

Cellular Phone Interference With External Cardiopulmonary Monitoring Devices

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- **Objectives:** To determine the potential effect (electromagnetic interference) of cellular telephones on external cardiopulmonary monitoring devices.

- **Methods:** For this study, we tested 17 different medical devices with 5 portable telephones (4 digital, 1 analog) to assess the potential for electromagnetic interference. The telephones were tested in a normal operating mode to simulate a typical hospital environment with patients or their families using their cellular phones. The medical devices were connected to the appropriate simulators for proper operation while the tests were under way. The screens and alarms of the medical devices were monitored

while the telephones were maneuvered in the y and z planes near the devices. Clinically important interference was defined as interference that may hinder interpretation of the data or cause the equipment to malfunction.

- **Results:** Any type of interference occurred in 7 (41%) of the 17 devices tested during 54.7% of the 526 tests. The incidence of clinically important interference was 7.4%.

- **Conclusions:** Cellular telephones may interfere with the operation of external cardiopulmonary monitoring devices. However, most of the test results showed that the interference would rarely be clinically important.

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Recently developed hospital policies on the use of wireless cellular phones within the hospital environment have not been based on objective experimental or clinical testing. Instead, cellular phones have often been banned from the hospital environment based on the theoretical concern that wireless technology could interfere with medical equipment. A considerable amount of research has been done in the field of wireless technology and its potential interactions with implantable devices.¹⁻⁸ Although there has been some general testing of the effect of cellular phone use on external equipment in the hospital environment, the results have been inconclusive.^{4,9-15} Our purpose was to assess a variety of cardiopulmonary monitoring devices in a laboratory to evaluate the potential for electromagnetic interference created by the cellular phones and whether interference noted might be clinically important.

METHODS

The research was conducted in a 15 × 20 ft room with wooden tables and benches. In the center of the room was a 3-ft-high wooden table with a surface measuring approximately 8 × 4 ft where the equipment was placed for testing (Figure 1). The table was covered with a 1 × 1 in paper grid to provide an easy measurement tool during the tests.

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Because the protocol of the study was to approach the medical device with the cellular phone from various distances and angles and the devices were of different sizes, a method was devised to measure distances in the y and z planes. Strings attached to 3-ft grooved wooden dowels were placed above the device being tested. The dowels were grooved every 2 in so that the string also provided the angle for testing to the device. The dowels were placed on the table at 3, 6, 9, and 12 o'clock. The string (in 4-ft and 8-ft lengths, depending on equipment size) had 1-in marks to note the distance of the cellular phone to the equipment.

For editorial comment, see page 7.

A radiofrequency measurement system consisting of a readout device (Holaday HI-4416) and a magnetic and electric field probe (Holaday HI-4433) were used to display the electric field measurements. The probe has a frequency range from 500 kHz to 6 GHz and a dynamic range of 3 to 300 V/m. The electric field was measured prior to and continuously during the testing to determine if any external interference occurred that would affect the device under test. Initial electric field measurements were very low.

The devices under test were operating in "normal" mode with the appropriate simulators connected. Testing for an individual piece of equipment was an 18-step procedure (Table 1), including the vulnerability test, the distance/angle test, and the ringing test. Prior to testing with a phone, each medical device underwent a maintenance check to verify that it was operating properly. After a test, a maintenance check was redone to determine that no dam-

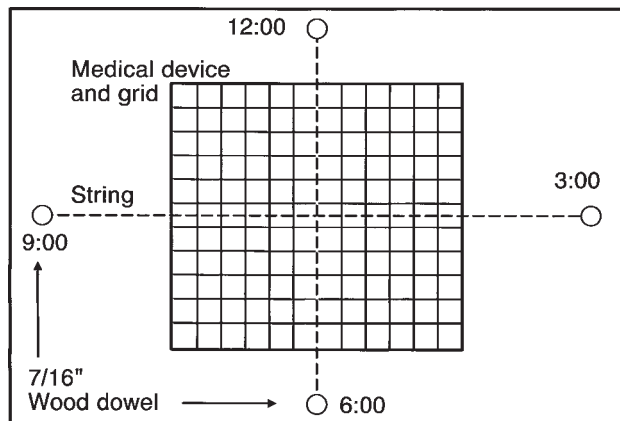


Figure 1. Table layout for cellular phone interference testing (not to scale).

age or changes occurred as a result of the testing. Then the test was repeated to determine if the results from the first test were replicable.

