APPLIED RADIOLOGY

APPLICATIONS IN Contrast Imaging

MR Imaging Update

May 2011 • Supplement to Vol. 40, No. 5

This quarterly supplement to *Applied Radiology* confers 0.5 ARRT Category A Continuing Education credits, which will be awarded upon completion of an online post test. The entire text of this supplement and the post test are available at www.appliedradiology.org/aici.

This supplement and the ensuing post test are designed to be completed within 30 minutes. The goal is to provide an overview of the benefits of contrast-enhanced imaging and how to optimize the use of contrast power injectors, as well as identify practical strategies to mitigating artifacts in MR imaging.
Date of release: 05-01-2011
Date of expiration: 04-30-2012

Additionally, *Applied Radiology* is offering a free iPad to be awarded in a random drawing of those individuals who visit our website at www.appliedradiology.com/contrast and opt-in for electronic delivery of the supplements in this series.

Managing MR Artifacts

Kathleen M. Dallessio

What are artifacts?

In medical imaging, an artifact is any structure that appears within the image that is not actually present in the body being examined.[1] With magnetic resonance imaging (MRI), artifacts can be caused by a broad range of factors, including malfunction or limitation in the imaging system hardware or software; human factors, such as movement, blood flow, or implants; or environmental factors, such as heat or humidity or interference from other objects within the imaging suite. Some artifacts are caused simply by the inherent physics of the MRI process.[1]

Artifacts can range anywhere from just a few pixels out of balance to large, noticeable distortions within the image.[1] "Artifacts in the images can disrupt the diagnostic quality of the exam," noted Frank G. Shellock, PhD, FACC, FACSM, Adjunct Clinical Professor of Radiology and Medicine, Keck School of Medicine, University of Southern California, and Founder, Institute for Magnetic Resonance Safety, Education, and Research (IMRSER), Los Angeles, CA. "Sometimes the artifacts can be so subtle that they are not easily recognized. The worst-case scenario is that you make an inappropriate diagnosis based on images that were affected by artifacts."

It is essential for MRI technologists to understand what causes artifacts, to recognize which ones are avoidable, and which are not, and to know how to mitigate their effects in order to consistently produce high-quality images. Examples of artifacts associated with MRI are shown in Table 1.

What causes artifacts?

"MR artifacts occur from a variety of sources," explained William H. Faulkner, BS, RT(R)(MR)(CT), FSMRT, President, William Faulkner & Associates, LLC, and Director of Education, Chattanooga Imaging, Chattanooga, TN. In general, these causes can be grouped into 3 main categories: inherent physics, physiologic, and equipment.

Inherent physics

Some artifacts occur simply because of the physics involved in MRI, for example, chemical shift. The protons in water have a different resonance frequency than that of the protons in fat as a result of the differences in their chemical environments. This change in frequency, known as chemical shift, can result in misregistration of the fat content in the image.[2]

"Then there are artifacts that are due to sampling issues," Faulkner continued. "This is in large part based on how we currently collect data and use Fourier transform to reconstruct the image. Fourier transform, for example, is somewhat limited when it comes to stark edge reconstruction, so we often get what are known as concavation artifacts."

"There are also sampling artifacts," Faulkner added. "The most common one is aliasing or wraparound; some people call it fold over." This occurs when the field of view (FOV) is smaller than the body part being imaged, and the area outside the FOV is projected on the other side of the image. This type of artifact can be corrected by oversampling the data.[3]

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Physiologic

Physiologic artifacts are common and are caused by movement and flow, including both voluntary movement by the patient and such involuntary motion as respiration and cardiac activity. Such artifacts typically appear as blurring of the image or ghosting.[2] "There is nothing you can do about this," said Faulkner. "You are going to have motion artifacts. Even if the patient lies very still, there are all kinds of involuntary motions. Some of the newer techniques have greatly reduced the impact of flow and motion artifacts over time, but it still occurs."

Equipment related

Problems with the MR scanner itself can also leave artifacts on the image. "Equipment errors in data collection can result in geometric patterns on the image," said Faulkner.

A typical example is a spike or herringbone artifact. Gradients applied at a very high-duty cycle can cause a spike in noise in the k-space. This can result in one or more points that have either very high or low intensity relative to the rest of the k-space. Such a defect produces dark stripes on the image. This type of spike noise is often caused by loose electrical connections or a breakdown of connections within the radiofrequency (RF) coil.[2]

"You can also get artifacts from the environment," Faulkner continued. Stray electromagnetic energy in the scanner room can lead to artifacts on the image. "One of the most common sources would be incandescent light bulbs," he explained. "Incandescent light bulbs are not ideal for the MR environment; direct current (DC) or *light*-emitting diode (LED) lighting is much better."

Proper shielding of the scanner room is another concern. "The RF shielding may be disrupted, particularly in older rooms where we have the copper fingers around the door," Faulkner continued. "Those get broken off, and many sites don't seem to want to take on the task of getting them replaced, and it just leads to artifact."

