OCCUPATIONAL ELECTROMAGNETIC FIELD EXPOSURE AND INDUCED CURRENT'S HAZARDS FROM ELECTROSURGERY DEVICES

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Abstract

The investigations concerning medical staff exposure to electromagnetic fields and induced currents hazards from electrosurgery devices have been completed. The exposure has been evaluated following the European Directive 2004/40/EC and national occupational safety and health regulations. The main sources of workers exposure are powered electrode and cables. Electromagnetic fields from electrosurgery devices are pulsed modulated and have heterogeneous spatial distribution. It has been found that in the vicinity of electrosurgical devices, the area of electromagnetic fields to which only workers operating the source of field should be exposed can exist up to the distance of tens of centimetres from the active electrode and supplying cables. In the case when the cables are placed directly on the surgeon's body the overexposure of workers can appear. The current flowing through the arm of surgeon keeping the electrode emitting electric field of the maximum strength (app. 1000 V/m or higher) can exceed the permissible value of 40 mA established by the Directive 2004/40/EC for contact current. The obtained results of measurements and suggestions for reduction of the surgeon's exposure are presented.

Keywords: electromagnetic fields, occupational exposure, induced currents, electrosurgery.

Introduction

Electrosurgery is used for various surgical treatments - to cut or to coagulate a patient's tissues. Electromagnetic hazards produced by these apparatus are essential for a big group of medical staff given a common use of electrosurgery devices. Electrosurgery devices consist of a generator (with output power of up to 500 W, but usually the output power used during surgical treatment is of 50-150 W), an active (powered) electrode connected with the generator by long cable and a passive electrode, fixed at a patient's body and connected by long cable with "0" electric potential of the generator.

Controllable surgical effect is a result of the flow of radiofrequency (RF) currents through the tissues of the body and local heating them. This current is the result of capacitive coupling of powered electrode with a patient's body. Current can flow with or without a direct contact between the active electrode and the body of patient if the potential of the electrode is higher than 200 V in the relation to potential of the tissues. Electric arc can be burned under the active electrode in the case of a higher potential of the electrode.

Currents of frequency above 300 kHz (up to approx. MHz) are used to avoid electrical stimulation of tissues. The waveforms of electric potential and current (and in consequences, electromagnetic field (EMF) produced in the vicinity of cables) depend on a type of a device and it's selected mode of a device operation. As a result, the EMF waveform changes from sinusoidal (usually exists during cut mode) to pulsed modulated (during different coagulation modes) – fig. 1, and additionally it is always pulsed modulated by the switch-on and switch-off actions of surgeon which are taking following surgical treatment needs.

The sources of the occupational exposure are mainly [2]:

- the active electrode at a high electric potential from which the RF current penetrates the tissue
- the cables connecting the generator with the active electrode, kept in the hand by a surgeon, and with the passive electrode (grounded plate), mounted to the patient's body.

The additional sources of EMF can be:

- the generator in the case of not leakproof housing (without electromagnetic shield),
- metallic objects located in the vicinity of the electrodes cables (for example, surgical or instrumentation's tables) and which can become secondary sources of EMF.

The EMF is produced from the moment of activation of an electrosurgery device. It may be operated by foot-control or through a button-control on the handle of the active electrode.

a) b)

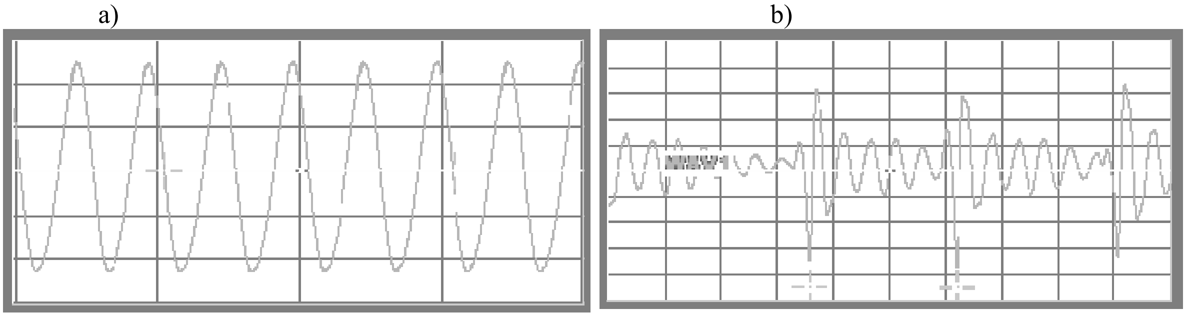

Fig. 1. Examples of EMF waveform registered in the vicinity of electrosurgery devices: a) pure cut mode; b) coagulation "spray" mode.

