

Use Caution When Applying Magnets to Pacemakers or Defibrillators for Surgery

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The application of a magnet to a pacemaker (intended to cause asynchronous pacing) or implanted cardioverter defibrillator (intended to prevent shocks) during surgery without a clear understanding of actual magnet function(s) or precautions can have unexpected, untoward, or harmful consequences. In this report, we present 3 cases in which inadequate assessment of cardiac implanted electronic device (CIED) function, coupled with magnet application, contributed to or resulted in inappropriate antitachycardia pacing or shocks, CIED damage, or patient injury. Although these cases might be rare, they reinforce the need for a timely, detailed preoperative review of CIED function and programming as recommended by the American Society of Anesthesiologists and the Heart Rhythm Society. (Anesth Analg 2013;117:422–7)

In describing recommendations for the perioperative management of a patient with a cardiac implantable electronic device (CIED), several published documents suggest that a magnet can safely be applied to a cardiac pacemaker (PM) to invoke asynchronous pacing or to an implantable cardioverter defibrillator (ICD) to disable antitachycardia therapies.^{1–3} However, placing a magnet over a PM or ICD can have unexpected or untoward effects, and several authors have cautioned against substituting magnet application for individualized treatment. Rasmussen et al.⁴ reported 4 cases wherein magnet application permanently deactivated antitachycardia therapy in Guidant (BOS-GDT, Boston Scientific, Natick, MA) ICDs, but subsequent programmer software revision now mostly prevents this problem. Allen⁵ raised the issue that magnet application can have very different effects due to programming, even when applied to different patients with apparently identical devices. Porres et al.⁶ postoperatively identified an ICD that had gone to battery end-of-life during surgery and attributed it to magnet placement. Although Stone and Apinis⁷ describe magnet use as “safe and reliable,” subsequently Stone et al.⁸ warned that “blind” magnet application might fail to address all necessary perioperative issues.

Herein, we present 3 cases from 3 different institutions in which inadequate preoperative assessment of CIED function, coupled with erroneous assumptions about the effects of magnet application, appear to have contributed to or caused inappropriate ICD therapy, CIED damage, or patient injury. Although both the American Society of

Anesthesiologists (ASA) and Heart Rhythm Society (HRS) advise either obtaining a timely preoperative interrogation or obtaining knowledge of device functionality and magnet effects, these recommendations were not followed. These cases should serve to caution clinicians involved in the care of CIED patients about the importance of routine and timely preoperative CIED assessment, and the potential hazards of indiscriminate magnet use without knowledge or verification of their true effects.

Because these cases are single events, retrospectively reviewed, without aggregated data, and devoid of “protected health information,” specific written IRB approval is not required.

Case Description

Case 1

A 33-year-old, 69-kg man with third-degree heart block and recurrent pericardial effusion presented for elective pericardial window without preoperative evaluation of his dual-chamber PM. He was an ambulatory outpatient with mild dyspnea, but significant orthopnea, having undergone previous pericardiocenteses. The cardiologist's note several days earlier recommended operative pericardial window and percutaneous coronary artery stent intervention for “80% left anterior descending lesion” if symptoms (New York Heart Association 2) did not improve. The anesthesiologist's note indicated the absence of a preoperative PM evaluation. The PM brand, model, settings, and implant date (BOS-GDT, Insignia, dual mode, dual chamber, dual sensing, 2 years earlier) along with his chemotherapy exposure (mustard, vincristine, procarbazine, doxorubicin, bleomycin, vinblastine, and dacarbazine for lymphoma approximately 20 years earlier) were not present in the anesthesiology notes.

