Technical Report

Electrocardiographic "pacemaker pseudo-spikes" and radio frequency interference

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Purpose: To present a case of apparent interference of an ECG monitor by radiofrequency interference (RFI) and to provide a brief review of RFI issues relevant to critical care medicine.

Clinical features: A 74-yr-old woman, with an implanted pacemaker, underwent major spinal surgery. In the post-anaesthesia care unit, the cardiac monitor demonstrated graphic evidence of pacemaker malfunction but there was no apparent effect on the patient. Investigation by the hospital's biomedical personnel led to the conclusion that RFI was being interpreted by the monitor as abnormal pacemaker activity.

Conclusion: With the emergence of portable, battery-operated communication devices, there is an increased risk of RFI within hospitals. Antennas and repeaters are required to receive and boost the signal levels of these devices to improve signal quality. They are located throughout hospitals and may be situated near patient care areas. Patient monitors may receive these signals, misinterpret them as being patient-generated and output erroneous information. In the case described, the monitor was presented with RFI signals and interpreted them as pacemaker spikes, generating a tracing suggestive of pacemaker malfunction. Troubleshooting strategies and minimizing the potential impacts of RFI on patient monitors are discussed.

Objectif : Présenter un cas d'interférence radiofréquentielle (IRF) apparue sur un moniteur ECG et passer brièvement en revue les problèmes de l'interférence radiofréquentielle en réanimation.

Éléments cliniques : Une femme de 74 ans porteuse d'un pacemaker implanté subissait une chirurgie rachidienne majeure. À l'unité des soins postanesthésiques, un enregistrement du moniteur cardiaque révélait un mauvais fonctionnement du pacemaker sans effet apparent sur la patiente. Un examen du personnel biomédical de l'hôpital permettait de conclure que l'IRF était interprétée comme une activité anormale du pacemaker.

Conclusion : L'apparition des instruments de communication portables alimentés par piles augmente le risque d'IRF à l'intérieur des hôpitaux. Dans le but d'améliorer la qualité des signaux, des antennes et des répéteurs sont utilisés pour recevoir et amplifier les signaux fournis par ces appareils. Ils sont localisés dans les hôpitaux et peuvent être situés près des secteurs de soins. Les moniteurs des patients peuvent capter ces signaux, les interpréter comme s'ils étaient générés par les patients et fournir ainsi de fausses informations. Dans le cas présent, le moniteur percevait des signaux d'IRF et les interprétait comme des pointes d'ÉCG, générant ainsi un tracé suggestif d'un dysfonctionnement de pacemaker. Les stratégies de détection et de correction destinées à minimiser les impacts potentiels de l'IRF sur les moniteurs font l'objet de la discussion.

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APPROPRIATE clinical decision-making is dependent upon receipt of accurate information from patient monitors. Although interference with biopotential recordings by monitors is common, it is usually readily apparent and unlikely to influence decisions. More subtle forms of monitor interference may occur and may not be so readily detected; an example is radiofrequency interference (RFI). Although ubiquitous in hospital settings, RFI is also highly variable across that environment. A case is presented of RFI monitor interaction which initially led to concerns about pacemaker malfunction which were only resolved after detailed analysis of the equipment and the environment by hospital biomedical engineers.

Clinical report

A 74-yr-old woman presented for spinal instrumentation and fusion for scoliosis. She had a history of congestive heart failure, chronic obstructive lung disease and complete heart block for which a DDD pacemaker (MedtronicTM Thera 96011, Medtronic, Minneapolis, MN) had been implanted. Preoperative laboratory test results were normal including serum electrolyte concentrations and acid-base balance. An ECG demonstrated a predominately paced rhythm, with appropriate atrial and ventricular responses. She underwent a 7.5-hr spinal decompression and instrumentation. Estimated blood loss was three litres and she was given 5.5 l crystalloid, four units packed cells and 1.2 l salvaged, washed cells. She developed a left haemopneumothorax postoperatively, which was treated with chest tube drainage, and she was given additional blood, plasma and platelets. Her serum potassium concentration decreased to 3.4 $mmol \cdot L^{-1}$ and serum chloride increased to 120 $mmol \cdot L^{-1}$ immediately after surgery. Her trachea was extubated on the second postoperative day and, after convalescence, she was discharged from hospital.

