Multicenter retrospective evaluation of magnetic resonance imaging in pediatric and congenital heart disease patients with cardiac implantable electronic devices

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BACKGROUND Guidelines addressing magnetic resonance imaging (MRI) in patients with cardiac implantable electronic devices (CIEDs) provide algorithms for imaging pediatric and congenital heart disease (CHD) patients. Guideline acceptance varies by institution. Guidelines also do not support routine MRI scans in patients with epicardial or abandoned leads, common in pediatric and CHD patients.

OBJECTIVE The purpose of this study was to determine the incidence of MRI-related complications in pediatric and CHD patients with CIEDs, including epicardial and/or abandoned leads.

METHODS A multicenter retrospective review included patients with CIEDs who underwent any MRI between 2007 and 2022 at congenital cardiac centers. The primary outcome was any patient adverse event or clinically significant CIED change after MRI, defined as pacing lead capture threshold increase >0.5 V with output change, P- or R- wave amplitude decrease >50% with sensitivity change, or impedance change >50%.

RESULTS Across 14 institutions, 314 patients (median age 18.8 [1.3; 31.4] years) underwent 389 MRIs. There were 288 pacemakers (74%) and 87 implantable cardioverter-defibrillators (22%); 52% contained epicardial leads, and 14 (4%) were abandoned leads only. Symptoms or CIED changes occurred in 4.9% of MRI scans (6.1% of patients). On 9 occasions (2%), warmth or pain occurred. Pacing capture threshold or lead impedance changes occurred in 1.4% and 2.0% of CIEDs post-MRI and at follow-up.

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CONCLUSION Our data provide evidence that MRIs can be performed in pediatric and CHD patients with CIEDs, including non–MRI-conditional CIEDs and epicardial and/or abandoned leads, with rare minor symptoms or CIED changes but no other complications.

KEYWORDS Cardiac implantable electronic device; Epicardial lead; Abandoned lead; Magnetic resonance imaging; Congenital heart disease; Pediatrics

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Introduction

Magnetic resonance imaging (MRI) scans are a widespread and valuable modality for diagnostic evaluation and routine monitoring in resource-intensive settings.[1,2] The pediatric and adult congenital heart disease (ACHD) populations frequently require cardiac implantable electronic devices (CIEDs) because of cardiac conduction abnormalities and other arrhythmias secondary to their underlying heart disease or complications from cardiac surgery. Although guidelines have been published for imaging of U.S. Food and Drug Administration (FDA)–approved MRI-conditional endocardial leads in children and ACHD patients,[3,4] institutional acceptance of the guidelines varies widely. Some institutions even exclude pediatric and ACHD patients with CIEDs from MRI. Additionally, citing insufficient data, guidelines do not support routine use of MRI in patients with epicardial and/or abandoned leads, which are commonly seen in pediatric and ACHD patients.[3,4] Currently, the Centers for Medicare & Medicaid Services will not reimburse for MRIs performed on patients with fractured, epicardial, or abandoned leads.[5]

Multiple small single-center studies evaluating MRI scans in patients with non–MRI-conditional CIEDs, including epicardial and abandoned leads, have found no significant adverse events to the patient or the CIED.[6–9] As a result of these small pilot studies, the 2021 Pediatric and Congenital Electrophysiology Society (PACES) CIED guidelines now provide a 2b recommendation for MRI scans in patients with abandoned, epicardial, or fractured leads. However, the PACES guidelines include a caveat to permit imaging after evaluating the risk-to-benefit ratio for each individual patient, thus providing no guidance other than acknowledging that it can be permitted in some (unspecified) settings. This is insufficient guidance for pediatric and ACHD centers to develop evidence-based institutional protocols. To address this knowledge deficit, we performed a multicenter study to evaluate the rate of adverse events among pediatric and ACHD patients with CIEDs undergoing MRI scans at participating pediatric cardiac centers across the United States.

Methods

Site and patient selection

This multicenter retrospective cohort study included all pediatric and ACHD patients with a permanent CIED or abandoned leads without a generator who underwent an MRI at participating institutions. Center recruitment was supported by PACES and supplemented with personal communication. For patients who underwent more than 1 MRI, each MRI counted as a separate datapoint. An Institutional Review Board waiver of consent and authorization was obtained at each participating site. The research reported in this paper adhered to Helsinki Declaration guidelines.

