Original Article

Testing of Common Electromagnetic Environments for Risk of Interference with Cardiac Pacemaker Function

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ABSTRACT

Background: Cardiac pacemakers are known to be susceptible to strong electromagnetic fields (EMFs). This *in vivo* study investigated occurrence of electromagnetic interference with pacemakers caused by common environmental sources of EMFs.
Methods: Eleven volunteers with a pacemaker were exposed to EMFs produced by two mobile phone base stations, an electrically powered commuter train, and an overhead high voltage transmission lines. All the pacemakers were programmed in normal clinically selected settings with bipolar sensing and pacing configurations.
Results: None of the pacemakers experienced interference in any of these exposure situations. However, often it is not clear whether or not strong EMFs exist in various work environments, and hence an individual risk assessment is needed.
Conclusions: Modern pacemakers are well shielded against external EMFs, and workers with a pacemaker can most often return to their previous work after having a pacemaker implanted. However, an appropriate risk assessment is still necessary after the implantation of a pacemaker, a change of its generator, or major modification of its programming settings.

1. Introduction

Electromagnetic interference (EMI) of electric appliances with active medical implants such as cardiac pacemakers has posed a challenge for decades. In particular, older pacemaker models have been shown to be susceptible to the electromagnetic fields (EMFs) emitted by everyday household and workplace appliances [1–5]. Difficulties have also arisen in electromagnetically hostile workplaces after an employee has had a pacemaker implanted. Many applications involved in supply and transmission of electric power emit high electric and magnetic fields that can cause EMI with pacemakers [6–8]. According to the European EMF directive 2004/40/EC, employers are responsible for ensuring the safety of workers with pacemakers or other active medical implants [9].

We have previously studied the occurrence of pacemaker EMI from an electronic article surveillance gate, an induction cook top, and a welding machine [10]. However, there are several other common EMF sources that could potentially interfere with pacemakers.

Mobile phones have been shown to cause interference in older pacemaker models, particularly with unipolar sensing settings, but also with bipolar sensing feature commonly used in modern pacemakers [11–14]. We found no previous data on EMI with pacemakers from mobile phone base stations. However, because EMFs emitted by base stations are similar to those emitted by mobile phones, they may also be possible sources of EMI in specific situations [15,16]. This may happen for instance if a maintenance worker with a pacemaker installs or maintains base station antennae with his chest close to an active transmitter.

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Only one study related to trains and pacemakers was found and it is about possible EMI in a magnetically levitated linear motor car [17]. We found no reports on EMI with pacemakers from EMFs in electric trains. However, our previous measurements indicated that the EMFs in certain sites inside old models of electric commuter trains are rather high, and may pose a danger to pacemaker patients. The areas with the highest magnetic fields were found to be close to the thyristor cabinets in the hallways of the trains. In Finland, electric trains use a 25 kV/50 Hz voltage, and the engines of the trains use electric current varying from 300 A to 600 A, depending on the driving speed. During acceleration the current can reach almost 1000 A [18].

Overhead high voltage transmission lines emit electric and magnetic fields that have been suspected to cause EMI with pacemakers [7,8,19,20].

In this study, we evaluated the occurrence of EMI with some frequently used pacemaker models near two mobile phone base stations, in an electric commuter train, and under 400 kV overhead high voltage power transmission lines.

2. Materials and methods

2.1. Volunteers and pacemakers

For this study, we chose 11 volunteers with pacemakers from three manufacturers: St Jude Medical (Sylmar, CA, USA), Boston Scientific (Natick, MA, USA), and Medtronic (Minneapolis, MN, USA). The volunteers were recruited from the Pacemaker Clinic of Helsinki University Central Hospital. Criteria for participation were the patient's age (only working-aged volunteers) and nature of heart disease (only clinically stable volunteers who were not dependent on their pacemaker).

Normal clinical programming with bipolar configuration was maintained in all the pacemakers. The models, modes, base rates, and sensitivities of the pacemakers tested are shown in Table 1. Atrial tachycardia and ventricular high rate detections of the pacemakers were programmed on in all but three pacemakers, with detection rates of 170–225 beats/minute. All the physiological pacemakers (DDD) had a mode switch feature programmed with auto mode switch base rates of 40–90 beats/minute in case of a detected atrial arrhythmia.

