Possible Exposure of Persons with Cardiac Pacemakers to Extremely Low Frequency (ELF) Electric and Magnetic Fields

Leena Korpinen, Rauno Pääkkönen, Fabriziomaria Gobba, Vesa Virtanen

***Abstract*—**The number of persons with implanted cardiac pacemakers (PM) has increased in Western countries. The aim of this paper is to investigate the possible situations where persons with a PM may be exposed to extremely low frequency (ELF) electric (EF) and magnetic fields (MF) that may disturb their PM. Based on our earlier studies, it is possible to find such high public exposure to EFs only in some places near 400 kV power lines, where an EF may disturb a PM in unipolar mode. Such EFs cannot be found near 110 kV power lines. Disturbing MFs can be found near welding machines. However, we do not have measurement data from welding. Based on literature and earlier studies at Tampere University of Technology, it is difficult to find public EF or MF exposure that is high enough to interfere with PMs.

***Keywords*—**Cardiac Pacemaker, Electric Field, Magnetic Field.

I. Introduction

In Western countries, persons with implanted cardiac pacemakers (PM) or implantable cardioverter defibrillators (ICDs) make up a large group. For example, in Finland, about 700 out of every million inhabitants received a PM in 2010. In addition, neurostimulators and drug pumps are quite popular nowadays.

A PM is a medical device with electrodes. The electrode configuration in PMs can be unipolar or bipolar. In the unipolar system, there is one electrode that lies within the heart as a cathode, where the anode is the metallic case of the PM itself. In the bipolar system, one lead has two electrodes very close within the heart [1].

In earlier studies [2]–[6], researchers found that some older PM models had shown to be susceptible to the electromagnetic fields (EMF) emitted by everyday household and workplace appliances.

In [7], investigators studied 11 volunteers with PMs and the possible interference when exposed to sine, pulse, ramp, and square waveform magnetic fields (varied up to 300 µT) with frequencies of 2–200 Hz, generated using the Helmholtz coil. They also used an induction cooktop and a metal inert gas (MIG) welding machine to produce exposure. They found that three PMs with unipolar settings were affected by the highest fields of the Helmholtz coil and one of them also by the welding cable. They did not find any interference with any of the unipolar PMs when using the induction cooktop.

EMF interference with PMs and ICDs has been studied, for example, in Finland and France [8]–[10], [4], [11], [6]. The PM tests (in Finland) found that the electric field (EF) under a 400 kV power line (6.7–7.5 kV/m) may disturb a PM in unipolar mode, for example, during tasks under 400 kV power lines or at 110 kV (or higher) substations. However, the risk of interference is not considered to be high because only one of the several PMs tested showed a major disturbance [8]. For the 50 Hz magnetic field (MF), PM tests (in France) showed no interference under 50 µT, in unipolar mode, or under 100 µT, in bipolar mode [4]. For ICDs, in vitro tests (in France) showed no interference until 3,000 µT, but only four devices were tested [11].

The European Committee for Electrotechnical Standardization (CENELEC) has also published some standards from this area [12], [13]. For example, according to the European Norm 50527-1, magnetic flux density (MFD) of 100 µT is considered to be the 'safety level' for PMs. In addition, Finland has an act giving recommendations on the exposure of the general public to EMFs at the frequency range below 100 kHz [14]. The act is based on the European Council Recommendation 1999/519/EC.

The aim of this paper is to investigate the possible situations where persons with PMs may be exposed to extremely low frequency (ELF) electric (EFs) and MFs that may disturb the PM. The paper is based on our earlier articles [8], [10].

II. Exposure to Electric Fields

A. Examples of 400 kV Power Lines

At Tampere University of Technology (TUT), we have measured EFs and MFs in different situations, so we will use our old measurement data on public exposure situations.

In Finland, we have 400, 220 and 110 kV power transmission lines (frequency 50 Hz), and the total length of this transmission system is about 22,000 km. In the TUT studies of public exposure to electric fields near 400 kV power lines, the highest measured EF value was 9.3 kV/m.