Initially, he had sinus rhythm, 75 to 80 bpm, with ventricular pacing that was tracking his atrial function and producing atrioventricular (AV) synchrony (called P-wave synchronous ventricular pacing). He underwent arterial line placement, then awake fiberoptic intubation in the sitting position using 2-mg midazolam and 100-μg (total) fentanyl to preserve spontaneous respiration and maintain hemodynamics. On administration of 20-mg ketamine, his arterial blood pressure decreased. A magnet was applied over the PM, intending to augment cardiac output by increasing heart rate from 75 to

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100 bpm. As his vital signs deteriorated, cardiopulmonary resuscitation was commenced, quickly followed by emergent minithoracotomy with improvement of conditions. Postoperative review of the electronic anesthetic record and electroencephalogram tracing at magnet application (Fig. 1, A and B) found magnet application, as expected, initiated asynchronous AV pacing at 100 bpm. However, complete failure of atrial capture and ventricular noncapture every other pace (ventricular electrical alternans) effectively converted the previously AV synchronous activity at 75 bpm to ventricular-only pacing at 50 bpm, which appears to have exacerbated the hemodynamic compromise. Postoperative PM check showed the most recent interrogation was 15 months before surgery. The postoperative interrogation also demonstrated new (since the prior interrogation) inadequate atrial and longstanding (known at the prior interrogation) inadequate ventricular pacing outputs relative to pacing threshold in this pacing-dependent patient.

Case 2

A 70-year-old man with a BOS-GDT H-170 biventricular-ICD presented for median sternotomy and revision of a prior esophagectomy—colonic interposition. His device was implanted 25 months earlier for ischemic cardiomyopathy and to provide cardiac resynchronization therapy. Immediate preoperative interrogation revealed an episode of antitachycardia pacing (ATP) for what appeared to be electrical noise (Fig. 2) approximately 8 months earlier. Investigation revealed that the ATP was delivered during his initial esophageal surgery. Data stored in the ICD indicated an interrogation 13 days before the first surgery, but no interrogation report was in his chart. The anesthesiologist who performed the first case reported that he placed a magnet on the ICD to prevent firing as instructed by the cardiologist. The anesthesiologist was unaware that this ICD likely had a disabled magnet switch in accordance with a manufacturer's product advisory⁹ issued 10 months earlier.

Case 3

A 69-year-old man with a medical history of congestive heart failure status post placement of a BOS-GDT H-175 ICD, coronary artery disease, renal artery stenosis, focal segmental glomerulosclerosis, nephrotic syndrome, chronic obstructive pulmonary disease, and peripheral vascular disease underwent elective thoracoabdominal aortic aneurysm repair in the right lateral position. Proximal extension of the arch aneurysm, discovered after initial dissection, necessitated institution of deep hypothermic circulatory arrest. The ICD was not evaluated preoperatively. The operative team used a magnet to prevent ICD firing, unaware that the magnet mode was disabled due to a manufacturer's product advisory.⁹ Electrosurgical dispersive pads were placed on the left buttock and the left medial thigh. After some shocks were noticed by the surgeon and anesthesiologist, the magnet was repositioned because of the belief that it had moved. A postoperative ICD check revealed at least 20 shocks and at least 12 ATP sequences for electrical noise (Fig. 3), resulting in premature battery depletion requiring ICD replacement. The patient also suffered a perioperative cerebrovascular accident.

DISCUSSION

Patients with CIEDs sometimes undergo invasive procedures without adequate knowledge of the device or its functionality by their perioperative caring teams. Possible explanations for this behavior include inconvenience, as well as personnel and economic barriers to preoperative CIED interrogation. In each of our 3 cases, 1 or more of these issues, combined with the apparent assumptions that: (1) all devices work properly and (2) magnet placement will confer safe care, appear to have contributed to preventable adverse events and patient injury, such as cardiopulmonary resuscitation or inappropriate high-energy therapy. Several reports,^{10–14} including a recent, large, randomized trial,¹⁵ have highlighted myocardial injury or increased mortality from both appropriate and inappropriate shock. Even ATP has been identified as a cause of myocardial injury¹⁶ and increased mortality.¹⁵