In addition to the possibility of stray RF leakage from outside the scanning room, MR imaging technologists must be concerned about RF output or interference from any equipment designed to be used within the MR system room.

"Equipment that remains outside the MR scanner itself, but within the MR system room, still may cause artifacts because of the nature of the equipment," said Shellock. "Going back to the mid- and late-1980s, we started doing studies on monitoring equipment and other patient-support devices that had electronic components and found out that there were situations where the equipment may have looked like it was working perfectly fine, and yet when we looked at the images there were artifacts. If the monitoring equipment is working well, but it is generating artifacts, that is a huge problem."

"It's particularly challenging to determine what is causing the artifacts when you have different types of scanners operating at different RF frequencies because everything is going to be specific to the scanner and frequency with which you are working," explained Shellock. "The best-case situation is to have something that produces no electromagnetic noise under any circumstances, in which case, that type of a device will work in virtually all MRI settings." The EmpowerMR Injector is designed to virtually eliminate RF transients in the MR suite and is compatible with MR systems of up to 7 Teslas.

He added, "Some of the things that manufacturers have done to prevent artifacts include removing the offending electronic component that was producing the noise or shielding the equipment so that it would not generate electromagnetic interference."

"At this point, 25 years later, there are many systems and devices that have been developed from the ground up in order to not cause issues in the MRI environment," Shellock explained, "but equipment sometimes breaks. I have known monitoring equipment to put out stray RF. Typically it occurs when there is a problem with the system, and having it properly maintained and regularly serviced, in my experience, typically takes care of the problem." Shellock also noted that it is important to "pick the manufacturer that has a piece of equipment that has been proven to work safely and effectively in the MRI environment" and to follow the manufacturer's recommendations for proper installation and use."

"In many respects, no MR image is artifact free," concluded Faulkner. "Therefore, it is important that the technologist has the education to recognize and effectively manage artifacts."

Erratum

In *Applications in Contrast Imaging,* a supplement to *Applied Radiology*, Vol. 39, No. 10, *Applied Radiology* did not obtain proper permission to use ECRI Institute's product ratings.

In addition, the citation should have read: Safety features on CT contrast injectors: Enhancing patient protection [evaluation]. *Health Devices.* 2010 May;39:150–165.

ECRI Institute has a strict no-commercialization policy and is not in any way related to or funded by Bracco, ACIST Medical Systems, or the ACIST EmpowerCTA.

Applied Radiology regrets the error.

Table 1. Common sources of image artifacts and general correction strategies[4]

	Artifact source	Correction
Resonant Offsets	Main field inhomogeneity	Measure or estimate field map
	Magnetic susceptibility	Use field map to deblur or remove artifacts
	Chemical shift	
Hardware Limitations	Gradient nonlinearities	Measure errors and compensate
	Concomitant gradients	Use error-tolerant designs and approaches
	Timing errors	Use up-to-date hardware and calibration
	RF* field nonuniformity	
	Limited dynamic range	
Motion and Flow	Respiration	Acquire data only during stationary intervals
	Cardiac cycle	Discard data not acquired during stationary intervals
	Blood and **CSF flow	Estimate motion and compensate data acquired during movement
	Peristalsis and swallowing	
	Voluntary patient motion	
Miscellaneous	Prescription: aliasing, slice overlap, magic-angle	Adjust prescription
	RF interference	Locate and silence interference source
	Truncation	

*RF = radiofrequency **CSF = cerebrospinal fluid

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1. MRI artifacts. Magnetic resonance—Technology information portal. http://www.mr-tip.com/serv1.php?type=art. Accessed March 1, 2011.
2. Zhuo J, Gullapalli RP. AAPM/RSNA physics tutorial for residents: MR artifacts, safety, and quality control. *Radiographics.* 2006;26:275-297.
3. MRI tutor web site and MRI/radiology teaching files. Aliasing or "wrap-around." Available at: http://www.mritutor.org/mritutor/alias.htm. Accessed on March 11, 2011.
4. Smith TB, Nayak KS. MRI artifacts and correction strategies. *Imaging Med.* 2010;2:445-457.

Effective Delivery of Contrast in MR Imaging

With some magnetic resonance imaging (MRI) studies, the differences in the relaxation characteristics of normal and diseased tissue might not be significant enough to produce noticeable differences in signal intensity.[1] The addition of contrast media to the imaging protocol can often improve the diagnostic quality of the resulting image. In addition to increasing sensitivity, visualizing the patterns of contrast enhancement can also provide the clinician with valuable diagnostic information.[1]

Benefits of contrast enhancement

Contrast media in MRI procedures provides several benefits, explained Faulkner. "Number one, it improves disease detection. Many of us have seen examples in which without contrast you can't see the lesions, but when you add contrast you can," said Faulkner.

"Contrast media can also help improve specificity in that the radiologist can observe how the lesion enhances," he continued. "There are some well-recognized patterns of enhancement. This is certainly a component of breast-MR imaging; by looking at the perfusion of gadolinium through the area of interest, we can gather a lot more information."