In general, the values were lower [15]. Fig. 1 shows an example of a place under 400 kV power lines, where the EF is

L Korpinen is with Department of Electronics and Communications Engineering, Tampere University of Technology, P.O.Box 692, 33101 Tampere, Finland (Phone: +358 3 3115 11; fax: +358 3 364 1385; e-mail: leena.korpinen@ tut.fi).

R. Pääkkönen is with Tampere University of Technology, P.O.Box 692, 33101 Tampere, Finland (e-mail: rauno.paakkonen@gmail.com).

F. Gobba is with the Department of Diagnostic, Clinical and Public Health Medicine, University of Modena and Reggio Emilia Italy, Modena, Italy (e-mail: f.gobba@unimore.it).

V. Virtanen is with The Heart Center, Tampere University Hospital, Tampere, Finland (e-mail: Vesa.Virtanen@sydansairaala.fi).

6.7–7.5 kV/m [8].

Fig. 1 Example place under 400 kV power line

Fig. 2 Example of measurements in kitchen

Fig. 3 Example of measurements in kitchen

B. Examples of 110 kV Power Lines

In another study at TUT, the EF was measured at 10 tower spans near 110 kV transmission lines. The maximum measured EF values were between 0.5–2.3 kV/m, and the mean value of maximum values ± standard deviation (SD) was 0.98 ± 0.56 kV/m [16].

III. Exposure to Magnetic Fields

A. Examples of Power Lines and Cables

In a previous TUT investigation of 110 kV power lines, the maximum measured MFs were 0.6–6.0 µT, and the mean value of maximum values ±standard deviation (SD) was 2.98 ± 1.63 µT [16]. Near 400 kV power lines (Fig. 1), the measured MF was 2.4–2.9 µT [8].

Likewise, in another TUT study, MFs were measured near 110 kV underground power cables. Measurement places were chosen by calling different electric utilities and asking them about the currents in their 110 kV cables. Six cable routes from the service areas of two utilities were chosen, and measurements were made for both sides of the cable route. The maximum values were 1.7 µT at the height of 1 m from the ground and 5.0 µT at ground surface [16].

B. Examples in Homes

At TUT, [17] studied the MFs in rooms above indoor distribution substations, and the maximum values at the floor level were 0.37– 41.6 µT. Moreover, we previously we measured magnetic fields in the kitchen. Figs. 2 and 3 show some examples [18].

Table I shows some examples of the MF measurements from different devices in a household kitchen.

TABLE I
Examples of MF Measurements from Different Kitchen Devices

Kitchen Devices	MF (µT)
Mixer with whisks	0.4–0.5
Mixer with whisks	0.8–0.9
Mixer with whisks	0.6–0.7
Mixer with dough hooks	0.9–1.1
Mixer with dough hooks	0.6
Mixer with dough hooks	0.5–0.6
Microwave oven 1	14
Microwave oven 2	6.7
Refrigerator 1	0.2
Refrigerator 2	0.3
Electric kettle	0.3–0.3

MFs were 0.4–1.1 µT around the mixer and varied between 0.2 and 0.3 µT around the remaining equipment. In the proximity of the microwave oven, the MFD was 6–14 µT. The measurement distance was 20 cm, and in the measurements of the refrigerator, the height was 0.5 m. In the mixer measurements, three different power levels were also used [18].

C. Examples of Smart Meters

The use of smart meters has increased around the world. In Finland, these smart meters most often send information or communicate using either a radio frequency (800-3000 MHz) aerial signal to masts or a 50-100 kHz electromagnetic field signal through cables. TUT studied the possible magnetic field exposures of the smart meters. TUT employed 46 smart meters that used Power Line Communication (PLC). The highest magnetic field was 0.48 µT, which is 2% of the ICNIRP guidelines to public exposure [19]-[21].

Fig. 4 shows an example of the smart meter measurement with the MF meter MFM 3000—the separate probe version—by Combinova (frequency range 40–100 kHz and 10 nT-10 mT).