Commonly held, but incorrect, beliefs about magnet application include the following: (1) magnet application to a conventional PM always produces asynchronous pacing; (2) asynchronous pacing is safe and effective under all circumstances; and (3) all ICDs suspend antitachycardia therapy with magnet application. However, application of a magnet over a CIED can have unpredictable or unreliable effects (Table 1).^{2,17,18}

Both the ASA¹⁹ and HRS¹ recommend preoperative collection of CIED programmed variables. The ASA further recommends preoperative CIED evaluation and caution with magnet use. In case 1, magnet application did indeed produce asynchronous pacing. However, it caused acute loss of AV synchrony, because atrial pacing never depolarized the atrium, ventricular pacing depolarized the ventricle only 50% of the time, and the patient's complete heart block prevented native ventricular depolarization. Although this patient had tamponade physiology and received positive pressure ventilation, the loss of atrial transport caused by magnet application likely further compromised the worsening hemodynamics. In cases 2 (BOS-GDT H-170) and 3 (BOS-GDT H-175), knowledge of the BOS-GDT ICD tone functions could have allowed determination that magnet placement did not disable antitachycardia therapy. Although both of these ICDs will emit tones on magnet placement to indicate the presence of a magnet and status of antitachycardia therapy, neither record has documentation suggesting that tones were sought or that auscultation of the device was performed. In both instances, the magnet switch had been disabled in response to a product advisory,²⁰ and no tones would have been emitted, alerting the anesthesiologists that ICD antitachycardia therapies were still active. In case 3, the failure of the operative personnel to reliably observe movement during shocks likely reflects use of muscle relaxants and the incomplete operative view of the heart in the right lateral position.

Since the publication of the report "To Err is Human" by the Institute of Medicine²¹ more than 10 years ago, Landrigan et al.²² posited that no significant improvement has occurred despite considerable effort and dollars expended. Parry et al.²³ recently suggested using "morbidity and mortality reviews, executive walk-rounds, root-cause analyses, and failure modes and effects analyses" to

