Mobile phone interference with medical equipment and its clinical relevance: a systematic review

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ABSTRACT

Objective: To conduct a systematic review of studies on clinically relevant digital mobile phone electromagnetic interference with medical equipment.

Data sources: MEDLINE and SUMSEARCH were searched for the period 1966–2004. The Cochrane Library and Database of Abstracts of Reviews of Effects were also searched for systematic reviews.

Study selection: Studies were eligible if published in a peer-reviewed journal in English, and if they included testing of digital mobile phones for clinically relevant interference with medical equipment used to monitor or treat patients, but not implantable medical devices.

Data synthesis: As there was considerable heterogeneity in medical equipment studied and the conduct of testing, results were summarised rather than subjected to meta-analysis.

Results: Clinically relevant electromagnetic interference (EMI) secondary to mobile phones potentially endangering patients occurred in 45 of 479 devices tested at 900 MHz and 14 of 457 devices tested at 1800 MHz. However, in the largest studies, the prevalence of clinically relevant EMI was low. Most clinically relevant EMI occurred when mobile phones were used within 1 m of medical equipment.

Conclusions: Although testing was not standardised between studies and equipment tested was not identical, it is of concern that at least 4% of devices tested in any study were susceptible to clinically relevant EMI. All studies recommend some type of restriction of mobile phone use in hospitals, with use greater than 1 m from equipment and restrictions in clinical areas being the most common.

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In Australia, 72% of households own a mobile phone, an increase of more than 10% in 2 years.[1] Mobile phone use is restricted within hospitals because of a perceived risk of interference with medical equipment which could endanger the safety of patients. Many of these restrictions relate to outdated mobile phone technology, leading to debate as to their validity.[2-6] Digital mobile phones are now used in Australia, and we need to ascertain if interference caused by these phones is clinically relevant.

Digital mobile phones in Australia (GSM and CDMA) currently operate at frequencies around 900 MHz with single-band technology and between 800 MHz and 1800 MHz with dual-band technology; there are plans to extend the band spectrum to 2100 MHz for GSM mobile phones.[7,8] The amount of electromagnetic radiation (EMR) emitted is low, and is governed by the inverse square law (exponential decay of radiation with distance from the emitting object). Typically, even in standby mode, mobile phones produce EMR of up to 42 V/m at 0.1 m, dropping to below 7 V/m at 1 m.[9] Phones overseas may operate at different frequencies and have different EMR profiles.

1 Selection of studies from total 317 studies regarding mobile phones

Effects of EMR exposure on humans	122
Communication/applications mobile phones	52
Effects on implantable devices	21
Effects of EMR using animal models	20
Mobile phone effects on attention/ driving	18
Psychosocial impact of mobile phones	8
Mobile phone as a risk to humans (not EMR)	6
Privacy	2
Environmental impact of phone production	1
Effects of mobile phones on medical equipment:	67
Digital mobile phones at frequency used in Australia	7
Analogue and digital results mixed	1
Ambiguous reporting of data	2
Review/summary articles	7
Case reports	6
Letters/opinions	8
Descriptive technical papers	36

EMR = electromagnetic radiation.

The first issue concerning mobile phones is the EMR they produce, and the safe distance they should be used from medical equipment that may be susceptible to EMR. The second issue is the ability of medical equipment to resist EMR. Most world standards relate to the United States Food and Drug Administration, which issued a voluntary standard in 1979 specifying that medical equipment should be immune from interference in fields of up to 7 V/m within the frequency range of 450–1000 MHz.[9] Clearly, mobile phones may breach these limits if operated within one metre, but this does not automatically translate to electromagnetic interference (EMI).

Finally, hospital construction needs to take into account EMR from different areas within the hospital, as well as external sources, to limit interference with medical equipment.[10] For example, allowing mobile phone use in a hospital corridor adjacent to a ward with sensitive medical equipment susceptible to EMR could be problematic.

The focus of this review is to assess whether studies can establish if the interference created by EMR from mobile phones is clinically relevant in Australia.

