.
42. **Spinal Abnormalities**
   A tethered cord is a condition in which the spinal cord is pulled down below its normal position. Symptoms include bladder dysfunction and leg pain or clubbed feet.

43. **Congenital Spinal Deformity**
   Another congenital anomaly of the spine is a transitional vertebral segment. This condition occurs when the first sacral segment becomes like an additional lumbar vertebra, articulating with the second sacral segment and causing difficulty in movement. Incomplete separation of the fifth lumbar vertebra makes it difficult to differentiate the vertebra from the sacrum. Transverse processes of the fifth lumbar body that are atypically large are called a batwing deformity.

   It is important to identify a transitional segment to establish the number of lumbar bodies. If the number of lumbar vertebrae is interpreted incorrectly, surgery or treatment may not be performed at the correct level. The arrow on this slide points to a sixth vertebral body.

44. **Incidental Vertebral Findings**
   A Schmorl node occurs in utero when part of the nucleus pulposus herniates downward into a vertebral body. It appears hypointense relative to the vertebral body. Hemangiomas are benign tumors that line the blood vessels within the vertebral bodies. Hemangiomas are hyperintense relative to the vertebral body. Both of these findings are considered incidental.

45. **Spinal Cord Compression**
   Spinal cord compression is considered an MR emergency. A tumor encroaching on the cord may cause permanent damage because neural tissue does not regenerate. The image on the left is a case of cord compression in the thoracic spine resulting from two malignant tumors. Not only can cord compression occur because of a tumor, severe degenerative disc disease may also compress the cord. The case on the right illustrates severe degeneration of multiple disks in the cervical spine, which are pressing on the spinal cord.

46. **Ependymoma**
   An ependymoma arises from the ependymal cells that line the ventricles and are found at the end of the spinal cord. These tumors usually are benign and asymptomatic. Over time, however, they tend to grow and become malignant. Ependymomas in the spinal area often occur at the conus. Depending on the size and location of an ependymoma, a patient may experience pain, bowel or bladder dysfunction. Treatment for larger ependymomas can include chemotherapy, radiation therapy or surgery.

47. **Syrinx**
   A syrinx, or syringomyelia, is a fluid-filled cyst that arises in the center of the spinal cord. A syrinx can form anywhere along the length of the spinal cord and causes pain or numbness in the extremities. Contrast must be administered to make sure that the syrinx is not caused by a tumor.

48. **Myelopathy vs. Radiculopathy**
   Myelopathy indicates a tumor in the spinal cord, whereas radiculopathy refers to a pinched nerve root. Radiculopathy can occur when a patient has back surgery to alleviate pain from a compressed nerve, yet continues to have pain. The pain can be the result of an accumulation of
scar tissue around the nerve root. A routine MR study is performed, then sagittal and axial images are acquired after the injection of a gadolinium-based contrast agent. Disk pathology has a hypointense appearance, whereas scar tissue enhances. The axial image on the left was acquired precontrast; the image on the right demonstrates enhancement of the scar tissue.

49. Knowledge Check
Answer the following question.

50. Metastasis
The spine also is a frequent metastatic site for primary tumors of the breast, lung and prostate. Look at these images. The image on the left is a sagittal T1 thoracic/dorsal image with lung cancer that has metastasized to the spine. The cancer is outside of the cord and is categorized as an extradural metastatic lesion. The image on the right is a sagittal T1 lumbar image postradiation. The cancerous area in the vertebra and bone is dark, or hypointense, because of the increased fluid content. Note that the sacrum also is affected.

51. Spinal Subluxation
Subluxation is yet another condition that may cause nerve impingement and pain. When ligaments and other stabilizing structures begin to break down because of age or trauma, the lumbar vertebrae can slip forward, or subluxate.

52. Patient Care
As with all imaging modalities, the MR technologist must constantly be concerned about patient care. This next section will discuss that topic.

53. Patient Identification
According to the Joint Commission, it is important “to reliably identify... the person for whom the service or treatment is intended.” The Joint Commission recommends using two patient-specific identifiers when providing treatment and services to an individual. In an outpatient setting, the patient should be asked to provide his or her full name and date of birth. If an inpatient is alert and oriented, the same method of stating one’s full name and date of birth may be used.