Fig. 4 An example of the smart meter measurement

The exposure of smart meters were so low, that there is not specific need to improve the sheltering of the meters from the public or to measure magnetic field emissions from all smart meters in the future. [21]

TUT also studied radiofrequency electromagnetic field exposure detected by smart meters during the remote reading of the smart meter. The measured values were less than 1-3% from the recommended values of ICNIRP. [22]

D.Examples of the Metro Station

TUT studied the exposure to ELF magnetic fields in the metro stations in Finland. The measurements concentrate on dynamic conditions. TUT measured magnetic fields in 20 cases when a train was leaving the platform in the same station. The magnetic field meter was MFM 3000. [23]

The maximum MF value measured was 5.4 µT. The distance to the conductor rail was 4.3 m and the measurement height was 1 m. The MF only maintained this level momentarily, and the train influenced the general exposure situation for about one minute as the train left. The fields measured were thus quite low when we compare them to the ICNIRP guidelines. The studied metro are powered by 750 V DC voltage supplied through a conductor rail next to the running rails, meaning. Therefore, it is possible that there are also DC magnetic fields near the metro as the train leaves the station. [23]

IV. Comparison EF Exposure and PM Disturbances

As indicated above, the pacemaker tests found that the EF under a 400 kV power line (6.7–7.5 kV/m) may disturb a PM in unipolar mode [8]. When we compare the EF exposures near 400 kV or 110 kV power lines to this study, we found that disruptive EFs are possible only in some places near 400 kV power lines. Such EFs are not possible under 110 kV power lines. When there is high voltage, then there is a high EF. Therefore, we know that in all other public places, EFs are lower than near 400 kV power lines. In addition, it is important to remember that we found disturbances only with a unipolar electrode configuration [8].

V.Comparison MF Exposure and PM Disturbances

The MF is based on a current. In the places where we can find high currents, it is possible to find high MFs. Near power lines, MFs are not very high. Therefore, EFs are more important near 400 kV power lines.

As indicated above, pacemaker tests (in France) with MFs showed no interference under 50 µT, in unipolar mode, or under 100 µT, in bipolar mode [24]. It is possible that MFs of over 100 µT may be found near welding machines. Above indoor distribution substations, it is possible to find MFs that are high enough to cause disturbances, but in general, values are below 50 µT.

VI. Conclusion

Based on literature and earlier studies at Tampere University of Technology, it is generally difficult to find public exposure to EFs or MFs that are sufficient enough to interfere with pacemakers. Only the EF under a 400 kV power line may disturb a PM. However, in our earlier study, only one type, out of several tested PMs, showed a major disturbance, and that was only with a unipolar electrode configuration. The risk of disturbances is, therefore, not deemed to be high. Possibly near welding machines, the magnetic field can be so high that disturbances are possible, but as we do not have any measurements, we can only speculate.

Acknowledgment

The assistance of the staff of the Environmental Health research group, Tampere University of Technology (Markus Annila, Tero Haapala, and Markus Wirta) is gratefully acknowledged. We thank Harri Kuisti (Fingrid Oyj), Jarmo Elovaara (Fingrid Oyj) and Hiroo Tarao (Department of Electrical and Computer Engineering, Kagawa National College of Technology, Japan) for their advice.

REFERENCES

[1] G. Chiara, V. Primiani, and F. Moglie, "Experimental and numeric investigation about electromagnetic interference between implantable cardiac pacemaker and magnetic fields at power line frequency," *Ann. Ist. Super Sanita,* vol. 43, no. 3, pp. 248–253,2007.

[2] D. Marco, G. Eisinger, and D. L. Hayes, "Testing of work environments for electromagnetic interference," *Pacing Clin. Electrophysiol.,* vol. 15, pp. 2016–2022, 1992.

[3] M. Hirose, M. Hida, E. Sato, K. Kokubo, M. Nie, and H. Kobayashi, "Electromagnetic interference of implantable unipolar cardiac pacemakers by an induction oven," *Pacing Clin. Electrophysiol.,* vol. 28, pp. 540–548, 2005.