Patient and CIED monitoring

All MRIs were performed using 1.5-T MRI scanners. Each institution had its own protocol for selecting and monitoring patients and CIEDs before, during, and after the MRI. The protocols generally included the following: (1) an electrophysiologist reviewed the patient's information and approved the MRI; (2) informed consent was obtained from the patient, parent, or guardian; (3) an electrophysiologist or other qualified advanced practice provider monitored the patient during the entire MRI; (4) continuous electrocardiogram and pulse oximetry monitoring was performed during the scan; and (5) when feasible, patients notified staff of any symptoms experienced during the MRI. Before the MRI, CIEDs were reprogrammed according to recent recommendations.[3] An MRI-conditional CIED system consists of an MRI-conditional CIED generator and CIED lead(s), that is, the entire system has been approved for MRI by the CIED manufacturer and the FDA. A non–MRI-conditional CIED system is defined as a system in which 1 or more of the CIED generator and/or lead(s) is not MRI conditional or is not approved for MRI by the CIED manufacturer and the FDA. All epicardial leads are not approved by manufacturers for an MRI and, therefore, are non–MRI conditional.[3] Device interrogations evaluating battery voltage, capture and sensing thresholds, and pacing impedance were performed before and after each MRI.

Statistical analysis

Patients were analyzed as one entire group, and summary statistics were reported for 4 separate, nonmutually exclusive subgroups of (1) patients <18 years of age; (2) patients with epicardial leads; (3) patients with abandoned endocardial leads; and (4) patients with abandoned epicardial leads. Each subgroup represents a population for which there are few data on adverse events during MRI scans.

The primary outcome was defined as an adverse event to the patient (death, symptoms, or arrhythmia) or clinically significant changes in CIED pacing threshold, impedance, or P- or R- wave amplitudes between device interrogations at 3 timepoints: pre-MRI, post-MRI, and the first follow-up device interrogation. For the CIED parameter changes, summary statistics were reported by computing the absolute value of the difference between device parameters for each MRI at these timepoints: post-MRI minus pre-MRI (*pre–post*), and follow-up minus post-MRI (*post-MRI–follow-up*). To account for normal variations that can occur between

routine CIED interrogations,[10,11] we defined a clinically significant CIED parameter change as (1) pacing threshold change >0.5 V plus a change in programmed output; (2) impedance change >50%; or (3) P-wave amplitude or (4) R-wave amplitude decrease >50% plus a change in programmed sensitivity. These parameters are similar to those used in other studies evaluating MRI scans with CIEDs.[12,13] Descriptive statistics of continuous patient and CIED variables are given as median [25%–75%; range] due to distribution skew. Categorical variables are summarized as count (percentage). We intended to statistically compare the adverse event rate between MRI-conditional and non–MRI-conditional CIEDs, but this was not feasible because of the low number of adverse events. Statistical analyses were performed in R Version 3.2.4 (R Foundation for Statistical Computing, Vienna, Austria).[14]

Results

Patient and center characteristics

Across 14 institutions, 314 patients (median age 18.8 [11.3–31.4; range 0.1–77.4] years underwent 389 MRIs (Table 1). Congenital heart disease was present in 258 patients (82%). The median number of patients from each institution was 12 [11–23; range 2–83]. Most patients (n = 223 [71%]) underwent 1 MRI, 53 (17%) underwent 2 MRIs, and 38 (12%) underwent ≥3 MRIs.

CIED and MRI characteristics

Of the 389 MRIs, most (n = 287 [74%]) were performed on non–MRI-conditional CIEDs (Figure 1); 183 (47%) in patients <18 years of age; in 201 (52%) with epicardial leads; 17 (4%) with endocardial abandoned leads; and 51 (13%) with epicardial abandoned leads (Table 1). Most MRIs (n = 288 [74%]) were performed on patients with pacemakers; 87 (22%) in patients with implantable cardioverter-defibrillators (ICDs); and 14 (4%) in patients with abandoned leads without a generator (Table 2). Sixty-five (MRIs 17%) occurred in pacing-dependent patients. Of the abandoned leads, 3 were ICD leads, 1 was a subcutaneous array, and the remainder were pacemaker leads. Most MRIs were cardiac (n = 174 [45%]). The remaining MRIs scanned the brain, spine, abdomen, pelvis, orbits, lymphatic system, breasts, or an extremity (Table 1). Median time between MRI and follow-up outpatient clinic CIED interrogation was 36 [1–73; range 1–839] days.