The study design was approved by the Coordinating Ethics Committee of the Hospital District of Helsinki and Uusimaa. All volunteers were fully informed in writing of the study and gave their written consent prior to the study.

2.2. Measurement procedure

Prior to the exposure tests, the pacemakers were interrogated. The patients underwent an ambulatory three-channel electrocardiogram (ECG) recording (BMS/Braemar, Burnsville, MN, USA) during the tests. The ECG recording was started after the initial interrogation and completed just prior to the final interrogation of the pacemakers. The beginning of every exposure was labeled with a trigger button of the ECG recorder. This made it possible to link the exposure and the corresponding sections in the ECG in order to find possible traces of EMI. ECG recordings were then analyzed in order to find traces of possible interference, e.g., inappropriate atrial or ventricular sensing resulting in loss of pacing or inappropriate pacing, asynchronous pacing due to magnet response or noise reversion mode, and mode switch episodes. After the exposures, all the pacemakers were interrogated again and checked for possible malfunctions due to EMI, including possible stored episodes of false atrial or ventricular high rate detection, mode switch, and magnet response.

2.3. Mobile phone base station transmitters

Two small indoor pico-size GSM base station transmitters were located next to each other on the wall in the basement of a workplace. The volunteers were asked to stand in front of the antennae for 30 seconds so that the distance between their chest and the base stations was approximately 50 cm. The electric field measured at that point was 16 V/m. The electric field measurements were performed using a Narda EMR-300 with a 33c electric field probe (Narda Safety Test Solutions, Pfullingen, Germany).

2.4. Electric commuter train

The magnetic flux density in an electrically powered commuter train was measured to be approximately 170 µT above a bench attached to a thyristor cabinet where the volunteers were asked to sit while the train accelerated twice. This field level was consistent with magnetic fields previously measured in several different trains of the same model. The volunteers also stood in the hallway of the train, leaning against the thyristor cabinet while the train accelerated. The highest temporal magnetic flux density next to the thyristor cabinet was measured to be approximately 170 µT which also complied with our previous measurements. The field levels at the two test sites varied slightly between the tests depending on the level of the train's acceleration. All magnetic field measurements were made using a Narda ELT 400 magnetic field meter (Narda Safety Test Solutions, Pfullingen, Germany). The two exposure situations took a few minutes per volunteer, depending on the delays between the train's accelerations.

2.5. High voltage transmission lines

The EMI tests were conducted while the volunteers walked for approximately ten minutes under 400 kV transmission lines. The

Table 1
Manufacturers, models, and basic parameters of the pacemakers tested

Manufacturer	Model	Mode	Base rate (beats/min)	Atrial sensitivity (mV)	Ventricular sensitivity (mV)
St Jude Medical	Identity ADx SR 5180	AAIR	70	0.5	—
	Identity ADx XL DR 5386	DDD	40	0.75	2.0
	Accent DR RF 2212	DDD	50	0.2	0.5
	Accent DR RF 2212	DDIR	60	0.4	1.0
	Accent DR RF 2212	DDD	50	0.5	2.0
	Victory XL DR 5816	DDD	50	0.5	2.0
Boston Scientific	Altrua 60 S 602	VVIR	60	—	2.5
	Altrua 60 S 602	DDD	50	0.23	4.1
	Altrua 50 S 502	DDIR	60	0.75	4.0
Medtronic	Kappa KSR 401/403	VVI	50	—	2.8
	Kappa KDR 901	DDDR	60	0.5	2.0

national grid company provided the details of the currents and voltages of the power lines at the time of the tests. These details were used to calculate analytically the magnetic and electric fields under the transmission lines. In all positions, the magnetic and electric field levels were less than 3 μT and 4 kV/m, respectively. We were unable to measure the field intensities under the transmission lines because of the freezing weather of the day with temperature below the operation temperature of the meters.

3. Results

The study population consisted of six women and five men. The mean age was 52 years with a range 34—64 years. One of the pacemakers was programmed to AAI(R) mode, two to VVI(R) mode, six to DDD(R) mode, and two to DDI(R) mode [21,22]. The mean time in use of the pacemakers was 2.5 years (range, 0.3—7.0 years). Indication of pacing was sick sinus syndrome in four patients, disturbed atrioventricular conduction in five patients, and atrial fibrillation with bradycardia in two patients.

