Cardiovascular Magnetic Resonance in Patients With Magnetic Resonance–Conditional Cardiac Implantable Electronic Devices

What Can We See?

Orlando P. Simonetti, PhD; David C. Gross, PhD

Patients with pacemakers and implantable cardioverter defibrillators (ICDs) have commonly been withheld from magnetic resonance imaging (MRI) procedures because of magnetic resonance (MR) safety concerns. In response to this clinical need, MR-conditional pacemakers and ICDs have been developed to allow these patients access to MRI. The potential interactions between MRI and recently developed MR-conditional implantable electronic devices have been extensively studied and reviewed. These interactions include magnetic force and torque, radio frequency-induced heating, induction of electric currents, and electromagnetic interference. Medical device manufacturers have modified the designs of pacemakers and ICDs by using less ferromagnetic material, developing innovative lead wires to reduce radio frequency heating, and advancing circuitry and shielding to reduce electromagnetic interference. The safety and efficacy of these MR-conditional devices have been the primary end point of clinical studies with 275 enrolled subjects in 42 centers. The focus of the clinical study was to confirm the safety and efficacy of an MR-conditional ICD system (Evera MRI ICD Medtronic, Inc, Minneapolis, MN) in patients subjected to a 1.5T MRI examination. In this issue of Circulation: Cardiovascular Imaging, Schwitter et al report on the diagnostic quality of cardiovascular magnetic resonance (CMR) images acquired in patients enrolled in the Evera-MRI trial. Steady-state–free precession (SSFP) and fast gradient echo (FGE) cine CMR pulse sequences were used to acquire images of the left ventricle and right ventricle (RV) and graded for image quality. In a similar previous study by the same group, Schwitter et al reported on the impact of the Advisa MRI pacing system on the quality of CMR images and found that high-quality CMR images were attainable in the presence of an MR-conditional pacemaker system. Because of the larger size and greater metallic content of an ICD generator when compared with a pacemaker, more significant artifacts would be expected with an ICD. The study by Schwitter et al in this issue sought to determine whether CMR would be feasible in patients implanted with the Evera MRI ICD. Although image quality overall was not as good as shown in their previous study of patients with pacemakers, their findings showed that FGE performed better than SSFP in patients with MR-conditional ICDs and provided good to moderate image quality in 74% of left ventricle and 84% of RV acquisitions. This study identified the ICD generator as the primary source of image artifacts compared with the relatively minor artifacts caused by the leads. The authors conclude that in most cases, CMR can offer diagnostic image quality for patients implanted with the Evera MRI ICD.

With the availability of MR-conditional pacemaker and ICD systems, MRI safety concerns surrounding these devices have largely been mitigated, and it is now important to evaluate the impact of image artifacts and implement strategies to minimize these effects. The overall majority of clinical MRI scans are of the brain, spine, and joints, that is, structures that are of potentially greater distance from the generator than is the heart; however, in patients with cardiovascular disease the ability to run routine CMR scans with adequate image quality is of increasing importance. Although the Evera-MRI trial was not specifically designed to evaluate image quality, the authors were able to show that cine CMR scans of adequate quality were acquired in the majority of patients. There was a high total fraction of scans (144/520) that could not be evaluated because of image quality issues not caused by the device. The authors attributed this to the fact that the trial, designed to test safety and not image quality, did not allow for any scans to be repeated in case of failed breath-hold or other factors that may have affected image quality. For example, in only 77 of 152 subjects were the RV FGE images scored for image quality. The fact that this combination (RV FGE) yielded the highest image quality should perhaps come as no surprise because many of the images were determined to be unusable and, therefore, were not included in the image quality evaluation. Because such a large percentage of scans were rejected as unsuitable for analysis, it would have been useful to subject a cohort of normal control subjects, without implanted devices, to the same MRI protocol. This may have revealed whether

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See Article by Schwitter et al

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device artifacts, while not obvious, were somehow contributing to the poor image quality that caused many images to be rejected as unsuitable for analysis. SSFP cine images in the left ventricle short-axis orientation provided the least reliable image quality; unfortunately, this is the workhorse pulse sequence and most important scan plane for the assessment of cardiac function.