For the unconscious or confused patient or a patient who has impaired communication, the person may be identified using the information on the patient armband. In this case, the MR technologist should match the full name, date of birth and medical record number or other unique patient identifier to the information provided on the patient’s requisition. The patient’s room number or physical location is not an acceptable identifier.

54. Evaluation of MR Orders
The MR technologist should verify that the instructions and clinical indications on the physician’s order match the requisition and exam ordered. A review of a patient’s medical history before imaging can help identify patients who will benefit from contrast administration.

55. Patient Rapport
It is important that MR technologists establish a good rapport with patients. Technologists should introduce themselves and explain their role in the patient’s care. If a patient understands
what is expected, the MR scan is more likely to be successful. The technologist should address patient needs and answer questions or concerns promptly.

56. **Patient Education**

Education is a key component to ensuring the cooperation of the patient. The patient needs to know that remaining still during the examination helps produce motion-free images and minimizes the time he or she is in the scanner by decreasing the need to repeat a series. The MR technologist should demonstrate the intercom system and squeeze ball as well as the levels of bore lighting and bore fan speed. It’s also essential to remind the patient about the loud noises that occur during the examination. Informing the patient about the expected exam length may help the patient better tolerate any discomfort.

57. **Patient Screening**

Safety screening is a very important part of MR exam preparation and should be performed by trained MR staff. Screening provides the first indication there is a potential safety hazard. For this reason, patients should be screened more than once, by completion of a formal screening form and a patient interview. Often, the patient provides the information needed for proper safety screening.

Obstacles to obtaining safety information include language barriers, visual impairment, hearing impairment and mental disabilities. If there’s a language barrier, it’s important to use a medically trained interpreter, rather than a family member or friend, to ensure that the medical terms and information are translated correctly and to keep the patient’s information confidential. A trained medical interpreter should also be used for people who have visual or hearing disabilities. If the patient is unconscious or has a disability that makes it uncertain whether he or she can answer screening questions properly, it may be necessary to invoke the patient’s health care power of attorney or involve a close relative familiar with the patient’s medical history.

58. **Knowledge Check**

Answer the following question.

59. **Screening for Outside Metal**

Everyone who enters the MR environment should be thoroughly screened for metal of any kind. Ferromagnetic materials are not allowed in the MR suite because they can be attracted to the magnet and produce magnetic susceptibility artifacts or cause heating injuries. In addition, ferrous metal objects on the outside of the body can become airborne projectiles that could severely harm the patient, other people in the room and the equipment.

Patients often are asked to disrobe and wear clothing provided by the facility, such as a patient gown or scrubs, before the MR exam. If the patient is asked to wear a gown or scrubs, the technologist should show if the gown opens in the front or in the back and offer assistance if needed.

60. **Noncompatible Metal Items**

MR technologists should be familiar with the safety screening form and which objects to ask patients about. We’ll discuss some potentially dangerous items; however, it’s best to follow the rule, “when in doubt, take it out.” Be aware of these objects:
• Body piercing and other jewelry. Jewelry may contain ferromagnetic or magnetic materials.
• Hair accessories containing metal. Hair pins can potentially become dangerous projectiles, flying into the magnet at 60 to 90 mph.
• Bras with metal hooks or underwire. Some women may experience a deflection, or twisting of the metal in the magnetic field, or a mild heating sensation or burn if the garment is left on.
• Mascara containing iron particles. The iron particles could increase the likelihood of a heating sensation and may create a magnetic susceptibility artifact on the images.

61. **Screening for Metal Inside the Patient**
Screening for metal inside the patient is equally as important as screening for outside metal. Some items are safe to scan, such as orthopedic hardware, mesh from hernia surgery, cataract surgery implants and catheter ports. However, avoid scanning other implants or devices, including:
• Noncompatible cardiac pacemakers or other electronic implants.
• Cochlear or other ear implants.
• Thalamic/neural stimulators.
• Epicardial and intracardiac pacing wires.
• Ferrous intracranial aneurysm clips. Certain aneurysm clips may be safely scanned, but there are a large number that should not be near the MR magnet.
• Metallic foreign bodies. Examples of these objects include bullets, pellets and shrapnel. Some bullets and fragments may be safely scanned, but should be evaluated on an individual basis. Knowing the metallic composition of the bullet or fragment, the location and how long the object has been in the body help the radiologist determine whether the metallic object should be scanned.
• Metallic orbital foreign bodies. MR technologists should question patients about being struck previously in the eyes with pieces of metal. If there is a chance that metal is still in the eye, orbital radiographs should be taken before proceeding with the MR examination.

