Pausing With the Gauze: Inhibition of Temporary Pacemakers by Radiofrequency Scan During Cardiac Surgery

Matthew R. Williams, MD,†‡ Douglas B. Atkinson, MD,‡§ Vassilios J. Bezerides, MD, PhD,*† Koichi Yuki, MD,‡§ Kathryn Franklin, BSN, RN, CNOR,‡ Alfonso Casta, MD,‡§ and Mark E. Alexander, MD*†

BACKGROUND: Radiofrequency identification (RFID) detection systems are used to detect retained surgical sponges and may cause electromagnetic interference (EMI), altering intended function of cardiac pacing systems. Three pediatric patients requiring temporary pacing for postoperative atrioventricular block experienced transient inhibition of ventricular pacing during the use of RFID detection system. Bench testing was performed to evaluate the mechanism of pacemaker inhibition.

METHODS: Impedance of temporary pacing wires was obtained using a pacing system analyzer. Temporary pacemakers (Medtronic 5388, Medtronic 5392, and Biotronik Reocor D) at nominal settings (VI 120 bpm, output 10 mA) were attached at the ventricular terminal to temporary pacing wires and a resistor for sham impedance in physiologic range. An RFID detection system and wand (RF Assure, model 200) or mat was tested over wires. Induced current and voltages were recorded via an oscilloscope attached to lead terminals. Inhibition of pacing was determined for the following variables: distance from wires, sham impedance, and programmed sensitivity.

RESULTS: In bench testing, the RFID system induced a stereotyped EMI signal in temporary pacing wires with peak root-mean-square voltage demonstrating an exponential decay relationship with increasing distance from pacing wires. Induced voltages overlapped with normal sensing range of temporary pacemakers, resulting in pacemaker inhibition at nominal settings (ventricular sensitivity 2.0 mV, distance from wand <23 cm). Increasing height, decreasing device sensitivity, or increasing sham impedance (at fixed sensitivity) attenuated EMI and inhibition for all 3 temporary pacemakers used and with the automated RFID detection mat in place of the wand. Programming pacemakers asynchronously prevented inhibition.

CONCLUSIONS: Normal operation of RFID detection systems may cause inhibition of temporary pacing systems consistent with oversensing from EMI. Precaution should be taken, including considering pacing asynchronously to avoid effects of inhibition. (Anesth Analg 2016;123:1143–8)

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Postoperative complete heart block, whether transient or permanent, is a well-known potential complication of surgical repair of congenital heart disease. Approximately 1% to 3% of patients require permanent pacing for complete heart block during the course of their postoperative convalescence. Many patients require temporary pacing in the immediate period postbypass period. Other types of cardiac surgery, including coronary artery bypass, may be associated with transient or permanent atrioventricular (AV) block. Abnormalities of intended pacemaker function may occur as a result of electromagnetic interference (EMI), including oversensing leading to inappropriate inhibition of pacing. With the proliferation of wireless technology in the hospital setting, sources of EMI may sometimes appear subtle. In the operative setting, radiofrequency identification (RFID) systems to detect retained surgical materials have proliferated in the past several years. These systems have been shown during in vitro testing to cause significant EMI in implantable pacemakers and ICDs as well as other medical devices. As a result, the potential for RFID interference is noted in operating specifications of these devices. However, labeling is not prominent, and a recent report highlights a single clinical case of temporary pacemaker inhibition from use of an RFID scanning system. Previous descriptions of in vitro interference have not reported RFID interference with normal permanent pacemakers in a clinical setting nor has the potential for interference with temporary pacing systems and wires been fully investigated.

We report 3 cases of inhibition of temporary epicardial pacing systems in the immediate perioperative period related to the use of an RFID detection system, corroborating the single case reported recently. RFID inhibition in temporary pacing systems was then investigated using a...
Clinical Background
The RF Assure Detection System (RF Surgical Systems, Carlsbad, CA) is a patented RFID device that has been designed for use in the operating room to locate and identify tagged surgical objects that may have been misplaced or retained in a patient. The device consists of a detection system, interface box and surgical sponges, or other materials individually tagged with small RFID transponders. Two essential models exist. In the wand-based system, a user-manipulated circular wand is passed sequentially over the surgical field to detect retained sponges embedded with tags that trigger an alarm. Alternatively, antennae are embedded in a mat placed under the surgical field. These antennae are then activated sequentially to perform the same detection process. Both mechanisms alert operating room staff to re-evaluate for retained sponges. The use of RFID detection systems has been incorporated into intraoperative surgical equipment count protocols at many institutions. Although the device directions for use include precautions regarding temporary pacing, these are not prominently displayed. There may be gaps in training, awareness, and operating room practices regarding the potential implications of RFID-induced EMI in intraoperative pacing systems. Thus, pacing-specific timeouts, coordination with anesthesiology staff, and other appropriate precautions may not be implemented if the potential ramifications of RFID use by operating room staff are not fully appreciated.