The vulnerability test was used to determine whether the medical device being tested displayed any signs of interference. Interference was quantified by visual observation of the electrocardiographic (ECG) waveform and measurement on the ECG waveform strips. Two types of interference were observed: noise at the baseline and baseline movement. It was called the vulnerability test because the greatest chance for interference typically occurs when the radiofrequency-emitting device is close to the device under test. Generally the testing was done from a distance of 1 to 2 in from what was thought to be the most vulnerable site for the particular medical device. The cellular phone was then rotated (at a rate of $5^\circ/\text{s}$) 180° clockwise and returned to 0° and then rotated 180° counterclockwise and returned to 0° . If any noticeable effect on equipment operation (noise at baseline, ie, randomized spikes in the data not normally present; baseline movement, ie, subtle change of the level of the ECG; equipment malfunction) was found, the distance/angle test was done. The distance/angle test was omitted when no interference occurred. The ringing test was completed on all devices.

The distance/angle test consisted of testing from 4 different directions. A clock orientation was used to distinguish between the different directions. The front of the medical device was considered the 6-o'clock position, 180° opposite was the 12-o'clock position or 0° , and the right and left sides were the 3- and 9-o'clock positions, 90° and 270° , respectively. The purpose of this test was to determine the effect of approaching the device with the phone from different angles and to determine at what distance along that angle interference began to occur. Testing started at the 9-o'clock position 12 in away from the medi-

cal device. If interference was present, the phone was moved back at a constant rate (1 in/5 s by watching the clock). However, if no interference was seen, the phone was moved closer to the medical device at the same rate. The test was repeated from the same direction to show that the results could be replicated. After the 9-o'clock direction was completed, the testing continued in a clockwise fashion to 12-, 3-, and 6-o'clock following the same procedure. On completion of all 4 directions in the distance/angle test, the results were recorded, and the ringing test followed.

The ringing test was used to determine the effects of an incoming call (a ringing cellular phone) on the medical devices. For this test, a landline phone in the same room was used to call the cellular phone. The cellular phone was held 1 to 2 in from the most vulnerable site as determined earlier, then rotated (at a rate of $5^\circ/\text{s}$) 180° clockwise and returned to 0° and then rotated 180° counterclockwise and returned to 0° . As in the case of the previous tests, the ringing test was repeated to ensure reproducibility of results.

The order for testing the phones (Table 2) was chosen randomly by pulling a numbered (1-5) bottlecap from a paper bag. All 5 phones were tested on each medical device with attention to any deviation in equipment operation. Any type of interference (noise at baseline, baseline movement, or equipment malfunction) was quantified by visual observation of the devices and changes in the data displayed. Testing with a sixth phone was limited to the Veolar-Hamilton ventilator that malfunctioned on testing with analog phone 5. Because it was hypothesized that the analog phones would result in the same outcomes, phone 6 was tested to verify results with phone 5 (analog) (Table 2).

RESULTS

Seventeen different external cardiopulmonary monitoring devices were tested over a 3-month period (Table 3). Interference occurred in 7 (41%) of the 17 devices tested. The incidence of any type of interference was 54.7% in the 526 tests performed. The incidence of clinically important interference (any interference that may hinder interpretation of the data or cause the equipment to malfunction) was 7.4%.

The majority of the interference occurred in devices that display ECGs. The only medical device that showed interference that does not display ECGs was the Veolar-Hamilton ventilator.

Interference occurred also in the following ECG or monitoring equipment: Hewlett-Packard Viridia 24C vital sign monitor, Hewlett-Packard Merlin vital sign monitor, Hewlett-Packard telemetry pack 7810A, Protocol Propaq 106 EL blood pressure and 3-lead ECG monitoring device, Datascope model 97 intra-aortic balloon pump, and

Table 1. Cell Phone Testing Procedure

1. Perform site survey of room or area using the magnetic and electric field probe.
2. Select equipment to be tested, document type, model, and identification number.
3. Check equipment for proper function following manufacturer's or institutional guidelines.
4. Determine each equipment's site (or sites) of expected greatest vulnerability to interference.
5. Select a phone randomly.
6. Turn on the cell phone and put it as close as possible to the site determined in step 4, then rotate the phone (180° clockwise and return to 0°, then 180° counterclockwise and return to 0° at a rate of 5°/s). Determine if there is any adverse effect on the equipment under test. Record results of test.
7. Repeat step 3.
8. Repeat step 6. If there is an adverse effect on the equipment under test, go to step 9. If not, go to step 14.
9. If it has been determined from the above steps that any of the cell phones tested cause the piece of equipment to malfunction in any way, starting from 1 ft away from equipment, bring the phone closer to equipment at a constant rate (1 in/5 s) to determine the distance at which interference starts. Record the results.
10. Repeat step 3.
11. Repeat step 9.
12. Repeat step 3.
13. Repeat step 9 but from a different angle (4 measurements at 90° increments).
14. Place cell phone as close as possible to the most vulnerable site on the equipment, as determined in step 4. Then using a landline phone, call the cell phone. While the phone is ringing, rotate phone (180° clockwise and return to 0°, then 180° counterclockwise and return to 0° at a rate of 5°/s). Determine if there is any adverse effect on the equipment under test. Record results of test.
15. Repeat step 3.
16. Repeat step 14.
17. Go to step 5 until all cell phones have been tested.
18. Repeat procedure until all pieces of equipment have been tested.