The sensitivity of the balanced SSFP sequence to the susceptibility gradients and local field inhomogeneity caused by an implanted metallic device is directly related to the sequence repetition time (TR); for FGE, this sensitivity is determined by echo time (TE). Although the authors do mention that TR and TE were minimized, the specific values were not reported, and it was also not stated whether additional steps toward pulse sequence parameter optimization were taken in an effort to minimize TE and TR. These parameters can vary widely between scanner manufacturers depending on the gradient system performance and the trade-offs made between spatial resolution, temporal resolution, receiver bandwidth, and radio frequency pulse design. It would have been informative to indicate whether image quality was dependent on TR and TE, and the variability of these parameters across the centers. The authors show the potential for artifact reduction in a phantom using a specialized zero echo time pulse sequence; however, this is an unconventional approach that will require further development for cardiac applications. Results from accelerated acquisitions using Compressed Sensing (CS) are also shown, but there is no direct relationship between magnetic susceptibility artifacts and CS reconstruction. There may be an indirect benefit derived by combining CS with FGE. Although FGE is less prone to artifact than SSFP, it requires a longer scan time; CS could potentially be used to accelerate an FGE acquisition to maintain a reasonable scan time. FGE also tends to have lower signal:noise ratio than SSFP, and CS reconstruction tends to better preserve signal:noise ratio.

There are some relatively simple steps that could be taken to reduce the sensitivity of SSFP cine to local field inhomogeneity, as described by Wu et al., in the context of CMR at 3.0T. By implementing a shortened radio frequency excitation pulse, increasing receiver bandwidth, and slightly reducing image resolution they were able to reduce TR from 3.4 to 2.7 ms. This was shown to reduce artifact caused by static field inhomogeneity at 3.0T, and similar improvement would be expected in reducing the artifact around metal at 1.5T. A frequency scout acquisition has also been commonly used at 3.0T as a method to shift the SSFP dark band artifacts away from the region of interest; such an approach could also be useful in the context of patients with implanted devices at any field strength. The effectiveness of other relatively simple steps taken to reduce artifact, specifically for late gadolinium enhancement imaging, have been demonstrated by Rashid et al. They found that the resonant frequency at the heart can be shifted by as much as 6000 Hz when a device generator is implanted at a typical distance of 5 cm to 10 cm from the heart. The late gadolinium enhancement sequence is most typically an inversion recovery FGE acquisition, with the inversion recovery pulse used to create image contrast by nulling the signal from viable myocardium. Artifactual myocardial hyperintensity on late gadolinium enhancement images may potentially mimic infarct or fibrosis when the resonant frequency offset caused by the metal of the device generator exceeds the bandwidth of the inversion pulse. Rashid et al. and Stevens et al. showed that by simply increasing the bandwidth of the inversion recovery pulse, the inversion became much more uniform in the face of local field inhomogeneities, and the artifact was reduced. A wideband inversion pulse was also shown to be successful in reducing artifacts in late gadolinium enhancement imaging of patients with ICDs scanned at 3.0T, where the local susceptibility gradients surrounding a metallic implant are twice what they are at 1.5T. Hong et al. used a similar method to demonstrate the feasibility of myocardial T1-mapping in patients with implanted ICDs. Thus, with relatively minor pulse sequence modifications and scan parameter optimization, significant gains in image quality may be possible for the results presented in the study by Schwitter et al.

Evaluation and optimization of image quality will again be of importance following the recent FDA approval (Micra, Medtronic Inc, Minneapolis, MN) and CE Mark (Nanostim, St. Jude Medical Inc, St. Paul, MN) of leadless, MR-conditional pacing systems. Although the artifact and potential heating risk associated with lead wires are eliminated, the miniature generator is implanted within the chamber of the RV, so the feasibility and quality of cardiac MRI in patients implanted with such a device will require investigation.

The Evera system and other currently available ICDs are MR-conditional only at 1.5T. The severity of artifact in both SSFP and FGE sequences is related to the magnitude of the susceptibility gradient surrounding the metallic generator, and the susceptibility gradient scales proportionately with field strength. Thus, the degree of artifacts reported by Schwitter et al. would be expected to be, in simple terms, twice as severe at 3.0T. We can anticipate with continued improvement in devices designed for MR compatibility that future devices will be MR-conditional at 3.0T, and the exacerbation of metal artifact at 3.0T will become an important consideration. Although MRI manufacturers continue to push toward higher magnetic field strengths, with recent advances in MRI receiver systems and reconstruction algorithms, it may be appropriate to explore the potential for lower field MRI systems. A field strength of 0.5T, for example, would be expected to dramatically reduce concerns for heating of implanted devices (because of the longer wavelength in tissue and reduced specific absorption rate for the same imaging parameters), and would reduce metal-related artifacts substantially. The feasibility of CMR at low field has been demonstrated in the past. Perhaps, this concept should be revisited in the context of a growing number of patients receiving implanted devices and the increasing probability that they will require a CMR examination at some point in time.

In conclusion, the encouraging results shown by Schwitter et al. indicate that CMR will be feasible in most patients with the Evera MRI ICD, and FGE-based pulse sequences are expected to perform better than SSFP. Optimization of scan parameters and specific pulse sequence modifications designed to mitigate the impact of local field inhomogeneities on image quality are still needed to improve the success rate of CMR in these patients.
Disclosures

None.

References


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