When in doubt about the compatibility of an implant or device, MR technologists should check with the equipment manufacturer for the most recent information.

62. **Ancillary Staff in the MR Environment**
Any other personnel who enters the MR environment should be screened and educated regarding what is allowed in the MR room and what is banned. Personnel should be reminded that the magnet is always on, even when patient scanning is not in progress. It also is a good idea to educate housekeeping, security and safety personnel about the MR environment.

63. **Screening for Contrast Contraindications**
Referring clinicians often request that patients have contrast injections to help demonstrate pathology. Asking a patient about prior experience with gadolinium contrast agents can indicate how the patient might respond to contrast administration during the current exam. MR technologists should be familiar with the policies and protocols of their institution regarding contrast administration.

64. **Positioning for Routine MR Exams**
When positioning the patient, the MR technologist must balance obtaining good image quality and making the patient as comfortable as possible. To obtain good image quality, it is ideal to position the patient supine and in the center of the table. The body part being examined should be centered on the coil and not tilted.

Symmetry in positioning is especially important for internal auditory canal imaging and orbital images in which asymmetry could mimic pathology. Alternative positioning may be needed, especially with patients who have special needs or those whose body structure may be atypical.

The technologist may place cushions alongside the anatomy being imaged to help stabilize the body part, which minimizes motion and increases patient comfort. A head pillow is not used for neuroimaging examinations because of the coil’s construction and placement. A very small pad or cushion may be placed under the patient’s neck if absolutely necessary for cervical spine and neck imaging. The technologist should be careful not to decrease the signal-to-noise ratio by having the body part being imaged too far from coil contact.

A cushion may be placed in the natural lordotic areas of the spine to provide comfort for spinal imaging. Placing a pillow under the patient’s knees can provide relief for patients who have back pain.

65. **Special Needs Patients**
Extra care should be taken with special needs patients to ensure patient comfort and avoid movement during scanning. For example, some patients might require additional padding. Others might have drains, IVs, Foley catheters and other medical devices. MR technologists should remain aware of a patient’s breathing tube and any other lines when placing coils so that the tube or line is not disturbed or disconnected.

66. **Special Positioning**
Technologists encounter situations that are not “textbook perfect,” such as claustrophobic patients, and at times conventional coils might not fit some patients. For example, the head of a patient with acromegaly and facial bone enlargement might not fit into the usual head coil for a pituitary scan.

Some patients are confined to wheelchairs, are on stretchers or have a body habitus or condition that presents positioning challenges. For example, MR technologists may need to be creative for the lateral decubitus-positioned patient and perhaps use a flexible coil or other coil for the patient’s brain scan.

67. **Patient Monitoring**
Special patient monitoring may be needed for unconscious patients, those who are hard of hearing or who have weak voices, pediatric patients, special needs patients or those under sedation. Typical monitoring equipment includes a pulse oximeter, blood pressure cuff and electrocardiogram (ECG) equipment.

When monitoring a patient’s ECG findings, it’s important to understand the magnetic-hemodynamic effect on ECG waveforms in a magnetic field. The ECG waveform may not be sufficient for accurate patient monitoring when running certain sequences.
68. **Traumatic Brain Injury**
In the United States, more than one million people experience closed head injuries each year. These injuries are caused by automobile accidents, blows to the head and falls. An epidural hematoma is a tear of the middle meningeal artery, which accounts for approximately 0.5 percent of all head injuries. Nearly 30 percent of all head injuries are subdural hematomas. A tear in the draining venous sinus can cause blood to collect between the arachnoid and the dura mater. Intracerebral hemorrhage is the result of a burst aneurysm or hemorrhagic tumor.

