MRSO Exam Prep Course

Module 12

Artifacts

At this stage in the course, you have a pretty good idea of the safety risks that can be present in the MR environment. So now let's discuss how the MR environment itself affects the accuracy of imaging devices. We are going to spend some time understanding the different types of artifacts so we can be better equipped to mitigate the risks associated with them.

An image artifact is a pattern or structure in the image created by a signal distortion associated with the image creation technology. As a result, it's an unwelcome pattern or structure that doesn't correspond to human anatomy. Image artifacts can be deceptive and obstruct diagnosis. Unfortunately, the complexity of MRI has resulted in a plethora of perplexing imaging abnormalities. Fortunately, many can be deciphered and do not impede diagnosis. Each new imaging technique or pulse sequence, on the other hand, introduces the possibility of additional artifacts.

In the next submodules, we will discuss the different classifications of artifacts. In this course, we are going to focus on some of the primary artifacts classified under "Reconstruction Artifacts", "Noise-Induced Artifacts", and "Magnetic and Radiofrequency Field Distortion Artifacts". Each of these artifact categories can contribute to the development of artifacts thorough patient-related issues or system-related issues.

Here is a breakdown of the artifacts we are going to cover in this course:

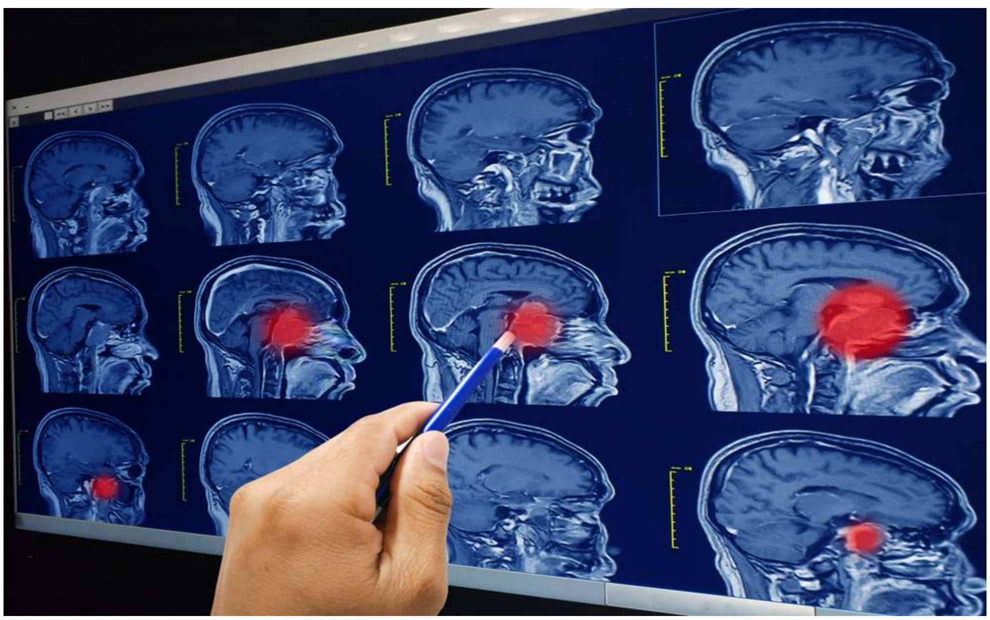

Image 12.1

Reconstruction Artifacts

Patient-Related

- Aliasing (wraparound)
- Partial volume averaging

System-Related

- Truncation
- Zero frequency

Noise-Induced Artifacts

Patient-Related

- Voluntary motion
- Involuntary motion a. Bowel peristalsis b. Respiration c. Cardiac and vessel pulsation d. Swallowing
- Fluid motion a. Blood flow b. Cerebrospinal fluid flow c. Urine movement
- Misregistration

System-Related

- Frequency line/point
- Phase line/star
- Extraneous RF
- Off-resonance turning

Image 12.2

Magnetic & Radiofrequency Field Distortion Artifacts

These types of artifacts are broken down into the following categories:

