Collaboration Project

Investigative Research into Electromagnetic Interference with Medical Equipment from Radio Waves Emitted by Mobile Telephones and Smartphones

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To promote the use of mobile telephones and smartphones in hospitals, NTT DOCOMO has been surveying electromagnetic interference on medical equipment due to radio waves emitted from these radio communications devices. Radio systems we surveyed are the 3G/LTE, 4G and WLAN systems supported by recent smartphones. We also surveyed candidate 5G frequencies.

This research was conducted jointly with Kanazawa University Hospital (Professor Keisuke Nagase, Department of Corporate Planning).

1. Introduction

During the spread of mobile telephones in the 1990s, there were heightened concerns about the potential for radio waves emitted by terminals electromagnetically interfering with other nearby electronic devices, in particular medical devices. Regarding these effects, the Electromagnetic Compatibility Conference Japan (EMCC)*1 surveyed first generation mobile communications systems (the analog NTT system), second generation mobile communications systems (Personal Digital Cellular (PDC)) mobile telephones, Personal Handy-phone Systems (PHS) and amateur radio etc. NTT DOCOMO was a key partner in proactively developing these research methods etc. [1]. In 1997, the Association published "Guidelines for the Use of Mobile Handsets to Prevent Electromagnetic Interference with Medical Electrical Equipment" in light of these research findings [2]. These guidelines prohibited bringing mobile telephone terminals into operating rooms or Intensive Care Units (ICUs) etc., and recommended switching mobile telephone terminal power off in laboratories, consultation rooms, patient rooms and treatment rooms etc., fundamentally prohibiting the use of mobile telephones etc. in hospitals. Furthermore, the Ministry of Internal Affairs and Communications conducted research on electromagnetic interference on medical equipment caused by third generation mobile communications

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*1 EMCC: A joint industry-academic-government association concerned with issues such as electromagnetic interference.

system (3G) mobile telephone terminals including Wideband Code Division Multiple Access (W-CDMA), PHS and Wireless Local Area Network (WLAN) terminals, and published a report in 2002 [3]. It was determined from these findings that the continued application of the above guidelines was justified. Under those circumstances, individual hospitals formulated their own rules regarding the use of mobile telephones in hospitals upon making generalized judgments focusing on aspects such as mobile phone etiquette.

However, with the subsequent development of radio communications systems and smartphones etc., demands to use these devices in hospitals have increased from both workers and patients. This joint research was conducted in light of the latest conditions arising in medical equipment, and with the aim of understanding and analyzing the risks of electromagnetic interference with medical equipment. Specifically, in 2011, we conducted research on electromagnetic interference with medical equipment due to 3.9th generation mobile communications systems (Long-Term Evolution (LTE)) using 3G and its High Speed Packet Access (HSPA) standard and Frequency Division Duplex (FDD)*2 system, then from 2016 to 2017, conducted similar research on WLAN, fourth generation mobile communications systems (4G), in other words LTE-Advanced as LTE with Time Division Duplex (TDD)*3 system using the 3.5 GHz band, and candidate frequencies for fifth generation mobile communications systems (5G). This article describes an overview of this research and its findings.

This research was conducted jointly with Kanazawa University Hospital (Professor Keisuke Nagase, Department of Corporate Planning). To determine operational settings of various medical equipment and adverse effects due to electromagnetic interference, and to evaluate the degree of those effects, we received the cooperation of the clinical engineers in charge of operations, maintenance and inspection etc. of medical equipment in the hospital.

2. Overview of the Research

The following describes an overview of this research. Please refer to Reference [4] for details of external trends and various relevant standards.

2.1 Main Radio Waves Specifications

Table 1 shows the main specifications of radio systems and radio waves studied in this research. With 3G/FDD-LTE and TD-LTE, we used signals modulated in line with actual operating conditions for channels near the center of each frequency band assigned to NTT DOCOMO. For WLAN, we used signals modulated by selecting channels mainly

Table 1 Main specifications of radio systems and radio waves investigated

Radio system	3G/FDD-LTE	TD-LTE	WLAN (IEEE 802.11a, 11g)	5G (Candidate frequencies)
Frequency	800 MHz band, 1.5 GHz band, 1.7 GHz band, 2 GHz band	3.5 GHz band	2.4 GHz band, 5.2 GHz band, 5.6 GHz band	3.7 GHz band, 4.5 GHz band, 28 GHz band
Antenna	Half-wave dipole/terminal device			Half-wave dipole/horn

*2 FDD: A bidirectional communications mode that uses different frequencies and frequency bands for uplink and downlink communications.

