Mobile Phones in Hospitals

WERNER E. IRNICH, ROLF TOBISCH

Werner E. Irnich and Rolf Tobisch tested medical devices, primarily those used in intensive care units, for electromagnetic interference from mobile phones using six different test procedures. Four of 224 investigated devices experienced interference caused by mobile phones at distances of more than 1 m. Twelve of these devices experienced interference caused by walkie-talkies at distances of more than 1 m.

The authors concluded that prohibition of mobile phones in patient wards is not justifiable in terms of compromising patient safety.

Irnich and Tobisch have the following recommendations:

- *All medical devices used outside hospitals must be made resistant to mobile phones.*
- *If apnea monitors and respirators are made resistant to EMI, the problem of interference is resolved because a minimum distance of 1 m between mobile phones and medical devices is recommended.*
- *Medical devices with more than 50-cm distance interference should be exchanged or be subsequently equipped with protection from interference.*
- *A safety distance of 1.5 m should be maintained from walkie-talkies to life-saving or life-supporting devices.*

PEER-REVIEWED RESEARCH

In some areas of hospitals and wards, signs resembling traffic signs forbid the use of hand-held mobile phones. Questions to the staff regarding reasons for this measure are answered with reports of interactions between mobile phones and medical devices. To the extent that this may endanger patients, it would be wise to prohibit the use of mobile phones.

The current prohibitions of mobile phone use may have resulted from findings of the United States Food and Drug Administration (FDA). They investigated medical devices such as wheelchairs, infant apnea monitors, and external and implanted cardiac pacemakers to determine their susceptibility to radiofrequency (RF) emissions from mobile and immobile RF transmitters outside hospitals.[1] The mobilization of a wheelchair by the transmitters of an emergency vehicle exemplifies the dilemma. No one would want to forbid using a mobile phone to rescue people. Prohibition of transmitters in emergency vehicles would probably endanger sick people more often than it would avoid critical effects on medical devices. The solution is to make all medical devices compatible with RF waves that prevail in today's environment, which may be supposed to be bombarded with RF waves.

We believe that prohibition of mobile phones in hospitals is problematic for several reasons:

- What are the consequences in hospitals that already use mobile phones in the form of a personal call system?
- What should emergency services do when they must simultaneously use RF communication systems, including mobile phones, and medical devices?
- How should users of medical devices such as implanted cardiac pacemakers, defibrillators, or wheelchairs behave if they are aware of hand-held phones in their immediate vicinity, as they are unable to forbid their use?
- Prohibition has only one practical advantage, which would still not guarantee safety: manufacturers would lose every incentive to make their medical devices compatible.

The authors' experience with implanted cardiac pacemakers[2] brought up considerations regarding interference with medical devices, whether it would be very different between device groups, brands and other models, and whether some devices would be resistant to all types of mobile phones in Germany. The investigation's aim was to systematically test not only whether the medical devices were resistant or susceptible, but also the distance to which interference occurred and even possibly represented a threat to patients' health. In the long term, it would be desirable that manufacturers of medical devices consider safety as a measure of their product lia-

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bility by building in electromagnetic compatibility or by advising safety distances. However, to test the medical devices adequately, a standard such as IEC 601-1-2 is needed.[3] The study's goal was also to investigate the practicality of this standard with respect to mobile phone interference.

Method

Many different medical devices, mainly used in intensive care units (ICUs), were tested for electromagnetic interference (EMI) from several mobile phone systems, and the distances from which EMI occurred were measured. Devices were categorized according to their susceptibility to EMI, to indicate whether the EMI might have clinical implications.

Three mobile phone nets are used in Germany today. Because they act differently on pacemakers, they are described in more detail. For simplicity, the different nets are called C-, D-, and E-nets in Germany. Table 1 briefly summarizes the main characteristics of these phone systems.

The C-net has a carrier frequency of around 450 MHz. Information is coded in FM and analog mode, and the transmission is continuous waves. Maximum transmission power is 0.5 W for hand-held phones. During a call, a "pulsing" yields DC pulses of about 0.5 Hz frequency after demodulation within a diode circuit.

The D-net, according to the European GSM standard, has a carrier frequency of around 900 MHz. The information is digitally coded. Transmission is pulsed with a maximum output power, only during pulses, of 2 W for hand-held phones. Demodulation of the pulsed signal occurs at 217 Hz, with a combination of 2 Hz and 8 Hz during call organization and in DTX mode (when the user is listening).

The E-net is equivalent to the D-net, except that carrier frequency is approximately 1,800 MHz.

A walkie-talkie operating at 435 MHz and 2.5 W continuous waves was also investigated because it is in use at our hospital. This phone is nearly identical to C-net phones except for the higher output power.