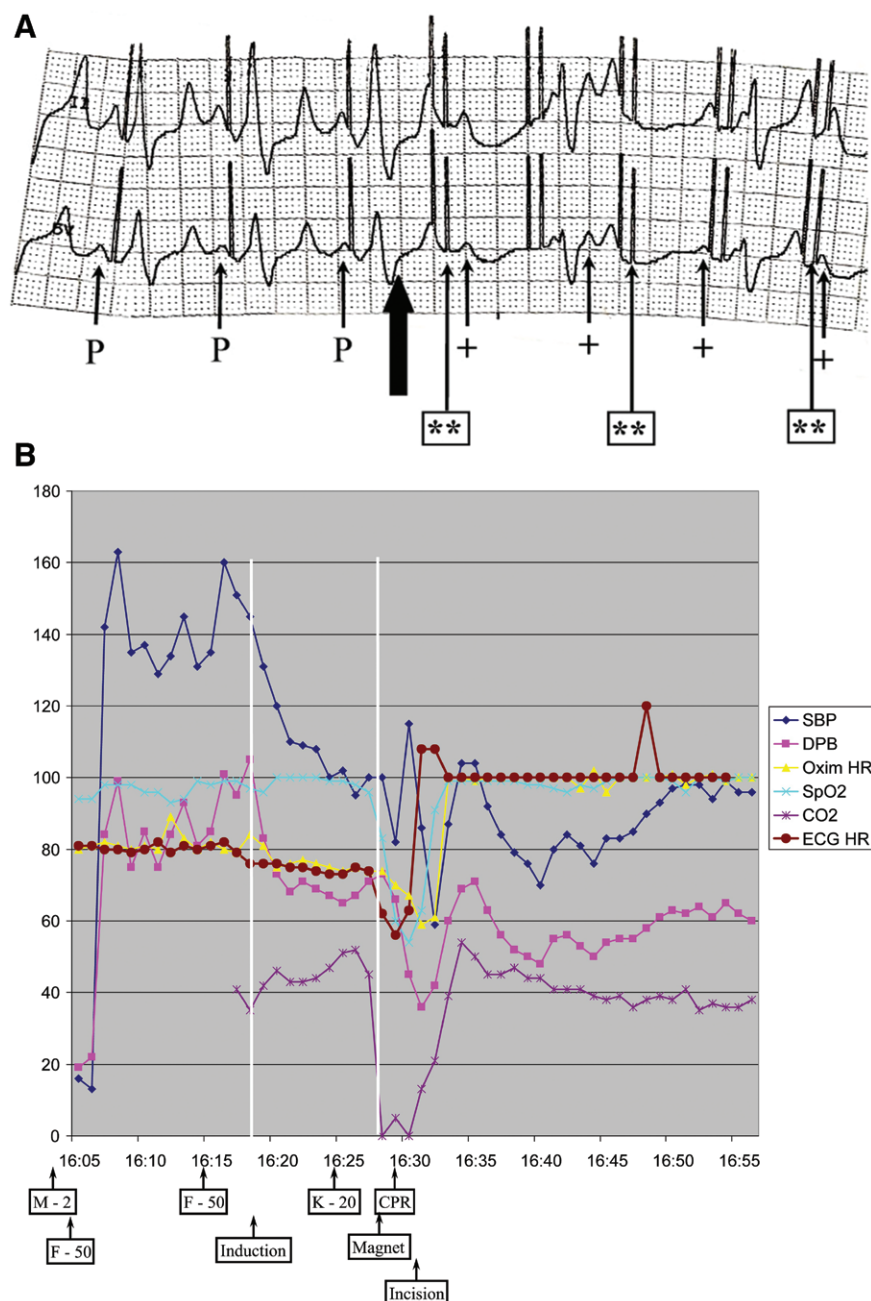


Figure 1. A, Magnet application to a dual chamber pacemaker programmed to DDD mode actually reduces effective heart rate and abolishes atrioventricular (AV) synchrony. A 33-year-old man with recurrent lymphomatous pericardial effusion and third-degree heart block with a pacemaker developed hemodynamic compromise during his anesthetic induction. A magnet was applied (up-arrow), intending to increase his heart rate from 75 to 100 bpm and improve cardiac output. However, inadequate pacing outputs on both leads resulted in complete atrial noncapture as well as intermittent ventricular noncapture, producing loss of AV synchrony and actual reduction in effective heart rate, likely reducing his cardiac output and worsening his hemodynamic status. The electrocardiographic tracing at the time of magnet placement is shown. Although asynchronous dual chamber pacing began at 100 bpm with an AV delay of 100 milliseconds (normal magnet function for a Guidant pacemaker), atrial pacing failure-to-capture (“+,” note no change in P-wave rate) and ventricular electrical alternans (note noncaptured ventricular pacing “**” every other pace) effectively produced asynchronous ventricular-only pacing at 50 bpm. Postoperative interrogation revealed a last-check date 15 months before this surgery, inadequate atrial and longstanding (known at the prior interrogation) inadequate ventricular pacing outputs relative to pacing threshold in this pacing-dependent patient. B, Selected vital signs and actions around the time of cardiopulmonary resuscitation (CPR) in a pericardial window. Data recovered from the electronic medical record (EMR) are presented, along with drug administration and relevant events (induction, magnet placement, and CPR) documented by the anesthesia care team. As shown, the EMR documents each vital sign every 60 seconds. However, each of these vital signs can be acquired at different time points during this period, each vital sign could have been affected by the CPR, and the data averaging of each signal might be different. For example, the electroencephalogram (ECG; A) clearly shows an instantaneous change in the ventricular rate from 75 to 50 bpm on magnet placement. However, the EMR inaccurately reports that the ECG rate decreased over 2 minutes, and the lowest documented pulse oximeter heart rate was 59 bpm. Drugs were M-midazolam (2 mg), F-fentanyl (50 μ g twice), and K-ketamine (20 mg). SBP = systolic blood pressure, DBP = diastolic blood pressure, HR = heart rate.