Patient-Related

- Foreign materials
- Magnetic susceptibility
- Body shape, conductivity, and extension
- Chemical shift

System-Related

- Inhomogeneity in the primary static magnetic field
- Inhomogeneity of the magnetic field gradient
- Inhomogeneity of the RF coil
- Inaccuracy in gradient coil switching and timing

Section 12.1 Reconstruction Artifacts

As the RF pulse sequence is activated during a scan, sometimes the computer reconstruction process results in MRI artifacts being reported. Aliasing, partial volume averaging, truncation, and quadrature artifacts are among them.

Patient-related reconstruction artifacts include aliasing artifacts and partial volume average artifacts. System-related reconstruction artifacts include truncation artifacts and zero frequency artifacts.

12.1.1 Aliasing

One of the most prevalent artifacts in the “Reconstruction” group is the aliasing artifact. When parts of the patient's body are outside the specified field of view (FOV) yet inside the area of RF excitation, this is known as aliasing or "wraparound." As a result, RF signals that can't be correctly decoded are generated. When hydrogen nuclei outside the imaging FOV are excited, the signal they produce is regarded as coming from inside the imaging FOV. The image is then projected on the opposite side of its original location over the real component of the image.

12.1.2 Partial Volume Averaging

This artifact is comparable to that seen in CT scans. When the structure of interest is encompassed inside two contiguous slices, partial volume averaging occurs. Thick slices and huge voxels exacerbate the artifact.

12.1.3 Truncation

Truncation is a geometric term for the cutting off or lopping of a cone or cylinder's vertex. The reduced portion is the remainder. When the number of phase-encoding acquisitions is low, the truncation artifact is more noticeable. Truncation occurs at interfaces between fat and air or fat and cortical bone when there is a significant change in signal intensity. High spatial frequencies make up the stark contrast borders of these interfaces. There isn't enough data in a small matrix to adequately depict such high frequencies. The artifact can be oriented along both frequency and phase encoding axes.

12.1.4 Zero Frequency

RF feed-through from the RF transmitter along the frequency-encoding direction at the core or reference frequency of the imaging sequence causes a zero line or zipper artifact. It's most common on photos where only one average is taken since no signal is collected in the matrix's centerline.

Section 12.2 Noise-Induced Artifacts

Patient-related noise-induced artifacts include voluntary motion artifacts, involuntary motion artifacts, and misregistration. System-related reconstruction artifacts include off-resonance artifacts.

12.2.1 Voluntary / Involuntary Motion Artifacts

Motion artifacts are among the most prevalent with respect to "Voluntary / Involuntary Motion Artifacts." Patient motion can cause ghost images or diffuse image noise in the phase-encoding direction. Periodic movements, including blood vessel or cerebrospinal fluid (CSF) pulsation and cardiac activity, produce ghost images. Conversely, diffuse image noise is generated by non-periodic movements. The intensity of the ghost image increases in tandem with the amplitude of the moving tissue's signal and the signal strength. Voluntary, involuntary, and even microscopic physiologic movements generate yet another set of artifacts. A picture of a moving item, like photography, is difficult to capture. If motion happens during the imaging time, the MR image is substantially damaged. This is especially true if the motion happens near the acquisition's midpoint. Motion artifacts can be caused by the physiologic motion of the blood, heart, larynx (swallowing), diaphragm, colon, and CSF in the brain and spinal canal. To reduce the potential for motion artifacts, consider the following processes:

- Patient Immobilization
- Cardiac Gating
- Respiratory Gating
- Signal Suppression of the Tissue
- Selecting the Shorter Dimension of the Matrix as the Phase-Encoding Direction
- View-Ordering or Phase-Reordering Methods
- Swap Phase and Frequency-Encoding Directions

Patient Immobilization

During MRI scans, patient immobilization is essential to reduce involuntary movements and ensure high-quality imaging. This process involves using cushions, straps, or other devices to securely hold the patient in the desired position. Immobilizing the patient helps ensure consistent positioning between MRI, CT, and irradiation scans. This consistency is crucial for accurate dose calculation and to minimize registration errors across different imaging modalities.

