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A personal monitoring study of occupational RF exposure to the medical equipment used in physiotherapy centers: Diathermy is the top emission device

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ABSTRACT

Purpose: In physiotherapy centers, equipment emitting electromagnetic fields (EMF) is used daily and diathermy is reported as the top emitting device used. The purpose of this work is the evaluation of the levels of radio frequency (RF) electric fields that can be reached and physiotherapists are exposed to, in relation to the action levels (ALs) of the 2013/35/EU Directive.

Material and Methods: Thirty five physiotherapists in 30 private physiotherapy centers participated in this study. RF personal monitors were used to record physiotherapists' exposure during their normal working routine, while handling physiotherapy equipment.

Results: The recorded average exposure levels were found, in general, lower than the ALs of the Directive. Nevertheless, the recorded maximum exposure levels instantaneously exceeded the ALs, but these levels are actually very low when averaged over the 6 minute period provisioned in the Directive. Moreover, specific medical equipment and clinical practices are associated with higher measured values.

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Conclusions: Compared to the occupational exposure ALs, as established in the Directive, the measurement results showed that high levels of RF electric fields were practically recorded only during the operation of diathermy equipment. On the contrary, when only the rest of the medical equipment of the physiotherapy centers was used, very low exposure values were recorded.

KEY WORDS
Occupational EMF exposure; Physiotherapists; Diathermy; RF electric fields

Introduction

Occupational exposure to electromagnetic fields (EMF) in physiotherapy departments is associated with the operation of the electromedical equipment used for the treatment of patients. According to the national legislation (Presidential Decree 29/1987), every physiotherapy center in Greece must be equipped with therapeutic devices such as microwave (MW) diathermy (which operates in the frequency of 2450 MHz), or short-wave (SW) diathermy (operating mainly at the frequency of 27 MHz) [1].

Apart from diathermies, the medical equipment most commonly encountered in physiotherapy departments is: i) lasers, ii) ultrasound, iii) infrared heating light, iv) interferential currents and v) Transcutaneous Electric Nerve Stimulation (TENS). More specifically:

i) In physiotherapy centers usually Soft and Mid lasers are used. Soft lasers are of low power (0.5-50 mW), consisting of a mixture of helium and neon (10:1) inside a small bore capillary tube (Helium–Neon laser or HeNe laser). The pressure inside the tube is 1 mm Hg and the laser emits a 632.8 nm wavelength in the red part of the visible spectrum. Mid lasers are of medium power (5-20 W) using Gallium, Aluminum and Arsenic (Ga-Al-As), as the active material [2].
ii) Physiotherapy ultrasound employs alternating compression and rarefaction of sound waves with a frequency greater than 20 kHz. Ultrasound's frequency used is 0.7 to 3.3 MHz [3].
iii) Infrared (IR) is electromagnetic radiation, used for tissue heating, with longer wavelengths than those of visible light used for tissue heating, extending from the nominal red edge of the visible spectrum at 700 nm up to 1 mm. The power of infrared heat light ranges between 50 and 1000 W [4].
iv) The interferential current therapy is based on the crossing of two different currents, generally in the range between 4000 to 4100 Hz [5].
v) TENS delivers a low voltage electrical current to nerves via conductive pads (electrodes) placed over specific skin areas. A typical battery-operated TENS unit is able to modulate pulse width, frequency and intensity (generally TENS is applied at frequencies above 50 Hz [6]).

International Commission on Non-Ionizing Radiation Protection (ICNIRP) has since 1998 established limits (basic restrictions and reference levels) in its guidelines on limiting exposure to time-varying electric, magnetic and EMF (0-300 GHz) [7], concerning the general public and the workers. It must be underlined that, concerning occupational exposure to EMF in physiotherapy departments, the related physical quantities in the above guidelines have exactly the same values with the exposure limit values (ELVs) and action levels (ALs) in the 2013/35/EU Directive [8, 9]. It should also be noted that the ELVs and the ALs of the Directive 2013/35/EU [9] are identical to the limits (ELVs and action values-AVs) set in the previous expelled Directive (2004/40/EC). The ALs for exposure to electric fields from 10 MHz to 300 GHz are depicted in **Table 1**.