Marquette MAC 12 ECG cart. The interference occurring in the ECG or monitoring equipment included noise on the baseline (Figure 2, top), baseline movement (Figure 2, bottom), or a combination of both. Noise on the baseline was the most common form of interference, generally produced by the digital phones. Baseline movement was found primarily during testing with the analog phones; however, some baseline movement was found during testing of the digital phones.

The farthest distance interference that occurred with a device was with a telemetry pack using an analog phone. One of the analog phones (phone 5) produced baseline movement as far away as 84 in. The second analog phone (phone 6) also created baseline movement of the ECG signal. The maximum distance at which the second analog phone created baseline movement was 48 in.

Interference was also found during testing of the Veolar-Hamilton ventilator. Phones 1 through 5 caused the ventilator to shut down and restart. This occurred when the phones were held 2 in from a communication port located on the back of the ventilator. The ventilator recovered once the phone was removed or turned off. Due to the results of these tests, a second ventilator of the same model was tested, with similar results at the same distance. Phone 6

was used in this second test also, and it caused interference but did not cause the ventilator to shut down and restart. However, the numbers displaying the "Vt Expiration" increased. On completion of a maintenance check, the test was repeated with the same phone with the same results.

Maintenance checks were completed after each test without errors or problems. All interference that occurred during testing was temporary. Once the phone was removed or turned off, there was no indication of residual effects on the device under test.

DISCUSSION

Baseline interference was the most common form of interference and was generally produced by the digital phones,

Table 2. Cellular Phone Models Tested

Phone model	Type
1. Motorola M75A	Digital
2. Motorola M70A	Digital
3. Nokia 2160	Digital
4. Ericsson DH 318	Digital
5. Motorola MicroTAC/Piper e	Analog
6. Motorola MicroTAC DPC 550	Analog

Table 3. Cardiopulmonary Devices Tested*

Device	Type of interference/ phone model†	Distance (in)/angle (°)/ phone model‡
1. Hewlett-Packard Viridia 24C ICU/vital sign monitor	X,Y/1; X/2-4; Z/5	25/270/1
2. Nellcor pulse oximeter N-200§		
3. Imed infusion pump model Gemini PC-2§		
4. Bard Criticare fluid output flow monitor§		
5. Critikon Dinamap noninvasive blood pressure monitor model 8100§		
6. Hewlett-Packard Merlin ICU/vital sign monitor	X/1-4; Z/5	42/270/4
7. Hewlett-Packard telemetry pack 7810A	Y/1,2; X,Y/3; X/4; Z/5,6	84/0/5
8. Protocol Propaq 106 EL blood pressure and 3-lead ECG monitoring device	X,Y/1; X/2-4; Z/5	30/180/4
9. Medtronic Lifepak 10C defibrillator/monitor/pacemaker§		
10. Datascope system 97 intra-aortic balloon pump	X/1,2,4; Y/3; Z/5	3/0/3
11. Medtronic Lifepak 12 defibrillator/monitor§		
12. Veolar-Hamilton ventilator	A/1-5; B/6	4/0/1
13. Nellcor Puritan Bennett ventilator 7200§		
14. Siemens Servo ventilator 300§		
15. Siemens Elema 900C ventilator§		
16. Nellcor Puritan Bennett Infant Star model 500 infant ventilator§		
17. Marquette MAC 12 ECG cart	X/1,2,4,5; C/3	4/0/4

* ECG = electrocardiography; ICU = intensive care unit.

†A = equipment reset; B = equipment displayed wrong value; C = no interference; X = noise on ECG signal; Y = noise on ECG signal and baseline movement; Z = baseline movement of ECG signal. Numbers correspond to phone models listed in Table 2.

‡Values reflect the "worst case" interference, ie, farthest distance and most obtuse angle at which interference occurred.

