Managing Metallic Artifacts in MRI

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Background

Magnetism is a fundamental property of matter. As such, all substances have some type of magnetic property. Magnetic susceptibility refers to an object's or substance's ability to become magnetized. If two substances with different magnetic susceptibilities are close to one another, a small local magnetic field gradient is induced. The greater the difference in magnetic susceptibility between the two, the greater the induced gradient magnetic field will be. This induced gradient magnetic field can result in an image artifact seen as signal loss and even geometric distortion of the anatomy.

The presence of metal typically induces a fairly significant local magnetic field gradient. The images in Figure 1 demonstrate the effect on the local magnetic field and the resultant image distortion due to the presence of a paper clip.

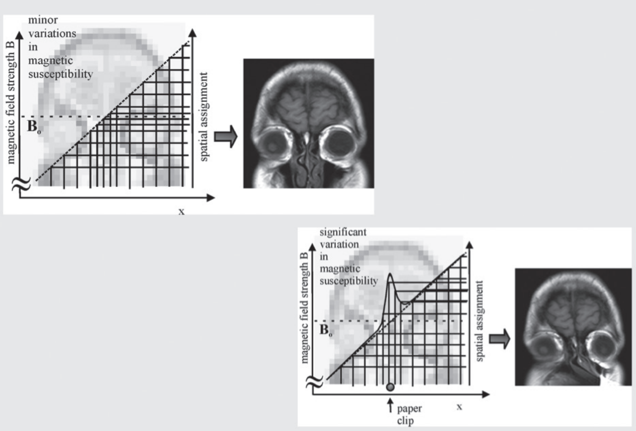

Figure 1: The presence of the paper clip (bottom image) distorts the local magnetic field and results in spatial distortion in the image.
"The Physics of Clinical MR Taught Through Images", Val Runge, M.D., Thieme Medical, 2004

The larger or more ferromagnetic the metallic object, the larger and more significant the artifactual loss of signal and distortion will be.

There are several technical factors which can also affect the size of the susceptibility artifact. The parameters and recommended adjustments are shown in the table below.

Parameter/Sequence	Adjustment/Alternate Sequence
Slice Thickness	Reduce
Imaging Matrix	Increase
TE (Gradient Echo)	Reduce
Receiver Bandwidth	Increase
Spin Echo Sequence	Fast (Turbo) Spin Echo
SSFP	Fast Gradient Echo (FGE)
Fat Saturation	STIR or Dixon-Based Technique

Image artifacts associated with the presence of metal are a type of artifact due to magnetic susceptibility differences between substances. While they cannot be eliminated entirely they can be minimized by strategically selecting the pulse sequence (when possible) and specific sequence parameters.

Pulse Sequence

A spin echo sequence uses a 180-degree RF pulse prior to the formation and sampling of the echo. The main purpose of this 180-degree pulse is to correct for the effects of chemical shift and local field inhomogeneities. A gradient echo pulse sequence does not utilize such a "refocusing" pulse. As such, local field inhomogeneities are much more readily apparent when gradient echo sequences are utilized. Figure 2 shows two axial cervical spine images acquired on a patient with surgical wire in the posterior aspect of the cervical vertebrae. The signal loss and distortion is much more significant on the image acquired with the gradient echo sequence.

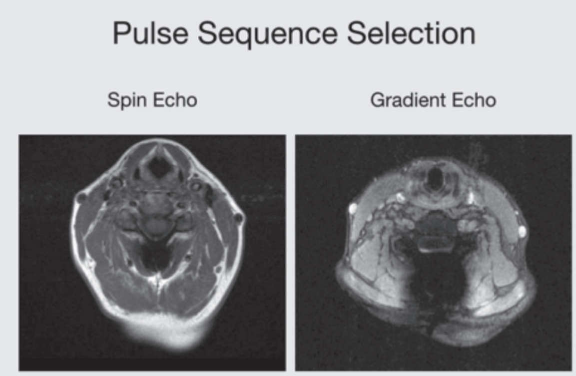

Figure 2: These images were acquired on the same patient with wires in the posterior aspect of the cervical spine. The image on the left was acquired using a spin echo sequence. The image on the right was acquired using a gradient echo sequence.