ALs are referred to the external field (outside the human body), they are calculated over any 6 min time interval (in average mode) taking into account the whole frequency contribution and they are relatively easy to be assessed [9]. In its newest report, ICNIRP has increased the average time to 30 min, taking into account the efficiency of the human thermoregulatory system [10]. ELVs are the actual limits as they refer to the internal field (inside the human body) but they are difficult to be assessed. Compliance with ALs ensures compliance with ELVs, as proper modelling has been performed for their definition and also large safety factors have been introduced. Moreover, exposure over the ALs does not necessarily mean that also the ELVs are exceeded;

Table 1. ALs for exposure to electric fields from 10 MHz to 300 GHz (f is the frequency expressed in Hz).

Frequency range	Electric field strength ALs (E) [Vm^{-1}]
10≤f<400 MHz	61
400 MHz≤f<2 GHz	$3\times10^{-3} f^{1/2}$
2 GHz≤f<300 GHz	1.4×10^{2}

in these cases demanding computer modelling should be performed. All the above limits are set in order to protect the workers from direct effect of heat stress, expressed as a whole body temperature rise of no more than 1° C. This is the only acceptable adverse health effect for the range of radiofrequencies. This effect was reaffirmed in all recent reviews of the relevant scientific literature [10, 11].

The standard EN50499, [12] prepared under Mandate M/351 and given to CENELEC by the European Commission and the European Free Trade Association, covered essential requirements of EC Directive 2004/40/EC providing the framework for workplace EMF exposure assessments and containing a list of workplaces and equipment likely to require further assessment in order to prove their compliance with this standard. In this list, all medical equipment using intentional radiation with electromagnetic exposure or application of currents and especially diathermy equipment is noted [12].

The purpose of this work is the evaluation of the levels of radio frequency (RF) electric fields that physiotherapists are exposed to, in relation to the ALs of the 2013/35/EU Directive.

Material and Methods

Thirty five physiotherapists participated in this research, while carrying out their normal working routine, in 30 private physiotherapy centers. Personal electric field monitors were used to record their EMF exposure while handling physiotherapy equipment and treating their patients. The physiotherapists were keeping a log book noting the exact clinical routine and the relevant medical devices used in consecutive half hour time periods **(Figs. 1, 2)** of a typical working day.

At the same time, they were wearing a special device (the ESM-30 Radman XT, ELF-immune version, manufactured by Narda STS), a personal monitor that records the RF electric (E) field exposure of the physiotherapists in the frequency range of 27 MHz - 40 GHz. It is a small and handy instrument which provides warning of the presence of RF E-fields in the areas of application. Radman XT measures according to the 1998 ICNIRP's guidelines reference values for occupational exposure that, as already said, are identical to the action levels (ALs) of the 2013/35/EU Directive in the frequency range that the monitor operates. The device was worn on the body by attaching it to clothing using a plastic clip as shown in **Fig. 3** [13].

Specific instructions were given to the physiotherapists on how to attach the Radman XT to their medical uniform. They were also advised not to carry their cell phones in the electrotherapy room so that no measurement interference would be caused. The patients were also not allowed to carry their cell phones with them during their treatment.

The RF E-field levels were measured continuously during the operation of the medical devices used according to the physiotherapist's schedule. The monitors were set to record the maximum and the average exposure values every minute.

The personal monitor used (Radman XT) measures isotropically using three independent sensors that are arranged in such a way yielding uniform measurements, regardless of its orientation in the field. The Radman XT indicates the magnitude of the RF E-field by means of four LEDs (12.5%, 25%, 50% and 100% LED). The x% LED indicates that x% of the limit permitted by the relevant standard (1998 ICNIRP occupational reference levels values) has been reached. More specifically, the 50% LED indicates the first alarm state by a flashing red colour. The device also emits an audible beep twice a second as an additional warning signal. This status is maintained for as long as Radman XT continues to measure this level of E-field strength. The 100% LED indicates a second alarm state also by a flashing red colour. The device again emits an audible beep but this time at 4 times per second. The beep is heard for as long as Radman XT continues to measure this level of electric field strength [14]. These different beep repetition rates enable physiotherapists to easily locate the field maxima without looking at the device. When the device is switched on, the RF E-field strength is measured and recorded continuously.