§No interference.

and baseline movement was found primarily during testing with the analog phones. Although the degree of baseline and baseline-movement interference varied greatly, even in the worst case the interference was not thought to have the potential to be clinically important. Although the most severe interference could potentially hinder interpretation of ECG recording or monitoring, these occurred when testing was done 6 to 33 in from the monitoring equipment. Had the phone been used in a patient's room but outside a 60-in radius from the equipment, we hypothesize that interpretation would not have been compromised. The 60-in radius was based on tests completed for this study and the distance within which interference occurred. At a distance of 60 in, the field strength of a 0.6-W handheld cell phone is approximately 1.1 V/m. This is well below the US Food and Drug Administration voluntary standard of 1979 specifying that medical equipment should be immune from interference in fields of up to 7 V/m within the frequency range of 450 to 1000 MHz.¹⁶ Clinical testing is needed to confirm these measurements.

Assuming that phones were kept far enough from ECG monitoring equipment to preclude inability to interpret the recordings, the only incidence of interference that would have been clinically important had it occurred in an actual patient was the shutdown and restart of the Veolar-

Hamilton ventilator. The ventilator was thought to be functioning normally when tested both before and after phone exposure. The malfunction occurred with multiple phones, 4 digital and 2 analog, and occurred when a second ventilator of the same type was tested. However, the malfunction occurred only when the phone was placed near a communicator port of the ventilator located on the back of the device.

Although the interaction with the ventilator is reason for caution when considering the most appropriate policy for cellular telephones in the hospital environment, it does not necessarily justify policies currently in place in many hospitals. From a practical standpoint, it is unlikely that a patient or visitor using a cellular phone would have been in a position to use the phone near the back of the ventilator. Likewise, if a cellular phone was used at some reasonable distance (60 in based on our laboratory results) from electrical equipment within the patient's room or central nursing stations, it is unlikely that any serious malfunction would occur.

However, this experimental study is inconclusive and has several limitations. First, even though we tested a variety of equipment types from a number of manufacturers, literally thousands of pieces of electrical equipment commonly used in hospitals could be tested. Our study

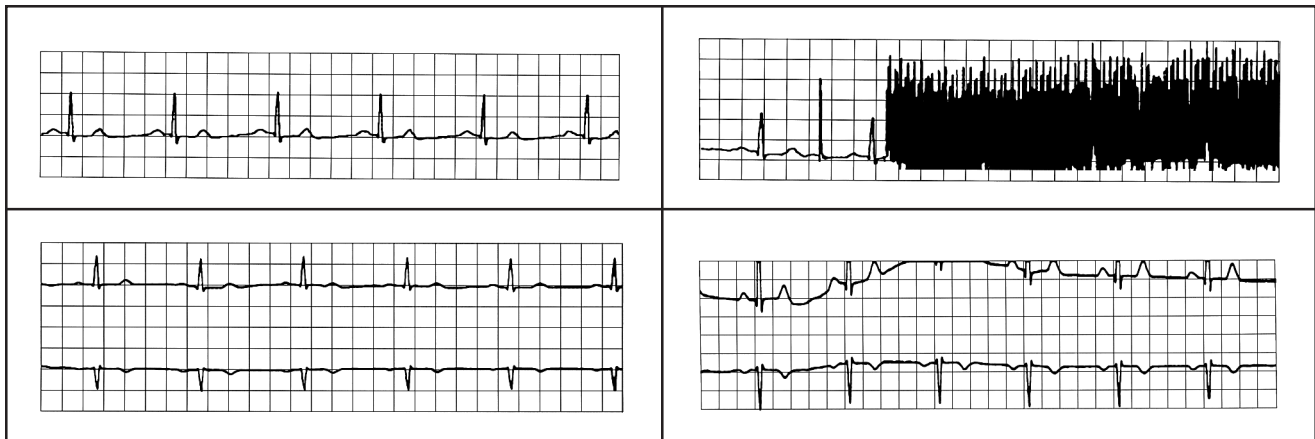


Figure 2. Top, Minimal (left) and maximal (right) baseline interference. Bottom, Minimal (left) and maximal (right) baseline-movement interference.

was limited to cardiopulmonary monitoring equipment. Second, experimental results cannot necessarily be translated into clinical outcomes. Although somewhat unlikely, it is possible that, with human interface with the equipment, the outcomes could be different. Therefore, further laboratory and clinical testing is necessary. When additional testing is completed, policies regarding cellular phone usage within the hospital environment can be constructed objectively.

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