Reviews

Electromagnetic Interference and Implanted Cardiac Devices: The Nonmedical Environment (Part I)

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ABSTRACT

The number of patients with cardiovascular implantable electronic devices (CIEDs), such as permanent pacemakers and implantable cardioverter-defibrillators, is dramatically rising due to an aging population and recent clinical trials showing benefits in mortality and morbidity. Coupled with this increase in the number of patients with CIEDs is the proliferation of technology that emits electromagnetic signals, which can potentially interfere with CIED function through electromagnetic interference (EMI). Despite continuous efforts of manufacturers to create "EMI-proof" CIEDs, adverse events from EMI still occur. Physicians caring for patients with CIEDs should be aware of potential sources of EMI and appropriate management options. This 2-part review aims to provide a contemporary overview of the current knowledge regarding risks attributable to EMI interactions from the most common nonmedical (Part I) and medical (Part II) sources.

Introduction

Cardiovascular implantable electronic devices (CIEDs), such as permanent pacemakers and implantable cardioverter-defibrillators (ICDs), are now commonly encountered in all fields of clinical medicine. In an analysis of the discharge records in the Nationwide Inpatient Sample (a large database comprising >1000 US hospitals, maintained by the Healthcare Cost and Utilization Project), approximately 3 million pacemakers and 1 million ICDs were implanted between 1993 and 2008, with an annual increase of almost 5%.[1] In a recent survey, >1 million pacemakers and 300000 ICDs were implanted worldwide in 2009 alone.[2] Coupled with this increase in the number of patients with CIEDs is the proliferation of technology that emits electromagnetic signals, which can potentially interfere with CIED function through electromagnetic interference (EMI). Manufacturers of CIEDs have responded to this challenge with improved device protection from abnormal or unwanted effects, such as the use of titanium cases, special circuitry designed to filter out signals from EMI sources with commonly used frequencies, and specialized algorithms designed to distinguish between noise and true intracardiac signals. Moreover, most implanting physicians now use bipolar leads more frequently than unipolar leads, minimizing the "antenna" effect and thus the proclivity toward sensing unwanted electrical signals. Despite these developments, adverse events from EMI still occur, and physicians caring for patients with CIEDs should be aware of potential sources of EMI and appropriate management options.

Sources of EMI can be classified by type and frequency of emitted energy, but it is more practical to categorize EMI as being derived from medical and nonmedical sources. There are many possible interactions from a variety of sources (Table 1); a list of all the published medical literature of CIED and EMI interactions is available in the 2011 Heart Rhythm Consensus Statement on Perioperative Management of CIEDs.[3,4] This 2-part review will focus on potential EMI and CIED interactions from the most common sources in both the nonmedical (Part 1) and medical (Part 2) environments.

Device Responses to Electromagnetic Interference

Before discussing EMI from specific sources, it is important to emphasize that the clinical consequences of the interaction will depend on the type of interaction, type of device, and patient characteristics (Table 2). All

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Table 1. Possible Sources of Electromagnetic Interference From Nonmedical Sources

Source	Possible Effect(s)
Cell phones	None
Security gates	EMI sensing
EAS systems	EMI sensing
Taser	Rapid pacing (shunting of electrical activity to the lead tip); EMI sensing
Magnets (speakers, headphones, jewelry clasps)	Magnet mode
iPods	Interference with ECG recording systems
Other (microwaves)	None

Abbreviations: EAS, electronic article surveillance; ECG, electrocardiographic; EMI, electromagnetic interference.

