Cardiac magnetic resonance imaging using wideband sequences in patients with nonconditional cardiac implanted electronic devices

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BACKGROUND Magnetic resonance imaging (MRI) has been performed safely in patients without MRI-conditional cardiac implantable electronic devices (CIEDs), but experience specifically with cardiac magnetic resonance imaging (CMR) is limited in this patient population.

OBJECTIVE Evaluate the safety of CMR in non–MRI-conditional CIEDs and the interpretability of images using wideband sequences.

METHODS We performed 114 consecutive CMR studies in 111 patients (mean age 59 ± 14 years, with 12 pacemakers, 73 implantable cardioverter defibrillators, 29 biventricular defibrillators) using a wideband pulse sequence for late gadolinium enhancement (LGE) imaging. A standardized protocol for device management and patient monitoring was followed. Patients were evaluated for major clinical adverse events and device parameter changes immediately after CMR and at clinical follow-up.

RESULTS In total, 111 CMR studies were completed successfully. There were no patient deaths, new arrhythmias, immediate generator or lead failures, electrical resets, or pacing capture failures in dependent patients. Right atrial, right ventricular, and left ventricular lead impedances were significantly lower post CMR, with median differences −7 Ω (interquartile range [IQR] −20 to 0 Ω; $P < .0001$), 0 Ω (IQR −19 to 0 Ω; $P = .0001$), and −10 Ω (IQR −30 to 0 Ω; $P = .023$), respectively. These changes persisted through the follow-up period, with median differences −18.5 Ω (IQR −41 to −66 Ω; $P = .007$), −19 Ω (IQR −44 to −7 Ω; $P = .006$), and −30 Ω (IQR −130 to 0 Ω; $P = .003$), respectively. Ninety-seven studies (87%) had no artifact limiting interpretation.

CONCLUSIONS CMR can be performed safely in non–MRI-conditional CIEDs using a standardized protocol. Use of a wideband pulse sequence for LGE imaging yields a high rate of studies unaffected by artifact.

KEYWORDS Cardiac magnetic resonance imaging; Cardiac implanted electronic device; Imaging protocol; Ventricular tachycardia; Viability assessment

ABBREVIATIONS **ACLS** = advanced cardiac life support; **AF** = atrial fibrillation; **ARVC** = arrhythmogenic right ventricular cardiomyopathy; **CIED** = cardiac implantable electronic devices; **CMR** = cardiac magnetic resonance imaging; **CRT-D** = cardiac resynchronization therapy defibrillator; **HCM** = hypertrophic cardiomyopathy; **ICD** = implantable cardioverter defibrillator; **ICM** = ischemic cardiomyopathy; **IQR** = interquartile range; **LGE** = late gadolinium enhancement; **LV** = left ventricular; **MRI** = magnetic resonance imaging; **NICM** = nonischemic cardiomyopathy; **RA** = right atrial; **RV** = right ventricular; **SD** = standard deviation; **VT** = ventricular tachycardia

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Introduction

Over the past decade, there have been many advances in the use of magnetic resonance imaging (MRI) in patients with cardiac implanted electronic devices (CIEDs). Since 2010, several MRI-conditional CIEDs have been developed and approved for use with multiple MRI imaging modalities.[1–4] However, the large majority of current CIED patients have non–MRI-conditional devices implanted. Protocols have been developed for the safe performance of MRI studies in patients with non–MRI-conditional devices.[5,6] Whereas 2

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decades ago CIEDs were viewed as absolute contraindications to performing MR,[7] many MRI studies are now being performed safely using published protocols.[5,8–11] However, in most centers, the presence of a CIED is still considered a contraindication to MRI.

The biggest concern arises in thoracic imaging, and particularly cardiac MRI (CMR), where the focus of the gradient magnetic field and the radiofrequency energy is over the area of the device generator and leads. Device and lead artifact is also a major concern, potentially limiting image interpretability and clinical applicability.[12–14] In patients with ventricular tachycardia (VT) who are being considered for catheter ablation, CMR may be pivotal in defining scar location for preprocedural planning and risk stratification, making this a particularly important area to clarify, as many of these patients will have implantable cardioverter defibrillators (ICDs).[15–18]

In this study, we present our single-center experience with CMR imaging in patients with non–MRI-conditional CIEDs, which is considered the highest-risk study in these patients. We assessed imaging quality using a wideband technique for late gadolinium enhancement (LGE) sequences that has been previously described.[12]