Cardiac Gating

Cardiac gating in MRI utilizes an electrocardiogram (ECG) to synchronize image acquisition with the heart's motion. This technique allows imaging to be timed with specific phases of the cardiac cycle, resulting in improved temporal resolution and reduced motion-related artifacts.

Respiratory Gating

Respiratory gating is a technique that synchronizes the imaging process with the patient's respiratory cycle. This technique is especially beneficial for imaging the upper abdomen and chest, as it helps mitigate motion artifacts caused by breathing. By acquiring images at specific points in the respiratory cycle, respiratory gating enhances the image quality and reduces blurring due to respiratory motion.

Signal Suppression of Tissue

Tissue suppression in MRI refers to techniques that selectively suppress the signal from specific tissues, allowing for enhanced visualization of other structures. Commonly targeted tissues for suppression include fat and water. These techniques include fat saturation, inversion recovery, opposed-phase imaging, chemical (or spectral) saturation, frequency-selective presaturation, and spatial presaturation in the field of view (FOV).

Selecting the Shorter Dimension for Phase-Encoding Direction

Choosing the shorter dimension of the body part to be imaged as the phase-encoding direction can help prevent wrap-around artifacts. By aligning the phase-encoding direction with the shorter dimension, a rectangular matrix with fewer phase-encoding steps can be achieved, minimizing the occurrence of wrap-around artifacts.

View-Ordering or Phase-Reordering Methods

View ordering and phase reordering are critical techniques for reducing motion artifacts and enhancing image quality. View ordering refers to the sequence in which radial lines are collected in radial fast spin-echo (FSE) imaging. On the other hand, phase reordering involves a method similar to a linear phase shift of k-space without corrupting stationary structures.

Swapping Phase and Frequency-Encoding Directions

Swapping the phase and frequency-encoding directions in MRI can have various benefits, including mitigating motion artifacts, reducing chemical shift artifacts, and addressing wrap-around artifacts. Additionally, it can modify other artifacts, sequence parameters, and aliasing, contributing to improved overall image quality.

12.2.2 Misregistration

If there is patient mobility between a mask image and the next image, the removed image will have misregistration artifacts. In the picture matrix, the same anatomy is not registered in the same pixel. Reregistration of the mask, that is, adjusting the mask by one or more pixels so that superimposition of pictures is achieved again, is a common way to remove this type of artifact. Reregistration, on the other hand, might be a time-consuming operation.