METHODS

Data sources

We searched two databases, MEDLINE and SUMSEARCH, using the terms "mobile

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2 Studies of EMI-related events in medical equipment caused by digital mobile phones operating at frequencies used by single- and dual-band mobile phones in Australia (800–915 MHz)

First author, year	Number of devices tested	Tests per device	EMI observed	Clinically relevant EMI observed	Devices showing clinically relevant EMI	Maximum distance at which EMI recorded (cm)*	Conclusions
Irnich[15] 2002	203	6	107 (53%)	20 (10%)	Apnoea monitor	70	Use mobile phones > 1 m from medical equipment
					Dialysis machine	20	Make sensitive medical equipment used in hospitals resistant to EMR from mobile phones up to 50 cm, thus changing "1 m rule" to "arm's-length rule"
					External pacemaker	90	
					Heart lung machine	30	All medical devices used outside hospital must be made resistant to EMR from mobile phones
					Respirator	80	
Hietanen[16] 2000	23	1	13 (57%)	3 (13%)	Anaesthesia machine	70	Restrict use of mobile phones in clinical areas
					Respirator	5	Patients and visitors should use mobile phones only in designated areas
					Endoflator	10	Hospitals should assess their own risk of interference from the EMR of mobile phones
Trigano[17] 1999	9	3	4 (44%)	4 (44%)	External pacemaker	200	Be aware of potential interference with external pacemakers
							Develop pacemakers resistant to EMI
MDA[18] 1997	224	3	82 (36%)	9 (4%)	Anaesthesia machine	50	Restrict use of mobile phones in clinical areas
					Respirator	0	
					Infusion pump	0	
					External pacemaker	0	
					Defibrillators	100	
Robinson[14] 1997†	5	2	3 (60%)	3 (60%)	Infusion pump	55	Use mobile phones > 1 m from medical equipment
					ECG monitor	99	
Clifford[9] 1994	15	1	8 (53%)	7 (47%)	Infusion pump	200	Use mobile phones > 2 m from medical equipment
					ECG monitor	200	Switch off mobile phones in operating theatres and intensive care units and adjacent areas if it is possible to operate a mobile phone within 2 m of equipment
					Telemetry	20	

ECG = Electrocardiography. EMI = Electromagnetic interference. EMR = Electromagnetic radiation. MDA = Medical Devices Agency, Department of Health, United Kingdom. * The maximum distance from any single device within the category. † This study used a mobile phone simulator, which was a signal generator coupled with a radiofrequency amplifier and antenna pulsed at the same frequency as phones used in Australia.

phone" and "cellular phone" initially, then combined with "hospital", for the period 1966–2004. The MeSH terms "equipment and supplies" plus "phone" and "telephone" were also used.

The Cochrane Library and Database of Abstracts of Reviews of Effects were searched for systematic reviews on this topic.

Searches for any publications by key authors were undertaken, and the reference lists of all identified publications were examined to find further relevant articles.

Definitions

Our definition of clinically relevant EMI was interference sufficiently altering the operation of medical equipment that it might endanger a patient. Specifically, this included switching off, faulty action and interrupted function of equipment, including altering set parameters such as the rate of an infusion pump.

Study selection

Studies were eligible if they were published in a peer-reviewed journal in English. They had to include testing of digital mobile phones (or radiofrequency-emitting devices simulating digital mobile phones) for clinically relevant interference against medical equipment used to monitor or treat patients, but not implantable devices. In addition, the EMR had to be in the frequency range used by mobile phones in Australia (800–1800 MHz) and frequencies had to be clearly reported in the findings. We further divided mobile phone frequencies into 900 MHz and 1800 MHz.

Documented reports of mobile phone use in hospitals and reports of interference with medical equipment were also sought.

As there was considerable heterogeneity in the equipment studied and the testing procedures, we considered it inappropriate to pool the data for meta-analysis.

Ideally, studies would test mobile phones in a controlled, reproducible environment against a variety of medical equipment devices in multiple device categories. Clinically relevant EMI would be clearly defined. To ensure validity, equipment tested should be serviced before and after testing, phones selected at random, and tests done on multiple occasions.