Effect of MRI on patients and CIEDs

Symptoms, patient arrhythmias, or clinically significant CIED changes occurred in 4.9% of MRI scans (6.1% of patients). Most of these complications occurred in brain or

Table 1 Summary of patient demographics and characteristics of MRI scans

	All	<18 years of age	Epicardial leads	Abandoned endocardial leads	Abandoned epicardial leads
No. of patients	314	131	140	11	35
No. of MRIs	389	183	201	17	51
Age at MRI (y)	18.8 [11.3–31.4]	10.4 [5.3–15.6]	13.2 [5.8–23.8]	22.0 [20.3–32.5]	20.4 [15.6–26.9]
Male	202 (52)	97 (53)	106 (53)	11 (65)	22 (43)
Body surface area (m^2)*	1.7 [1.1–1.9]	1.1 [0.7–1.6]	1.2 [0.7–1.7]	1.7 [1.6–2.1]	1.7 [1.5–1.9]
Presence of CHD	308 (79)	121 (66)	177 (88)	16 (94)	51 (100)
Indication for pacing					
Sinus node dysfunction	153 (39)	49 (27)	73 (36)	8 (47)	15 (29)
Atrioventricular block	130 (33)	86 (47)	89 (44)	3 (18)	17 (33)
Atrial arrhythmia	16 (4)	3 (2)	3 (1)	1 (6)	2 (4)
Other	24 (6)	18 (10)	15 (7)	1 (6)	2 (4)
Not paced†	64 (16)	26 (14)	14 (7)	2 (12)	3 (6)
MRI types‡					
Cardiac	174 (45)	70 (38)	79 (39)	7 (41)	25 (49)
Brain	130 (33)	79 (43)	80 (40)	3 (18)	20 (39)
Upper torso¶	71 (18)	37 (20)	38 (19)	4 (24)	13 (25)
Lower torso§	87 (22)	35 (19)	47 (23)	6 (35)	12 (24)
Extremity	17 (4)	6 (3)	7 (3)	1 (6)	1 (2)
Lymphangiogram	2 (1)	2 (1)	0	0	0
Other	2 (1)	0	0	0	0
Follow-up interrogation (d)¶	36.5 [1–73]	36.5 [1–73]	36.5 [1–73]	36.5 [1–73]	36.5 [1–73]

Values are given as n, median [25th–75th], or n (%).

CHD = congenital heart disease; MRI = magnetic resonance imaging.

*There were 38 missing values for body surface area.

†Patients with abandoned leads only or implantable cardioverter-defibrillator without pacing need.

‡These variables are not mutually exclusive, as some MRIs scanned multiple body sites.

§Upper torso includes MRIs of the chest (not cardiac MRI) or thoracic or cervical spine, and lower torso includes MRIs of the abdomen, pelvis, or lumbar or sacral spine.

¶Median number of days from MRI to next follow-up cardiac implantable electronic device interrogation.

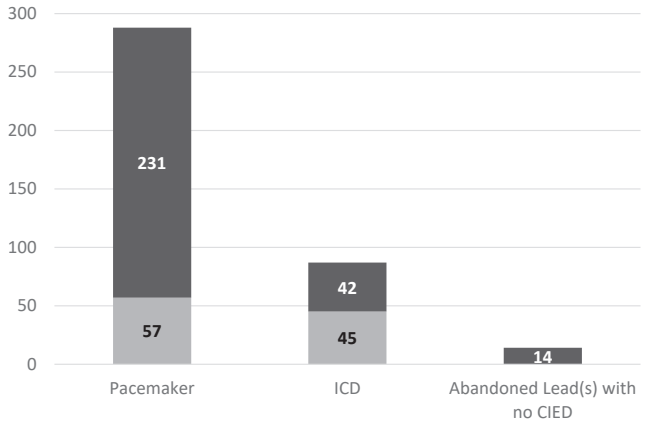

Figure 1 Distribution of MRI-conditional* and non–MRI-conditional CIEDs among the 389 MRIs of pediatric and adult congenital heart disease patients with CIEDs. *MRI-conditional = meets U.S. Food and Drug Administration criteria for conditional use in magnetic resonance scanners.[3] CIED = cardiac implantable electronic device; ICD = implantable cardioverter-defibrillator; MRI = magnetic resonance imaging.