Clinical Cases
A 2-year-old girl with a partial AV canal defect presented for surgical repair consisting of closure of her primum atrial septal defect and mitral valve cleft. She underwent uneventful anesthesia, cardiopulmonary bypass (CPB), and surgical repair with monitoring including direct arterial and central venous pressure monitors in addition to American Society of Anesthesiologists standard monitors. External temporary pacing was initiated with a Medtronic 5388 (Minneapolis, MN) dual-chamber temporary pacemaker programmed DDD 130 beats/min via temporary epicardial wires. Atrial sensitivity was set to 0.5 mV, and atrial output was 10 mA with a ventricular sensitivity of 2.0 mV and output of 10 mA. During use of the RF Assure device, inhibition of pacing occurred in a pattern identical to the aforementioned case with resumption of pacing when the RFID wand was removed.

A third pediatric patient undergoing surgery for congenital heart disease subsequently experienced similar transient (<3 seconds) inhibition of pacing during RFID wand use in the acute postoperative setting while using identical pacing equipment and sensitivity settings. Pacing resumed once the RFID wand was removed, and the patient did not experience any lasting effect.

Each patient had Ethicon TPW20 (Somerville, NJ) temporary pacing wires implanted as part of standard clinical practice for perioperative rhythm management in patients undergoing surgical repair of congenital heart disease. In all 3 patients, inhibition of pacing was <3 seconds’ duration with resumption of pacing immediately after removal of the RFID wand. There were no lasting hemodynamic effects or adverse outcomes associated with transient inhibition of pacing. This is likely because of prompt recognition of the pacemaker inhibition and the brief nature of the episodes. Although significant adverse effects were not observed in this series, slightly longer pacemaker inhibition at a critical intraoperative period could result in significant and persistent hemodynamic changes, ischemic or pause-dependent arrhythmias, or other concerns. In addition, subsequent investigations of these pauses may divert attention from the other critical aspects of effectively and efficiently completing the operative procedure and transitioning to postoperative care.

METHODS
This study was reviewed by the institutional review board, and human research exemption was confirmed.

Testing was performed in vitro to clarify mechanisms of pacemaker inhibition, including EMI. To establish a range of impedances for ex vivo bench testing, temporary pacing-lead impedance was incidentally noted during routine rhythm analysis and lead testing for 9 atrial and 10 ventricular leads postoperatively, ranging from postoperative days 1 to 6 (median 3) using the Medtronic 2290 Pacing System Analyzer, measuring a single impedance per lead. Because
Permanent pacing leads have an inherently broad range of impedances clinically, we reasoned that a small sample of observed impedances of temporary pacing wires was a sufficient reference for bench testing. Impedances were averaged and expressed as mean ± standard deviation (SD). Of note, although common parlance refers to “lead impedance,” the predominant factor affecting impedance of the pacemaker-lead patient circuit is the lead–tissue interface, because an intact lead is itself a simple conductor, with minimal intrinsic impedance.

For bench testing, newly opened temporary pacing wires (Ethicon TPW20) were attached at the pacing terminal end to single-component axial lead resistors for sham impedances, an established surrogate for the complex impedance of the pacemaker electrode–tissue interface. Wires were extended in parallel between the lead terminals using standard connectors. Pacemaker-lead patient circuits were attached at the pacing terminal end of an oscilliscope attached in parallel arrangement with the pacemaker. Voltage amplitude (measured as peak RMS voltage) was also evaluated using the Medtronic 5388 device with wand (RF Assure, model 200) was tested above the pacing wires at various heights. Induced current and signals were recorded via an oscilloscope (BK Precision 2530B, Yorba Linda, CA) attached to lead terminals in parallel with the pacemaker. The peak root-mean-square (RMS) voltage of the induced signal was derived via analytic software included with the oscilloscope. This uses a calculus-derived equation to match the sinusoidal curve of the observed signal, a standard method for determining the voltage of an alternating current. The critical distance from the wires that exhibited inhibition of pacing was observed using graduated pacemaker ventricular sensitivity settings ranging from 1.0 to 8.0 mV. Using the Medtronic 5388 device, this critical distance was determined using a fixed pacemaker ventricular sensitivity setting of 2.0 mV over a graduated range of sham impedance, from 220 to 680 Ω. Induced signal and inhibition of pacing was also evaluated using the Medtronic 5388 device with sham impedance of 330 Ω using the automated RF Assure ConformPlus II detection mat in place of the manual wand. Additional details of the testing process are included in the Supplemental Materials (Supplemental Digital Content, http://links.lww.com/AA/B509).