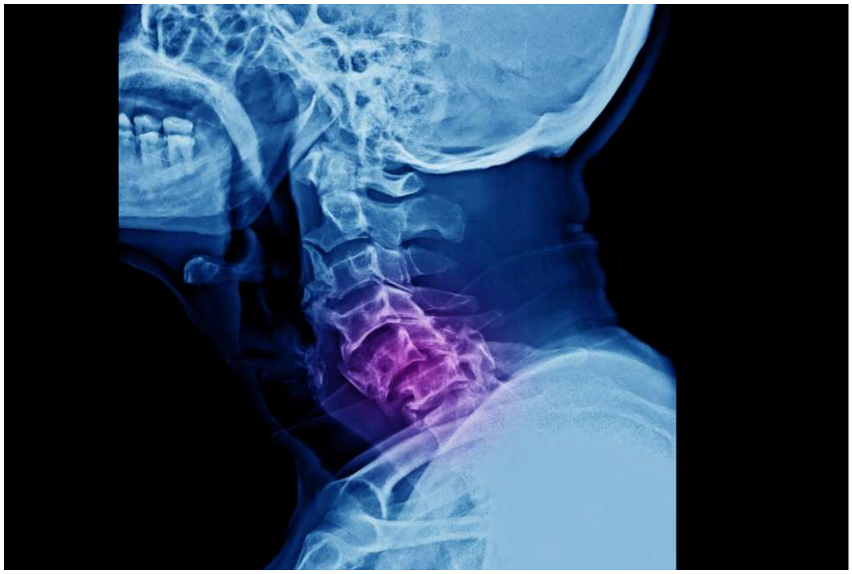

Image 12.3

12.2.3 Off-Resonance Artifacts

The picture degradation caused by inexact tuning of the RF transmitter and/or receiver to the Larmor frequency, resulting in overall noisy images, is known as the **off-resonance artifact**. This is most common when imaging small structures away from the magnet isocenter, like elbows or hands. When the RF pulses are duplicated inexactly, or the gradient magnetic fields between each acquisition are wrongly produced, a "bleeding" artifact arises.

As a result of the tiny mistakes in signal insertion into the appropriate pixel, a smeared image of wavelike patterns appears, comparable to “Ghosting” from motion. The off-resonance artifact resembles the truncation artifact in appearance; however, it is less regular and well-defined.

Ghosting in medical imaging is like a mysterious trail of repeated images haunting the main object. These ghostly figures appear due to signal instability during imaging, resulting in blurred, smeared, and shifted images. Imagine seeing these ghostly artifacts along the phase encode direction!

What causes these apparitions? Well, it could be anything from physical movements during imaging to machine-related issues like eddy currents disrupting the signal. For quality control, experts recommend using a neat metric called "Percent Signal Ghosting" to keep these phantoms in check. This involves measuring signals from specific regions of interest and calculating a ghosting ratio to ensure that it's all real and no funny business is going on.

So, keep an eye out for these ghostly companions in your medical images and make sure the ratio stays in check, preferably less than 1-3%. Happy ghost hunting!

Section 12.3 Magnetic & Radiofrequency Field Distortion Artifacts

A primary magnetic field that is homogeneous is required for MRI. Many modern MRI systems can achieve magnetic field homogeneity of 1 ppm (parts per million) throughout a 20 cm spherical volume.

It is possible for imperfections in the magnetic field at the isocenter to be caused by particular objects or materials in the field of vision. These objects may themselves have magnetism, leading to distortions in our view. Additionally, an implant's conductivity or other substance may conceal certain regions of the image. For instance, metals may cause abnormalities in our image compared to non-ferrous objects. The artifact produced also depends on the object's size, with larger objects generating more significant artifacts. The object's position also plays a crucial role in artifact formation, with any image voids becoming visible if the object is within the field of vision. If the metal object is beyond the range of vision, other susceptibility artifacts may still appear in our image.

Specific pulse sequences, like gradient echoes, cause increased distortions in our picture. These include gradient echo imaging, steady-state imaging, and echo planar imaging. Although spin echo pulse sequences also show artifacts in our picture, they may be limited to the actual size of the implant. Furthermore, the echo time (TE) parameter may affect the artifacts in our image. The magnetic susceptibility introduced into our image increases as we increase the echo time. As a result, the artifacts are magnified.

We can employ a significantly shorter echo duration to minimize the artifacts shown in our image, reducing our image's magnetic susceptibility. Additionally, spin echo sequences may reduce the artifacts more effectively. Increasing the picture matrix is another approach. Increasing the receiving bandwidth may result in capturing more samples and fewer artifacts in our image.

The patient or difficulties with the MRI device might create magnetic field distortion. The magnetic field can be distorted by a poorly shimmed magnet, gradient magnetic field miscalibration, and chemical shift of the Larmor frequency, tissue magnetic susceptibility, and foreign items within or on the body.

Patient-related magnetic and radiofrequency field distortion artifacts include magnetic susceptibility artifacts, body shape/conductivity/extension artifacts, and chemical shifts. System-related reconstruction artifacts include gradient-field artifacts.

12.3.1 Magnetic Susceptibility Artifacts

A magnetic susceptibility is a dimensionless number that describes the degree of magnetization that occurs in a substance when it is exposed to a magnetic field. A "susceptibility artifact" can occur when materials have magnetic characteristics that differ from the tissues in which they are embedded.

