Electromagnetic Interference of Communication Devices on ECG Machines

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ABSTRACT

Background: Use of communication devices in the hospital environment remains controversial. Electromagnetic interference (EMI) can affect different medical devices. Potential sources for EMI on ECG machines were systematically tested.

Hypothesis: Communication devices produce EMI on ECG machines. EMI impairs ECG interpretation.

Methods: The communication devices tested were: a global system for mobile communication (GSM) receiver, a code division multiple access (CDMA) receiver, an analog phone, a wireless local area network, and an alpha-numeric pager. EMI was tested on 3 ECG machines: MAC 5000, MAC 1200, and ELI 100. The devices were tested at 2 and 1 meter, 50, 25, and 0 cm from the acquisition module. The ECGs were presented to a heterogeneous group of clinical providers, (medical students, residents, nurses, industry representatives from cardiac devices companies, and attending cardiologists) to evaluate the impact of EMI on ECG interpretation skills.

Results: EMI was detected on the MAC 5000 ECG machine when activated GSM, CDMA, and analog phones were placed on top of the acquisition module. No EMI was seen on the other ECG machines or when phones were at a longer distance or deactivated. EMI was incorrectly diagnosed in 18% of the cases. EMI was confused most frequently with atrial fibrillation or flutter (52%), ventricular arrhythmias (22%), and pacemaker dysfunction (26%). Medical students ($p<0.003$) and non-cardiology residents ($p = 0.05$) demonstrated significantly worse performance on EMI interpretation.

Conclusions: Digital and analog phones produce EMI on modern ECG machines when activated in direct contact to the acquisition module. EMI impairs ECG interpretation.

Introduction

Electromagnetic interference (EMI) over medical devices has been widely established,[1] yet its clinical consequences remain controversial.[2,3] Some groups have recommended the outright ban of the in-hospital use of cellular phones to avoid any possible malfunction of medical devices.[3] Other groups, recognizing the difficulty of enforcing such bans in addition to the close proximity needed between devices to produce EMI, suggest that cellular phone use be limited to noncritical care areas of a hospital.[2]

Mobile cellular phones and other wireless communication devices are widely used by in-hospital care providers.[4] However, these devices have not been specifically designed for in-hospital use; and it has been established that these devices produce EMI that may interfere in the operation of cardiac monitors,[5] pacemakers,[6] implantable defibrillators,[7] and ventilators.[8,9]

Electrocardiograms (ECGs) are recorded in many health care settings and often represent the first-line of testing undertaken by ECG technicians, nurses, physicians, and personnel under training to establish a diagnosis. Although ECG recordings are frequently done, the quality of recording is essential for proper interpretation. Artifact due to EMI on ECG recordings may lead to interpretation mistakes, unnecessary medical treatment, and potentially dramatic medical errors.[10,11]

For the purpose of this study, we hypothesized that cellular phones and other commonly encountered in-hospital communication devices may produce EMI that adversely affects the operation of ECG machines. The resulting artifact may lead to the inability of different groups of care providers to properly interpret ECG results.

Methods

Communication Device Testing

Electromagnetic emissions produced by 5 communication devices commonly used at our institution were tested on the 3 ECG machines available in the hospital: MAC 5000 (General Electric, Chicago, IL, USA), MAC 1200 (General Electric, Chicago, IL, USA) and ELI 100 (Mortara,

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Milwaukee, MN, USA). The tested communication devices included: a global system for mobile communication (GSM) receiver (Motorola V220; 900 MHz, 1800 MHz, 1900 MHz), a code division multiple access (CDMA) receiver (Sanyo SCP 2300; 800 MHz, 1900 MHz), an analog phone (Nokia 6275i; 800 MHz), a commonly encountered in-hospital cordless phone (Nortel WLAN Handset 2211; 2 400–2483.5 MHz), and an alpha-numeric pager (Suntelecom ST800 Flex; 900 MHz).

GSM and CDMA devices represent current generation digital cellular phones and differ in the frequency that they transmit and receive information. Both GSM and CDMA technologies are utilized in North America, while GSM is more predominant in European mobile devices. Analog devices represent the previous generation of cellular devices and are utilized in modern phones in addition to CDMA or GSM technology in order to provide better coverage in areas where digital signals are not available.