The mean programmed atrial sensitivity was 0.48 mV ± 0.19 mV, and the mean ventricular sensitivity was 2.3 mV ± 1.1 mV. In the patients with an atrial lead, atria were mostly paced in three patients and atrial sensing was predominantly present in six. Among the patients with a ventricular lead, ventricles were paced in three patients, and the remaining seven patients exhibited predominantly ventricular sensing.

In this study, none of the pacemakers tested experienced EMI during the various tests. No episodes of asynchronous pacing due to magnet response or noise reversion mode, or inhibition of atrial or ventricular pacing due to inappropriate sensing of the EMFs were observed during the continuous ECG recording of the study participants. Inappropriate ventricular pacing in the dual chamber devices due to atrial oversensing was not witnessed. Moreover, no stored episodes of mode switch or falsely detected atrial or ventricular arrhythmias were observed when the pacemakers were interrogated after the EMF exposures, and no abnormalities in the pacemaker parameters and function were noticed, either.

4. Discussion

The main finding of our study was that EMFs created by mobile phone base stations, commercial trains and transmission lines did not result in EMI with modern pacemakers programmed to bipolar settings. High EMF exposure from mobile phone base stations may not be relevant to most workers, because base station antennae are normally located near the roof, far away from normal working environments. However, areas with field levels similar to those measured in this study may sometimes be accessed by technical personnel installing and maintaining the base stations.

The tests in the electric commuter train were conducted in two spots that were known to have high magnetic field levels. The train conductor normally stands next to the thyristor cabinet in the hallway of a train, sometimes even leaning on it when collecting fares after each station. Public transportation (including commuter trains, trams, and underground) is a global source of EMFs not only to employees but also to passengers.

High voltage transmission lines can produce considerably high electric and magnetic fields in the surrounding area and below. These fields are reported as possibly affecting the operation of pacemakers [7,8,19,20]. This can cause problems for any pacemaker patient moving near transmission lines, but especially to workers who maintain the lines. Although we found no EMI between the transmission lines and the pacemakers in this study, high voltage transmission lines still remain a potential source of EMI.

A thorough individual risk assessment is required prior to when a worker can safely return to work after a pacemaker implantation [23]. At most workplaces, such as offices, schools, and shops where EMFs are generally weak, only a general risk assessment is needed. First, the employer has to identify the need for a risk assessment. This involves a survey to determine general details about pacemakers, as well as basic operational methods about the pacemaker of the worker. Also the special instructions concerning EMI that may have been given to the employee need to be determined. Next, the level of the risk assessment must be evaluated. It is important to recognize possible sources of EMI in the workplace. When it is not clear whether or not strong EMFs exist in the work environment, a special risk assessment is to be carried out, including the measurement of EMFs. The findings, and possible actions they require, must be estimated so that the areas the employee needs to avoid can be defined, and his/her working methods can be rearranged. All the findings should be documented for possible further use. The assessment shall be maintained, and updated every time fundamental changes are made at the workplace or to the pacemaker's programmable settings.

The fact that only 11 pacemakers of eight different models were tested can be considered a study limitation. Moreover, some of the pacemaker models were old, although they are still used in pacemaker treatment. By contrast, modern pacemakers are likely to be even more resistant to EMI than older models. A great majority of pacemakers are implanted with bipolar settings. However, one cannot apply our results to unipolar pacemaker systems, which are known to be more susceptible to external EMFs. The pacemakers tested were not programmed to the most sensitive settings and not every pacemaker had its episode triggers on. It was decided to leave all of the programming settings of the pacemakers as the initial values clinically programmed to every volunteer. This decision was due to the occupational safety approach of this study.

One study limitation was the fact that electric and magnetic field intensities could not be measured under the high-voltage transmission lines at the time of the tests due to the freezing weather of that day.

In conclusion, mobile phone base stations, electric commuter trains, and high voltage transmission lines appear to cause no problems for patients with bipolar pacemakers. However, an appropriate risk assessment or its update is necessary at the workplace after an employee has a pacemaker implanted or its generator changed, as well as after every major alteration to its programmed settings.

Conflicts of interest

No potential conflicts of interest relevant to this article was reported.

Acknowledgments

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