Methods

We retrospectively evaluated all consecutive patients with non–MRI-conditional CIEDs who underwent CMR between April 2013 and October 2016 at the Ronald Reagan Medical Center, a tertiary care hospital. The study was approved by the hospital institutional review board. All patients were referred for a clinically indicated scan, where the referring physician confirmed that no other imaging modality could provide essential information available from MRI. Each patient was evaluated by a cardiac electrophysiologist and reviewed with an MRI radiologist prior to undergoing CMR. All patients provided informed consent prior to undergoing CMR.

A standard protocol adopted from that previously outlined by the European Society of Cardiology[6] was followed for all cases (Figure 1). All patients underwent preprocedural device interrogation to evaluate baseline device settings and parameters. The pacing mode was changed to asynchronous pacing in pacemaker-dependent patients and programmed off in others. All tachyarrhythmia detections and therapies were programmed off in patients with ICDs. A recent chest radiograph was reviewed to check for abandoned leads. Intraprocedural monitoring by an advanced resuscitation–certified nurse practitioner with expertise in device management was performed by means of verbal communication with continuous electrocardiographic, pulse oximetry, and noninvasive blood pressure measurements (In-Vivo Systems, Canberra Industries, Meriden, CT). Following completion of the CMR study, device interrogation was performed to reevaluate parameters and reprogram original settings.

Devices were reinterrogated within 1–6 months following the study or as clinically indicated for other concerns in patients followed longitudinally at our center. We evaluated patients for major clinical adverse events, including clinical deterioration or death during the CMR study, device generator failure requiring replacement, lead failure requiring replacement, new onset atrial or ventricular arrhythmia, loss of capture in pacemaker-dependent patients, or electrical reset. In addition to evaluating for statistically significant device parameter changes, we also evaluated for clinically significant changes in device parameters, which were defined as a 0.5-V increase in capture threshold or any increase in pulse width, a change in pacing lead impedance $\geq$50 Ω or change in high-voltage lead impedance $\geq$3 Ω, a decrease in sensing amplitudes $\geq$50%, or a decrease in battery voltage $\geq$0.04 V. These parameters are similar to the secondary clinical outcomes defined by the Magnasafe Registry study.[10]

CMR studies were performed on a 1.5-T MRI scanner (Avanto, Siemens Healthcare, Erlangen, Germany). Standard cine CMR was performed using a spoiled gradient recalled echo sequence to evaluate cardiac function. Subsequently, gadolinium contrast agent (gadobenate dimeglumine, MultiHance, Bracco Diagnostics, Gorizia, Italy) was injected intravenously at a typical dose of 0.15 mmol/kg body weight (range 0.1–0.2 mmol/kg body weight). Ten minutes following gadolinium injection, LGE images were obtained using a wideband inversion pulse sequence,[19] which is a hyperbolic secant pulse with a bandwidth of 3.8 kHz and B_1 amplitude of 11.2 μT (Supplementary Figure 1). All studies adhered to a specific absorption rate limit of 2 W/kg. The actual specific absorption rate for the wideband LGE sequences varied from 0.07 to 0.1 W/kg, and the scan time for each wideband LGE slice was 10–12 seconds. The gradient slew rate used in the wideband LGE sequence ranged from 96 to 122 mT/m/ms among the 3 encoding axes.

Statistical analysis

Patient variables are expressed as mean plus or minus standard deviation (SD). Device variables are expressed as median with interquartile range (IQR). Comparisons of post-CMR and longer-term follow-up device parameters to those pre-CMR were performed using the Wilcoxon signed-rank test. Agreement between changes in device parameters was compared between the post-CMR and follow-up measurements using the McNemar test and numerical correlation using simple linear regression. Statistical significance was determined to be $P < .05$. All statistical tests were 2-sided. Correction for multiple comparisons was not performed, because of the potential for discounting differences in device parameters following CMR, when differences may truly exist. Statistical analysis was performed using JMP Pro 13 software (SAS Institute Inc, Cary, NC).

Results

In total, 114 CMR studies were performed in 111 patients with mean age 59 ± 14 years (Table 1), out of 333 MRI studies in non–MRI-conditional CIED patients during the period. Three patients underwent 2 studies each. A