The mobile phones were placed as close as possible to all sides or parts of the device to provoke interference. If there was interference, the distance up to which realistic danger could be assumed and up to which any threat could be observed was determined. For instance, broadening the beam of a monitor or adding noise to loudspeaker monitors was judged to be interference but would not harm the patient.

For all three mobile phone systems, we used our own test-base station, with which the output power of each phone could be set to its maximum value. Normally, the output power of hand-held phones is controlled by the base stations such that it emits the minimum power sufficient to install a stable contact between mobile phone and base station. The advantage is that the battery is used less and there is no cross-talk beyond the cellular borders.

All possible operating conditions of a mobile phone were tested, including call organization and normal operation with and without DTX mode (possible in D-net and E-net only). In investigating the walkie-talkies, the switch on and switch off were studied.

TABLE 1. Main Characteristics of the German Mobile Phones

	C-NET	D-NET	E-NET
Carrier frequency	450/MHz	900/MHz	1.800/MHz
Information coding	FM	Digital	Digital
Transmission	CW	PW	PW
Maximum power	2W	2W	1W
Frequency of demodulation product	0.5 Hz	2*/8*/217 Hz	2*/8*/217 Hz

*In DTX-mode, user is silent or organizing the call. FM, frequency modulation; CW, continuous waves; PW, pulsed waves.

Results

A total of 224 medical devices or device systems belonging to 23 different device groups and a stationary personal light-call system were investigated with respect to EMI behavior. A device system is a reanimation unit possessing a defibrillator, pacemaker, electrocardiographic monitor, and pulse oximeter. The personal call system was included because it was suspected that there were several possible ways for mobile phones to induce faulty alarms or even suppress regular alarms, presenting critical implications in an ICU. A total of 224 devices and one call system were tested with six different test procedures, resulting in a total of 1,350 tests.

The medical devices were found to fall into three groups with respect to their EMI behaviors in response to phone use:

- no EMI at all with all mobile phones systems tested;
- either C-net or D-net phones affected them; or
- they were affected by all three nets.

E-net affected medical devices that were also affected by D-net phones. The EMI distance for E-net interfer-

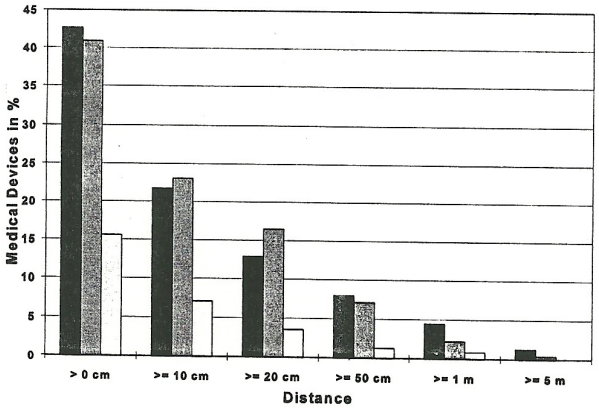


Figure 1. Distances at which interference occurs and portions of devices affected for the three nets. Black bar, C-net, 0.5 W; shaded bar, D-net, 2 W; white, E-net, 1 W.

ence, however, was normally less. Figure 1 shows the results of the three different nets for any sign of EMI, and Figure 2 lists those devices that had interference with the potential for harm to a patient.

Similarly, Table 2 shows the results, with the number of elements investigated (N), the portion of EMI-affected devices under the provocation test (P), and the ratio of affected devices possibly endangering patients (R).

For those devices in Table 2 that reacted with critical implications, Table 3 shows the three most sensitive elements in each device group, with their interferences and the distances of realistic danger. There were usually large differences among the most, second, and third sensitive elements with regard to EMI distance. A total of four devices (two apnea monitors, two respirators) of 224 investigated devices proved to experience interference caused by mobile phones at distances of more than 1 m. It was especially apparent with respirators that there were two of 18 elements (11%) with interference distances of more than 1 m, whereas the third most sensitive respirator reacted only at or less than 15 cm.

Figure 3 shows the undisturbed devices in terms of distances. Even with the antennas of the mobile phones as close as possible to the surfaces of the devices, more than 50% did not experience interference. At 10 cm, corresponding to a field strength of an undisturbed field of 100 V/m, between 76% and 92% remained unaffected. An interference distance of 50 cm or more, corresponding to 20 V/m, resulted in more than 90% of all devices' becoming resistant to the mobile phones of the three German nets.