Radman XT monitors were set to record the maximum and average exposure values in one minute intervals. A new set of data is recorded each time the instrument is switched on. The data sets were processed using the ESM-TS software

TIME	DIATHERMY	T.E.N.S.	U/S	INTERFER-ENTIAL CURRENTS	LASER	maxE[%]	avgE[%]
12:31- 13:00			■		■	6.797	5.137
13:01- 13:30	■		■		■	13.01.31: 144.434 13.02.31: 90.625 13.03.31: 66.836 13.04.31: 144.434 13.05.31: 70.234	13.01.31: 28.406 13.02.31: 14.362 13.03.31: 11.427 13.04.31: 29.724 13.05.31: 22.141
13:31- 14:00	■		■		■	13.31.31: 7.930... 13.44.31: 144.434 13.45.31: 40.781 13.46.31: 17.559 13.47.31: 113.281	13.31.31: 5.173... 13.44.31: 24.085 13.45.31: 6.858 13.46.31: 17.559 13.47.31: 16.387
14:01- 14:30					■	6.797	5.145
14:31- 15:00	■			■	■	14.31.31: 6.797 14.32.31: 6.797 14.33.31: 6.797 14.34.31: 144.434	14.31.31: 5.145 14.32.31: 5.145 14.33.31: 5.145 14.34.31: 16.918
15:01- 15:30		■				6.797	5.145
15:31-16:00					■	6.797	5.145
16:01- 16:30		■		■		6.797	5.145

Fig. 1. *The measurements presented above correspond to a physiotherapist from the first group (Group A) who, according to the working schedule, had to use the diathermy device on that specific day. According to the physiotherapist's log book, the representative checkerboard was created. The shaded cells correspond to the devices in use. For example, during the first half working hour (12:30-13:00) Ultrasound (U/S) and Laser were used, during the second half working hour Diathermy, U/S and Laser were used, etc. The maximum as well as the average E-field levels are depicted as percentages of the ALs of the 2013/35/EU Directive.*

provided by the manufacturer. Each saved data set contains the average and maximum values from all the E-field values that were measured during operation.

Physiotherapists were categorised into two groups. The first group (Group A), comprising of those who used the diathermy device during their working day, and the second (Group B) of those who did not. The measurements presented in **Fig. 1** correspond to a physiotherapist from Group A, who, according to his working schedule, had to use the diathermy device on that specific day.

All physiotherapists that, according to their schedules, used the diathermy equipment present quite similar measurements. In the cells where only one value is presented, the same value was recorded on every minute of that time period, while in the other cells the time variations of the recorded E-field are depicted. For example, during the half time period from 13:01 until 13:30, a rate of 144.434% (maxE(%)) was recorded at 13.01.31, while the avgE(%) was at the same time up to 28.406%.

Fig. 2 corresponds to the data presented in **Fig. 1**, presenting the exposure as a percentage of the ALs [9], using the recorded maximum values during every half hour period. For example, during the 30 minute period between 13:00-13:30, the maximum exposure percentage that was reached, according to the Directive's ALs, was 144.434%.

In **Fig. 4**, the data analysis that derived from a physiotherapist from the second group (Group B) are presented. In this case, no high values were recorded in data from a physiotherapist that did not have to use the diathermy equipment that particular day. Quite similar measurements were recorded from all the relevant physiotherapists and there were actually no variations of the recorded electric field strength value every minute.

Relating the measurements of the clinical routine from the physiotherapist from Group B **(Fig. 4)**, the exposure as a percentage of the ALs [9] is depicted in **Fig. 5**, using the