RESULTS

After all potentially relevant studies had been found, those that did not fulfil our selection criteria were excluded (Box 1). No studies testing only analogue phones were found. One study was excluded because it

3 Studies of EMI-related events in medical equipment caused by digital mobile phones operating at the frequency used by dual-band mobile phones in Australia (1800 MHz)

First author, year	Number of devices tested	Tests per device	EMI observed	Clinically relevant EMI observed	Devices showing clinically relevant EMI	Maximum distance at which EMI recorded (cm)*	Conclusions
Fung[19] 2002	11	2	2 (18%)	2 (18%)	Haemoglucostix	1	Mobile phones may interfere with medical devices
					Ventilator	20	Results from this study not generalisable
Irnich[15] 2002	203	6	68 (33%)	8 (4%)	Apnoea monitor	7	Use mobile phones > 1 m from medical equipment
					External pacemaker	6	Make sensitive medical equipment used in hospitals resistant to EMR from mobile phones up to 50 cm, thus changing "1 m rule" to "arm's-length rule"
							All medical devices used outside hospital must be made resistant to EMR from mobile phones
Hietane[16] 2000	23	1	3 (13%)	1 (4%)	Sphygmomanometer	5	Restrict use of mobile phones in clinical areas
							Patients and visitors should use phones only in designated areas
							Hospitals should assess their own risk of interference from the EMR of mobile phones
Trigano[17] 1999	9	3	2 (22%)	2 (22%)	External pacemaker	80	Be aware of potential interference with external pacemakers
							Develop pacemakers resistant to EMI
MDA[18] 1997	211	3	48 (23%)	1 (< 1%)	Infusion pump	0	Restrict use of mobile phones in clinical areas
							Less risk with 1800 MHz digital phones than those at other frequencies

EMI = Electromagnetic interference. EMR = Electromagnetic radiation. MDA = Medical Devices Agency, Department of Health, United Kingdom.
* The maximum distance from any single device within the category.

did not differentiate between digital and analogue phones,[11] and another two were excluded because ambiguous reporting of results made drawing conclusions difficult.[12,13] Of the studies testing phones at frequencies used in Australia, one tested only at 900 MHz,[9,14] four tested at both 900 MHz and 1800 MHz,[15-18] and two tested only at 1800 MHz[19] (Box 2 and Box 3). Thus, seven studies fulfilled our selection criteria.[9,14-19]

The 29 categories of equipment tested and the presence of clinically relevant EMI are summarised in Box 4. The maximum distance from a device at which EMR caused clinically relevant EMI ranged from 5 cm to 200 cm (Box 2) at 900 MHz and 5 cm to 80 cm at 1800 MHz (Box 3). Most clinically relevant EMI occurred at less than 1 m, with three ECG monitors, two external pacemakers and two infusion pumps recording EMI at up to 2 m.

The studies confirm that EMI occurs when mobile phones operate close to sensitive medical equipment. However, clinically relevant EMI is much less frequent. In the two largest studies, 23%–53% of individual devices were affected by EMI, but only up to 10% were clinically relevant.[15,18] Conclusions were similar among the studies, with all recommending some form of restriction.

Only one study[13] fulfilled all our ideal criteria for testing, but it was excluded because of ambiguous reporting of results. Further, low numbers of tests were done, weakening study validity in some cases. This may explain the heterogeneity of results and reflects the lack of standardised testing, recording and reporting procedures.