New treatments for disease have also increased the importance of high-quality imaging. "In the early days of MR, if the patient had metastatic disease in the brain, for example, it really didn't matter if there were 3 or 4 or more lesions," Faulkner said. "But today, with new methods of treatment — gamma knife, for example — it is important that we are able to identify the full extent of the disease so that the patient can be more accurately treated."

Timing of contrast delivery

"As we go to more rapid data acquisitions, there are certain exams in which the timing of contrast delivery is extremely critical," Faulkner explained. "For example, in MR angiography (MRA) we have a specific technique for imaging the carotid artery. We collect the low-frequency or high-signal data points in the first part of the scan, and, in reality, we collect them in about the first 5 sec. So if we are only collecting high-signal data for about 5 sec, we really have to be right on the money." The EmpowerMR Contrast Injector System provides information management options for efficient data analysis and review with its IRiSMR® Decision Support System, manufactured by ACIST Medical Systems, a Bracco Diagnostics company.

"In liver imaging, we need to image the liver in the arterial phase," he added. "In breast imaging, most of the literature shows that breast cancers enhance at 90 sec or so after injection. Therefore, if we are doing multiple dynamic

acquisitions, we must have good timing to get the proper kinetic curves."

Use of power injectors in the MR suite

To properly administer contrast during MR imaging, many facilities now routinely use power injectors.[2] "Power injectors, I think, do a lot of good things for us," said Faulkner. "Number one, it makes it easier for a single technologist to be in control of both the injection and the scan, as opposed to having one person in the room injecting and somebody else at the console or the button to initiate the scan."

In addition, power injectors provide greater speed, accuracy, and consistency of contrast delivery. "Very rapid injections are important in certain studies, such as perfusion imaging of the brain," he noted. "If you are hand injecting, some people will be able to inject more rapidly than others; it depends on the size of the needle and the strength of the technologist."

"The other thing is consistency," Faulkner added. By using power injectors, as opposed to manual injection, delivery rates can be more consistent within individual studies and across a variety of technologists. "If you are doing a test bolus to calculate circulation time for the actual scan, obviously you want to do the test injection at the same rate as the actual study," Faulkner explained. "To do that manually is difficult at best. I think power injectors, in large part, make that much more consistent."

Contrast and injector safety

Ensuring patient safety when using contrast media is "a matter of following the proper labeling information, giving the right dose based on the patient's body weight, and recognizing which contrast agent has the best safety profile for the given population," said Shellock. "Whether it is for adult or pediatric applications or patients who have kidney disorders or impaired renal function, you need to select the correct contrast agent based on the pertinent information."

In choosing a power injector system, Shellock concluded, it is important to find a system that provides reliable functionality and ease of operation and does not produce electromagnetic interference in the MR scanner room.

References

1. Contrast enhanced MRI. Magnetic Resonance—Technology Information Portal. http://www.mr-tip.com/serv1.php?type=db1&dbs=Contrast%20Enhanced%20MRI. Accessed March 1, 2011.
2. Brummett D, Fidler J, Stark D. Power injectors for MRI. *Applied Radiol.* 1999;28:16-20.

Quiz

Post your quiz answers to appliedradiology.org/aici to receive your CE certificate for this activity. Opt-in to receive a digital version of the next supplement in this series at appliedradiology.com/contrast and you will be automatically entered into a raffle for an Apple iPad®!

1. Magnetic resonance imaging (MRI) artifacts can be caused by 3 factors:
   A. Implants, heat, blurring
   B. Blood flow, software, ghosting
   C. Interference, movement, software
   D. Objects, blood flow, blockage

2. Causes of MRI artifacts can be categorized in these categories:
   A. Concavation, fold over, and movement
   B. Physics, physiologic, and equipment
   C. Blurring, ghosting, and motion
   D. Hardware, software, and objects

3. Fold-over artifacts can be corrected by oversampling the data?
   A. True
   B. False

4. What types of artifacts are due to sampling issues:
   A. Fourier transform
   B. Stark edge reconstruction
   C. Misregistration
   D. Concavation

5. Incandescent light bulbs are ideal for the MR environment.
   A. True
   B. False

6. Contrast media in MR imaging does not provide the following benefit:
   A. Improved specificity
   B. Deflection of electromagnetic interference
   C. Support for disease detection
   D. Identifies patterns of enhancement

7. In performing MR angiography of the carotid artery, when are low-frequency or high-signal data points collected:
   A. Once the scan has been completed
   B. Before the frequency signal is detected
   C. 90 sec after contrast injection
   D. In the first 5 sec of the scan

8. Very rapid contrast injections are important for breast studies.
   A. True
   B. False

9. Using a power injector to administer contrast is superior to a manual injection because:
   A. It is not possible to do a test bolus with a manual injection.
   B. Manual injections may not be consistent.
   C. New treatments for disease require the use of power injectors only.
   D. A manual injection tends to deliver contrast too quickly.

10. While power injectors provide greater speed and accuracy in contrast delivery, they lack consistency.
    A. True
    B. False

MR Imaging Update
Date of release: 5-1-2011
Date of expiration: 4-30-2012