The stationary light-call system, suspected of interference by mobile phones, could be influenced only if the C-net phone was closer than 5 cm to the printed circuit board installed within the wall at approximately 1.5 m height above a patient's bed. Suppressing alarms was not possible, as had been initially supposed.

Of the 224 elements, the eight most sensitive devices in the seven groups were tested as described in IEC 601-1-2. Besides the 1 kHz amplitude modulation, continuous waves, 50-Hz and 1-Hz amplitude modulated waves, and 217-Hz and 2-Hz pulsed waves were used in the tests. Carrier frequencies were 450 and 900 MHz. The maximum power output of the transmitter was 40 W, with which a maximum field strength of 20 V/m could be produced.

The results gained in the absorber hall are shown in Table 4. With a test field strength of 3 V/m applied and 1 kHz modulation frequency, four devices with 450 MHz and two devices with 900 MHz were found to be sensitive. In all devices, continuous waves created less interference than waves with 1-kHz modulation. One-kilohertz modulation was the most crucial test except in apnea monitors (1 Hz AM), in external pacemakers (2 Hz pulsed), and in electrocardiographic monitors which were more influenced by 50-Hz AM waves.

With 1 kHz AM and 450 MHz, all eight devices were found to be sensitive if exposed to 6.8 V/m electric fields. With 1 kHz and 900 MHz, all except one were sensitive at 20 V/m. The apnea monitor, uninfluenced at 20 V/m, was already affected at 7.8 V/m if the waves were amplitude-modulated at 1 Hz.

The results with the walkie-talkie are summarized in Table 5. Twelve devices proved to be susceptible at a distance of more than 1 m.

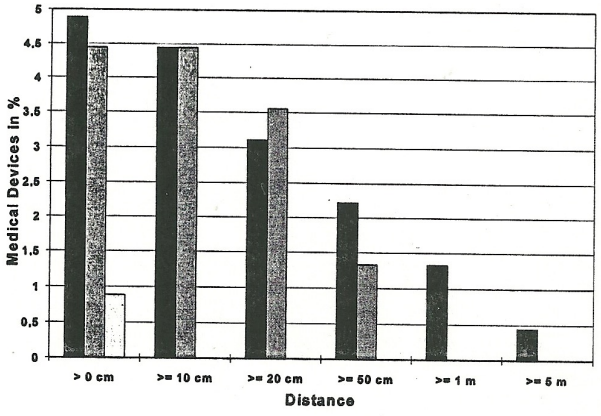


Figure 2. Distances at which interference occurs and portions of devices with critical reactions for the three nets. Black bar, C-net, 0.5 W; shaded, D-net 2 W; white, E-net, 1 W.

TABLE 2. Medical Devices Investigated and the Maximum Interference Distance (in cm)

		Influence				Realistic Danger			
Medical Device	**N**	**P**	**C**	**D**	**E**	**R**	**C**	**D**	**E**
Apnea monitor	4	100	800	70	7	75	800	70	7
Respirator	18	50	250	80		44	250	80	
Blood pressure monitor	2	50		5		0			
Blood weigher	1	100	50	50		0			
CO_2 monitor	3	33		9		0			
Defibrillator	14	50	400	30	5	0			
Dialysis machine	9	89	30	20	20	11		20	
ECG monitor	5	100	300	100	10	0			
External pacemaker	10	50	20	90	6	50	20	90	6
Fetal HR monitor	5	80	20	2,000	150	0			
Heart lung machine	23	26	60	50	5	9	60	30	
RF surgery	8	63	10	5		0			
Drop controlled pump	10	60	75	50	40	0			
Volume controlled pump	21	15	15	50	15	0			
Syringe pump	35	54	20	5		0			
Incubator	6	50		40		0			
Patient monitor	10	60	60	25	2	0			
Anesthesia apparatus	5	0				0			
O_2 monitor	10	70	700	30	10	0			
Pulseoximeter	2	0				0			
Thermal bed	2	50	600	80		0			
Total	203	53				7			

N, number of elements investigated; P, portion of elements interfered (%); R, ratio of elements possibly endangering (%); C, 450 MHz C-net; D, 900 MHz D-net; E, 1,800 MHz E-net.

Discussion

Although in 1991 the United States Food and Drug Administration had drawn attention to the problem of mobile phone interference with medical devices, a systematic investigation of EMI has not been carried out so far. Reports[4–7] of real or provoked interference of medical devices have been infrequent. Wheelchairs, apnea monitors, hearing aids, defibrillators, and electrocardiographic machines were found to be susceptible. However, these devices are mostly used outside hospitals. We are the first, to our knowledge, to study the effect of EMI on medical devices in ICUs on a large-scale basis. Our study is important, because prohibition of mobile phones in hospitals is more or less based on the suspicion that devices in ICUs could fail dangerously rather than on actual evidence. There is, so far, no case report in the literature describing any unintentional accident. Reports in the daily press or on television are, in the authors' experience, either fictional or falsely attributed to mobile phones.