Traumatic brain injuries, such as brain herniation, along with spinal cord injuries, are urgent trauma exams. When looking for blood in the brain from trauma, it is common to perform a gradient-echo sequence.

69. **Anesthesia**
Some patients are extremely anxious and cannot complete a scan even after sedation is attempted. These patients may require anesthesia. Although larger facilities might have MR-safe equipment, some anesthesia equipment is not MR safe and thus cannot be taken into the MR room. Anesthesia personnel who plan to be in the MR room must be screened for safety before entering.

70. **Image Acquisition**
When an MR technologist positions a patient within the magnetic field, a vector of the patient’s hydrogen protons aligns with the field. When an RF pulse is applied, the protons move to the transverse, or x-y, plane. The pulse is applied at a slice resonant frequency called the Larmor frequency. At this point, the hydrogen atoms become excited and emit a signal. The RF pulse is switched off, and specific coils are turned on to receive the signal from the tissues as the protons begin to relax. The receiver system converts analog signals to digital signals to generate the image.

71. **Coil Selection**
MR technologists should select the appropriate coil for the body part being scanned. For example, a coil designed for brain imaging should be used for an adult brain scan. At times, however, the technologist may need to adapt to a specific situation. The design of some scanners and spine coils allow patients to be scanned feet first or head first. This flexibility can help with problems caused by a patient’s emotional distress or body habitus.

72. **Coil Types**
Manufacturers offer many coil configurations to conduct MR examinations of the brain. A coil that can both transmit and receive an MR signal is called a transceiver, or volume, coil. Volume coils use two independent coil elements and generate signal-to-noise ratios 40 percent greater than linear coils. Birdcage coils excite smaller volumes of tissue, and thus require less RF. Currently, some vendors use the birdcage transmit-and-receive head coil, but others use a configuration that transmits a signal with the body coil and receives a signal with the upper segment of a phased-array spine coil. This is called a receive-only coil.

With the advent of multichannel coil technology, many elements are configured in an array with overlapping circumferential coverage. A coil that has multiple elements receives a signal from the patient’s anatomy and sends it through variable receive channels. The multichannel design leads to an increased signal-to-noise ratio, faster scan times and improved resolution. A
neurovascular array coil is useful when scanning the carotid arteries and the brain because the coil allows coverage from the aortic arch through the brain; this eliminates the need to change coils to scan the entire area.

73. Phased-Array Coils
Phased-array coils are used to examine the spine. They are composed of several small coils arranged in a multicoil configuration. The signal from each coil is added together; this use of several small coils decreases image noise. A phased-array coil provides greater surface coverage and maintains a high signal-to-noise ratio.

74. Localization
The technologist uses a laser light at the entrance of the bore of the magnet to locate a landmark on the patient indicating the center of the region of interest. Landmarks for common neurological MR exams include:
- The glabella for the head/brain.
- The menton for the cervical spine.
- The manubrial notch and sternal angle for the thoracic spine.
- The level of the iliac crest for the lumbar spine.

75. Imaging Planes
MR imaging can display anatomy with high spatial and temporal resolution. MR scanning allows imaging of anatomy and pathology in virtually any plane, including three routine orthogonal imaging planes or obliques: axial, sagittal and coronal. To review these planes, play this animation.

76. Imaging Planes
The planes the MR technologist selects depend on the position of anatomic structures within the body. The axial plane segments the area of interest into superior and inferior sections and the sagittal plane divides the area of interest into left and right slices. The coronal plane segments the area of interest into anterior and posterior sections. Multiple planes provide information that is helpful in diagnosis and treatment.

77. Slice Thickness
Thicker slices provide increased signal for imaging. Thinner slices are used to display small structures, such as the pituitary gland, temporal lobes, the internal auditory canal, cranial nerves or the orbital region. Thin slices afford higher detail or resolution.

78. Slice Direction
The direction in which the MR technologist dictates the scan plane is called the slice direction. On each slice, the long axis is the frequency direction and the short axis is the phase direction. Slice, phase and frequency differ depending on the plane the technologist chooses.

