ELECTROSURGERY

Occupational exposure to electromagnetic fields - assessment in practice

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ver. 1 - April 2008

ELECTROSURGERY DEVICES

Electrosurgery means the use of electric currents to cut or to coagulate a patient's tissues for various medical treatments. The sources of occupational exposure to electromagnetic fields (EMF) include:

- an active electrode at a high electric potential
- cables connecting the generator (output power of up to 500 W, usually during surgical treatment of 50-150 W) with the active electrode, held in the hand by a surgeon, and with the passive electrode (grounded plate), mounted to the patient's body (Fig. 1)
- a generator in case of not leak-proof housing (generator with insufficient electromagnetic shield)
- metallic objects located in the vicinity of cables (e.g. surgical or instrumentation tables), which can become secondary sources of EMF.

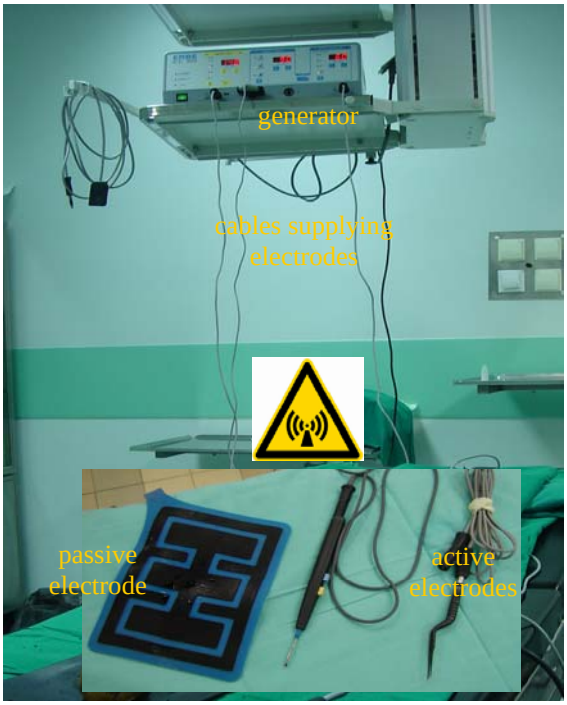

Fig. 1. Electrosurgery device

OCCUPATIONAL EMF EXPOSURE

Electrodes and supplying cables are sources of electric field (E-field) of high level because of the application of supplying intermediate frequency (IF) high voltage, of frequency exceeding 300 kHz (up to ~1 MHz).

The waveforms of EMF produced in the vicinity of cables depend on a type of a device and its mode of operation (Fig. 2).

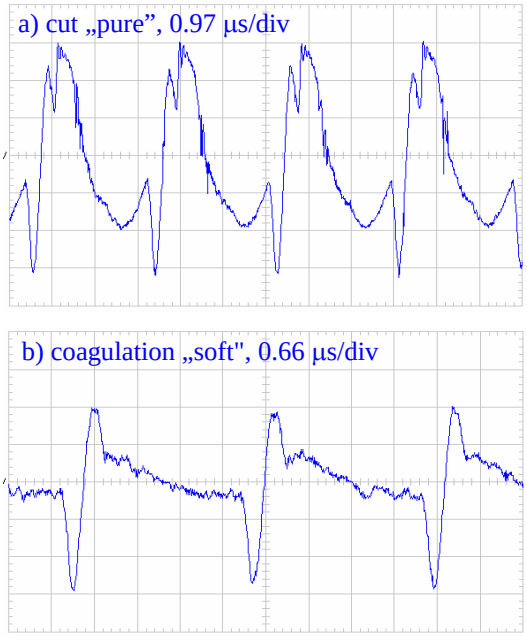

Fig 2. EMF of electrosurgery device - E-field v. time

The exposure to EMF of a surgeon and health care staff (attending physicians and nurses) depends on:

- mode of device operation
- type of active electrode in use
- location of cables connecting electrodes with generator.

The surgeon, who holds an active electrode in the hand, is usually the most exposed person from the team.

The hand exposure always exists, but other areas of the body can be also exposed as a result of a contact with cables, e.g. head or torso EMF exposure.