*3 TDD: A bidirectional communications mode in which different time slots are allocated to uplink and downlink communications using the same frequency.

used with its frequency bands, and for 5G, we used unmodulated signals on 5G candidate frequencies. For the maximum transmission power, we referred to the technical standards for each radio system. Also, because it is known from previous research findings that electromagnetic interference with medical equipment occurs easily due to radio waves in intermittent mode repeatedly turning ON and OFF approximately 60 times per minute (see **Figure 1** (a)), we used signals to reproduce this. For the antennas to radiate the radio waves, we used a half-wave dipole antenna*4 and a horn antenna*5 that are more efficient than the built-in antennas in mobile telephones and smartphones and cause interference easily. In cases where interference occurred or if it was difficult to use these antennas, we used combinations of actual mobile telephones and smartphones for the corresponding radio system.

2.2 Research Site

Because of the necessity to avoid leaking of radio waves outside, we used a shielded room or a shielded tent set up in a room in the Kanazawa University Hospital.

2.3 Procedure

The most prone condition for electromagnetic interference with medical equipment are:

- Intermittent mode
- Max. transmission power
- Close contact with the antenna and medical equipment

Under the conditions above, we investigated impacts of electromagnetic interference on the medical equipment by scanning all over its all surfaces with a radio wave source (an antenna), and by changing the orientation of the antenna. This is called a basic investigation. When the medical equipment had sensors or cables attached, we also investigated interference effects on them. When electromagnetic interference occurred:

- We switched from intermittent modes to continuous mode (see Fig. 1 (b))
- We moved the antenna away from the medical equipment but maintained maximum transmission power
- We maintained close contact with the antenna and medical equipment, but lowered transmission power

to perform follow-up investigations. In cases where interference occurred, or it was difficult to use these antennas, we replaced the antenna with a terminal device. **Figure 2** and **Photo 1** provide an

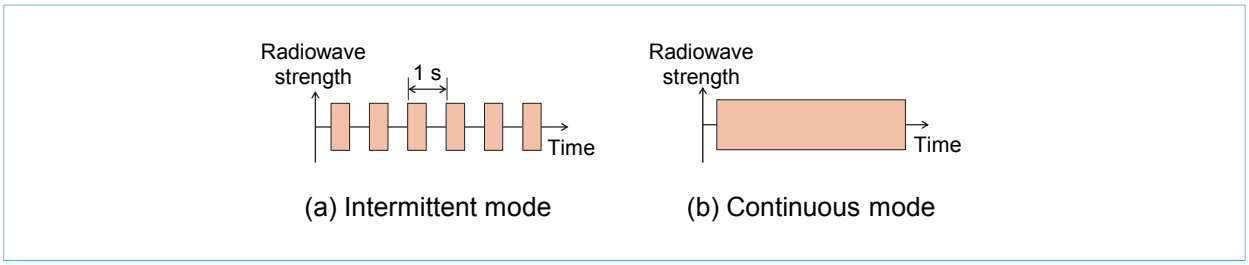


Figure 1 Transmission modes

*4 Half-wave dipole antenna: A very basic antenna which has two 1/4-wave length elements arranged in a straight line at the end of the cable (the feed point).

*5 Horn antenna: A type of antenna with a cone or pyramid shape, which emits a signal that is strong in a particular direction.

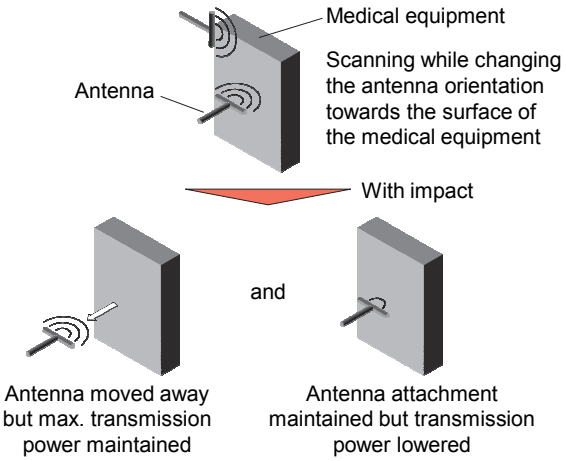
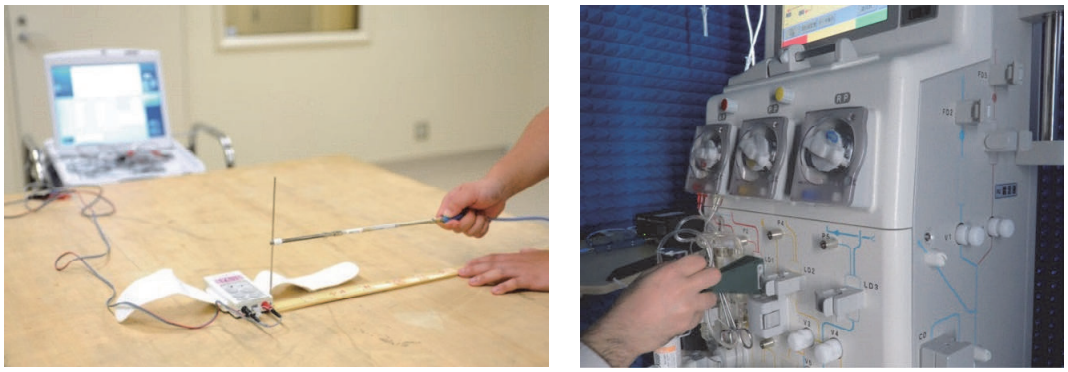