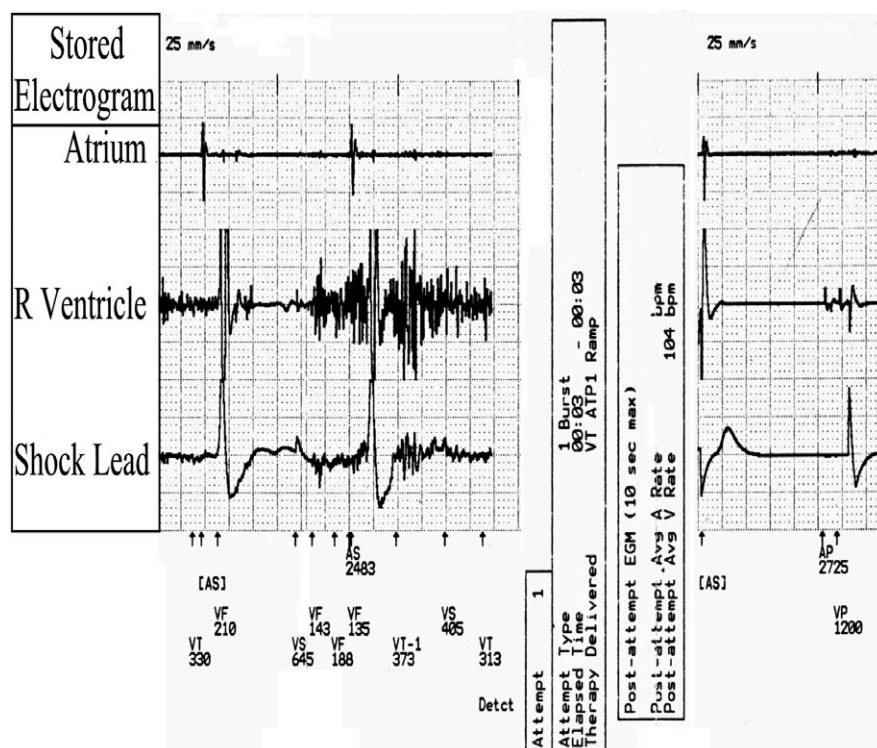


Figure 2. Electromagnetic interference (EMI) during surgery results in antitachycardia pacing from a Guidant (Boston Scientific, Natick, MA) H-170 implantable cardioverter defibrillator (ICD). An episode of antitachycardia pacing during median sternotomy and esophagectomy revision caused by EMI from monopolar electrosurgery took place despite the presence of a magnet on this Guidant ICD, as the perioperative personnel were unaware that the magnet switch had been disabled. The 3 traces show electrical signals (called intracardiac electrograms) from the atrial lead (top), right ventricular pacing lead (middle), and the right ventricular ICD shock coil (bottom). The patient's underlying sinus rhythm at 48 bpm appears on all leads, but EMI can be seen on the right ventricle and shock signals. The interpretation made by the ICD (called the marker channel) is shown under the gratitudes. The ICD has identified this "rhythm" as >2.5 seconds of ventricular tachycardia (VT), resulting in the delivery of antitachycardia pacing ("VT ATP1 RAMP"), which was deemed successful therapy because the EMI ceased. Had a stethoscope been placed on this ICD while the magnet was present, the lack of an audible sound would have indicated the lack of magnet response. The chart speed is 25 mm/sec. AS is atrial sense; the brackets ([AS]) indicate that the ICD has ignored the event. AP/VP are atrial/ventricular pace and VT-1, VT, and VF reflect ventricular sensed events that are in timing windows associated with the 3 programmed zones of tachycardia detection. The numbers associated with each symbol is the time (in milliseconds) from the last event on that lead.