79. Pulse Sequences
MR imaging has long been known for its high sensitivity in demonstrating minute abnormalities; however, the MR technologist must use several pulse sequences to demonstrate specific tissue. A pulse sequence is a combination of RF pulses, specific echo times and periods of tissue recovery. Repetition time (TR) refers to the time from one excitation pulse to the next, whereas echo time (TE) is the time from the application of one RF pulse to the peak of a signal induced in
a receiver coil. Both TR and TE are measured in milliseconds. Today’s MR equipment offers a variety of pulse sequences.

80. **Pulse Sequences**
The case study shown on this slide displays the same slice acquired with multiple pulse sequences. The T1 precontrast image shows anatomic structures, and the T2-weighted image demonstrates a few bright areas of pathology. The FLAIR sequence suppresses the fluid in the ventricles, which helps to display stroke. Finally, a lack of enhancement on the T1-weighted postcontrast image confirms that a stroke occurred in the past. Note the enhancement in the choroid plexus on the postcontrast image. The number of sequences used for MR neuroimaging generally depends on radiologist preference.

81. **Standard Screening Pattern**
A standard screening pattern when searching for abnormalities of the brain begins with T1-weighted images, which best demonstrate anatomy, congenital abnormalities and ventricular size. Cerebellar tonsils, sinuses, the corpus callosum, posterior fossa, brainstem and pharyngeal tissue also are examined using T1 weighting.

82. **Tissue Characteristics of T1**
Three substances are bright on a T1-weighted sequence: fat, contrast media and hemorrhage that is at least three days old. Let’s look at some images.

83. **Case Study**
This image displays fat in the corpus callosum and clivus areas.

84. **Case Study**
This image shows an enhancing meningioma.

85. **Case Study**
This image displays hemorrhage in the temporal lobe.

86. **Knowledge Check**
Answer the following question.

87. **Tissue Characteristics of T1**
Five tissue types and substances typically appear dark on T1-weighted sequences: air, bone, calcifications, healthy blood flow and hemosiderin. Let’s look at some images.

88. **Case Study**
Air and bone are dark because they lack significant amounts of hydrogen protons.

89. **Case Study**
Unlike radiography and computed tomography (CT), which show calcified tissue as hyperintense, calcification is hypointense on MR in every sequence.

90. **Case Study**
This axial image of the brain illustrates healthy blood flow.
91. Knowledge Check
Answer the following question.

92. Hemosiderin
The images on this slide show hemosiderin, which has a dark appearance on every sequence. As you recall, the increased iron causes a voiding artifact, or dark ring, around the hemorrhagic area in the image on the right.

93. Spin-Echo Sequences
Because of increased signal-to-noise ratio, a spin-echo sequence is regarded as the foundation for MR imaging. Basic spin-echo sequences are T1, T2 and proton density. To acquire a T1-weighted image using a 1.5 T magnet, the TR ranges between 450 and 800 milliseconds and the TE ranges between 12 and 15 milliseconds. On a T1-weighted image, fat is bright (hyperintense), and fluids such as edema or CSF are dark (hypointense). Today, faster techniques have replaced traditional spin-echo sequences.

94. Tissue Characteristics of T2
A T2-weighted axial sequence helps to check the orbits, sinuses, basal ganglia, cerebellum, internal auditory canal and the lobes of the cerebrum. This sequence also shows ventricular size, edema and hemorrhage.

Proton-density-weighted images have increased signal-to-noise ratios and best display the differences in the gray and white matter.

Myelin, which is an insulator, has a large fat component. An area of disease can have increased vascularity or edema surrounding a mass; therefore, a T2-weighted sequence best demonstrates this pathology. The parameters for a T2 sequence are a long TE and a long TR. A proton-density sequence best demonstrates the demarcation between gray and white matter. Proton-density sequences have short TEs and long TRs.

95. Fast Spin-Echo
Turbo or fast spin-echo, acquires images more quickly than traditional spin-echo. Multiple 180-degree pulses reduce magnetic susceptibility artifact, which masks small hemorrhages in the brain. The number of pulse sequences used for MR neuroimaging generally depends on radiologist preference.

Note that the vascular globe of the eye is bright and the fatty tissue surrounding the orbit is also bright or hyperintense.