Electrodes and supplying cables are sources of strong electric field because of radiofrequency (RF) high voltage between electrodes. The exposure to EMF of a surgeon and medical staff depends on the selected mode of device operation, the kind of active electrode used and the location of cables connecting electrodes with generator.

During patient's treatment, generator and cables can be located in various places against to the surgical table and medical staff bodies. It is crucial for the level of exposure to electric field and capacitive coupling between elements of electrosurgery device and the worker's body and it determines the level of current flowing through the worker's body, similarly to currents through the patient's tissues. If the cables create loops, an increased magnetic field exists also in their vicinity.

The surgeon, who keeps the active electrode in hand, is usually the most exposed person from the team. The hand's exposure always exists, but other parts of the body can be also exposed as a result of the contact with cables, e.g. head's or torso's EMF exposure.

Methods

The EMF measurements have been performed to assess the medical staff exposure to EMF during the use electrosurgery devices [2]. The measurements of RMS electric and magnetic field strength have been conducted according to the Polish Standard PN-T-06580:2002 [6]. Broadband electric and magnetic field strength meter EMR 300 from Wandel & Goltermann with H-field probe type 13 (0.02-250 A/m; 300 kHz – 30 MHz) and E-field probe type 8 (1-800 V/m; 100 kHz – 3 GHz) has been used. The obtained results have been evaluated according to the Polish national regulations concerning the limitation of occupational exposure to EMF of 0 Hz - 300 GHz frequency range [5, 7]. This regulation stated that the worker's exposure assessment should be performed on the results of the spot measurements of RMS value of unperturbed (it means existing in the workplace during the absence of workers) electric and magnetic field strength (the maximum result of measurements over the worker's body position in the workplace).

Additionally, the investigated EMF exposure of medical staff has been analysed following the internationally published limitations [5], European Directive 2004/40/EC [1], ICNIRP's guidelines [3] and IEEE standard [4]. According to the 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 for particular time, which depends on the frequency of assessed fields. For example, 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. Electric field strength (E) and magnetic field strength (H) were included into the set of the Directive's "action values", which were defined as the set of external measures, which can be used to describe the EMF exposure for testing and roughly assessing environmental conditions in the workplace. The exposure results inside exposed body, which were taken as "exposure limit values" (internal measures) refer to the physical quantities as current density (J) and specific energy absorption rate (SAR) should be considered in the case of environmental exposure conditions exceeding above-mentioned "action values". Additionally, Directive's provisions refer to contact current (I_C) and limb induced current (I_L), which can be also used for testing the compliance with "exposure limit values".

Exposure limitation in the frequency range of EMF produced by electrosurgery devices established by Polish national regulations and European Directive is shown in table 1.

Table 1.

Electric and magnetic field strength – exposure limitation established in Poland [6] and by European Directive's "action values" [1].

Frequency range	Exposure limitation in Poland				Directive 2004/40/EC	
	Electric field strength, E [V/m]		Magnetic field strength, H [A/m]		Electric field strength, E [V/m]	Magnetic field strength, H [A/m]
	prohibited exposure	8-hours exposure	prohibited exposure	8-hours exposure		
300 kHz $< f \leq$ 800 kHz	1000	100	100	10	610	$1.6/f$
0.8 MHz $< f \leq$ 1 MHz	1000	100	$80/f$	$8/f$	610	$1.6/f$
1 MHz $< f \leq$ 3 MHz	1000	100	$80/f$	$8/f$	$610/f$	$1.6/f$

f - frequency in MHz

Measurements of RMS current flowing through surgeon's hand (fig. 2) keeping the active electrode (Holaday HI-3702 clamp-on meter) and through feet (Narda 8850 stand-on meter) have been also conducted. These currents are the results of coupling between element with high electric potential (active electrode or cable) and workers body. This current should be considered rather as induced current than contact current.