An isolated room without metallic objects and no operating electrical devices was used as the test site. Any object that could potentially absorb or reflect electromagnetic radiation produced by the communication devices was removed. To ensure that the cellular phones operated at or near maximal power output, a testing site with weak incoming signal strength was selected. The floor at the study site was marked with tape at distances of 2 m, 1 m, 0.50 m, and 0.25 m from the ECG acquisition module. All the communication devices were tested in their activated (ON) and deactivated (OFF) functional modes and tested at a height of 1 m. External phone calls were made to each of the communication devices while they were activated and ECGs were obtained during the phone calls to determine if EMI resulted in artifact. This procedure was repeated, but with the communication device deactivated (OFF). The entire protocol was repeated for each subsequent communication device. To ensure that cellular telephone EMI did not cause a change in the function of the ECG machine, maintenance checks were performed after each stage of the experiment to ensure normal functioning. Electronic and hard copies of all ECGs were stored for further analysis. Two blinded investigators (Damian P. Redfearn, Christopher S. Simpson) analyzed the ECGs for EMI. Disagreement was resolved by consensus.

Clinical Impact of EMI on ECG Interpretation

To assess if EMI artifact on ECG recordings could impair proper ECG interpretation we administered a test consisting of a series of 6 randomly organized ECGs to different groups of health care providers (medical students, registered nurses, ECG technicians, industry representatives from cardiac devices companies, cardiology residents, non-cardiology residents, and attending cardiologists). The test consisted of 3 typically encountered scenarios in clinical practice (ventricular tachycardia, atrial flutter, and ventricular paced rhythm with underlying atrial fibrillation) alternated with 3 normal sinus rhythm ECGs with EMI induced artifact. The test was administered under supervision and was timed, allowing 12 min for completion. The test was anonymous, but demographic data (age, gender, position) were collected. Instructions were given that only 1 diagnosis per ECG would be accepted and in the event of multiple responses, the first one was used for analysis.

Statistical Analysis

Data were entered into an Excel spreadsheet, and imported into SPSS (Version 14.0, SPSS Incorporated, Chicago, IL, USA, 2006) for analysis. Data were described using frequencies for categorical data, and means and standard deviations for numeric data. Data for the 3 EMI altered ECGs were combined, coded as to whether they were correct or incorrect due to EMI, and assessed for an effect of position and age using chi-square tests (Pearson's or Fisher's exact as appropriate) and an independent samples *t* test.

Results

The test of all devices was done without technical difficulties during the same day. It took 8 h to complete the tests. A total of 150 separate phone calls were performed from an external wire phone. In the instance of any observed EMI, the test was repeated to ensure reproducibility of the artifact.

EMI was found when the GSM digital phone (Figure 1), the CDMA digital phone (Figure 2), and the analog phone (Figure 3) were activated within close proximity (on top) of the acquisition module of the MAC 5000 ECG machine. EMI was easily reproducible by repeating a phone call to the same device at the same distance. At distances of 2 m, 1 m, 0.50 m, and 0.25 m, no EMI was detected and normal ECGs recordings were obtained. No EMI was detected when devices were tested in their deactivated mode (OFF). The cordless phone and the pager did not alter the quality of any of the ECG recordings.

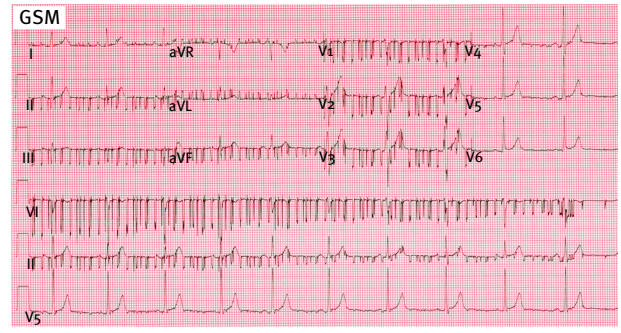

Figure 1. EMI induced by a GSM phone: GSM cellular phone induced EMI on the operation of the GE MAC 5000 showing a series of very sharp high-voltage spikes at a cycle length of approximately 130 msec.

Figure 2. EMI induced by a CDMA phone: CDMA cellular phone induced EMI on the operation of the GE MAC 5000 showing very sharp high-voltage almost continues spikes. Note lead I free of interference.

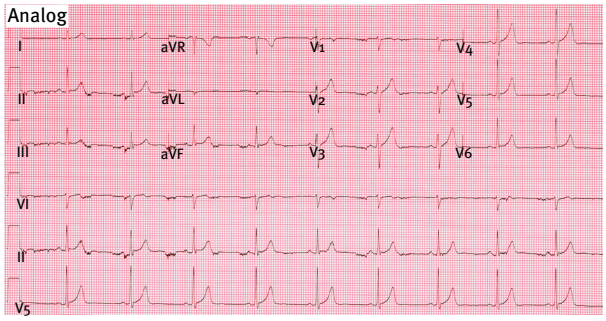

Figure 3. EMI induced by an Analog phone: Analog cellular phone induced EMI on the operation of the GE MAC 5000 showing low-voltage irregular spikes.