cardiac MRIs, but these were also the most common MRI types in our study. One patient experienced pain/warmth and clinically significant impedance changes post-MRI. The remaining patients experienced either symptoms or CIED parameter changes only. During most of the MRIs (n = 380 [97.7%]), patients did not experience symptoms or arrhythmias (Table 3). Patient-reported symptoms or arrhythmias (not mutually exclusive) included warmth in 5 (1.3%), tingling in 3 (0.8%), pain in 3 (0.8%), presyncope in 1 (0.3%), and bradycardia in 1 patient (0.3%) who was programmed in a nonpaced mode). A total of 17 MRIs (4.4%) required premature termination, primarily due to significant artifact affecting MRI quality (n = 13 [3.3%]). Other indications for premature MRI termination included patient symptoms of warmth or pain in 2 (0.5%), claustrophobia in 1 (0.3%), and bradycardia in the aforementioned 1 patient (0.3%). The same patient underwent a repeat MRI 1 month later in VOO mode without issue. Of the patients with symptoms, most (8/9 [89%]) had a non–MRI-conditional CIED, and 4 (44%) had epicardial leads.

Patient and CIED characteristics at follow-up

Eleven patients in this study died during the follow-up period, all for reasons unrelated to the CIED or the MRI. During the follow-up period, 5% of CIED generators and 2% of leads required removal (Table 3). Indications for generator removal included generator approaching end of life/elective replacement indicator (n = 6) or generator upgrade (n = 5). Indications for lead removal included lead fracture (n = 3) and heart transplant (n = 3). Two of the 3 fractures were reported as unrelated to the MRI; for the third (atrial lead), no data indicating cause of lead fracture were available.

Due to missing data from device interrogations post-MRI and at follow-up, comparative *pre–post* MRI parameter data were available for 359 CIEDs, and comparative *post-MRI–follow-up* MRI data were available for 296 CIEDs. Clinically significant CIED parameter changes occurred in 3.4% of MRIs: 1.4% immediately after the MRI and 2.0% at follow-up (Table 3). A clinically significant pacing capture threshold change occurred in 1 CIED immediately after the MRI; this was a non–MRI-conditional CIED with epicardial leads. At follow-up, a clinically significant pacing capture threshold change occurred after 1% of the MRIs, all of which were MRI-conditional CIEDs. A clinically significant impedance change was identified after 1% of the MRIs on the post-MRI interrogation. Two of these occurred in non–MRI-conditional CIEDs with epicardial leads, 1 in a non–MRI-conditional CIED with endocardial leads, and 1 in an MRI-conditional CIED. At follow-up, a clinically significant impedance change was identified after 1% of the MRIs. Two of these occurred in non–MRI-conditional CIEDs with epicardial leads and 1 in a non–MRI-conditional CIED with endocardial leads. No clinically significant changes to P- or R-wave amplitude or high-voltage lead impedance occurred in any of the CIEDs post-MRI or at follow-up.

Table 2 Summary of CIED characteristics

	All	<18 years of age	Epicardial leads	Abandoned endocardial leads	Abandoned epicardial leads
No. of MRIs	389	183	201	17	51
CIED type					
Pacemaker	288 (74)	147 (80)	171 (85)	11 (65)	34 (67)
ICD	87 (22)	31 (17)	17 (9)	3 (18)	4 (8)
No CIED*	14 (4)	5 (3)	13 (7)	3 (18)	13 (26)
CIED generator age at MRI (y)†	3.7 [1.9–6.1]	3.3 [1.6–5.6]	3.9 [2.0–6.6]	5.0 [2.5–6.0]	4.5 [2.3–6.3]
CIED lead age at MRI (y)†	5.0 [2.2–9.3]	3.6 [1.7–6.7]	5.3 [2.4–9.3]	10.7 [6.2–18.8]	10.5 [5.1–11.9]
Pacing dependent	65 (17)	32 (18)	40 (20)	3 (18)	13 (26)
MRI-conditional CIED generator	172 (44)	69 (38)	61 (30)	8 (47)	19 (37)
MRI-conditional system	102 (26)	35 (19)	1 (1)	7 (41)	9 (18)

Values are given as n, n (%), or median [25th–75th].

CIED = cardiac implantable electronic device; ICD = implantable cardioverter defibrillator; MRI = magnetic resonance imaging.

*Patients with abandoned leads but no CIED.

†There were 14 missing values for CIED generator age at MRI and 78 missing values for CIED lead age at MRI.