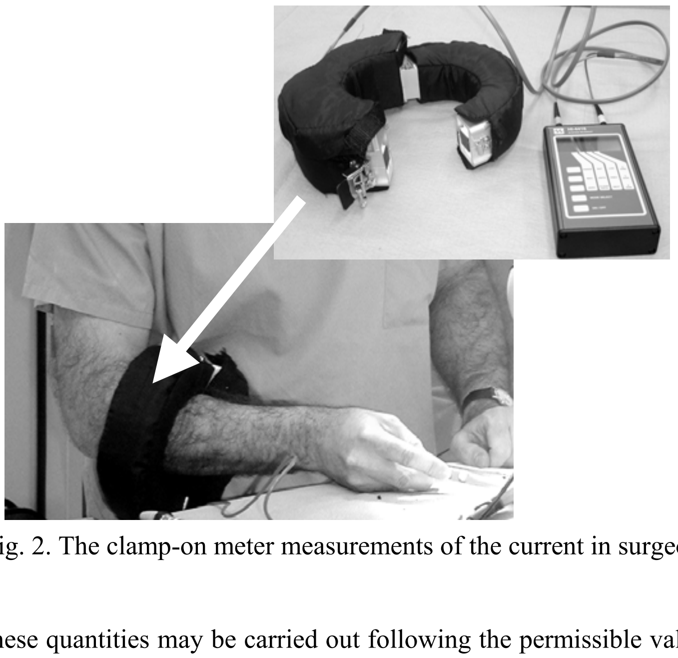

Fig. 2. The clamp-on meter measurements of the current in surgeon's hand.

The assessment of these quantities may be carried out following the permissible values as specified in Directive 2004/40/EC [1] and in ICNIRP guidelines [3] for contact current or permissible values for induced current in the feet specified in IEEE standard [4]. The Directive's criteria for induced current in limbs are not given for frequency below 10 MHz. Polish regulations don't refer directly to current inside workers body. Exposure limitation of contact and induced current in the frequency range of EMF produced by electrosurgery devices established by European Directive and IEEE standard is shown in table 2.

Table 2.

Contact and induced current – exposure limitation established by European Directive [1] and by IEEE [4].

Frequency range	Directive 2004/40/EC		IEEE			
	Contact current, I_C [mA]	Limb induced current, I_L [mA]	Contact current, I_C [mA]		Induced current in feet, I_L [mA]	
			for touch	for grasp	each foot	both feet
100 kHz $< f \leq$ 10 MHz	40	not specified	50	100	100	200
10 MHz $< f \leq$ 110 MHz	40	100	50	100	100	200

Measurements were performed for more than 30 types of common-used electrosurgery devices: various types of ERBE, Aesculap, Bovie, Valleylab and Olympus operated in the various modes. The output power during investigations (approx. 100-150 W) was a little higher than during normal work to obtain results representing the worst case of workers exposure conditions.

For the technical reasons, measurements have been performed during a simulated operation - absorbent cotton with saline has been used as phantom equivalent to the patient's body.

Results

The results obtained have shown that the surgeon is usually exposed to non-homogenous electric field. Metallic objects, which are in the operating theatre influence on spatial distribution of electric field. The level of exposure of medical staff can be changed by 2-3- fold depending on the location of these objects.

In the worst case implying the use of a monopolar electrode and non-shielded cables surgeon's hand keeping this electrode can be exposed to electric field exceeding 1000 V/m, head and torso up to a few tens V/m (fig. 3). When the cables touch the surgeon's body then the torso exposure is stronger, up to the level of the exposure of hand keeping electrode.

Near electrosurgical devices, the area of electric field strength exceeding 10 V/m can exist up to the distance of 70-100 cm from the active electrode and supplying cables.

Magnetic field in the nearest distance of electrodes and cables (5-10 cm) is usually below 1 A/m.

For the operation with output power less than 50 W or with the use of bipolar electrode, electric field exposing the hand is less than 80 V/m and less than 30 V/m in the case of head and torso exposure.

Electric field around the housing of the generator with effective EMF shielding is below 30 V/m during the use of both kinds of electrodes.