[4] A. Trigano, P. Deloy, O. Blandeau, and S. Levy, "Arc welding interference recorded by an implanted cardiac pacemaker," *Int. J. Cardiol.,* vol. 109, pp. 132–134, 2006.

[5] S. Lee, K. Fu, T. Kohno, B. Ransford, W. H. Maisel, "Clinically significant magnetic interference of implanted cardiac devices by portable headphones," *Heart Rhythm,* vol. 6, pp. 1432–1436, 2009.

[6] M. Souques, I. Magne, and J. Lambrozo, "Implantable cardioverter defibrillator and 50-Hz electric and magnetic fields exposure in the workplace," *Int. Arch. Occup. Environ. Health*, vol. 84, pp. 1–6, 2011.

[7] M. Tiikkaja, A. L. Aro, T. Alanko, H. Lindholm, H. Sistonen, J. E. K. Hartikainen, L. Toivonen, J. Juutilainen, and M. Hietanen, "Electromagnetic interference with cardiac pacemakers and implantable cardioverter-defibrillators from low frequency electromagnetic fields in vivo," *Europace,* vol. 15, pp. 388–394, 2013.

[8] L. Korpinen, H. Kuisti, J. Elovaara, and V. Virtanen, "Cardiac pacemakers in electric and magnetic fields of 400-kV power lines," *Pacing Clin. Electrophysiol.,* vol. 35, pp. 422–430, 2012.

[9] L. Korpinen, H. Kuisti, J. Elovaara, V. Virtanen, "Response," *Pacing Clin. Electrophysiol.,* vol. 36, no. 2, pp. 267–268, 2013.

[10] L. Korpinen, H. Kuisti, J. Elovaara, and V. Virtanen, "implantable cardioverter defibrillators in electric and magnetic fields of 400 kV power lines," *Pacing Clin. Electrophysiol.,* vol. 37, pp. 297–303, 2014.

[11] J. Katrib, M. Nadi, D. Kourtiche, I. Magne, P. Schmitt, M. Souques, P. Roth, "In vitro assessment of the immunity of implantable cardioverter-defibrillators to magnetic fields of 50/60 Hz," *Physiol. Meas.,* vol. 34, no. 10, pp. 1281–1292, 2013.

[12] CENELEC – European Committee for Electrotechnical Standardization, 2010. *Procedure for the assessment of the exposure to electromagnetic fields of workers bearing active implantable medical devices – Part 1: General*. Brussels, Belgium.

[13] CENELEC – European Committee for Electrotechnical Standardization, 2011. *Procedure for the assessment of the exposure to electromagnetic fields of workers bearing active implantable medical devices – Part 2-1: Specific assessment for workers with cardiac pacemakers*. Brussels, Belgium.

[14] STM (Ministry of Social Affairs and Health in Finland), 2002. *Decree on the limitation of public exposure to non-ionizing radiation (294/2002).* Helsinki, 47 p. (In Finnish).

[15] J. Elovaara, H. Kuisti, and L. Korpinen, 2009, "*Workers exposure to electric fields in 400 kV substation and overhead line works,"* in *2009 Proc. International Colloquium Power Frequency Electromagnetic Fields ELF EMF*, 3–4 June 2009, Sarajevo, Bosnia and Herzegovina, Committee for Bosnia and Herzegovina and CIGRE SCs, B2 – Overhead Lines, B1 – Insulated Cables, B3 – Substations, B4 – HVDC and Power Electronics, C3 – System Environmental Performance and C4 – System Technical Performance*,* paper 15, 8 p.

[16] R. Lehtelä, T. Laurila, L. Österholm, and L. Korpinen, "Magnetic field exposure of 110 kV underground power cables," in 2009 Proc. *BIOEM 2009, June 14-19, 2009, Davos, Switzerland,* 2 p.

[17] T. Keikko, "Technical management of the electric and magnetic fields in electric power system," Doctoral dissertation, Tampere University of Technology, 422.