In the Post Anaesthesia Care Unit (PACU) the patient was connected to a Spacelabs™ Medical PC1 (©Spacelabs Medical, Redmond, WA) monitor and a continuous ECG, arterial and central venous pressures and pulse oximetry were monitored. Markers were observed on the ECG trace that, although similar to pacemaker "spikes" in appearance, appeared at times other than that expected from a DDD pacemaker. These extra spikes produced no physiological responses in the patient and presented both as occasional signals (Figure 1A) and as a near-continuous signal (Figure 1B). Because of the typical pacer "spike" mark on the ECG trace, in the absence of an apparent physiological response to the pacemaker signal, concerns were expressed regarding the possibility of pacemaker malfunction as well as cardiac conduction abnormalities. A cardiology consultant offered no insight other than an opinion that the pacemaker was unlikely to be the source of the spikes.

Brief initial assessment by the hospital biomedical engineering department concluded that these markers were likely due to high frequency artifact. This was based on the short duration and fast rise-time ('spike' appearance) of the waveforms. However, given that the signal was present within an otherwise noise-free ECG trace, more extensive evaluation was felt to be indicated.

Investigation of cause

All power cords were moved from the patient and the ECG lead-wires to reduce nearby sources of electrical interference. The ECG electrodes and lead wires were then replaced to eliminate the potential for both poor electrode patient coupling and a fracture within any of the ECG lead-wires, respectively. All processing of ECG information on the monitor in question is performed within the multiparameter module; it was changed to eliminate it as the source of the artifact. The bandwidth was changed, via an on screen menu selection, to confirm that the baseline was noise free. In order to rule out high frequency artifact, the bandwidth setting was increased from monitor mode (range 0.5 Hz to 40 Hz) to extended mode (range 0.05 Hz to 100 Hz) to permit capture of more diagnostic information. When these methods for minimizing artifact failed to eliminate the phenomenon, the monitor's *Pace Mode* was turned off. This was done to determine the ECG signal appearance, without the monitor inserting the pacemaker markers. With the *Pace Mode* off, the ECG signal was noise free and demonstrated small pacemaker pulses in appropriate locations. (Figure 1C) Clinical assessment of the patient confirmed appropriate physiological responses to these pacemaker pulses. At about this time, the patient was transferred to the Intensive Care Unit (ICU) and connected to a Hewlett Packard™ CMS monitor (©Hewlett Packard, Greely, CO). The ECG trace generated by the Hewlett Packard™ monitor was free of noise. Additionally, there was no evidence of the extra spikes nor could they be reproduced.

By this time, we were confident that we had eliminated the patient, lead wires, pacemaker and ECG module as factors in the generation of the mystery spikes. Our attention was now directed towards the possibility of radio frequency interference (RFI) or fluctuations on the power line, including ground continuity, as the cause. Using a spectrum analyzer, the

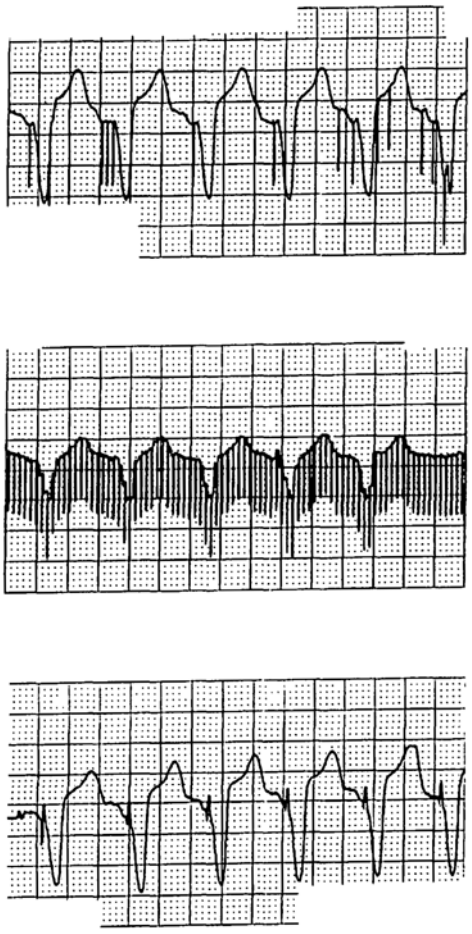

FIGURE 1 Electrocardiogram trace demonstrating occasional artifact spikes (A), near continuous artifact spikes (B) and the trace obtained with Pace Mode disabled (C).

presence of RFI in the PACU environment was assessed. The spectrum analyzer, modified with various antennas, allowed frequencies from 1 Hz to 9GHz to be monitored. With the exception of a small amount of 60 Hz interference, all other monitored frequencies were measured at levels <0.1 v/m, too low to cause interference. Since testing for RFI occurred several days after the patient was transferred to the ICU, similar types of equipment as had been in place during the patient's stay in the PACU were gathered in an attempt to determine the possible sources of RFI. Testing for RFI provided no insight to the problem and next, the ground continuity and the quality of the power was assessed. A line voltage monitor was placed in the PACU for one month. During that time there were no spikes or sags in the supply voltage of any magnitude. The ground continuity assessment indicated that the grounds were secure and intact. The pin retention values of the electrical outlets within the PACU were also determined; all measured values were greater than 20 ozs., ensuring the integrity of the electrical receptacles. Finally, we concluded that the origin of the abnormal signals was RFI emitted from a source which was portable and has since been removed from the site.