Cardiac studies with MRI rely on the use of very rapid gradient echo sequences. Historically, the most commonly used sequences are variants of SSFP (Steady State Free Precession). When performing a cardiac MRI study on a patient with a SureScan® system, the leads and certainly the device itself can contribute to susceptibility artifacts. The SSFP-based sequences are more prone to susceptibility-induced phase errors artifacts due to the underlying principles of the pulse sequence. Fast gradient echo FGE sequences are less susceptible to these errors. See examples on the following page that were acquired on a patient with an Evera MRI® ICD system courtesy of Torsten Sommer, MD, PhD.

As is readily apparent, the use of an FGE sequence results in reduced susceptibility artifacts from the leads and the ICD device.

In a clinical study that was conducted to confirm the safety and efficacy of the Evera MRI ICD system, image quality of cardiac scans was assessed. Following implantation (9 - 12 weeks) 156 patients underwent a cardiac MRI exam. The study concluded that FGE produced better image quality and smaller artifacts for cardiac MRI than SSFP. For studies of the left ventricle, diagnostic image quality was obtainable in 74% of the patients. For studies of the right ventricle, 84% of the exams were of diagnostic quality. (Analysis by Evera MRI clinical study scan committee physicians).

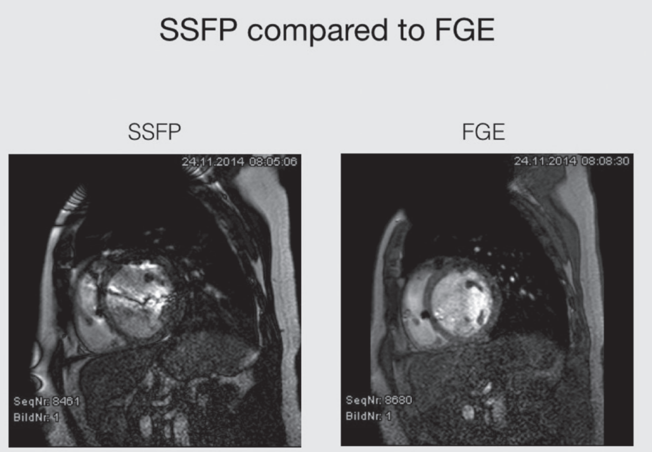

Figure 3: Image Courtesy of University of Bonn, Germany, T. Sommer

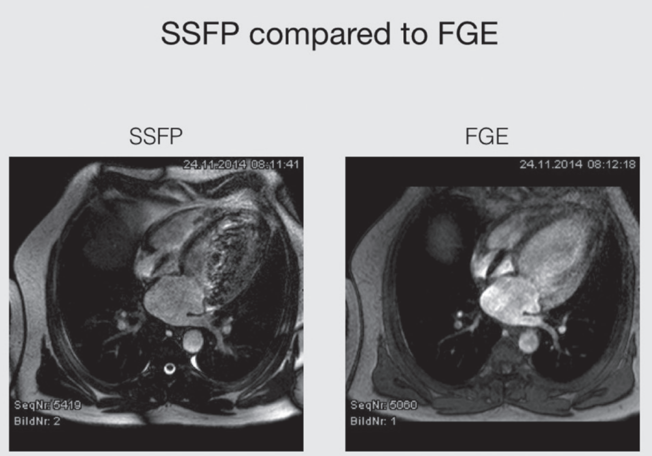

Figure 4: Image Courtesy of University of Bonn, Germany, T. Sommer

Voxel Volume and TE

Voxel volume is determined by the Field-of-View (FOV), acquisition matrix, and slice thickness. Figure 5 shows two images acquired on the same patient. The patient has an MR-Conditional intracranial aneurysm clip implanted in the area of the left middle cerebral artery. The image on the left is from a 3D Time-of-Flight (TOF) MRA sequence. For optimum visualization of flow in smaller vessels, 3D TOF sequences use small voxels and a short TE. The image on the right is a 2D gradient echo sequence acquired with a much thicker slice, reduced acquisition matrix, slightly larger FOV and a longer TE. The result is a significantly larger area of signal void due to the presence of the metallic clip.