The surgeon is usually exposed to non-homogenous E-field. Metallic objects, which are in the operating theatre influence the spatial distribution of E-field. The level of exposure of health care staff can change 2 or 3 fold, as a consequence of changes in the location of these objects.

In the worst case (use of a monopolar electrode and non-shielded cables, approx. 100-150 W output power), the surgeon's hand can be exposed to E-field exceeding 1000 V/m, but head and torso - up to a few tens of V/m only. When cables touch the surgeon's body then torso exposure is stronger, up to the level of the exposure of the hand holding the electrode. Magnetic field (H-field) is usually below 1 A/m in the distance of 5-10 cm from electrodes and cables. If cables create loops, an increased magnetic field exists also in their vicinity.

Level and waveform of EMF depend on the mode of electrosurgery devices operation (Fig. 3, Tab. 1).

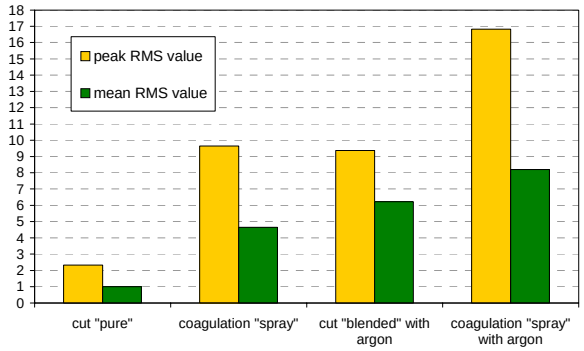

Fig. 3. Examples of variability of E-field produced in various modes of electrosurgery devices - comparison of relative E-field (mean RMS for *"pure" cut* = 1), registered by wide-band E-field meter

Table 1.
Example of relation of peak value (E_p) to mean RMS values (E_{RMS}) of E-field strength, registered by oscilloscopic method in the vicinity of cables of electrosurgery devices

Operation Mode - output power	Ratio, E_p/E_{RMS}	Waveform of EMF
cut „pure" - 150 W	1,4	sinusoidal 400 kHz
coagulation „spray" - 100 W	4,1	sinusoidal 400 kHz + pulse modulation 25-40 kHz
cut „blend" with argon - 100 W	1,8	sinusoidal 400 kHz + amplitude modulation 27 kHz
coagulation „spray" with argon - 100 W	3,8	sinusoidal 400 kHz + pulse modulation 40 kHz

The execution of electrosurgical treatment with an electric arc burned under an active electrode leads to a significant increase of E-field affecting on medical staff. The level of exposure during electric arc-surgery can be 4-fold higher in comparison to the operation without visible arc.

As a result of exposure to E-field and capacitive coupling between elements of electrosurgery device and the worker's body, induced electric current is flowing through the worker's body, similarly to currents penetrating the patient's tissues (Fig. 4).

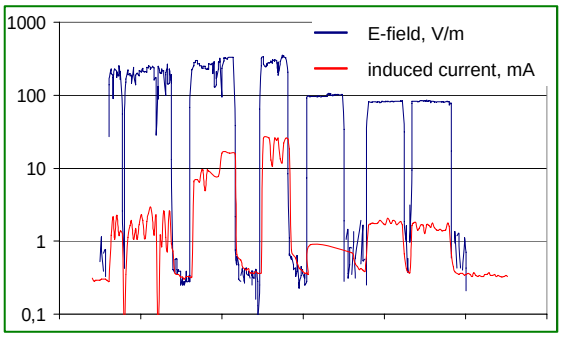

Fig. 4. Induced current measured at surgeon's hand, keeping an active electrode, and E-field measured over a surface of this hand (for various modes of operation and cable location, 5-minutes registration)

OCCUPATIONAL EMF EXPOSURE ASSESSMENT

Measurements

The level of EMF exposure of health care staff can be assessed with the use of three parameter, which can be measured in the workplace:

- electric field strength, *E*, in V/m
- magnetic field strength, *H*, in A/m
- induced current, *I*, in mA.

The measurements of EMF have to be executed by broadband meters. The frequency response of equipment used for measurements has to be adequate to the frequency of EMF produced by electrosurgery devices.