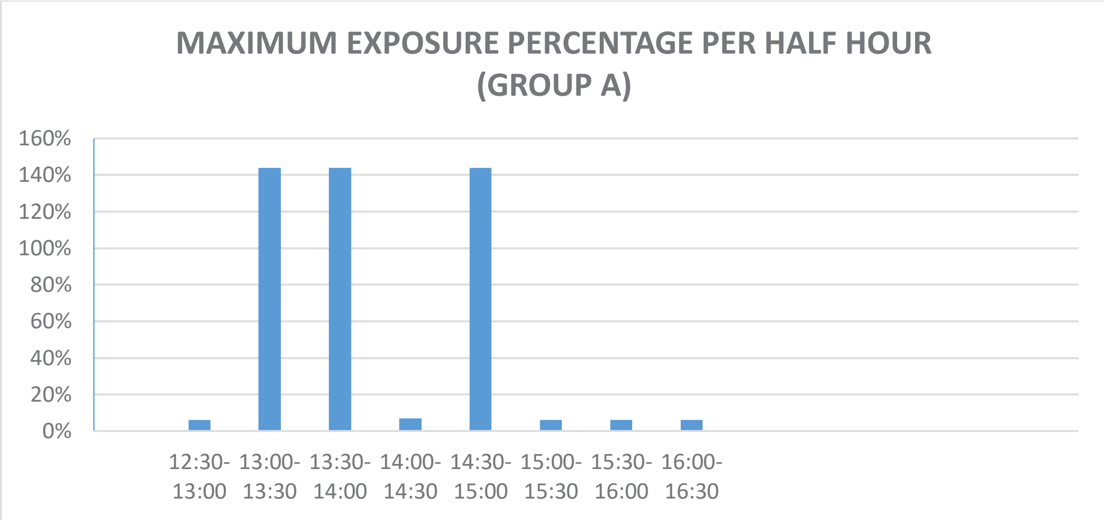

***Fig. 2** corresponds to the data presented in **Fig. 1** presenting the exposure as a percentage of the ALs [9], using the recorded maximum values during every half hour period. For example, during the 30 minute period, between 13:00-13:30, the maximum exposure percentage that was reached, according to the Directive's ALs, was 144.434%. The high values correspond to the operation of the diathermy unit.*

recorded maximum values during every half hour period. It can be seen that the operating medical devices lead to quite similar and low exposures. For example, the maximum exposure value that was recorded during the first hour did not surpass the percentage of 6% according to the Directive's ALs.

After checking every physiotherapist's daily working routine (35 physiotherapists in 30 physiotherapy centers), it became evident that the physiotherapists that participated in this study can be divided in two groups. Group A, comprising 16 physiotherapists (45.7%) that used the diathermy device during their working day and Group B comprising 19 physiotherapists (54.3%) that did not use it during the days that the personal monitor was given to them. In all the 16 physiotherapists' data files of Group A, high levels of RF E-field strength values were recorded while in all the 19 physiotherapists' data files of Group B, much lower average and maximum values were logged, compared to the occupational exposure ALs as established in the 2013 Directive.

These two specific cases are presented since each one is representative of the group that each physiotherapist belongs to. This selection is valid because almost the same results were recorded each time a physiotherapist used the diathermy device along with other devices, so **Fig. 2** correctly summarises Group A and may be considered as the average exposure of the physiotherapists belonging to this

***Fig. 3.** Personal monitor Radman XT was worn on the body, attached to clothing with a plastic clip.*

group. Respectively, almost identical results were recorded each time the physiotherapists used the rest of the medical equipment but not the diathermy equipment, so **Fig. 2** properly summarises Group B and may be considered as the average exposure of the physiotherapists belonging to this group.

Results

As shown in **Figs. 1** and **2**, the diathermy unit was in operation during the three half hour time slots during which

TIME	T.E.N.S.	INFRARED	U/S	INTERFER-ENTIAL	LASER	maxE[%]	avgE[%]
13:00- 13:30						6.104	5.141
13:30- 14:00						7.324	5.486
14:00- 14:30						7.324	5.486
14:30- 15:00						6.104	5.141
15:00- 15:30						6.104	5.141
15:30- 16:00						6.104	5.141
16:00- 16:30						6.104	5.141

Fig. 4. *Data analysis that derived from a physiotherapist from the second group (Group B) that did not have to use the diathermy equipment that particular day. In this case, no high values were recorded. Quite similar measurements were recorded from all the relevant physiotherapists and there were actually no variations of the recorded E-field strength value every minute. The shaded cells correspond to the devices in use.*

the high values were recorded. In general, the recorded one-minute average E-field exposure levels are found much lower than the established limits for occupational exposure. The recorded maximum exposure levels can reach instant values higher than 100% of the ALs, but these levels become very low if they are averaged over the 6 minute period provisioned in the guidelines.

It should also be noted that 14 out of the 16 physiotherapists (87.5%) of Group A, who used the diathermy device during their working day, stated that they received the audible signal from Radman XT mostly during the first minutes of the diathermy therapy. They also stated that they kept hearing the personal monitor's alarm signal as they were standing near the diathermy's electrodes and placing them close to the patient's body. These physiotherapists, upon listening to the alarm signal, were immediately aware of the presence of high levels of electric fields and they all noticed that moving even a few centimetres away from the diathermy device, the signal stopped. So, this behaviour is inevitably reflected in the measurements and of course influenced the results, meaning that, without the audible signal, higher values would have been recorded and for a longer time period. Nineteen physiotherapists that did not have to use diathermy equipment during the days that the measurements took place (Group B) did not hear the audible signal at all. The medical equipment that they used, such as laser, TENS, infrared heating light, ultrasound, interferential currents, magnetotherapy, etc. in any combination, was found to expose them only to very low levels of E-field values. As already mentioned, the personal monitor used measures the RF E-field exposure in the frequency range of 27 MHz - 40 GHz, meaning that emissions out of its measuring range (e.g. from laser or infrared heating lighting that belong to the optical range of the electromagnetic spectrum) cannot be recorded.