There was 100% agreement between the 2 blinded investigators in detecting the 3 EMI cases over 150 reviewed ECGs.

In all, 93 participants responded to the test, producing 279 observations (3 EMIs per participant). Age ranged from 23 to 62 years, with a mean of 34±9 years. The sample included 38 (41%) males and 53 (57%) females; an additional 2 did not indicate their gender. There were 21 (23%) medical students, 27 (29%) registered nurses and ECG technicians, 7 (8%) industry representatives, 14 (15%) cardiology residents, 18 (19%) non-cardiology residents, and 6 (7%) attending cardiologists.

EMI was confused with other common clinical diagnoses in 50 (18%) of the 279 cases. Within these 50, the most frequent misdiagnoses were: atrial fibrillation (40%), ventricular tachycardia or fibrillation (22%), pacemaker dysfunction (26%), and supraventricular arrhythmias including atrial flutter (12%). Incorrect answers were more frequent in medical students (33.3%) followed by non-cardiology residents (20.4%), industry representatives (19%), nurses and technicians (12.3%), cardiology residents (9.5%), and cardiologists (without mistakes); $p<0.003$ (Figure 4).

Discussion

Varying policies with respect to the use of wireless communication devices exist according to individual hospital regulations.[1,9] Regardless of the stringency of some of these rules, the presence of communication devices in health care settings is likely to grow given the need for improved and quicker communication between members involved in a patient's care as well as the growing use of these devices in the general population.

The initial restrictions on the use of wireless devices, such as cellular telephones, in hospitals were based on anecdotal reports and clinical studies of the possible interaction and malfunction on a wide variety of medical devices.[5–8,12] However, since these earlier reports, medical equipment and cellular telephone manufacturers have worked to increase the shielding of medical equipment to EMI as well as to decrease EMI causing emissions of communication devices.

A systematic literature review revealed little information on cellular phone- induced EMI on the operation of ECG machines. A single case report revealed a patient with a series of abnormal ECGs which were characterized by interference which was later attributed to the patient's cellular phone operating in its silent mode.[13]

In the present study, we assessed the ability of 5 commonly encountered in-hospital wireless communication devices on the function of 3 ECG machines available at our hospital. To assess whether technological changes by medical device manufacturers have reduced the potential for clinically relevant EMI, both current generation ECG machines (MAC 5000 and MAC 1200) and a previous generation machine (ELI 100) were used in our study.

Most of the ECG machines were immune to RF emissions produced by cellular phones. Only the MAC 5000, a new generation ECG machine with an external acquisition module, was vulnerable to the emissions produced by all the tested cellular telephones (GSM; 900 MHz, 1800 MHz, 1900 MHz, CDMA; 800 MHz, 1900 MHz, and analog; 800 MHz receivers), when placed in close proximity to the external acquisition module. No EMI was encountered at any other distances. The acquisition module is an external or internal component to the ECG machine and is the site where analog information is converted to a digital signal. The acquisition module has been found as a potential vulnerable site for RF emissions from wireless devices.[10] The effects of the CDMA cellular phone emissions were more pronounced qualitatively, than those produced by either the GSM or analog cellular phones.

The total incidence of EMI in this study was low (2%) and the only effect of EMI on these medical devices was artifact in the ECG recording. Also, although EMI did not impair the function of any of the ECG machines studied, this artifact had impaired proper ECG interpretation when it was evaluated by different groups.