manufacturers have developed noise-detection algorithms to minimize the clinical consequences of EMI. Historically, the most important concern was that EMI would cause inappropriate inhibition of pacing and lead to asystole in a pacemaker-dependent patient. Although there are manufacturer-specific subtleties, in general most employ some type of noise-sampling period at a time when intrinsic ventricular activity would be unlikely to be present, so that if electrical signals are sensed, it is defined as noise. If EMI is sensed, asynchronous pacing usually results. Although asynchronous pacing could lead to a life-threatening arrhythmia due to ventricular pacing during a vulnerable period (R-on-T wave), this is an extremely uncommon event. Continuous sensing of EMI usually initiates one of these specialized algorithms. These algorithms perform less well with intermittent EMI. If the noise algorithm is not activated, EMI in the ventricular channel of a pacemaker could be sensed and misinterpreted as intrinsic ventricular activity (oversensing) and lead to inhibition of pacing. In a pacemaker-dependent patient, this could result in asystole. In a patient with an ICD, oversensing in the ventricular channel could lead to erroneous identification of a ventricular arrhythmia that required antitachycardia therapy such as pacing or delivery of a shock. Oversensing of EMI in the atrial channel of a dual-chamber pacemaker or ICD can result in several different behaviors, depending on how the device is programmed to respond to sensed events. If the pacemaker is programmed to inhibit in response to atrial-sensed events (AAI and DDD pacing modes), inhibition of atrial pacing will be observed. If the pacemaker is programmed to initiate the atrioventricular (AV) interval in response to an atrial signal (DDD, VDD, VAT modes), repetitive activation of the AV interval will lead to rapid ventricular paced rates. Finally in CIEDs that have been programmed to "mode switch," the pacing mode will change from a pacing mode that tracks atrial activity (DDD) to a pacing mode that inhibits pacing in response to sensed activity (VVI or DDI). If a large amount of EMI is identified by the device, sometimes the device will change to the "power-on reset" mode, which can be thought of as a basic, manufacturer-specific set of functions that is analogous to the "safe mode" in the Microsoft Windows operating system. Finally, a strong magnetic field can activate the magnet response of a device, which varies from manufacturer to manufacturer and can be programmable, but which in most cases results in asynchronous pacing for pacemakers and disabling of tachycardia therapy in ICDs.

All management strategies for EMI/CIED interaction are designed either to reduce the likelihood of EMI exposure (eg, keep the EMI source as far away from the CIED as possible) or minimize the consequences if EMI is sensed (eg, use a magnet or reprogramming to disable antitachycardia therapies in patients with ICDs). As a general rule, minimizing the exposure of the CIED to EMI by avoiding EMI sources altogether, maintaining as large a distance as possible between the CIED and the EMI source, and minimizing the time that EMI is being generated are the best strategies, particularly for nonmedical sources of EMI.

Nonmedical Sources

In general, common household appliances such as microwave ovens or televisions do not interact with CIEDs.[4] Industrial equipment such as arc welders can potentially interact with CIEDs but can often be used if special precautions are followed.[4] Patients often ask physicians about possible interactions between their CIEDs and commonly encountered sources such as cell phones, security gates, and electronic article surveillance (EAS) devices.

Cellular Phones

Cellular phones are now a ubiquitous part of everyday life. In the mid 1990s, several investigators reported EMI effects on CIEDs in vitro and in vivo, such as temporary inhibition of output due to oversensing of emitted electrical signals from the cell phone, noise reversion or asynchronous pacing, and unwanted ventricular tracking from cell-phone signals detected by the atrial lead.[5,6] The highest incidence of interference was noticed when the telephone was placed directly over the pacemaker itself. In contrast, use of the telephone in the normal position at the ear was associated with the lowest incidence of interference, without any clinically significant events.[7] Early on, because of differences in frequencies used between different countries (United States: analog, 800 MHz; Europe: digital [Global System for Mobile Communication (GSM)], 900 MHz, 1800 MHz, 2100 MHz), more EMI interference was observed with cell phones using GSM technology because of the higher powers and continuous pulsing associated with digital signals.[5] In response to the dominance of GSM (now >80% of the mobile communications market) and the increased possibility of EMI interaction with cell phones, CIED manufacturers have developed special filters designed to minimize such interaction by filtering frequencies used by cell phones in the feedthroughs (the actual electrical connection from the header to the pulse-generator circuitry).[8–10] For example, in a recent in vivo study of 679 patients, interaction between cell phones and CIEDs was observed in only 0.3% of patients when bipolar leads were used in pacing systems that were programmed to nominal sensitivity values; no associated clinical symptoms were documented.[9] Not surprisingly,

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Table 2. Possible Clinical Responses to Electromagnetic Interference Depend on Device and Patient Characteristics

Device/Patient	Possible Observed Responses
Device type	
Pacemaker: ventricular channel	Asynchronous pacing due to activation of noise algorithms; safety pacing (pacing at short AV intervals); inhibition of ventricular pacing; magnet mode
Pacemaker: atrial channel	Asynchronous pacing; inhibition of atrial pacing; mode switch; magnet mode
ICD	Inappropriate antitachycardia therapy; magnet mode
Patient characteristics	
Pacemaker-dependent patient	Inhibition of pacing could cause slow heart rates and result in dizziness, syncope, etc.; inappropriate tracking could lead to fast paced rates and rapid heart rates; inappropriate sensing of EMI by an ICD could lead to inappropriate antitachycardia therapy, such as pacing or a shock.
Non–pacemaker-dependent patient	Inhibition of pacing generally does not cause symptoms; inappropriate tracking could lead to fast paced rates and rapid heart rates; asynchronous pacing can cause palpitations and rarely may lead to initiation of arrhythmias; inappropriate sensing of EMI by an ICD could lead to inappropriate antitachycardia therapy, such as pacing or a shock.