Discussion

The total number of physiotherapists that participated in this exposimetric research study is much higher than any other in previous studies in Greece and abroad. The main finding of this work is that the diathermy equipment emits substantially higher levels of RF electric fields in comparison to the rest of the medical equipment used in physiotherapy centers. Of course, high RF electric fields values in the vicinity of physiotherapy equipment and especially near their driving cables (electrodes) and their applicators

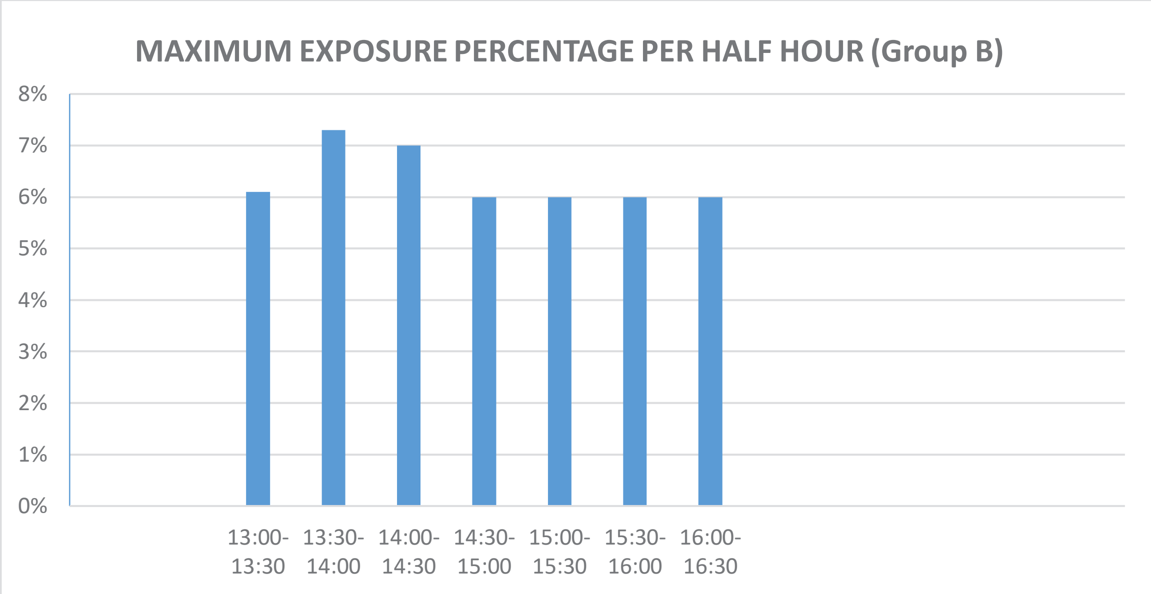

Fig. 5. *Maximum electric field exposures of the physiotherapists of the second group (Group B) depicted as percentages of the ALs of the 2013/35/EU Directive.*

(capacitors for capacitance diathermy or antennas for inductive diathermy) were expected due to the high voltages used and are already reported in the published literature that will be discussed below. Moreover, since there are several occasions in which the ALs given in the 2013/35/EU Directive may be exceeded in a physiotherapy clinic when the diathermy unit is in use, certain measures should be taken in order to mitigate workers and general public's exposure.

The above measured results are in agreement with these reported by Scotte J [15] and Martin CJ et al. [16]. Field values above the recommended whole body levels extend to 0.5-1.0 m from the electrodes and cables for continuous wave (CW) shortwave equipment, and up to 0.5 m for microwave units and pulsed shortwave models. Operators were exposed to local fields above these values for 2-3 min during CW shortwave treatments, but rarely exceeded the recommended exposure.

Li CY and Feng CK [17] conducted on-site measurements of stray electric and magnetic fields (27.12 MHz) close to CW short wave equipment. The results show that the operator's knees may have the highest exposure level for both E-field and magnetic field (H-field) in the normal operating position, i.e., behind the device console.