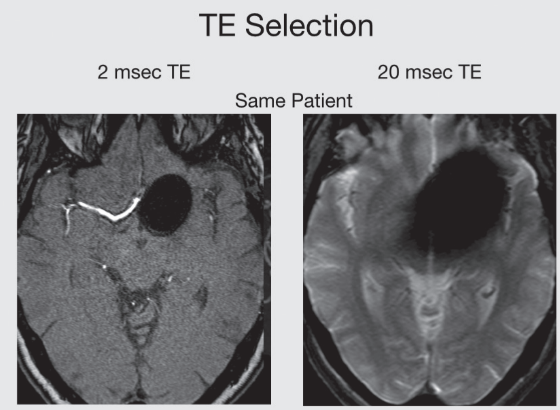

Figure 5: The gradient echo image on the left was acquired using a thin-slice 3D acquisition (3D TOF MRA) with a TE of 2 msec. The gradient echo image on the right was acquired using a 2D technique with a 5 mm slice and a 20 msec TE.

Receiver Bandwidth

When the echo is sampled in the presence of the readout gradient, a range of frequencies is collected. This range of frequencies sampled is what is referred to as the "receiver bandwidth." The receiver bandwidth can be expressed several ways. One way is to simply state the range of frequencies in units of kilohertz (kHz). One (1) kHz is a thousand (1,000) hertz. For example, if the range of frequencies sampled during the formation of an echo was from 0 (center) to +8,000 Hz and from 0 to -8,000 Hz, this could be expressed as either 16 KHz or +/- 8 KHz.

Another way to express the receiver bandwidth is in units of Hz per pixel. Given that the readout gradient is also known as the "frequency encoding" gradient, the pixels are those along the frequency matrix of the FOV. For example, selecting a frequency matrix of 256 pixels and a receiver bandwidth of 32 kHz would result in a receiver bandwidth of 125 Hz per pixel (Figure 6).

Frequency Matrix = 256

Receiver Bandwidth = 32 kHz (32,000 Hz)

$$\frac{32{,}000 \text{ Hz}}{256 \text{ pixels}} = 125 \text{ Hz / pixel}$$

Figure 6: Converting receiver bandwidth in units of kHz to Hz per pixel

As previously mentioned, the presence of metal produces a non-uniform or gradient field around the metallic object or device. For a metallic object of a given size and susceptibility, the frequencies of the hydrogen protons will be altered a certain amount. Reducing the Hz/pixel will increase the number of pixels affected by the variance in frequencies and thus increase the size of the susceptibility artifact.

Reducing/Minimizing Susceptibility Artifact Due to Presence of Metal

Pulse Sequence Selection

As a general rule, images acquired with Fast or Turbo Spin Echo sequences (FSE/TSE) will result in images with fewer susceptibility artifacts than those acquired using gradient echo sequences. However, it is not always possible to replace gradient echo sequences with FSE sequences. Strategic selection of sequence parameters can be very effective.

Slice Thickness

Reducing slice thickness reduces voxel volume and therefore reduces the size of susceptibility artifacts associated with metal. However, signal-to-noise ratio (SNR) is directly proportional to the slice thickness. Reducing the slice thickness by a factor of 2 will reduce SNR by a factor of 2 as well. The use of 3D techniques allows for very thin slices but with much higher SNR than thin 2D slices.

Receiver Bandwidth

Increasing the receiver bandwidth will reduce the size of susceptibility artifacts associated with metal. An example is shown in Figure 7. The patient has a significant amount of metallic dental work. Significant artifact and distortion is seen on the sagittal image (6a). The axial image (6b) was acquired using a receiver bandwidth of +/- 16 kHz and also shows significant artifact. The image 6c was acquired using a receiver bandwidth of +/- 64 kHz. All other parameters were identical. Although the SNR is reduced, the artifact from the metal dental work is significantly reduced, resulting in a more diagnostic image.