Table 3 Summary of events that occurred to patients or CIEDs after MRI

	All	<18 years of age	Epicardial leads	Abandoned endocardial leads	Abandoned epicardial leads
Total no. patients with symptoms, not mutually exclusive*	9 (2.3)	2 (1.1)	5 (2.5)	3 (17.6)	5 (9.8)
Warmth	5 (1.3)	0 (0)	0 (0)	2 (11.8)	52 (3.9)
Pain	3 (0.8)	0 (0)	2 (1.0)	0 (0)	1 (2.0)
Tingling sensation	3 (0.8)	1 (0.5)	2 (1.0)	1 (5.9)	1 (2.0)
Presyncope	1 (0.3)	1 (0.5)	1 (0.5)	0 (0)	1 (2.0)
Bradycardia when programmed in nonpaced mode	1 (0.3)	0 (0)	0 (0)	0 (0)	0 (0)
Premature termination of MRI*	17 (4.4)	8 (4.3)	7 (3.5)	2 (11.8)	2 (4.0)
MRI artifact	13 (3.3)	7 (3.8)	6 (3.0)	2 (11.8)	1 (2.0)
Patient symptoms	2 (0.5)	0 (0)	1 (0.5)	0 (0)	1 (2.0)
Claustrophobia	1 (0.3)	1 (0.5)	0 (0)	0 (0)	0 (0)
Bradycardia when programmed in nonpaced mode	1 (0.3)	0 (0)	0 (0)	0 (0)	0 (0)
CIED generator or lead removal post-MRI†	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
CIED generator or lead removal related to MRI at follow-up†	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Clinically significant CIED change post-MRI†	5 (1.4)	0 (0)	3 (1.7)	N/A	N/A
Atrial output change >0.5 plus pacing capture threshold change	1 (0.3)	0 (0)	1 (0.6)	–	–
Ventricular output change >0.5 plus pacing capture threshold change	0 (0)	0 (0)	0 (0)	–	–
Atrial sensitivity change >50% plus P-wave amplitude change	0 (0)	0 (0)	0 (0)	–	–
Ventricular sensitivity change >50% plus R-wave amplitude change	0 (0)	0 (0)	0 (0)	–	–
Atrial impedance change >50%	2 (0.5)	0 (0)	1 (0.6)	–	–
Ventricular impedance change >50%	2 (0.5)	0 (0)	1 (0.6)	–	–
Clinically significant CIED change at follow-up‡	6 (2.0)	3 (2.2)	2 (1.5)	N/A	N/A
Atrial output change >0.5 plus pacing capture threshold change	2 (0.7)	0 (0)	0 (0)	–	–
Ventricular output change >0.5 plus pacing capture threshold change	1 (0.3)	1 (0.7)	0 (0)	–	–
Atrial sensitivity change >50% plus P-wave amplitude change	0 (0)	0 (0)	0 (0)	–	–
Ventricular sensitivity change >50% plus R-wave amplitude change	0 (0)	0 (0)	0 (0)	–	–
Atrial impedance change >50%	2 (0.7)	1 (0.7)	1 (0.7)	–	–
Ventricular impedance change >50%	1 (0.3)	1 (0.7)	1 (0.7)	–	–

Values are given as n (%).

CIED = cardiac implantable electronic device; MRI = magnetic resonance imaging; N/A = not applicable.

*N = 389 for all patients, N = 183 for patients <18 years of age, N = 201 for epicardial leads, N = 17 abandoned endocardial leads, N = 51 for abandoned epicardial leads.

†Due to missing post-MRI device interrogations, N = 359 for all patients, N = 169 for patients <18 years of age, and N = 173 for epicardial leads.

‡Due to missing post-MRI and/or follow-up device interrogations, N = 296 for all patients, N = 132 for patients <18 years of age, and N = 131 for epicardial leads.

Discussion

This is the largest study evaluating MRI use in pediatric and ACHD patients with CIEDs and one of the largest evaluating the risk of epicardial and abandoned leads during an MRI. In most of the MRIs, no adverse events to the patient or CIED occurred. Adverse events that did occur were minor and included transient symptoms of pain, warmth, or presyncope in 2.3% of patients and changes to pacing capture threshold or impedance in 1.4% of CIEDs immediately after the MRI and 2.0% of CIEDs at follow-up. The low adverse event rate in our study is consistent with results from large studies evaluating MRI scans in patients with CIEDs and endocardial leads.[12,13] Thus, MRIs can be performed in pediatric and ACHD patients, many of whom have non–MRI-conditional CIEDs or epicardial and/or abandoned leads, with only rare, minor complications.