In the area of Bilbao (Spain), seven health centers and a hospital were selected in order to assess the occupational exposure in physiotherapy facilities according to the provisions of the 2004/40/EC Directive [8]. Similar personal monitors (Radman XT ELF immune) were used for the measurements and 16 physiotherapists were evaluated. This study showed that the exposures comply with the Directive's criteria as long as good practice codes are kept, exposure time near the sources is limited and right layout and correct maintenance of the equipment is guaranteed [18].

According to other published results, although most areas show substantially low levels of occupational exposure to electromagnetic fields for physiotherapists, a number of cases of over-occupational exposure limits do exist [19]. Conclusions and observations of overexposure caused by physiotherapy devices were also reported by Bulgarian physicists who performed risk assessment associated with the national legislation [20, 21].

Hence, many researchers [16-17, 22-28] agree that keeping a safe distance from electromagnetic sources is very important. According to Casciardi, Grandi and Shields et al. [26-28], even though high exposure levels are recorded at a 10 cm distance from these kinds of sources, these levels are not high at 1 m distance and according to Tzima, Scandurra and Martin et al. [22-24], when physiotherapists maintain 1 m distance from electromagnetic sources and metallic objects, then overexposure is not recorded. As shown of course, in measurements by Maccá [29] and Di Nallo et al. [30], the exposure minimisation when keeping a safe distance was not always achievable when metallic items such as chairs, portable curtains, etc. often found in the electrotherapy room, where placed close to the electromagnetic sources. Other researchers [31] also mention association between the occupational exposure of physical therapists to microwave diathermy radiation and fatigue, although it is difficult to isolate occupational exposure from other likely exposures that are present in a physiotherapist's work routine as well as the possible presence of other environmental factors which could contribute to the presence of fatigue. Furthermore, according to Andrikopoulos et al. [32], high spatial as well as time heterogeneity around microwave diathermy was detected and was based on the divergent properties of the electromagnetic radiation from each device used in the electrotherapy room. The distribution of non-ionising radiation in microwave diathermy frequently exceeded the limits introduced by the European Directive 2013/35/EC.

An important topic is also the quality control of the diathermy units in relation to the heterogeneity of the RF field around the devices. Little work has been reported over this issue. In this sense, a lot of measurements around the devices would be needed in order to estimate the occupational exposure [32]. An alternative approach is the one presented in this study with the use of personal exposimeters.

From our study, and taking also into consideration the existing literature, it can be said that there are several occasions when the ALs as described in the 2013/35/EU Directive are exceeded in a physiotherapy clinic when the diathermy unit is in use. In addition, there are reports of substantial overexposures concerning various types of shortwave and microwave diathermy devices and references that have to do with mainly near field measurements, in the vicinity of the devices for both the electric and the magnetic field [32], which are compared to the ALs of the 2013/35/EC Directive [9].

So, it is imperative that certain measures should be taken in order to mitigate workers and general public's exposure. According to our study, the following measures are proposed:

a) Access in the electrotherapy room should be supervised so that, while the diathermy unit is in operation, only the physiotherapist and the patient should be present. When it is absolutely necessary for someone else to be present (i.e. a person accompanying a patient), it is recommended that a distance of at least 3 m should be maintained.

b) The location of the diathermy unit in electromagnetically shielded boxes may be also recommended in order to reduce the volume of the space affected by EMF near diathermy [33].

c) The physiotherapist, after placing the patient and switching on the diathermy unit, should step away from it, if possible at a distance of at least 2 m. In every case, the physiotherapist should work in such a way in order to keep a distance of at least 25 cm from the diathermy and minimise his exposure to it [32-34].

d) Placement of the patient and every other operational detail shall be organised prior to operation of the diathermy device. This is due to the fact that exposure from the diathermy units is highly localised and physiotherapists received the audible signal from Radman XT (indicating an alarm state) mostly during the first minutes of the diathermy therapy.

e) Finally, it is very important to keep informing physiotherapists to follow safe practices in order to minimise exposure risk, keeping also in mind that an underestimation of the electromagnetic field strength cannot be excluded since the measuring equipment used is worn on the body [35].

This paper serves the need for further investigation of certain workplaces, such as physiotherapy or other medical centers where diathermy and other medical equipment are used. In this study, personal measures were used for the evaluation of individual exposures, keeping in mind that, although using appropriate and validated devices such as personal dosimeters is considered necessary [12], information about personal exposure of physiotherapists is, until now, scarce. **R**

Conflict of interest

The authors declared no conflicts of interest.

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