EMF exposure of health care staff should be measured following the procedures established by requirements of national regulations and standards, or in the case of the lack of such documents, following the internationally published standards (e.g. CENELEC or IEEE standard). The use of the results of laboratory measurements of EMF emission from electrosurgery devices is very limited because spatial distribution of E-field can be highly modified by the metallic structures and humans present in the vicinity of the field source.

The results of measurements of exposure parameters have to be analysed following the national regulations and standards, or in case of the

lack of such document, following the internationally published limitations and standards (e.g. European Directive 2004/40/EC, ICNIRP's guidelines or IEEE standard – see table 2). It should be considered that the permissible level of exposure, applicable for assessment of exposure from various modes of operation of electrosurgery devices, can be different as a result of the use of frequency-dependent exposure limitations.

Methods of measurements should be harmonised with assessment criteria (see Table 2 and 3).

Analysis of results of RMS measurements of *E*, *H*, *I* should take into account the waveforms of the investigated EMF - the most universal method for its identification is oscilloscopic registration. In case of modulated fields, the broadband meters calibrated for RMS value of sinusoidal fields can produce a significant error (exceeding 50 %) and correction factors harmonized with the waveforms of the assessed field should be considered before performing the worker's exposure assessment. As a consequence, for measurements of modulated EMF it is necessary to identify the waveform of EMF time-variability, as well as information on detailed technical parameters of the meter being used concerning the sensitivity of readings of this meter to various parameters of modulated fields. Exposure assessment criteria can also be modified in case of modulated fields (see Table 2 and 3).

Measurements can be performed during a simulated operation only, with phantom equivalent to the patient's body (e.g. absorbent cotton with saline, fresh fruit, vegetable, meat, etc.).

Assessment of surgeons exposure can be performed on the basis the measurements of RMS value of current flowing through the surgeon's hand holding an active electrode and through his feet, performed with the use of clamp-on meter (Fig. 5).

Criteria for induced current in limbs, given in the Directive 2004/40/EC, do not cover frequency below 10 MHz. Limitation of induced current of the frequency from the range typical for EMF produced by electrosurgery devices were published by IEEE standard (Table 3).

Fig. 5. The clamp-on meter for measurements of the current in the surgeon's hand

Numerical calculations

According to the provisions of European Directive 2004/40/EC in case of environmental exposure conditions exceeding limits given for *exposure action values*, the workers' exposure assessment should be performed using numerical calculations of physical quantities inside the numerical phantom of exposed body, i.e. *exposure limit values*, such as current density (*J*) and specific energy absorption rate (*SAR*). The conclusive assessment of the surgeon's exposure to EMF needs the use of the worker's body models (numerical phantoms) and an adequate representation of the workplace (Fig. 6).

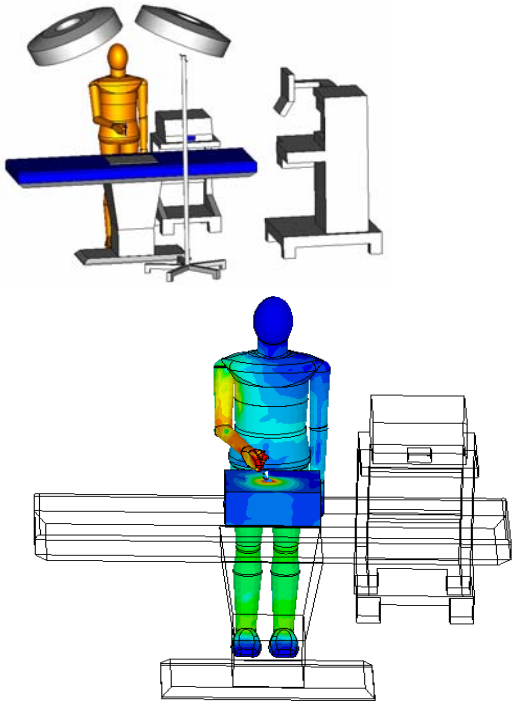

Fig. 6. Numerical simulations of the surgeon's exposure to EMF (numerical model and SAR distribution)

The basic problems for calculations are as follows:

- representation of the realistic posture of the worker's body
- adequate representation of the electrical grounding conditions at the workplace
- adequate representation of realistic impedance of near-field produced by electrosurgery devices
- adequate representation of dynamic changes of EMF level in the course of surgery treatment.