Figure 2 Investigation image



Investigating with a half-wave dipole antenna

Investigating with a horn antenna

Photo 1 The investigation scene

image of the investigation and the actual scene respectively.

2.4 Types of Electromagnetic Interference

When electromagnetic interference was confirmed, to determine the type of interference, we used the categories listed in a report published by the Ministry of Internal Affairs and Communications in 2002 as indices indicating the level of impact on actual medical treatment. These categories have been determined as physical types causing damage to medical equipment, and types adversely affecting medical treatment, as shown in **Table 2**. The higher the number of the category, the greater the impact on medical treatment.

Table 2 Categories of healthcare equipment failure

Physical types causing damage to medical equipment / Adverse impact on medical treatment	Normal	Reversible*1	Irreversible*2 (The following required for normal recovery)	
			Device operation	Device repair
No damage (normal)	1	–	–	–
Medical treatment disturbed*3	–	2	3	4
Misdiagnosis*4	–	3	4	5
Aggravated*5	–	4	5	6
Fatality*6	–	6	7	8
Catastrophe*7	–	8	9	10

Physical categories of medical equipment failure

*1 Reversible	The failure of the medical equipment can be reversed by moving the mobile phone that caused the interference away (or moving the medical equipment away).
*2 Irreversible	The failure of the medical equipment cannot be reversed by moving the mobile phone that caused the interference away (or moving the medical equipment away). The failure can only be rectified by human intervention or technical procedure.

Categories of medical treatment failure

*3 Medical treatment disturbed	Although the original medical purpose is maintained, the treatment does not go smoothly (small noise intrusions, baseline fluctuations, unpleasant sounds, character blurring etc.).
*4 Misdiagnosis	Medical equipment malfunction leads to wrong diagnoses and medical treatment errors. Although treatment is inappropriate, it does not put patient in danger (un-ignorable noise intrusions or baseline fluctuations, abnormal display values, stoppages due to alarms etc.).
*5 Aggravated	Medical equipment malfunction leads to medical treatment errors. If left unattended the malfunction could worsen the patient's medical condition (large changes in settings values, suspension of life support equipment, stoppages without alarms etc.).
*6 Fatality	Medical equipment malfunction leads to medical treatment errors. If left unattended the malfunction could cause patient fatality.
*7 Catastrophe	Medical equipment breakdown leads to major trouble. Patients could die or staff could be seriously injured.

2.5 Medical Equipment Investigated

The 2011 3G/FDD-LTE electromagnetic interference research included exhaustive investigations on a wide variety of medical equipment (53 devices in total) such as electric scalpels, infusion pumps, ventilators and ultrasonic echo devices in operating rooms, ICUs and laboratories in hospitals. In the following 2016 to 2017 investigation, and in light of the 2011 research results, electromagnetic interference was investigated using medical equipment thought to be susceptible to electromagnetic interference, which included 44 devices investigated with WLAN, 23 devices investigated with TD-LTE, and 23 devices investigated with 5G candidate

frequencies.

3. Findings

Table 3 shows a list of the maximum impact distance and maximum category for each radio system under the aforementioned easiest conditions to cause electromagnetic interference on the medical equipment. Similarly, **Figure 3** shows the maximum impact distance for each frequency band. The following describes findings for each of the radio systems and frequency bands.