In an attempt to simulate the tracings observed on the monitor, a volunteer agreed to be connected to the physiological monitor. *Pace Mode* was activated and sources of radio frequency (RF) emitting devices were placed in the environment. The only instance in which we were able to reproduce a similar ECG tracing was with a peripheral nerve stimulator (PNS) connected to the volunteer. However, this was not the source of artifact documented with our patient as no PNS was attached.

As part of the evaluation of the phenomena, recordings were forwarded to both the manufacturer of the pacemaker and the PACU monitor. The pacemaker manufacturer, Medtronic™, informed us that there was no circuitry within the pacemaker which would generate a signal similar to the one recorded. The Product Engineering Group at Spacelab™ Medical reviewed the tracing and suggested that the artifact was likely caused by 60 Hz interference in the monitor's environment which was interpreted by the monitor as pacemaker output.[1] They further commented that the interference wouldn't be noticed on the cardiac monitor with the *Pace Mode* off because of a 60 Hz notch filter.

The notch filter is contained in the multiparameter module. It is designed to attenuate 60 Hz noise, which is prominent in the electrical environment where power is supplied at 120 volts and a frequency of 60 Hz. Within North America, the 60 Hz notch filter is always activated in physiological monitors. It functions independently of *Pace Mode* and should have effectively filtered the interference if it were 60 Hz. If the problem had been related to a defective notch filter, the issue should have been resolved with the replacement of the multiparameter module. Thus, we do not agree with the opinion of Spacelabs™ Medical and do not believe that the source of the RFI was 60 Hz.

Pace Mode is a feature found on several, but not all, physiological monitors to ensure that the pacemaker spike is rejected as the QRS complex. Thus, pacemaker spikes will not be seen as heartbeats of the monitor. This is especially important in the event of an asystole episode (absent ventricular response to pacer dis-

charge), in a patient with an implanted pacemaker, where an accurate heart rate assessment is vital to activate appropriate alarms.[2,3]

Discussion

We have reported a case of RFI being misinterpreted by a cardiac monitor as pacemaker output. Although there have been many reports of interference of both pacemaker and monitor function by environmental noise, we believe this particular variation to be unique.

For diagnostic-quality ECG recordings, signal acquisition must be noise free. Since ECG signals are only of the order of 1 mV in amplitude, signal acquisition is susceptible to interference from other biological and environmental sources. This interference appears on the ECG signal as noise or artifact. For the purpose of this discussion we have defined low frequency to be <2 Hz and high frequency to be >20 Hz. Low frequency interference typically presents as baseline wander and is caused by respiratory and motion artifact. Motion artifact can make ECG interpretation difficult as measurements with respect to the isoelectric baseline are affected and the smaller amplitude atrial responses can be hidden within the noise. Higher frequency interference presents as a thick dark baseline; it is caused by higher intensity muscle artifact such as shivering, or 60 Hz interference. The human body generates muscle noise recorded as an electromyogram (EMG). The EMG noise is of the same order of amplitude as ECG signals but occurs at higher frequencies and it can be reduced by lowering muscle activity during the ECG recording.[4,5]

Electrical interference is probably the most pervasive problem in biopotential recording. Surrounding power cords, electrical instruments and transformers all radiate electrical energy, which become electrically or magnetically coupled to the body. The human body, the electrode leads, and the ECG monitor form a loop and environmental electromagnetic fields can induce a current in this loop. Induced current flowing through the ECG electrodes and the amplifier input can then add interference to the ECG signals. Other sources of environmental electrical interference are radio-frequency (RF) transmitters. Electrical and medical devices, such as electric motors and electrosurgical units (ESUs), generate the interference signals indirectly.[6–8] Such interference is picked up by electrical conduction or induction and may be minimized by: establishing a safe distance (1–3 m) between the source and the monitor; isolating the patient cables; using cables with built-in RF filters; reducing the bandwidth settings on the monitors; and ensuring the proper placement of the return electrodes for ESUs.