identify clues for improving hazardous systems. However, these efforts will detect only known causes of harm. We believe that our 3 cases represent "occult harm," as identifying all of the contributing factors in these cases remains

quite difficult. In case 1, we believe that inappropriate PM programming (inadequate pacing outputs) and the acute loss of AV synchrony with magnet placement worsened the clinical situation. In cases 2 and 3, both patients received

Table 1. Caveats for Magnet Placement on CIEDs

Improper magnet positioning	Only ICDs from BOS ^a (tones/beeping with magnet switch activation) and Sorin (rate change to 90 bpm) have a reliable means to ensure antitachycardia therapy has been suspended by magnet placement. A magnet might not alter CIED function in patients who are obese or have abdominal or submuscular implants.
Magnet switch off	All transvenous ICDs from BOS and SJM, and all PMs from Biot, BOS, and SJM have programmable magnet modes that include "OFF". All CIEDs from BOS are unresponsive to magnet placement after a reset ^b until the magnet function is reactivated by programming.
Low battery voltage	Battery voltage can affect magnet function, and magnet behavior becomes unpredictable when the battery voltage falls below EOL ^c values even if the CIED appears to be working correctly.
Magnet reapplication	Magnet removal and reapplication is required for some Biot ICDs at 8 h to obtain an additional 8 h of antitachycardia suspension.

CIED = cardiac implantable electronic device; ICD = implantable cardioverter defibrillator; Biot = Biotronik (Berlin, Germany; US—Lake Oswego, OR); BOS = Boston Scientific (Natick, MA, and includes Guidant and CPI brands); SJM = St Jude Medical (Syl Mar, CA); Sorin (Milano, Italy; US—Arvado, CO); PM = pacemaker.

^a Magnet application to the BOS subcutaneous ICD (US FDA approval 9/2012; CE mark 2009, formerly Cameron Health, San Clemente, CA) will prevent shock therapy while properly placed. For 60 s following magnet application, the subcutaneous ICD will emit beeping tones at 1 Hz to indicate magnet detection. Although beeping ceases at 60 s, shock therapy remains disabled until magnet removal.

^b All CIEDs regularly check memory and programming status to ensure appropriate function. On discovery of a memory or programming error, all CIEDs revert to a "reset" mode that is specific for each company and CIED type. Reset mode includes programmed parameters presumed to be safe for every patient.

^c End of Life (EOL)—The CIED has inadequate battery energy to ensure reliable service. As a result, operation is unpredictable, and it should be replaced immediately.

Therapy History:									
Episode and Attempt #	Date/Time and Elapsed Time	Stb ms	Ons	V > A	F i b	A/V Pre bpm	Therapy	A/V Post bpm	
273 1	17-AUG-14:29 00:01	74	56%	T	F	57/282	VF 31J, Biphasic	70/ 70	
272 1	17-AUG-14:26 00:07	21	41%	T	F	44/224	VF 31J, Biphasic	73/ 70	
271 1	17-AUG-14:24 00:05	129	12%	T	F	22/ 90	VT ATP1x1 Scan	/189	
2 2	00:15	34	--	T	F	/189	VT-1 No Therapy	/174	
3 3	00:33	48	--	T	F	28/166	VT ATP2x1 Ramp	/179	
4 4	00:43	48	--	T	F	/214	VF 31J, Biphasic	70/ 70	
5 5	01:15	21	--	T	F	54/214	VT 31J, Biphasic	/ 73	
6 6	01:41	46	--	T	F	43/183	VT 31J, Biphasic	84/ 84	
7 7	02:04	18	--	T	F	84/235	VF No Therapy	70/ 70	
227 1	17-AUG-12:50 00:05	56	16%	T	F	119/207	VT ATP1x3 Scan	160/209	
2 2	00:27	121	--	T	F	183/202	VT ATP2x3 Ramp	/200	
3 3	00:47	53	--	T	F	161/214	VT 21J, Biphasic	333/133	
4 4	01:00	68	--	T	F	106/180	VT 31J, Biphasic	72/ 72	
5 5	01:47	93	--	T	F	138/155	VT-1 No Therapy	/205	
6 6	01:35	109	--	T	F	125/186	VT 31J, Biphasic	130/133	
7 7	01:58	62	--	T	F	97/209	VT 31J, Biphasic	70/ 70	
226 1	17-AUG-2009 12:48 00:03	45	50%	T	F	145/211	VT ATP1x1 Scan	/188	
2 2	00:37	54	--	T	F	107/218	VF 31J, Biphasic	148/ 94	
3 3	00:37	79	--	T	F	127/203	VT 31J, Biphasic	/188	
4 4	00:54	54	--	T	F	58/207	VT 31J, Biphasic	92/ 92	