Prohibition of mobile phones in hospitals is based not on real evidence, but on an intellectual and precautionary impression without knowledge of susceptibility of the devices. Fatal accidents are very rare, because four contingencies must coincide to produce them: 1) the medical device must be sensitive and not fail-safe, 2) the mobile phone must have sufficient power output, 3) the phone must be within a critical distance, and 4) it must be activated by a call. These prerequisites are normally not fulfilled if a person (patient or staff) is initiating a call.

TABLE 3. Medical Devices with Realistic Danger: Interference Distances of the Three Most Sensitive Devices (in cm)

		Influence			Realistic Danger		
Medical Device Groups	**N**	**C**	**D**	**E**	**C**	**D**	**E**
Apnea monitor	4	800 150 5	70 40 10	7 3 1	800 150 5	70 40 10	7 3
Respirator	18	250 150 15	80 60 5		250 150 10	80	
Dialysis machine	9	30 20 15	20 20 15	20 20		20	
External pacemaker	10	20 20 15	90 40 40	6 5	20 20 15	90 40 40	6 5
Heart–lung machine	23	60 8 5	50 30	5	60	30	

N, number of elements investigated; C, 450 MHz C-net; D, 900 MHz D-net; E, 1,800 MHz E-net.

The study results offer a positive view of the situation, because they prove that more than 50% of all devices investigated are resistant to the use of hand-held telephones despite not being designed with compatibility of mobile phones in consideration. Because more than 50% are nevertheless resistant to EMI, electromagnetic compatibility is not difficult to achieve.

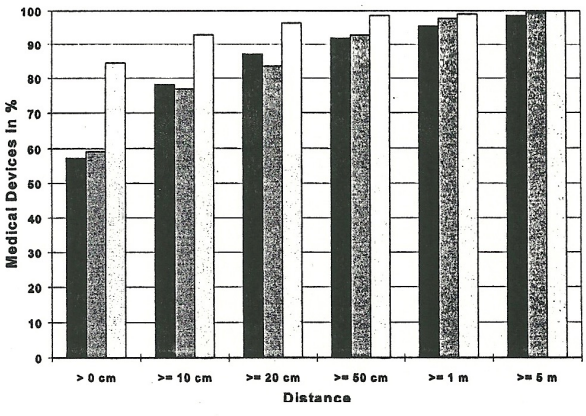


Figure 3. Nonsusceptible devices as a function of distance. The distance (D) can be converted into field strength (E) of a undisturbed field produced by a 2W mobile phone according to the formula: D·E = 10 V. Black bar, C-net, 0.5 W; shaded, D-net, 2 W; white, E-net, 1 W.

The study results also contradict an often-heard theory that digital mobile phones cause more interference than analog ones. The 0.5 W C-net phone caused interference on more devices and for a longer distance (except for the fetal heart rate monitor in Table 2), than did the D-net phones with their 2-W peak power (0.25 W RMS).

The comparisons according to IEC 601-1-2 of sensitive medical devices, with respect to mobile phones, teaches us that a field strength of 3 V/m is not sufficient to detect susceptibility. If it is increased to 10 V/m, interference at a distance of more than 1 m with 20 V/m of more than 50 cm could be detected (Figure 3). If 20 V/m were mandatory, one could simply describe a safety distance: one arm's length from a medical device would guarantee safe operation in case a mobile phone were activated.

Although the walkie-talkie proved to cause the most interference at distances more than 10 m, dangerous situations are normally rare because its use is restricted to short times. "Yes," "no," "okay" or whatever is transmitted and is normally of short duration except when the patient's problems are described on the way to the admitting hospital. That may be the reason real situations of interference are not reported worldwide except in the FDA's report on wheelchairs mobilized by rescue personnel.