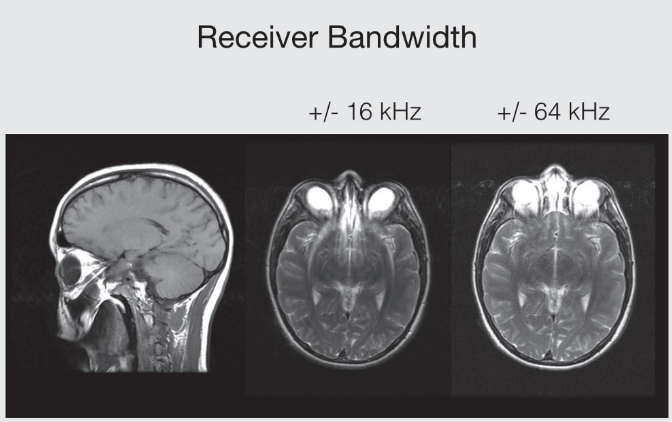

Figure 7: Patient with significant metallic dental work. 6a: Sagittal FSE. 6b Axial FSE +/- 16 kHz receiver bandwidth. 6c Axial FSE +/- 64 kHz receiver bandwidth

Sequences Utilizing RF Fat Saturation

Fat saturation sequences which suppress the signal from fat based on its spectral frequency rely on high homogeneity of the local magnetic field. The presence of metal significantly distorts the local magnetic field and will result in failed fat suppression (Figure 8).

Figure 8: The presence of the orthopedic screw distorts the local field resulting in failed RF fat saturation in the immediate area around the screw.

When possible, utilize inversion recovery sequences (STIR) for fat suppression. If fat suppression is desired after the administration of a gadolinium-based contrast agent, STIR sequences should not be utilized. Recent implementations of fat suppression based on the Dixon Technique may be considered. These techniques tend to be less sensitive to inhomogeneities as compared to standard RF (or spectral) fat saturation techniques (Figure 9).

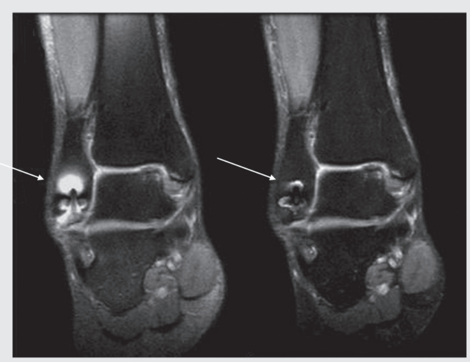

Figure 9: The image on the left was acquired using an FSE sequence with conventional RF fat saturation. The presence of a metallic staple distorts the local field resulting in failed fat saturation. The image on the right was acquired using an FSE sequence with a fat saturation technique based on the Dixon Technique. The area of failed fat saturation is much smaller.

Images courtesy of GE Healthcare

Specialized Pulse Sequences

Recently, several MR vendors have introduced specialized pulse sequences designed to be used when significant metal is present. An example of one type of these metal artifact reduction sequences is shown in Figure 10. The image on the left was acquired using a standard FSE sequence. The image on the right utilizes the specialized pulse sequence designed to significantly reduce metallic artifacts.

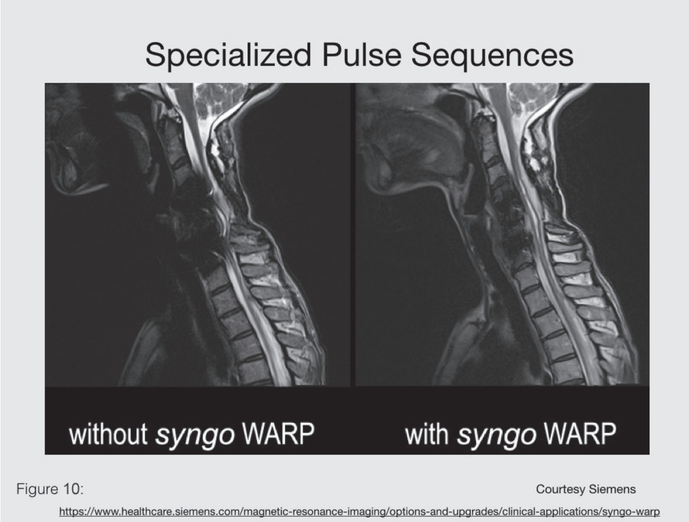

Figure 10: Courtesy Siemens
https://www.healthcare.siemens.com/magnetic-resonance-imaging/options-and-upgrades/clinical-applications/syngo-warp