Epicardial and abandoned leads

The 2017 Heart Rhythm Society guidelines exclude patients with epicardial or abandoned leads from their

recommendation on MRI scans in patients with CIEDs, citing theoretical risks of harm based on *in vitro* studies and limited clinical data demonstrating its safety.[3] In 2021, the PACES group was the first to recommend MRI in patients with epicardial and abandoned leads, providing a class 2b recommendation that MRIs "may be considered in patients with epicardial or abandoned leads based on an individualized consideration of the risk/benefit ratio." However, the level of evidence for the recommendation is C-LD (very limited populations), and the guidelines report that "the data on MRI use in epicardial or abandoned leads are inadequate to provide specific recommendations or an absolute contraindication."[4] By showing that MRI use in patients with epicardial and abandoned leads can be performed without serious adverse events and with low rates of clinically significant CIED changes, our study increases the level of evidence for this recommendation.

Multiple small single-center observational studies have evaluated MRI scans in patients with abandoned and/or epicardial leads. These studies report no more than minimal risks to the patient or CIED, and, similar to our study, the main reported symptoms were warmth or pain.[6–9,15,16] Since the publication of the 2021 PACES guidelines, 2 studies have evaluated MRI scans in patients with abandoned leads.[8,16] Similar to our study, there were no significant adverse events to the patients or CIEDs in either study, with only minor changes to CIED parameters and 1 report of transient warmth near the site of a subcutaneous array.

CIED parameter changes: What is a clinically relevant change?

Our study showed variations in pacing capture thresholds and impedances in 1.4% of CIEDs immediately after MRI and 2% of CIEDs at follow-up. Because there are no standardized criteria defining a clinically significant CIED parameter change, we used criteria from previous similar studies to create our own hybrid criteria.[6,13,17–20] These studies used vastly different criteria. Some studies, such as a 2017 *New England Journal of Medicine* study using the prospective MagnaSafe Registry, used strict criteria of a battery voltage decrease $\geq$0.04 V, pacing lead threshold increase $\geq$0.5 V, P- or R- wave amplitude decrease >50%, pacing lead impedance change $\geq$50 Ω, or a high-voltage (shock) lead impedance change $\geq$3 Ω.[13,17] Another *New England Journal of Medicine* study defined significant parameter changes as a percent difference of each parameter (impedance, amplitude, capture threshold, and battery voltage) compared to baseline: no change was defined as a difference $\leq$20% from baseline, expected change as >20%–50% change from baseline, and notable change as >50% from baseline.[12]

Our criteria for clinically significant CIED changes included the requirement that the clinician made a change to the CIED as a result of the CIED parameter change, as we determined that any parameter change not requiring a CIED change is not a clinically significant change. Developing criteria for a clinically significant CIED parameter change is a key area for future research, as it is challenging to discern the effect of MRIs on CIEDs if every study uses different criteria.

Among studies evaluating MRI in patients with CIEDs, changes to CIEDs vary considerably. Some larger studies have reported rare episodes of partial or complete reset during an MRI.[12,13,20] This rare phenomenon has not been reported in smaller studies evaluating MRI scans in patients with CIEDs.[17–19] Although we also did not encounter electrical resets, it is possible our study was not sufficiently powered to detect such a rare event.

It is notable that written informed consent was obtained in 100% of the MRIs in our study. As of the time of this writing, informed consent for MRI in patients with a CIED remains the standard of care at congenital heart centers.

Study limitations

This study was limited by data availability of some pre-MRI, post-MRI, and follow-up CIED interrogations. We also intended to evaluate change in battery voltage *pre–post* and *post-MRI–follow-up*, but, because of many missing values, this variable was excluded from our analysis. We did not collect data on length of MRI, so we cannot comment whether there is an association between length of MRI and development of complication(s). Because this study was retrospective from multiple centers, there were variations in the protocols used for patient selection and MRI completion at each center that we cannot account for. Another limitation is a lack of granular data on the 3 lead fractures in our study. Two of these were specifically reported to be unrelated to the MRI, but we have no data on the cause of the third fracture. To our knowledge, lead fracture has not been reported to occur in large studies evaluating MRI in patients with CIEDs, including epicardial leads,[6,7–9,12,13,15] but we have no data to clarify the relationship between MRI and lead fracture in the patients in our study. Finally, there may have been a selection bias for participants at low risk for MRI-related complications, as we do not have data on patients prohibited from obtaining an MRI at each institution.

Conclusion

Our multicenter study provides evidence that MRI scans in pediatric and ACHD patients with CIEDs, including patients with epicardial or abandoned leads, can be performed with <5% risk of minor adverse events to patients or CIEDs. Large prospective studies using a similar patient population should be performed to confirm our findings, with the goal of modifying restrictions of such a valuable imaging modality among these patients.

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