Abbreviations: AV, atrioventricular; EMI, electromagnetic interference; ICD, implantable cardioverter-defibrillator.

when sensitivity was increased to the lowest programmable value, interactions such as transient inhibition of output due to oversensing were more commonly observed (1.1% of patients); and, when unipolar sensing was programmed, interactions increased further, to 1.4%–4.1%, depending on the programmed sensitivity. It is important to note that interactions were observed only during the ringing phase when the cell phone was positioned <10 cm from the CIED. The most common interaction was activation of noise-detection algorithms that resulted in asynchronous (fixed rate) pacing (33 of 37 interactions); only rare cases of oversensing (3 of 37) or inappropriate tracking (1 of 37) were observed. Interactions were much more commonly observed in the ventricular lead in their study, but this observation is probably due to the larger number of ventricular leads studied, rather than a true impact of lead position. The same investigators using a similar study protocol found that cell phones did not interact with ICDs, even with the cell phone touching the skin overlying the device.[11] Another group found ICD–cell-phone interactions (loss of telemetry) only when the cell phone was adjacent to the ICD during active communication between the ICD and the programming head.[8]

In general, physicians should provide commonsense recommendations, such as using the ear contralateral to the CIED and avoiding physical proximity between the CIED and the cell phone such as that which occurs when keeping the phone in a breast pocket near the CIED.[4]

Airport Screening Devices

Walk-through or handheld metal detectors that sense disturbances in electromagnetic fields are used for security applications. Walk-through metal detectors operate in a continuous-wave (5–10 kHz) or pulsed (200–400 Hz) mode, providing considerably higher magnetic-field strengths compared with handheld detectors, which operate in much higher continuous-wave (80–130 KHz) mode.[12] The effects of interference from airport security systems on CIEDs have been studied during the last decade. In an older study of patients with pacemakers, no changes in pacing system behavior in patients walking through the airport metal-detector gates occurred, despite programming the pacemaker to the highest sensitivity setting.[13] Inhibition of pacing output for one stimulus was identified, but because exposure to the EMI was so transient, activation of noise-detection algorithms with consequent asynchronous pacing was not observed. Similar results were found in a study of 348 consecutive patients (200 pacemaker and 148 ICD recipients) who were tested for EMI effects within the electromagnetic field of an airport metal detector. No interference was observed in any of the patients, in part due to the short exposure time of the CIED to EMI.[14]

In a recent study of 388 patients (209 with pacemakers and 179 with ICDs of different models), 2 widely used handheld metal detectors programmed at the maximal sensitivity (maximal electromagnetic flux density) were swiped directly over the cardiac apex and the device for ≥30 seconds, which is far longer than the duration of conventional screening. No changes in device function, including pacing or sensing abnormalities or spontaneous device reprogramming, were observed in any of the patients.[15]

To summarize, although airport screening metal-detector gates and handheld metal detectors can detect the ferrous material in the implanted device and may cause the detector alarm to be triggered, CIED function will likely not be affected. The most recent Transportation Security Administration recommendations advise but do not require patients with CIEDs to alert security personnel that they have an implanted device. Security officers are required to investigate all alarms associated with metal implants, and most commonly a pat-down or hand search will be required.

Electronic Article Surveillance Devices

Electronic article surveillance devices have a widespread use in retail and public places. These devices have 2 pedestals: a transmitter and a receiver. The transmitter emits a magnetic field that is designed to interact with

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a tag installed in a store item. The tag then sends back a signal that is detected by the receiver and triggers an alarm. There have been sporadic reports of adverse CIED interactions (inappropriate shocks) with security systems in the retail environment.[16–19] Reports of such interactions are probably due to potentially longer exposure to EMI sources.[18] In a systematic study of 170 patients with ICDs and 3 different electronic surveillance systems, no interactions were identified during a 10–15-second mid-gate walk. However, EMI that could lead to inappropriate therapy was observed during prolonged exposure (2 minutes) with the ICD positioned within 6 inches of the gate.[20] Another single-center study evaluated 50 volunteers with pacemakers and 25 volunteers with ICDs with 3 different types of electronic security equipment systems.[16] Acousto-magnetic security systems that use a low-frequency pulsed magnetic field to detect tags at greater distances interacted with 48 of the 50 pacemakers. The interactions included asynchronous pacing (the predominant interaction), atrial oversensing with rapid ventricular pacing, ventricular oversensing with pacemaker inhibition, and paced beats resulting from the direct induction of current in the pacemaker. The interactions produced symptoms in some patients (palpitations, presyncope) only while patients were in the EAS field. The occurrence of these interactions was more frequent when patients leaned against the transmitter pedestal or were exposed for 5 minutes to the EAS field following the prespecified protocol. In that study, no ICD exhibited an abnormal response with any of the security systems. In a retrospective observational study of 336 patients during a 16-year period of analysis, there were no reports of inappropriate ICD discharge due to EAS-system exposure.[21]

In general, the risk of significant consequences with normal use and limited exposure to surveillance systems is minimal, but patients with CIEDs should be made aware of potential interactions and should be advised to avoid lingering between or near the security gates in retail and public settings.