For the surgeon's EMF exposure, adequate calculations for assessment of particular exposure situations need high professional skills, specialised software and can be very time-consuming and expensive.

EMF EXPOSURE REDUCTION

In consideration of a necessity to hold an active electrode in the hand, complete elimination of the surgeon's exposure is not possible. The exposure level of other persons from medical staff is relatively weak if they do not have contact with cables. The reduction of the workers exposure can be obtained when the location of cables supplying a monopolar electrode is proper (e.g. when cables are kept between a generator and surgeon's hand without contact with the body of any worker).

A radical reduction of EMF exposure level is rendered possible by the use of the bipolar electrode if it can by applied for a particular surgical treatment.

Table 2.
Electric and magnetic field strength – exposure limitation by Directive 2004/40/EC and by IEEE Standard

Frequency range	Directive 2004/40/EC		IEEE Std C95.1,	
	Electric field strength E , V/m	Magnetic field strength H , A/m	Electric field strength E , V/m	Magnetic field strength H , A/m
0.1 MHz < f ≤ 1 MHz	610	1.6/f	1842	16.3/f
1 MHz < f ≤ 10 MHz	610/f	1.6/f	1842/f	16.3/f

f - frequency in MHz

Table 3.
Induced current – exposure limitation by European Directive 20004/40/EC and by IEEE Standard

Frequency range	Directive 2004/40/EC	IEEE	
	Limb induced current I_L , mA	Induced current in feet, I_L , mA	
		each foot	both feet
0.1 MHz < f ≤ 10 MHz	not specified	100	200
10 MHz < f ≤ 110 MHz	100	100	200

Comments:
According to the provisions of European Directive, workers' exposure assessment should be performed on the results of measurements of RMS value of unperturbed (existing in the workplace during the absence of workers) electric and magnetic field strength averaged over the workers body position and averaged in particular time, which depends on the frequency of investigated fields (e.g. for the EMF of the frequency 100 kHz - 10 GHz, E and H should be averaged within any 6 minutes of worker's exposure and E^2 and H^2 should be averaged over the worker's body position.
Worker's exposure assessment can be performed on the results of a spatial averaging of RMS value, performed in relation to the straight line in the center of the projected area – equal to worker's position (according to IEEE standard) or on results of the spot measurements of RMS value (the maximum result of measurements over the worker's body position in the workplace).
According to Directive 2004/40/EC, in cases of exposure to non-sinusoidal EMF, as produced by electrosurgery devices, peak "action values" for the field strengths are calculated by multiplying the relevant RMS values by coefficient (i.e. multiplied by approx. 1.5 for 100 kHz, 4.4 for 500 kHz, 6.9 for 1 MHz).

References

1. Directive 2004/40/EC of the European Parliament and of the Council of on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (18th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC), O.J. Nr L-184, 2004.
2. ICNIRP Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (up to 300 GHz), Health Physics, 1998, 74, 4 (April), 494-522.
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4. Internet service: http:/www.ciop.pl/EMF

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This issue was compiled in relation to activities of EMF-NET project and is related to the following deliverables: D50 (WP10), D53 (WP11), D56 (WP11.1), D59 (WP11.2), D62 (WP11.3), D67 (WP12), D72 (WP12.1) and D77 (WP12.2).

Contract no.	SSPE-CT-2004-502173
Project acronym:	EMF-NET
Project title	Effects of the Exposure to Electromagnetic Fields: From Science to Public Health and Safer Workplace
Instrument	Coordination Action
Thematic Priority	8. Policy Support and Anticipating Scientific and Technological Needs

The results of National Programme Adaptation of Working Conditions in Poland to European Union Standards supported by the State Committee for Scientific Research of Poland, international project Centre for Testing and Measurement for Improvement of Safety of Products and Working Life (European Union 5th Framework Programme) were also use for compilation of this issue, as well as results of investigations executed in the cooperation with enterprises.