12.3.2 Body Shape, Conductivity, and Extension

Inhomogeneity of both the primary static magnetic field and the transmitted RF pulse is caused by the patient's form, electrical conductivity, and degree of coupling to the RF coil. Extending a body component beyond the maximum field homogeneity area frequently results in a metallic-like artifact at the area's margins.

12.3.3 Chemical Shift Artifacts

A chemical shift artifact appears in the frequency encoding direction at the contact point between fat and water. The differences in the resonance of protons between these two objects, while they are introduced to the MR Environment, create the Chemical Shift Artifacts. The artifact appears as a bright signal rim on one side of the organ and a dark rim on the opposite side, both orientated in the frequency-encoded direction. The protonic vibrational frequency of fat is marginally lower in comparison to that of water. Magnets with a strong magnetic field will increase the probability of these artifacts appearing. Reduce the potential for Chemical Shift Artifacts by employing the following processes:

- Fat suppression techniques (saturation or inversion-recover)
- Reduce the signal of fat
- Swap phase and frequency-encoding directions

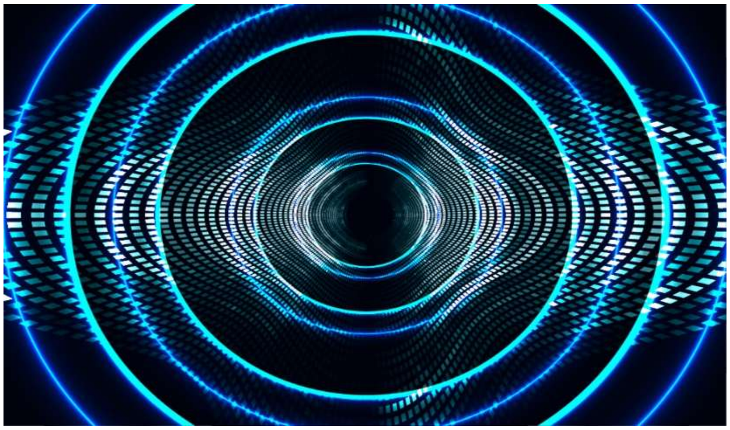

Image 12.4

12.3.4 Gradient Field Artifacts

Magnetic field gradients are employed for the purpose of spatially encoding the precise location of signals originating from excited protons inside the imaging volume. The volume (slice) is defined by the chosen slice gradient. The information in the other two dimensions is provided by the phase- and frequency-encoding gradients. We see distortions in our image when there are deviations present in our gradient. Specifically, loss of field strength happens in the periphery as the distance increases from the center of the applied gradient. Anatomical compression is observed and is particularly prominent in coronal and sagittal imaging. Distortion occurs when there is a variation in the phase-encoding gradient, leading to differences in the dimensions (width or height) of the voxel. Anatomical proportions exhibit compression along either the horizontal or vertical axis. It is imperative to acquire square pixels (and voxels). Ideally, it is recommended to allocate the phase gradient to the smaller dimension of the object while assigning the frequency gradient to the bigger dimension. In practical applications, achieving this objective may not always be feasible due to the inherent need to mitigate the effects of motion artifacts. One solution to address this issue involves modifying the parameters of the system, such as reducing the field of view, lowering the gradient field strength, or decreasing the frequency bandwidth of the radio signal. If the desired correction is not attained, it is possible that the underlying problem could be attributed to either a malfunctioning gradient coil or an anomalous flow of electrical current via the gradient coil.