Digital Music Players and Headphones

Digital music players can cause interference with pacemaker-interrogator telemetry but probably do not directly interact with CIEDs.[22–24] In a study of 67 patients, telemetry interference with the pacemaker programmer was observed in 16% of patients, but no actual changes in CIED function were observed, even with the digital music player placed directly over the CIED.[22] In a similar study, 54 patients were evaluated for a total of 162 tests. In a random fashion, the patients were exposed to 3 different iPod types, 3G, Photo, and Touch, for 1 minute each, in the presence of the telemetry wand and without the wand. Interestingly, although 36.4% of tests revealed telemetry interference, none of the tests showed any evidence of direct interference when the telemetry wand was removed.[24]

In contrast, portable headphones, which commonly use neodymium, a naturally occurring, concentrated, powerful magnetic substance, can produce EMI that can directly interact with CIEDs if they are within 3 cm of the CIED.[25] These magnets are also used in jewelry and clothing as clasps, and there have been scattered case reports of unexpected CIED function due to the powerful local magnetic field.[26] In a study of 100 patients (55 with pacemakers and 45 with ICDs), 30% of patients experienced clinically relevant interference, such as asynchronous pacing and inhibition of tachycardia detection.[27] Because the magnetic-field strength decreases dramatically as the distance from the magnetic source increases, all interactions were observed when the headphones were within 3 cm of the device. In addition, because interaction was dependent on magnetic-field strength, in-ear headphones that use smaller magnets did not interact with the devices.

Generally, patients with CIEDs should not be discouraged from using portable headphones, but they should be advised to keep them away from the pulse generator to minimize the potential for magnetic interference.

Tasers

Weapons that use electrical current are now more frequently used by law-enforcement agencies to subdue combative suspects. The most commonly used device, the Taser X26, shoots 2 tethered probes that deliver very short pulses of current with a peak voltage of 1000–1500 V. The electrical pulses can be sensed by CIEDs and may be interpreted as intrinsic cardiac activity or as noise. There have been 6 case reports in the medical literature of Taser use in patients with CIEDs.[28–30] In one case, the rapid electrical activity was sensed by an ICD as ventricular fibrillation; the capacitors were charged, but therapy was not delivered because the electrical activity had ceased.[30] In a second case, one Taser probe was delivered directly over a pacemaker pulse generator.[29] Rapid ventricular activity was observed, probably due to shunting electrical energy generated by the Taser to the electrode tip and ventricular capture.

Other Nonmedical Sources

Sporadic reports have suggested that slot machines may represent another source of EMI, with 4 patients receiving ICD shocks while playing slot machines.[31] The stored electrograms or R-R interval histories suggested electrical noise. Another interesting report is a case of interference between a pacemaker and an alternative-medicine treatment called the Zapper, which produces a square-wave output at a frequency ~33 kHz and is advertised as a treatment to "eliminate cancer, other chronic diseases, self-diagnosed parasites and germs." Electromagnetic interference from the Zapper caused ventricular oversensing and inhibition of pacing associated with dizziness and near syncope.[32] Interactions between pacemakers and household tools such as electric drills or chainsaws have not been reported in the medical literature, but manufacturers have made some general recommendations that are reasonable to pass on to the patient. These include trying to maintain a greater distance between the tool motor or ignition motor and the pulse generator (>6 inches is a reasonable recommendation), use tools that are properly grounded, use a ground-fault circuit interrupter outlet if possible, and avoid using the tool in a "locked-on" position.

It is important for the clinician to keep in mind that new electronics are being developed that may interact with CIEDs. For example, newly developed bioelectric impedance analyzers are used to estimate body fat (higher

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impedance corresponds with higher body fat) by delivering a small electrical current (<500 mA) through electrodes in contact with the skin. Although no interactions have been reported in the medical literature, the directions for these analyzers explicitly note that they should not be used in patients with CIEDs. As technology use in the nonmedical environment continues to increase and become more sophisticated, it is important for clinicians to always pause and consider whether a new potential source for EMI will affect their patients with CIEDs.

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