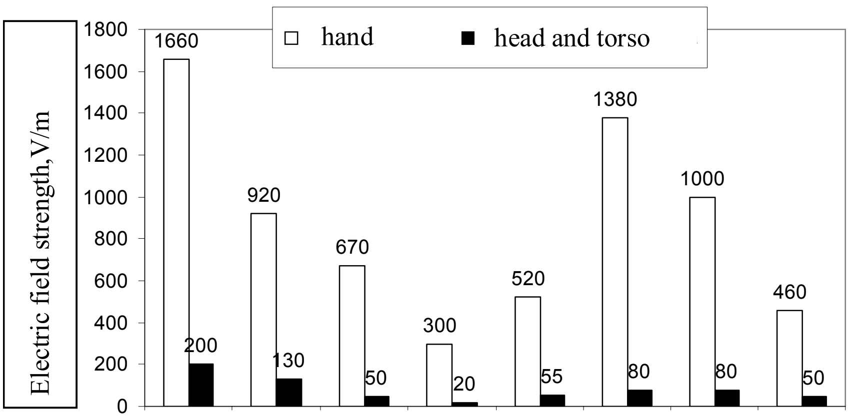

Fig 3. The examples of surgeon's exposure to electric field during the use of various electrosurgery devices (output power 100-150 W, a monopolar active electrode, cables far from the torso and head).

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

Waveform of EMF as well as the level of exposure in the vicinity of active electrode and supplying cables depend on the mode of electrosurgery devices operation. Figure 5 illustrates how electric field strength from the same electrosurgical device depends on it's selected mode.

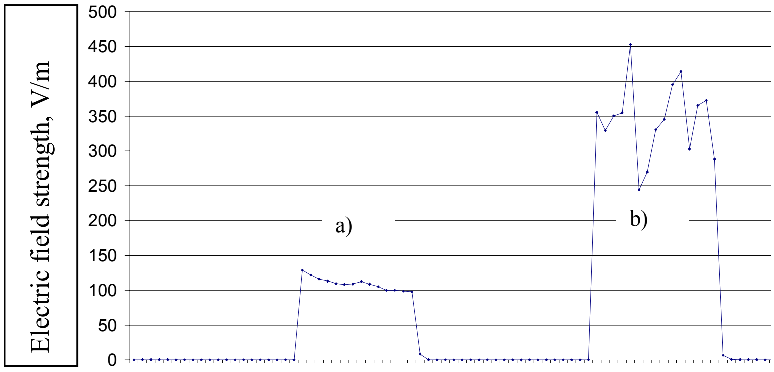

Fig. 4. The examples of registration of electric field strength in the vicinity of active electrode: a) cut mode without burned electric arc; b) cut mode with burned electric arc.

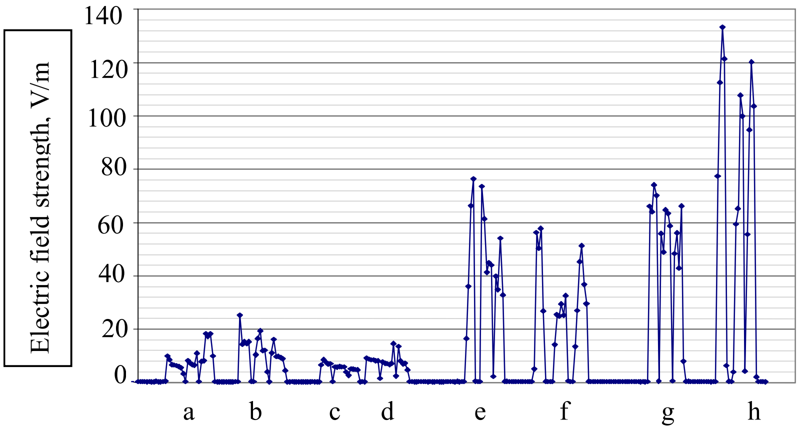

Fig 5. Examples of registration of electric field strength in the vicinity of electrosurgery device - various modes of operation: a) cut ”pure”; b) cut “blend”; c) coagulation „desicate”; d) coagulation „fulgurate”; e) coagulation „spray”; f) cut „pure” with argon; g) cut „blend” with argon; h) coagulation „spray” with argon.

The results presented indicate the possibility of a high exposure of the surgeon’s hand in the case of keeping the active electrode or touching the cable to forearm. Measurements of current in surgeon’s body may be used for additional assessment of exposure conditions and internal results in exposed body. The investigations carried out show, for example, that current in the hand keeping the active electrode can be of order 5 - 18 mA in the case of electric field strength of approx. 70 V/m in the distance of 5-10 cm from a monopolar active electrode (fig. 6), and significantly depends on the location of cable towards the hand.

Current in the feet of surgeon, insulated by shoes from ground and without direct contact with cables, is below 20 mA when electric field strength in the vicinity of monopolar active electrode is approx. 250 V/m. Taking into account the possibility of exposure to a stronger field (app. 1000 V/m or even higher) or a contact of the body with the cables, the current flowing through the arm of surgeon keeping the electrode can exceed the permissible values established in the Directive 2004/40/EC for contact current (40 mA).