Section 12.4 Other Artifacts

12.4.1 Metal Artifacts

Metal artifacts with varying magnetic susceptibilities are observed at the boundaries between tissues, resulting in the distortion of the external magnetic field in localized regions.
These distortions induce alterations in the precession frequency inside the tissue, resulting in the misalignment of spatial information. The extent of distortion is contingent upon various factors, including the specific metal utilized (with stainless steel exhibiting a more pronounced distorting influence compared to titanium alloy), the nature of the interface (notably, soft tissue-metal interfaces tend to yield the most prominent effects), as well as the pulse sequence and imaging settings employed. Metal artifacts result from the presence of exterior ferromagnetic substances, such as cobalt-containing makeup, as well as internal ferromagnetic materials like surgical clips, spinal gear, and other orthopedic devices. The manifestation of these artifacts exhibits variability, encompassing entire signal loss, peripheral high signal, and visual distortion. An approach to reducing the presence of these artifacts involves aligning the elongated axis of an implant or device parallel to the elongated axis of the external magnetic field. This method is achieved by the use of movable extremity imaging and an open magnet. Additional techniques employed include the selection of an optimal frequency encoding direction, as metal artifacts tend to be more prominent along this axis. They should be avoided because they can create magnetic fields that last longer than the pulse MRI secondary magnetic fields. Not only can ferromagnetic materials cause local signal loss, but they can also cause warping distortion in the surrounding areas. A partial rim of high signal intensity can sometimes be detected at the periphery of the signal void, allowing the metal to be distinguished from other causes of focal signal loss.

Patient-Related: Depending on their structure and position, metals have varying impacts on the surrounding magnetic field. Any metal can support the current created by the pulsing of the gradient and RF magnetic fields since it is a potential conductor of electricity. The currents generated by gradient coils alter the local magnetic field, causing visual distortion. Tissue heat and patient burns can be caused by the currents produced by the RF coils.

12.4.2 Gibbs Artifacts

Gibbs artifacts, alternatively referred to as Gibbs ringing artifacts or truncation artifacts, arise due to the inadequate sampling of high spatial frequencies at sharp boundaries inside the image. The presence of insufficient high-frequency components results in the occurrence of an oscillation at a distinct transition point, sometimes referred to as a ringing artifact. The observed phenomenon manifests as a series of evenly distributed parallel bands characterized by alternating intensities of luminosity and darkness, which gradually diminish in prominence as distance increases. The visibility of ringing artifacts tends to be more pronounced in digital images with lower matrix sizes. Further investigation is necessary to address the potential risks associated with Gibbs artifacts effectively. Only a limited number of commonly seen artifacts are acknowledged.

12.4.3 Flow Artifacts

Flow can present itself as modified intravascular signals (e.g., flow enhancement or flow-related signal loss) or artifacts associated with the flow (e.g., phantom images or spatial misregistration). Flow enhancement, called the Inflow Effect, arises when fully magnetized protons enter the imaging slice. At the same time, the stationary protons still need to recover their magnetization fully. The protons that are completely magnetized exhibit a significantly stronger signal in contrast to the surrounding elements. The consequence of this phenomenon is that the protons in question do not contribute to the echo and are instead detected as a signal void or a loss of signal associated with flow. Spatial misregistration occurs when an intravascular signal is displaced due to the position encoding of a voxel in the phase direction before frequency encoding, which is determined by the echo time TE/2. The magnitude of the artifact is contingent upon the signal magnitude originating from the vessel and becomes less conspicuous as the TE is prolonged. Gradient moment nulling (GMN), commonly referred to as flow compensation, is an established methodology employed to mitigate the adverse effects arising from the presence of flowing tissues, hence minimizing artifacts. GMN is a gradient pulse used for artifact reduction, often used to suppress flow artifacts of the head, abdomen, chest, and spine. Flow compensation is based on the principle of even-echo rephasing.

12.5 Artifacts Conclusion

There are so many variances in artifacts that we could create an entire course on them. We are only touching on some of the commonly occurring artifacts. Multiple artifacts might manifest during imaging. To mitigate artifacts throughout the process of imaging, it is imperative for radiologists and MRSOs to possess a comprehensive understanding of these artifacts. Furthermore, it is vital for MRI personnel to possess the ability to discern artifacts, comprehend their origins, and implement appropriate remedies to constantly generate images of superior quality.