DISCUSSION

There is no standard policy on mobile phone use in hospitals in Australia. In Victoria, hospitals set their own restrictions, and, in New South Wales, hospitals follow a 2003 Health Department directive restricting use in clinical areas.[20] There has been only one report of a death, which was caused by a respirator being switched off by EMI from a mobile phone.[21] Two articles involved monitoring the use of mobile phones by hospital clinical staff for up to 6 months, and found no clinically adverse effects.[16,22] Finally, two-way radios produce similar EMR and have been used for decades in hospitals, with no reports of medical equipment interference or malfunction.[18]

Not having a standard definition of "clinically relevant" EMI makes study comparison difficult. We chose a broad definition in an attempt to overcome the different definitions used. Irnich and Tobisch described clinically relevant EMI as that potentially causing "realistic danger", with individual event explanations.[15] The UK Medical Devices Agency classified EMI as events having a direct effect on the patient and those not directly affecting the patient.[18] The remaining five articles considered EMI as individual events, categorising them as those resulting in "interrupted function"; "faulty action", such as altering of an infusion pump rate; or "switching-off" of a device.[9,14,16,17,19] Simple screen interference or sounds not altering recordings were not considered clinically relevant. Finally, malfunctions caused by EMI may be "silent" (ie, the equipment may operate slightly outside its normal range, but not enough to trigger an alarm).[23] These events are difficult to record and quantify.

Only one study serviced equipment before and after testing (but was excluded from review because of ambiguous reporting of results)[13] and one study used a simulator instead of a handset.[14] Despite variable equipment and testing conditions, the presence of any recorded EMI for individual devices was greater than 10% in all studies. A much wider range occurred with clinically

4 Number of devices recording clinically relevant EMI within each category of medical equipment tested

	Devices tested at 900 MHz							Devices tested at 1800 MHz					
	Irnich[15] 2002	Hietanen[16] 2001	Trigano[17] 1999	MDA[18] 1997	Robinson[14] 1997	Clifford[9] 1994	Total	Irnich[15] 2002	Hietanen[16] 2001	Trigano[17] 1999	MDA[18] 1997	Fung[19] 2002	Total
Anaesthesia machine	0/5	1/1	—	1/1	—	—	2/7	0/5	0/1	—	0/1	—	0/7
Apnoea monitor	3/4	—	—	—	—	—	3/4	3/4	—	—	—	—	3/4
Blood pressure monitor	0/2	0/2	—	—	—	0/1	0/5	0/2	1/2	—	—	—	1/4
Blood weigher	0/1	—	—	—	—	—	0/1	0/1	—	—	—	—	0/1
Blood analysis	—	—	—	0/6	—	—	0/6	—	—	—	0/8	1/3	1/11
Carbon dioxide monitor	0/3	—	—	—	—	—	0/3	0/3	—	—	—	—	0/3
Communication aid	—	—	—	0/1	—	—	0/1	—	—	—	0/1	—	0/1
Defibrillator	0/14	0/2	—	5/18	—	0/1	5/35	0/14	0/2	—	0/10	0/2	0/28
Dialysis machine	1/9	0/2	—	—	—	—	1/11	0/9	0/2	—	—	—	0/11
Diathermy device	0/8	0/3	—	0/1	—	—	0/12	0/8	0/3	—	0/1	—	0/12
ECG monitor	0/5	0/3	—	—	1/1	2/4	3/13	0/5	0/3	—	—		0/8
Endoflator	—	1/1	—	—	—	—	1/1	—	0/1	—	—	—	0/1
External pacemaker	5/10	—	4/9	1/5	—	—	10/24	5/10	—	2/9	0/5	—	7/24
Feed pump	—	—	—	0/5	—	—	0/5	—	—	—	0/8	—	0/8
Heart–lung machine	3/23	—	—	—	—	—	3/23	0/23	—	—	—	—	0/23
Incubator	0/6	—	—	0/2	—	—	0/8	0/6	—	—	--	—	0/6
Infusion liquid warmer	—	0/1	—	—	—	—	0/1	—	0/1	—	—	0/1	0/2
Infusion pump	0/66	—	—	1/97	2/3	3/6	6/172	0/66	—	—	1/101		1/167
Insufflator	—	0/1	—	—	—	—	0/1	—	0/1	—	—	—	0/1
Nebuliser	—	—	—	0/4	—	—	0/4	—	—	—	—	—	—
Oxygen monitor	0/10	—	—	—	—	—	0/10	0/10	—	—	—	0/1	0/11
Pulse oximeter	0/2	0/3	—	0/16	0/1	0/1	0/23	0/2	0/3	—	0/15	0/1	0/21
Patient monitor (unspecified)	0/10	—	—	0/50	—	—	0/60	0/10	—	—	0/53	0/2	0/65
Respirator	8/18	1/2	—	1/9	—	—	10/29	0/18	0/2	—	__	1/1	1/21
Sound monitor	—	—	—	0/1	—	—	0/1	—	—	—	0/1	—	0/1
Telemetry	0/5	—	—	—	—	2/2	2/7	0/5	—	—	—	—	0/5
Thermal bed	0/2	—	—	0/3	—	—	0/5	0/2	—	—	0/2	—	0/4
Temperature device	—	—	—	0/3	—	—	0/3	—	—	—	0/3	—	0/3
Ultrasound device	—	0/2	—	0/2	—	—	0/4	—	0/2	—	0/2	—	0/4
Total	**20/203**	**3/23**	**4/9**	**9/224**	**3/5**	**7/15**	**46/479**	**8/203**	**1/23**	**2/9**	**1/211**	**2/11**	**14/457**