Figure 3. Partial episode list from a Guidant (Boston Scientific, Natick, MA) H-175 implantable cardioverter defibrillator (ICD) showing several shocks and antitachycardia pacing during a surgical case. Multiple episodes of antitachycardia pacing along with 21J and 31J shocks, sometimes in quick succession, during thoracoabdominal aneurysm repair owing to electromagnetic interference (EMI) from monopolar electrosurgery took place despite the presence of a magnet on this Guidant ICD. A magnet had been placed on this ICD intending to suspend antitachycardia therapy. Because no preoperative interrogation or investigation into the programmed variables took place, the perioperative personnel were unaware that the magnet switch had been disabled. Had a stethoscope been placed on this ICD while the magnet was present, the lack of an audible sound would have indicated the failure of the magnet to disable antitachycardia therapies. Postoperative interrogation of this ICD revealed at least 20 shocks and at least 12 antitachycardia pacing sequences for electrical noise, resulting in premature battery depletion during the case because of the large number of therapies delivered.

inappropriate antitachycardia therapy (ATP and/or shock), both of which appear to shorten patients' lives.¹⁵ At this time, it is impossible to know whether the multiple shocks in case 3 contributed to the patient's stroke.

Except for true surgical emergencies, clinicians caring for these patients should ensure appropriate device function preoperatively, either through contact with the patient's CIED physician/clinic (as recommended by HRS) or a de novo interrogation (as recommended by ASA). For planned intraoperative magnet use, a full understanding and verification of magnet function before proceeding to the operating room seems indicated. Collaboration by the CIED manufacturers to consider standardizing the response to magnet placement²⁴ would likely be a useful additional step towards minimizing risk. For several years, the Association for the Advancement of Medical Instrumentation (Fairfax, VA) has been attempting to create a "universal magnet mode response," but at this time, no such development has taken place.

In hospital, electromagnetic interference (EMI)-induced shocks might be a significant issue in ICD patients. A review of 2000 randomly selected telephonic records after 1 or more shocks between 2001 and 2008 showed 5248 shocks, 1570 (30%) of which were inappropriate, and that 76 of these 1570 (4.8%) were due to EMI.²⁵ These cases, in which EMI appears on multiple leads, EMI is isolated to only 1 day with a narrow time window, and EMI stops around the time of the therapy should be suspicious for in-hospital occurrence. We believe that inappropriate antitachycardia therapy owing to EMI within a hospital environment should become a reportable event to the United States Food

and Drug Administration or the Joint Commission, as it represents potential patient injury. ■

DISCLOSURES

Name: Peter M. Schulman, MD.

Contribution: This author helped design and conduct the study, analyze the data, and write the manuscript. Dr. Schulman wrote many of the revisions.

Attestation: Peter M. Schulman approved the final manuscript.

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Name: Marc A. Rozner, PhD, MD.

Contribution: This author helped design and conduct the study, analyze the data, and write the manuscript. Dr. Rozner wrote many of the revisions.

Attestation: Marc A. Rozner approved the final manuscript.

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