[18] F. Gobba, R. Pääkkönen, H. Tarao, and L. Korpinen, "The possible exposure of children to extremely low frequency magnetic fields in the home," in 2012 Moscow Proc. PIERS, pp. 2012, Moscow proceedings, August 19–23, 2012, Moscow, Russia. Progress in Electromagnetics research symposium 286–288.

[19] R. Pääkkönen, M. Lundström, J, Mustaparta, L. Korpinen, "Preliminary measurements of smart meter electromagnetic field (50-100 kHz) emissions in Finland" 8th International Workshop on Biological Effects of Electromagnetic Fields. 21st -25th September 2014, Varna, Bulgaria

[20] R. Pääkkönen, M. Lundström, J, Mustaparta, L. Korpinen, "Examples of electromagnetic field (50–100 kHz) emissions from smart meters in Finland" Radioprotection, (in press)

[21] R. Pääkkönen, L. Korpinen, Emission of smart meter electromagnetic field (50–100 kHz) in Finland, CIRED2015- 23rd International Conference on Electricity Distribution, Lyon, 15-18 June 2015 (accepted)

[22] R. Pääkkönen, M. Lundström, J, Mustaparta, L. Korpinen, "Exposure to RF fields during the remote readings of the smart meter in Finland", 8th International Workshop on Biological Effects of Electromagnetic Fields. 21st -25th September 2014, Varna, Bulgaria

[23] L. Korpinen, A. Lähdetie, Å. Amundin, H. Piippo, L. Sydänheimo, "Example measurements of exposure to ELF magnetic fields on the metro station in Finland", 8th International Workshop on Biological Effects of Electromagnetic Fields. 21st -25th September 2014, Varna, Bulgaria

[24] A. Trigano, O. Blandeau, M. Souques, J. P. Gernez, and I. Magne, "Clinical study of interferences with cardiac pacemakers by a magnetic field at power-line frequency," *J. Am. Coll. Cadiol.,* vol. 45, pp. 896–900, 2005.

Professor Leena Korpinen is a multidisciplinary scientist who is a licensed doctor of medicine and holds a PhD in technology. Her doctorates handle electric power engineering, more precisely the health effects of exposure to low frequency EMF on employees in work settings. In 1998 she was awarded a professorship in electric power engineering. From 2001–2007 Dr. Korpinen led the Laboratory of Electrical Engineering and Health at TUT, and due to structural changes at TUT in 2008, her professorship has since been in environmental health, more specifically researching "the environmental effects of energy production and distribution, and of traffic." She is also a member of the Bioelectromagnetics Society (BEMS), the European BioElectromagnetics Association (EBEA), and the Conseil International des Grands Réseaux Electriques (CIGRE), and she serves as the Secretary of the Scientific Committee on Radiation and Work of the International Commission on Occupational Health (ICOH).

Rauno Pääkkönen is an Adj. Professor, DSc, at Tampere University of Technology and is the CEO of his own company. He also works as a counselor in environmental issues at the Finnish Supreme Administrative Court. His research has been focused on work environmental factors and well-being. He has contributed to more than 300 scientific texts and 150 popular articles. Earlier he was a director of the theme that included all types of well-being solutions at work at the Finnish Institute of Occupational Health.

Professor Fabriziomaria Gobba, Associate Professor of Occupational Health, is the head of CRESCE, Chair of the Scientific Committee on Radiation and Work of the International Commission on Occupational Health (ICOH), a member of the Board of the Italian Association for Radioprotection (AIRM), and the coordinator of the Emilia-Romagna Regional Section of the same association. He has 30 years of experience in epidemiological studies on adverse effects of chemical and physical risk factors in workers. For about 20 years, he has been performing research on occupational and environmental exposure to EMF, mainly ELF, and on possible adverse health effects, and he has published several papers on this topic in international scientific journals. He is also member of EBEA and BEMS.

Vesa Virtanen is Adj. Professor, MD at the Turku University, specialist in internal medicine and cardiology, and PhD at the Tampere University, Headof Cardiology Dept. at Heart Hospital, Tampere University Hospital. His research has been focused on cardiology.