96. Inversion Recovery Sequence
Two types of inversion sequences are short tau inversion recovery (STIR) and fluid-attenuated inversion recovery (FLAIR). STIR sequences are used to saturate fat and FLAIR sequences are used to nullify the signal from fluid or CSF.

97. STIR Imaging
STIR imaging is useful to display fractures or bone bruises in the spine. Fat is hypointense and fluid appears hyperintense. The tau time to saturate fat varies depending on the magnet’s field strength. The TE and TR depend on radiologist preference and your facility’s protocols.
An MR technologist may employ saturation bands to null signal from certain areas that involve motion (such as swallowing or breathing). If trauma is suspected, particularly to the cervical spine, MR technologists should perform a STIR sequence to ensure that the anterior longitudinal ligament is not torn. Healthy ligaments should be hypointense in every sequence. Anterior saturation bands should not be placed too close to the ligament so that the band does not obscure any hyperintense areas that could represent a tear.

It’s important to scan STIR sequences before administering contrast because the sequence suppresses both the fat signal and signal from an enhancing lesion or scar tissue in the spine. The TE is moderately long and the TR is long. The tau time to saturate fluid varies depending on the magnet’s field strength.

FLAIR sequences are selected for brain or spinal cord imaging. Suppressing the signal from the CSF in the ventricles makes it easier to demonstrate stroke or multiple sclerosis (MS) plaques. The TE is moderately long and the TR is long. The tau time to saturate fluid varies depending on the magnet’s field strength.

98. **Gradient-Echo Sequences**
   T2-weighted images can be acquired using a spin-echo, fast spin-echo, or a gradient-echo sequence. Gradient-echo sequences have a short TE, TR and flip angle (less than 90 degrees) compared with a spin-echo or fast spin-echo. These parameters allow for shorter scan times. This sequence uses gradient rephasing rather than a 180-degree RF pulse to move the protons into the transverse plane.

99. **Gradient-Echo Sequences**
   Severe trauma to the brain may result in tiny shearing hemorrhages at the gray-white matter interfaces as shown on this image. Another advantage of gradient-echo sequences is that they can be acquired in a 3-D slab of information. This information allows MR technologists to postprocess the images into multiplanar reconstruction images.

100. **Echo-Planar Imaging**
   Echo-planar imaging (EPI) is another gradient-echo pulse sequence. This sequence is extremely fast and is more effective in identifying acute brain ischemia than conventional MR techniques or CT. An EPI image can display stroke within a matter of minutes because of the increased amount of water in intracellular compartments. The resulting signal is a hyperintense area.

101. **EPI Sequences for Stroke**
   Acute stroke may be detected by using EPI sequences known as diffusion-weighted imaging and perfusion-weighted imaging. These sequences provide physiological details about the brain. Normal brain tissue has freely diffusing water, which appears dark on images. In the event of a stroke, water becomes restricted, thereby appearing bright. The contrast of diffusion-weighted images is controlled by selecting the appropriate b-value. A higher b-value increases the background suppression.

   Perfusion-weighted imaging evaluates regional blood flow in patients with suspected stroke. MR images are acquired rapidly and repeatedly during intravenous (IV) contrast administration. An apparent diffusion coefficient (ADC) map is a postprocessing technique that is reconstructed from a diffusion-weighted imaging sequence with at least two b-values. If an area appears
hyperintense on the diffusion-weighted image and hypointense on an ADC map, the stroke is real. If the area is hyperintense on both the EPI and the ADC map, it is not a stroke, but rather the result of “T2 shine-through,” and there may be a diffusion-perfusion mismatch on the images. The perfusion abnormality is larger than the diffusion abnormality indicating an area of at-risk tissue.

102. **Magnetic Resonance Angiography**
On a spin-echo sequence, flowing blood is hypointense. If there is abnormally slow flow or an occlusion in a vessel, the area is hyperintense. Magnetic resonance angiography (MRA) is a gradient-echo sequence used to display flowing blood. Using ultrashort parameters ensures that the background tissue is dark compared with flowing blood. Placing an RF saturation band superior to the vessels helps display the arterial flow of the circle of Willis.

103. **Magnetic Resonance Venogram**
Using an inferior saturation band helps demonstrate the superior sagittal sinus and venous system by saturating signal from the arteries that flow upward from the heart.