The use of a wand-based RFID scanning system induced a consistent, stereotyped signal (145 kHz cycle) detectable in a physiologic sensing range for temporary pacemakers. Figure 2. Oscilloscope tracing of voltage induced by radiofrequency identification wand over temporary pacing wires, corresponding to a consistent, stereotyped signal (145 kHz cycle) detectable in a physiologic sensing range for temporary pacemakers.

**RESULTS**

Temporary pacing wires had measured impedances similar to those of standard permanent pacing leads: atrial 417 ± 105.7 Ω (n = 9) and ventricular 344 ± 66.3 Ω (n = 10). Given the average measured ventricular impedance of 344 Ω, we selected a sham impedance of 330 Ω and configured temporary pacing wires and pacemaker as detailed previously. The use of a wand-based RFID scanning system induced a well-circumscribed and stereotyped current in the pacing wires with a 145-kHz cycle (Figure 2), as measured with the oscilloscope attached in parallel arrangement with the pacemaker. Voltage amplitude (measured as peak RMS voltage of induced signal) varied in a predictable fashion, decreasing with increased distance of wand from pacing wires and increased sham impedance load. Figure 3 demonstrates the amplitude of voltages induced by the RFID wand when temporary wires were configured with sham impedance of 330 Ω while varying the distance of wand from wires. This exhibited an exponential decay relationship with increasing RF wand distance above wires, consistent with the physical principles of electromagnetic radiation (inverse square law). Most notably, at normal operating distances, the induced voltage signals overlap with the normal range of sensing for temporary pacemaker systems. At the programmed ventricular sensitivity of 2.0 mV (nominal setting), this resulted in reproducible pacemaker inhibition at distances <23 cm. This compares with the maximum distance of 24 cm for reliable detection of RFID tags during routine clinical operation. Repeating these measurements 3 times at each height resulted in reproducible findings with SDs ranging from 0.3 to 0.01 mV or 3% to 0.1% of the overall measurement. As expected, the variability was greater when closer to the table, where small differences in height...
that at 680 Ω, there was no inhibition even at very close distances (Figure 5).

The effects were reproduced in each of the temporary pacemaker systems tested (Medtronic 5388, Medtronic 5392, and Biotronik Reocor D) without any difference in function, oversensing, or inhibition in each of these units programmed with nominal ventricular sensitivity settings. Specifically, increasing height, decreasing device sensitivity, or increasing sham impedance (at fixed sensitivity) attenuated EMI and inhibition for all 3 temporary pacemakers when used with either the RFID detection mat or the wand. The critical height for inhibition could be mitigated by decreasing the sensitivity or by increasing the impedance of the system. With pacemakers programmed asynchronously (no sensing), no inhibition was observed. No interference with pacing function was observed with nominal settings when no wires or impedance were attached to the pacemaker.

**DISCUSSION**

Clinical inhibition of temporary epicardial pacing was observed in 3 patients undergoing surgical repair of congenital heart disease during the use of RFID detection system. In each of these cases, temporary pacemakers were programmed to a synchronous mode (DDD). The pattern of inhibition was consistent with oversensing of an electromagnetic signal produced by the RFID system.

Bench testing to replicate the clinical findings demonstrated that the RFID system induced a reproducible and stereotyped electromagnetic signal in temporary pacing wires attached to a sham physiologic impedance. The induced signal had characteristics overlapping with the normal range of pacemaker ventricular sensing. The RFID-induced signal resulted in oversensing and pacemaker inhibition during bench testing in all 3 temporary pacemaker models tested under normal operational parameters for the RFID detection system. The observed mechanics of signal induction and inhibition are consistent with known physical principles of electromagnetic radiation and EMI. These findings demonstrate the clinical relevance of these principles and were reproducible across different devices and test parameters. However, given the intrinsic variability of the biologic system, a false sense of precision regarding these results is unsupported (eg, exact height or sensitivity setting to avoid inhibition).

These findings support the hypothesis that RFID detection systems may induce clinically significant EMI when used in conjunction with temporary epicardial pacing systems in the acute perioperative setting. Although the package insert for the RFID system used includes general precautions about possible EMI and effects on pacing, specific labeling was not concisely or prominently displayed, which may lead to oversights in training and implementation. A rigorous approach is warranted to avoid potential clinical consequences during a period of physiologic vulnerability. As expected, programming temporary pacemakers in an asynchronous mode resolved the issue of oversensing in vitro.

Of note, oversensing and inhibition of permanent pacing systems have not been observed during use of the RFID detection system. This may be the result of common
operating room management of permanent pacemakers, which may include making them asynchronous with a magnet or periprocedural programming or improved shielding and noise reduction with permanent pacing leads and systems. The failure to recognize events does not mean that the events have not occurred. The combination of unipolar electrocautery interfering with the electrocardiographic monitor and music or other alarms interfering with attention to the pulse oximeter is an easily plausible scenario where inhibition may not be recognized.