3.1 3G/FDD-LTE

Testing exhaustively selected medical equipment showed that roughly 40% was affected by electromagnetic interference. The maximum impact distance was 80 cm, and the maximum category was 4. Medical equipment that is comparatively prone to electromagnetic interference included external cardiac pacemakers, electrocardiograms, nerve stimulators, infusion pumps and

Table 3 List of findings

Investigation	Radio system/ frequency band	No. of healthcare devices	Maximum impact distance	Maximum category
2011	3G/FDD-LTE	53	80 cm	4
2016	WLAN	44	28 cm	5
2017	TD-LTE	23	45 cm	4
	5G (Candidate frequency bands)	23	40 cm *No interference at 28.5 GHz	4

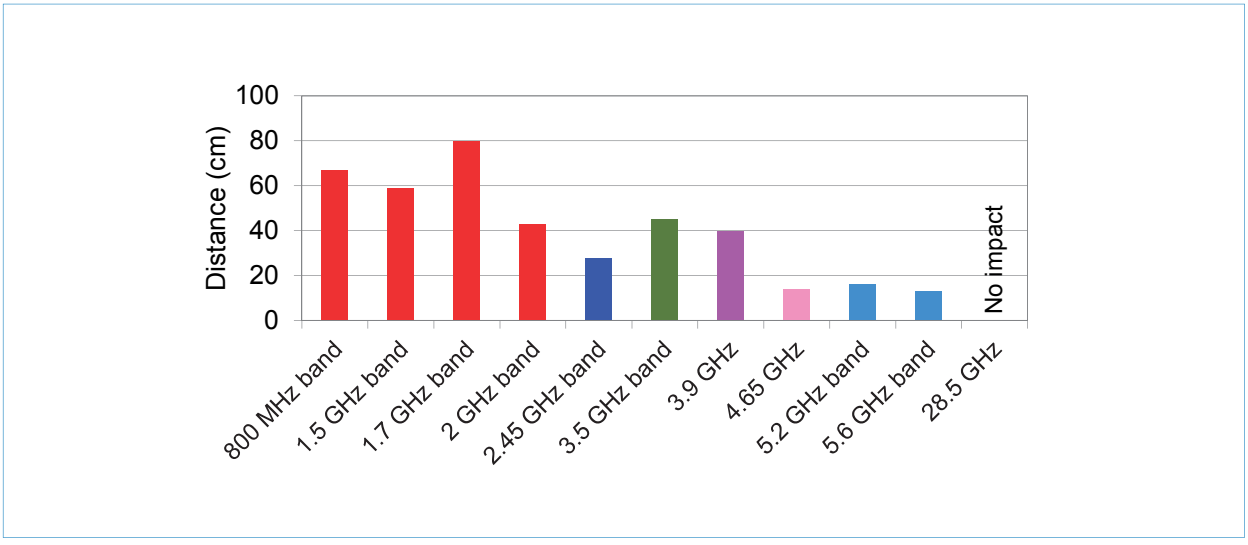


Figure 3 Maximum impact distance by frequency band

ventilators. We also confirmed that electromagnetic interference does not depend on radio wave Peak to Average Power Ratio (PAPR)*6 or modulation method, but is mainly dependent on radiated power [5]. This measured data was reflected in "Report on the Use of Mobile Phones and Other Devices in Hospitals" [6] issued by the EMCC in 2014. In light of past and most recent investigation findings, the Association has issued "Guidelines for the Use of Mobile Phones and Other Devices in Hospitals" [7] that include guidelines permitting use of mobile telephones etc. at distances of 1 m or greater from medical equipment according to appropriate rules created by hospitals.

3.2 WLAN (802.11a/g) and 3.5 GHz Band TD-LTE (LTE-Advanced)

Testing of medical equipment selected for its comparative proneness to electromagnetic interference showed that roughly 40% was affected by some form of electromagnetic interference. Resulting from WLAN and TD-LTE tests, the maximum impact distances were 28 cm and 45 cm, and the maximum categories were 5 and 4 respectively. However, with WLAN testing, even with actual terminals, only one medical device was affected by electromagnetic interference, which implies that the probability of electromagnetic interference from actual WLAN products is extremely small.

3.3 5G (Candidate Frequencies)

Testing of medical equipment selected for its comparative proneness to electromagnetic interference showed that roughly 20% was affected by some form of electromagnetic interference with the 3.7 GHz and 4.5 GHz bands. The maximum impact distances were 40 cm and 14 cm respectively, and the maximum category was 4. There was no electromagnetic interference caused in the 28 GHz band.

4. Conclusion

This article has described research into electromagnetic interference with medical equipment from radio waves emitted by mobile telephones and smartphones. The results of these investigations have contributed to the EMCC's guideline formulation and provided backing for their validity, and have formed the basis for relaxing the long-standing prohibitions on the use of mobile telephones in hospitals, hence enabling the use of mobile telephones and smartphones [6]. We have been investigating other radio systems including 5G, and in future we will contribute to achieving a world with ICT solutions to issues in the healthcare field by enabling safe and secure use of mobile telephones and smartphones in medical institutions.

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*6 PAPR: Peak-signal-power to average-signal-power ratio. An index that indicates the peak signal power compared to the average signal power.

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