Summary

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What image artifact do you expect with Medtronic SureScan MR-Conditional pacemakers and ICDs?

<u>Medtronic SureScan MR-Conditional pacemakers</u>

- A clinical study demonstrated that the presence of a SureScan pacemaker system did not reduce the likelihood of obtaining a cardiac MRI exam of good diagnostic quality. The study found that 98% of Left Ventricular and 95% of Right Ventricular acquisitions were of diagnostic quality.[1]

<u>Medtronic SureScan MR-Conditional ICDs</u>

- Magnetic susceptibility artifact will be significantly greater in SureScan ICD patients compared to patients implanted with Advisa MRI® SureScan pacemakers. The impact on the diagnostic quality of cardiac MRI scans is strongly related to the distance between the ICD and the region being imaged.
- According to Torsten Sommer, MD, PhD, Professor of Radiology, Chief of Cardiovascular Imaging, University of Bonn, the image artifact will typically overlap most of the LV for patients with a SureScan ICD implanted on the left side, but it is generally possible to image the RV with acceptable image quality.
- Sasaki, et al.[2] characterized cardiac MRI image artifact in patients with pacemakers and implantable cardioverter-defibrillators and concluded that: "Despite the presence of some artifact in most image sequences, images were completely (18/55 scans, 32.7%) or partially (31/55 scans, 56.4%) interpretable in most patients with left-side ICD/BiV-ICD systems." And "It was possible to evaluate cardiac function using cine CMR in 86% of patients with left sided ICD. The most significant predictors of the capability to assess cardiac function were BMI and LVEDD. Both associations are probably mediated by the distance between the PM/ICD generator and the heart."

Why is there greater artifact with a SureScan ICD than with a SureScan pacemaker?

- The difference is due to the larger battery relative to Advisa MRI SureScan pacemaker and ferromagnetic material in the high-voltage transformer of the SureScan ICD.

References

[1] Schwitter J, Kanal E, Schmitt M, et al. Impact of the Advisa MRI pacing system on the diagnostic quality of cardiac MR images and contraction patterns of cardiac muscle during scans: Advisa MRI randomized clinical multicenter study results. *Heart Rhythm*. June 2013;10(6):864-872.

[2] Sasaki T, Hansford R, Zviman MM, et al. Quantitative assessment of artifacts on cardiac magnetic resonance imaging of patients with pacemakers and implantable cardioverter-defibrillators. *Circ Cardiovasc Imaging*. November 2011;4(6):662-670.

Brief Statement
SureScan™ Pacing, Defibrillation, and Cardiac Resynchonization Therapy Defibrillation (CRT-D) Systems

The SureScan systems are MR Conditional, and as such are designed to allow patients to undergo MRI under the specified conditions for use. When programmed to On, the MRI SureScan feature allows the patient to be safely scanned while the device continues to provide appropriate pacing. A complete SureScan system, which is a SureScan device with appropriate SureScan lead(s), is required for use in the MR environment. To verify that components are part of a SureScan system, visit http://www.mrisurescan.com/. Any other combination may result in a hazard to the patient during an MRI scan.

See the Advisa MRI™, Evera MRI™, Visia AF MRI™ or Claria MRI™ /Amplia MRI™ SureScan Technical Manual before performing an MRI Scan and Device Manual for detailed information regarding the implant procedure, indications, contraindications, warnings, precautions, and potential complications/adverse events. For further information consult Medtronic's website at www.medtronic.com or www.mrisurescan.com.

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