The completion of a cardiac procedure involves multiple integrated steps by the operating room staff. The physiology is often quite dynamic with both recovery and development of AV block during the immediate perioperative period. Temporary pacemakers are frequently used as part of stabilizing patients. This report emphasizes that explicit attention to the pacing mode should be made before RFID detection protocols. Clinically, our institution’s protocol for use of the RFID system in postoperative cardiovascular surgical patients was modified to specifically include programming the temporary pacemaker (if in use) to asynchronous pacing before using the RFID system. No further clinical episodes of pacemaker inhibition or other concerns have been observed. Although asynchronous pacing effectively mitigates concerns for over-sensing and pacemaker inhibition, there are clinical contexts in which asynchronous pacing is suboptimal such as with frequent mechanical or spontaneous ectopy that could result in an R-on-T pacing event11–13 or during implantation and testing of permanent pacemaker systems while using temporary pacing for acute support. The possible risks of asynchronous pacing versus brief asystole from transient pacemaker inhibition as well as other concerns should be considered on an individual basis for patients undergoing cardiovascular surgery. A comprehensive intraoperative rhythm/pacing management strategy should be incorporated for each patient after weighing the different variables involved. Best practice suggests choosing appropriate pacing modes before transfer to the intensive care unit.14 To prevent adverse events, it is prudent to consider changes in hospital device implementation policies, operating room protocols and timeouts, and staff training to ensure that the potential effects of EMI on pacemaker function are well appreciated and anticipated and an appropriate treatment strategy implemented. Changes in device labeling to make possible EMI effects on pacemakers more explicit and prominent may be helpful in ensuring that this potential consequence is uniformly recognized.

RFID had been in use for several months before our first recognized episode of inhibition. There are multiple potential reasons for the delay in recognition. Temporary pacemakers are frequently in a backup mode because of concern about previous or potential AV block or in patients with reasonable escape rhythms. Inhibition in those situations has no physiologic effect and hence would only be recognized by observing the change in the sense indicator on the temporary pacer. Similarly, if the lead impedance is relatively high, the threshold for inhibition is increased.

CONCLUSIONS
RFID systems commonly in use to detect detained surgical materials may cause clinically significant transient inhibition of temporary pacing systems in the acute postoperative setting. This effect was replicated in bench testing and found to be consistent with inhibition because of over-sensing of induced EMI. The characteristics of the observed EMI are consistent with the expected physics and engineering of both the RFID and the pacing systems. Care should be taken to program pacemakers asynchronously before use of the RFID system or to otherwise take precautions to avoid clinically significant effects of pacemaker inhibition during an acutely vulnerable physiologic period. 🏷️

DISCLOSURES
Name: Matthew R. Williams, MD.
Contribution: This author helped design the study, conduct the study, collect the data, analyze the data, and prepare the manuscript. He was the primary author of the manuscript.
Name: Douglas B. Atkinson, MD.
Contribution: This author helped design the study, conduct the study, collect the data, analyze the data, and prepare the manuscript. Dr. Atkinson was part of the team that recognized this clinical phenomenon. He summarized the case series, which was presented (as a case series alone) to a local anesthesia meeting.
Name: Vassilios J. Bezzerides, MD, PhD.
Contribution: This author helped design the study, conduct the study, collect the data, analyze the data, and prepare the manuscript. He designed the model, provided the instrumentation, and assisted with variations of the model.
Name: Koichi Yuki, MD.
Contribution: This author helped collect the data, analyze the data, and prepare the manuscript. He was part of the team that recognized this clinical event, helped facilitate prompt clinical assessment of the interaction, and critically reviewed the manuscript.
Name: Kathryn Franklin, BSN, RN, CNOR.
Contribution: This author helped collect and analyze the data. Ms. Franklin was the lead nurse in the operating room at the time of the event, assured that operating room protocols changed to reflect the new findings, and critically reviewed the manuscript.
Name: Alfonso Casta, MD.
Contribution: This author helped collect and analyze the data. He was part of the team that recognized this clinical event, helped facilitate prompt clinical assessment of the interaction, and critically reviewed the manuscript.
Name: Mark E. Alexander, MD.
Contribution: This author helped design the study, conduct the study, collect the data, analyze the data, and prepare the manuscript. He performed the initial in-hospital review, arranged for additional expertise, facilitated room and equipment for additional testing, coordinated with vendors for alternative devices, and edited the manuscript.
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Intraoperative Temporary Pacemaker Inhibition by RFID Scan


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