The results obtained also indicate that current measured by clamp-on meter in the hand keeping the active electrode is approx. 2-fold higher than current measured by stand-on meter in the feet.

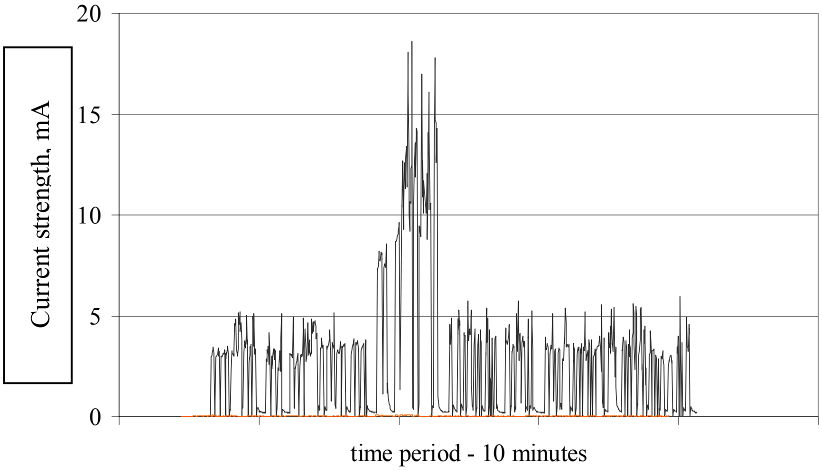

Fig 6. The examples of registration of current in surgeon’s hand exposed to EMF from the electrode's cable.

The conclusive assessment of surgeons exposure to EMF, presenting compliance with European Directive provisions concerning internal measures (“exposure limit values”), will be possible after publishing harmonised European standards. These standards should fixed in details the protocol for measurements or calculations, necessary for such exposure assessment. The numerical simulations for the verification of the compliance of particular EMF exposure scenarios with the Directive provisions need the use of a high resolution of the worker’s body models and an adequate representation of the workplace environment. For the electro-surgeon's EMF exposure, the conditions such as calculations for particular exposure situations need high professional skills, specialised software and they are very often time-consuming. The basic problems identified during pilot calculations are: the representation of the realistic posture of worker's body, the adequate representation of the electrical grounding conditions at the workplace and the adequate representation of realistic impedance of near-field produced by electrosurgery devices, as well as it's dynamic changes in the course of surgery treatment.

The additional problem with assessment of measurements results can appear for highly modulated EMF, when the properties of the used EMF meters calibrated in harmonic field cannot be relevant to such field's measurements and then the use of correction's factors taking into consideration the waveform of incident fields should be recommended. It was analysed for various kinds of modulations of EMF produced by various devices examined that the value of the measurement's uncertainty component coming in consequences of measurements of modulated fields in the case of common electrosurgery devices can be on the level of 50%. It is possible to find both effects, overestimation and underestimation in the EMF strength measurement's results.

Conclusion

In consideration of a necessity to keep the active electrode in the hand, complete elimination of surgeon's exposure to strong electric field is impossible. The reduction of the surgeon's exposure can be reached by the proper positioning of the cables supplying a monopolar electrode. The exposure of others persons from medical staff is relatively weak if they don’t have a direct contact with cables. In the worst case of cable's location and electrosurgery devicee's output power, the EMF overexposure can occur. The surgeon’s EMF exposure assessment for the case of the use of a monopolar electrode should be completed with measurements or calculation of currents flowing through the body.

The results of the investigations presented show that the effective reduction of the surgeon exposure can be obtained by keeping cables between the generator and the surgeon’s hand without a contact with the bodies of workers. Cables located at the surgical table decrease the surgeon’s exposure but increase the influence of electric field on other medical workers (e.g. nurses). A compromise is indispensable in that situation. A radical reduction of the EMF exposure level is possible by the use of the bipolar electrode if a kind of surgical treatment allows for that. Avoiding work with burned electric arc under the electrode reduces the exposure of personnel, too.

If weak electric field near the electrode is found (usually in the case when output power is approx. 50 W or less, the use of bipolar electrodes or shielded cables) measurements of electric field strength can be considered as sufficient to confirm a low level of exposure there. The measurements uncertainty and the consequences of a high modulation of EMF from electrosurgery devices for the measurement's results should be analysed very carefully in every case when a relatively high level of exposure is found at the workplace.

Acknowledgments

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