The standard draft IEC 62A/206/CD[8] lists "Recommended Separation Distances" for "Example 2" in Annex

TABLE 4. Comparison of Maximum Interference Distances with Mobile Phones and Corresponding Electric Field Strengths According to IEC 601-1-2 Test

Interference Distance (cm)			Field Strength for Interference (V/m)									
			450 MHz				900 MHz					
Device	C-Net	D-Net	Continuous Wave	1 kHz	50 Hz	1 Hz	Continuous Waves	1 kHz	217 Hz*	50 Hz	2 Hz	1 Hz
Apnea monitor	150/40†	70/10†	7.2	4.6	—	1.2	>20	>20	>20	>20	—	7.8
ECG monitor	60	70	>20	6.5	4.1	—	>20	8.6	—	3.0	—	—
Infusion pump 1	75	50	>20	6.8	—	—	>20	6.4	4.4	—	—	—
Infusion pump 2	0	50	>20	2.8	—	—	>8.7	2.2	7.8	—	—	—
O_2 monitor	130	30	0.7	0.7	—	—	6.0	4.7	12	—	—	—
Pacemaker	20	90	4.4/8.6‡	4.4/5.9‡	—	—	16/>20‡	9.6/11.2‡	6.4	—	2.9	—
Respirator	250	80	1.4	0.7	—	—	4.8	3.6	6.6	—	—	—
Thermal bed	600	80	1.2	0.9	—	—	3.7	1.8	—	—	6.7	—

*Pulsed with 0.58 ms.
†First value: antenna was moved rhythmically; second value: antenna stationary.
‡First value: inhibition; second value: switched off.

BBB, which are quite realistic for avoiding any influence on even the most sensitive device. In our opinion, the EMI effect of walkie-talkies is underestimated. For 435 MHz, the distance should be 12 m. However, is it realistic to recommend distances that cannot be controlled? We see the problematic nature of mobile phone-induced EMI as less aggravating.

If it were generally accepted and required that apnea monitors and respirators, which are also used outside hospitals, must be resistant to mobile phone interference, the distance of separation necessary would be drastically less. A distance of 1 m would be sufficient for 2-W digital mobile phones and 0.5-W analog phones as well.

Recommendations

What strategies should be developed for the present and the future? It is important to define a test procedure that is accepted generally. In addition to testing according to IEC 601-1-2, but with 20 V/m field strength and with the amplitude modulations suited for pacemakers and apnea monitors, as mentioned previously, one could test with real mobile phones under worst-case scenarios, as was done in this study. If a medical device is resistant to EMI in the provocation test, one can be sure that it is safe in a hospital environment in which mobile phones are not restricted. With such tests being accepted and carried out, one can formulate the following recommendations:

■ All medical devices used outside hospitals must be made resistant to mobile phones. Such devices include apnea monitors, home dialysis machines, external and implantable pacemakers, defibrillators, and devices in emergency vehicles. This requirement is absolutely necessary because mobile phones cannot be controlled nor prohibited in those circumstances where the devices are used.

■ If apnea monitors and respirators are made resistant to EMI (in or outside hospitals), one could resolve the problem of interference, in that a minimum distance

TABLE 5. 435 MHz-1.5 W Walkie Talkie Interference

Device	Interference Distance (m)*	Impact†
Apnea monitor	14/4	–
Respirator	8.5/3	+
ECG monitor	5/1	–
Pacemaker	1.3/1.2	+
Heart–lung machine	1.5	+
Infusion pump	3.5/1	+
Fetal HR monitor	1.5	–
O_2 monitor	10/5	–

*The distance of the most and second most sensitive device.
†+ Endangering; – Tolerable.

between mobile phones and medical device of 1 m is currently recommended.

■ Medical devices with more than 50-cm distance interference should be exchanged or be subsequently equipped with protection from interference. This becomes mainly a shielding problem. If this is accomplished, the "1-m" rule could be replaced by the "arm's-length" rule.

■ Walkie-talkies in hospitals and in emergency situations should be handled with care, because they are more powerful than hand-held phones. A safety distance from life-saving or life-supporting devices of 1.5 m is sufficient.

Conclusions

Our recommendations for the use of mobile phones in hospitals will probably not be adopted by all people working in hospitals. There are also those who would profit from a general mobile phone prohibition: Manufacturers of medical devices would not have any impetus to improve their devices. Hospital administrations will consider patients' mobile phones a possible competitor to their own installed telephone systems. We think prohibition of mobile phones in patients' wards is not justifiable in terms of compromising the patients' safety.

Finally, it should be emphasized that all sorts of medical devices outside hospitals must be made resistant against the EMI of phones either by exchange or by subsequent redesign. This should be the very first step necessary to reduce the mobile phone risk to zero. Medical devices in emergency vehicles must be tested and, if necessary, replaced by resistant devices. Also, apnea monitors must be checked and rendered resistant to mobile phones, if unsafe. If these devices are safe, it is not reasonable to assume that devices in hospitals are susceptible. The industry should see electromagnetic compatibility of their devices as one important element of the devices' product liability.

Unusual "J" Words

jiao - Chinese coin
jaeger - Arctic sea bird
jobbernowl - a blockhead
juba - a group dance
jablonski - Author of
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