EMI = electromagnetic interference. MDA = Medical Devices Agency, Department of Health, United Kingdom.

relevant EMI and, although pooling of data was not the object of this study, it is worth noting that, overall, clinically relevant EMI was observed in 45 of 479 devices tested (9%) at 900 MHz, and in 14 of 457 devices tested (3%) at 1800 MHz.

One should be cautious about drawing conclusions from overall study results. Of 29 categories tested, none were consistent across all studies (Box 4), and it is impossible to ascertain (and unlikely) that any two devices tested were identical. Devices were not matched and numbers of devices in each category were different. For example, 66 infusion pumps were tested by Irnich and Tobisch, with none having clinically relevant EMI,[15] whereas Clifford et al found half of their six infusion pumps showed clinically relevant EMI.[9] Attempting to minimise bias between individual devices, we also report results by category (Box 4). However, some studies chose only one representative device in a category, and again these were not matched, potentially skewing overall category results in either direction.

Based on the available evidence and accepting its limitations, some form of restriction on mobile phone use in hospitals in Australia seems sensible. It appears at least 4% of medical devices could experience clinically relevant EMI when a mobile phone is within 2 m. However, the number of events when mobile phones are used

more than 1 m from medical equipment is almost negligible, with only 0.01% (7/479) of all devices tested at 900 MHz showing clinically relevant EMI at this range.

Mobile phones operating at 1800 MHz appear to cause less clinically relevant EMI and need to be closer to medical equipment to affect it. However, in Australia, dual-band mobile phones operate at both frequencies, and it is impossible to be sure which frequency is in use at any one time. In contrast, in Europe and Asia, phones operate predominantly in the 1800 MHz band. This information will be more relevant when phones operating in the 2000 MHz band become available in Australia, although further testing will be necessary.

We do not believe that mobile phone detection devices that alert or verbally warn owners to switch off phones (used in some hospitals in the United Kingdom) are warranted.[4] The safest option is the "1 m rule" proposed by Irnich and Tobisch[15] — restrict mobile phone use to greater than 1 m from equipment. Staff, patients and visitors need to be made aware of the risk to patient safety if mobile phones are used, particularly within 1 m of sensitive medical equipment. To avoid confusion, it is probably best to restrict use by patients and visitors unless they are in mobile phone "friendly zones" within a hospital.[16] Although policies have been recommended in Australia to take into account changing mobile phone technology and relax some restrictions, their local implementation is difficult and may be costly, involving education of clinicians, patients and the public to be successful.[20]

Future research into clinically relevant EMI in medical equipment from mobile phones needs to be standardised to enable adequate comparison. Firstly, with testing, the 18-step method proposed by Tri and colleagues could be adopted.[13] Furthermore, the definition of clinically relevant EMI needs to be clearly stated. Definitions should be standardised across studies and a large sample of devices tested in each study — only then can further conclusions be drawn. Ultimately, medical equipment needs to be manufactured to resist EMI from mobile phones, with standards that take into account new phone technology.

COMPETING INTERESTS

None identified.

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