Increasingly, personal pagers, hand-held, two-way radios and cellular phones are utilized within patient care areas.[9] All are RF-transmitters and generate RFI in the environment. Hand held radios used in the hospital environment are typically powered at 3–6 W but operate at that level only when receiving or sending. Antennas and repeaters are required to ensure adequate signal strength and placement of these antennas and repeaters is critical for proper operation. However, if they are placed in proximity to patient care areas, unexplained artifacts and pseudo-equipment failures may occur.[10–17] The goal is to place the antennas and repeaters in locations that optimize signal strength while minimizing the impact on patient monitors. Patient care areas can be assessed periodically to ensure that RFI does not reach levels likely to impact on the proper function of patient monitors. Although it is possible to shield patient care areas to minimize the magnitude and impact of RFI, this is usually a more costly proposition than limiting RFI generation proximate to these areas.

Conventional cellular phones typically have a maximum power output of 600 mW, although some may be as high as 1.2 W.[9] While powered on and in *standby* mode, they constantly send impulses to their cell (outpulsing), to determine their location within a cell (a geographic area). Outpulsing is done at the maximum power of the unit. While in use, many phones have an *autogain* feature that allows the phone to adjust power, often scaling it down, to maintain adequate signal strength. Thus, a phone in *standby* mode often poses a greater threat of RFI than one actually in use.

Strategies to reduce excess RFI in patient care areas include: 1) not allowing patients or visitors to use conventional cellular telephones or other RF transmitting devices in the hospital; 2) ensuring that cellular phones brought into the hospital are turned OFF, not on *standby*, because transmission will occur in the standby mode even while the phone is not in use; ensuring that hospital users of RF-transmitting devices are aware of the possibility of interference with clinical equipment so that unnecessary transmissions can be avoided while in proximity (~1 metre) to medical devices in such areas as patient rooms, critical care units, emergency rooms, operating rooms, diagnostic and treatment areas, and clinical laboratories. Restrictions concerning patient use of transmitting devices may be relaxed in long-term rehabilitation areas, in which interference is unlikely because of distance from devices of concern and in which such use may enhance feelings of well-being and promote recovery.

A pacemaker applies voltage pulses to the heart to initiate depolarization and contraction.[6,18,19] Although

the heart normally responds to each pacing pulse by contracting, in some instances, the heart does not respond. This is referred to as "loss of capture" and the ECG monitor should not respond to the pacemaker output as a valid myocardial signal; it should alarm. Failure to reject the pacemaker signal as a valid heart beat will result in an erroneous heart-rate display and no heart-rate alarm indicative of failed capture.

Failure of pacemaker capture may also occur with lead fracture or displacement. Acute changes in electrolyte concentrations or acid-base balance may alter the response to pacemaker output. For example, acute hypokalaemia may cause loss of capture. A pacemaker can produce a dangerous tachycardia in a number of ways. If a failing (failure to sense) pacemaker intersperses its stimuli midway between competing sinus beats, the effect is a series of interpolated beats producing a tachycardia at about twice the native rate. This "runaway pacemaker" may fire at a rate of several hundred times a minute, driving a rapid and possibly lethal tachycardia. These factors fostered the concern for our patient; she had just experienced a major surgery and resuscitation and was acutely hypokalaemic. Additionally, there was graphical evidence of multiple pacemaker spikes without evidence of capture.

A pacemaker pulse is represented as a spike or marker by cardiac monitors. These markers are generated within the monitor and are superimposed on the ECG rhythm strip each time a pacemaker pulse is detected. The Association for the Advancement of Medical Instrumentation (AMMI) criteria for pacemaker marker generation is threefold: 1) the amplitude of the detected pulse must be >2 mV amplitude; 2) the pulse width of the detected pulse must have a pulse width between 0.1 and 2.0 msec; and 3) the rise time of the detected pulse must be less than 10% of the pulse width (0.01 to 0.2 msec).[20] The RFI produced by a portable, handheld transmitter may satisfy the above mentioned criteria.[21–23]

Conclusion

In any technological environment, there is the potential for the operation of one device to interfere with that of another. In critical care areas, the most common way in which this occurs is by 60-Hz interference. Electromagnetic emissions and the propagation of signals through power cords are additional means. Device failures in clinical areas usually necessitate only a moderate level of troubleshooting to identify the problem. Occasionally, however, problems are encountered that are more complex and that require a higher intensity assessment by the biomedical engineering group.

Manufacturers of patient monitoring equipment are continuing in their efforts to enhance the immunity of their monitors to interference. However, it is our opinion that clinicians should be aware of the potential impact of RFI on patient monitors as it may occasionally result in the generation of erroneous information.

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