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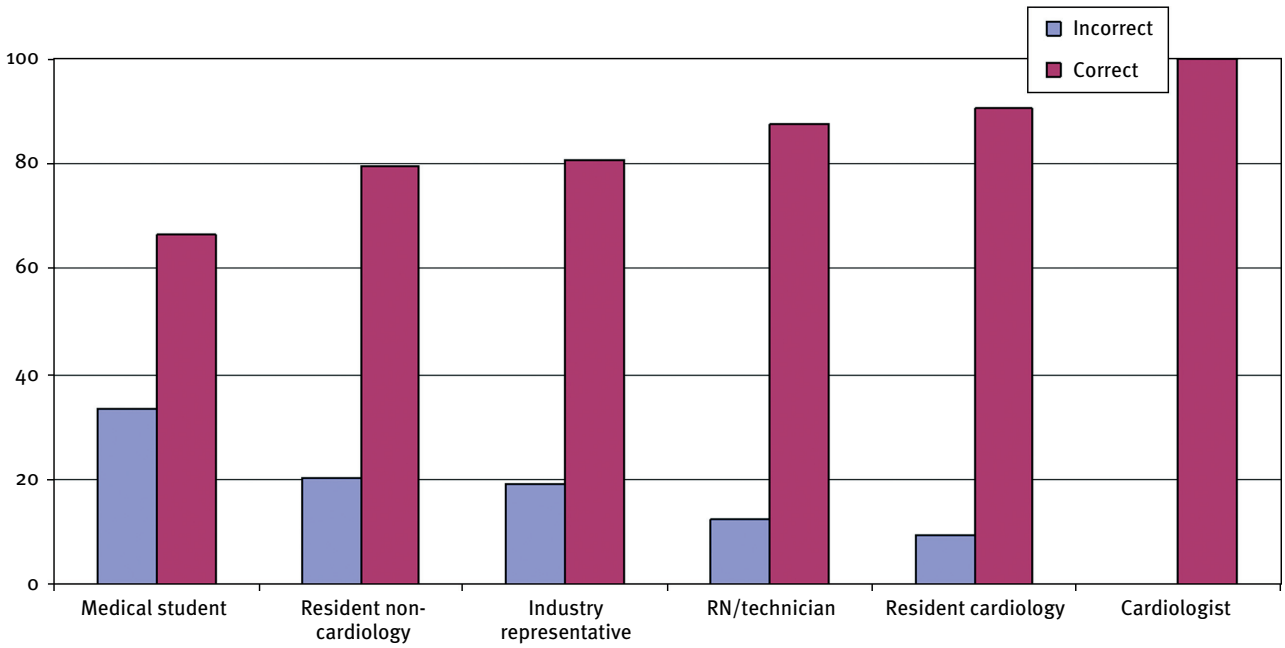

Figure 4. Interpretation of ECG recordings: Interpretation of EMI- induced artifact on ECGs recordings according to different health care providers (in percent). Medical students did significantly worst and cardiologists significantly better (Pearson chi-square = 18.1, $p < 0.003$).

Analysis of the responses from different health care professionals revealed a significant difference between groups in terms of interpretation of EMI artifact on ECGs (medical students and non-cardiology residents did significantly worse than cardiology residents and cardiologists, $p<0.003$). This may result in potentially serious medical errors.[10,11] In some academic institutions, medical students and junior residents are the initial call for patient care and thereby the initial decision maker. This instance could result in potential misdiagnosis due to EMI artifact on an ECG and could lead to inappropriate medical treatment. A significant number (40%) of EMI misdiagnoses corresponded to atrial fibrillation and consequently anticoagulation would be potentially started based on this incorrect interpretation.[14,15] Ventricular tachycardia or fibrillation was also a frequent misinterpretation and this could potentially result in severe medical errors such as providing unnecessary antiarrhythmic medication or delivering electrical cardioversion.[16] Finally, another frequent EMI misdiagnosis was a dysfunctional pacemaker that could result in unnecessary consultations if the decisions were made based solely on ECG interpretation.

The lack of EMI affecting ECG recordings at distances longer than 0.25 m, should allow health care providers in charge of recording ECGs, the use of any communication devices. Precaution about the distance or deactivating the cellular phone during the ECG recording may be enough to prevent distortion of the recordings.

Limitations

Other types of communications devices, which are becoming more prevalent in hospital environments, such as personal digital assistants and "Blackberry" type devices, were not tested in our study. These devices operate at frequencies and power levels similar to that of other cellular telephones, and would be expected to produce EMI- induced artifact on ECG machines similar to that seen in our study.

Different frequencies in multi-band cellular devices were not systematically tested in order to determine the effect of frequency on EMI production. Further studies would be needed to better characterize medical device susceptibility to those particular frequencies.

The protocol of this study was limited to the ringing phase of the cellular telephone, which was previously found to be the phase with higher probability of inducing EMI.[3,5–7,9] Other operations such as speech and other forms of data transmission were not evaluated.

Finally, other modalities of cardiac rhythm monitoring such as telemetry units and ambulatory Holter and Event monitors were not tested in this experiment.

Conclusion

Communication devices (cellular phones) produce EMI on ECG machines. This occurs when cellular phones are activated in direct contact to the acquisition module. Certain current generation ECG machines with external acquisition modules are more susceptible to EMI.

EMI is not well recognized during ECG interpretation and is frequently misdiagnosed as other serious conditions. These misinterpretations may result in preventable medical errors.

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