104. **Pulse Sequences for MRA**
MRA images should be acquired in a plane perpendicular to blood vessel flow for optimum signal. Individual slices in a 3-D MRA stack are referred to as raw data. Maximum intensity projection (MIP) is a postprocessing technique for reformattting time-of-flight MRA images. Time-of-flight mathematically filters strong vascular signals from a 3-D volume data set and reformats the data as a 2-D image in a specific plane. Flowing or contrast-enhanced blood projects a strong signal, which helps to display the blood vessels. When images are acquired in a volume, they may be reconstructed in multiple planes, a process known as multiplanar reconstruction.

105. **MR Spectroscopy**
MR spectroscopy is used to detect cancers, aid in biopsies and plan or monitor therapy. MR spectroscopy evaluates the chemical makeup of tissues. Rather than create an image, MR spectroscopy displays chemical shift and frequency differences between elements. Single and multivoxel techniques often are used to acquire multiple voxel peaks. It’s then possible to compare the increase or decrease of chemical peaks within brain tissue. For example, a drop in the N-acetylaspartate peak indicates tumor invasion. Elevated choline indicates tumor growth; lactate changes indicate infection or a lack of oxygen to the area. Lipid elevation indicates tissue death, or necrosis.

The image on the right is a single voxel technique and the image the left is a spectral map, which identifies the chemical peaks.

106. **Contrast Administration**
MR technologists should follow their facility’s guidelines for contrast administration. If the patient is to receive a contrast medium, the technologist should explain possible side effects. Disease processes that warrant the injection of contrast include a suspected or confirmed neoplasm, intra-axial and extra-axial tumors, bone metastases and neurofibromatosis. Infectious processes such as cerebritis, meningitis and encephalitis also require contrast injection. Additional conditions indicating a need for contrast are syrinx, multiple sclerosis, CSF leaks and scar tissue surrounding nerve roots in the spine. Contrast agent administration depends on the
specific area being scanned, the patient’s history, referring physician order and radiologist preference.

107. **Contrast Agents**
A number of U.S. Food and Drug Administration (FDA)-approved gadolinium-based contrast agents are on the market. These contrast agents are valuable because they can pass through the blood-brain barrier of the CNS. Gadolinium primarily affects the T1 relaxation of tissues. Therefore, tumors, infection, infarction and inflammation enhance and display a hyperintense signal on T1-weighted images after gadolinium administration. The pituitary and pineal glands, choroid plexus of the ventricles and mucous membranes also enhance with contrast. Gadolinium-based contrast agents help distinguish postoperative scar tissue from disk impingement in and around the spinal cord. Brain tumors and inflammation break the blood-brain barrier whereas cysts do not break the blood-brain barrier. Therefore, cysts have a hypointense signal on the T1 image, since they do not absorb contrast.

108. **Image Artifacts**
During MR scanning, technologists may encounter a number of artifacts. Let’s discuss some of the more common types of artifacts in MR imaging.

109. **Motion Artifact**
This image shows a motion artifact, which is one of the most common artifacts. Motion can be caused by the patient being uncomfortable, disoriented or claustrophobic. The MR technologist should make every effort to make the patient comfortable so that patient doesn’t move.

110. **Susceptibility Artifacts**
A susceptibility artifact appears as a large signal void at the air-tissue interface or areas where metal is present. If a patient has metal in or around the CNS, such as bur holes in the skull, orthodontic braces or rods and screws in the spine, a spin-echo or fast spin-echo sequence helps to minimize the chance of a susceptibility artifact. Let’s look at some images that contain artifacts.

111. **Image Artifacts**
This series of images shows surgically placed metal in the patient’s spine.

112. **Image Artifacts**
On these images you can see the dark void created by a hair band that had a small metal piece. Even a small amount of metal can generate a large dark area or signal void.

113. **Image Artifacts**
The metallic clave on the left produced the artifact in the image on the right.

114. **Zipper Artifact**
A straight horizontal line, or zipper artifact, on an image is the result of an RF leak. Leaks can occur because of damaged RF shielding around the door, a problem with the head coil or a faulty light bulb. The artifact also may occur when someone opens the MR suite door while a scanning sequence is in progress.

115. **Ghosting**
RF presaturation bands can be applied over any area that might pose a motion problem. Gradient moment nulling (flow compensation) reduces ghosting by flowing vessels. Occasionally, a large artifact might occur from contrast accumulation at the confluence of the sinuses, where several large veins converge in the posterior fossa.

116. Conclusion
MR imaging provides an enormous amount of information in multiple imaging planes without the need for ionizing radiation. Using multiple pulse sequences, and in many instances adding gadolinium-based contrast agents, helps radiologists distinguish healthy tissues from disease processes. Patient education, screening and preparation are key to the MR technologist’s ability to produce a high-quality diagnostic study.

117. Conclusion
This concludes MR Basics Module 9 — Neuroimaging. You should now be able to:
• Identify common anatomic structures and pathology of the central nervous system.
• State positioning criteria for different areas of the body.
• List the coils available for magnetic resonance (MR) imaging and their specific applications.
• Describe considerations in designing an imaging protocol and how to apply protocols in specific situations.
• Understand how to apply MR imaging parameters in the clinical setting.
• Describe various imaging options typically used to optimize image quality.

118. Bibliography

119. Bibliography

120. Bibliography

121. Bibliography

122. Bibliography

123. Bibliography

124. Acknowledgements

125. Development Team

126. Module Completion
Bibliography


Guidance for industry and FDA staff criteria for significant risk investigations of magnetic resonance diagnostic devices. U.S. Food and Drug Administration website.


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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.

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

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.

<table>
<thead>
<tr>
<th>Desired outcome</th>
<th>Adjusted Parameter</th>
<th>Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximize SNR</td>
<td>Increase NEX</td>
<td>Increased scan time</td>
</tr>
<tr>
<td></td>
<td>Decrease matrix</td>
<td>Decreased scan time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decreased spatial resolution</td>
</tr>
<tr>
<td></td>
<td>Increase slice thickness</td>
<td>Decreased spatial resolution</td>
</tr>
<tr>
<td></td>
<td>Decrease bandwidth</td>
<td>Increased minimum TE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increased chemical shift</td>
</tr>
<tr>
<td></td>
<td>Increase FOV</td>
<td>Decreased spatial resolution</td>
</tr>
<tr>
<td></td>
<td>Increase TR</td>
<td>Decreased T1 weighting</td>
</tr>
<tr>
<td></td>
<td>Decrease TE</td>
<td>Increased number of slices</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decreased T2 weighting</td>
</tr>
<tr>
<td>Minimize scan time</td>
<td>Decrease TR</td>
<td>Increased T1 weighting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decreased SNR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decreased number of slices</td>
</tr>
<tr>
<td></td>
<td>Increase phase encodings</td>
<td>Decreased spatial resolution</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increased SNR</td>
</tr>
<tr>
<td></td>
<td>Decrease NSA/NEX</td>
<td>Increased SNR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increased motion artifacts</td>
</tr>
<tr>
<td></td>
<td>Decrease slice number in volume</td>
<td>Decreased SNR</td>
</tr>
<tr>
<td></td>
<td>averaging</td>
<td></td>
</tr>
<tr>
<td>Maximize spatial resolution</td>
<td>Decrease slice thickness</td>
<td>Decreased SNR</td>
</tr>
<tr>
<td>(assumes a square FOV)</td>
<td>Increase matrix</td>
<td>Decreased SNR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increased scan time</td>
</tr>
<tr>
<td></td>
<td>Decrease FOV</td>
<td>Decreased SNR</td>
</tr>
</tbody>
</table>

FOV = field of view; NSA/NEX = number of signal averages/number of excitations; TE = echo time; TR = repetition time; SNR = signal-to-noise ratio.
B₀ — (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).

B₁ — symbol used to represent the radiofrequency (RF) field in the MR system; the RF coils, or transmitter coils, at the Larmor frequency produce the B₁ 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 \( (\omega) \) of the nuclear magnetic moment is directly proportional to the product of the magnetic field strength \( (B_0) \) and the gyromagnetic ratio \( (\gamma) \) 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 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 ($\omega$) is equal to the product of the gyromagnetic ratio of hydrogen ($\gamma$) 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.