

Evaluation of the electromagnetic field intensity in operating rooms and estimation of occupational exposures of personnel

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Abstract: *Introduction:* Operating rooms in hospitals are facilitated with different types of electronic systems, which produce electromagnetic waves. High intensities of magnetic waves may have harmful effects on biological environments. This study aims to evaluate the electromagnetic field intensity at different parts of operating rooms at the first stage and estimate the occupational exposure to operating room personnel at the next phase. *Materials and methods:* At this cross-sectional study, the magnetic field intensity was evaluated using teslometer at several parts of operating rooms, during operating procedures, while electrical instruments were working. Background electromagnetic field intensity was measured when all the electrical systems were idle. Statistical analysis was performed using SPSS software. The results were compared with ICNIRP standards. *Results:* The maximum intensity of magnetic field was measured around high-voltage systems at the distance of 50 cm in the personnel's standing area at DCR and PCNL operating procedures were 5.9 and 5.6, respectively. The number of on-mode electrical systems was inconsistent with the intensity of electromagnetic fields at the standing area of operating room personnel's. The intensity of magnetic fields around high-voltage systems, which was about 46.75 mG at the distance of 10 cm, was the highest among measured electromagnetic fields. *Conclusions:* The highest magnetic field intensity measured in this study was related to high-voltage systems and is lower than advised intensity by ICNIRP for occupational exposure. Based on this study, it can be concluded that there are no considerable risks of electromagnetic exposure for operating room personnels.

Keywords: electromagnetic waves, operating room, occupational exposure, magnetic field, intensity

Introduction

Due to the new life styles, most people are exposed to undesirable magnetic fields (MFs) radiation, which are mostly, extremely low-frequency MFs [1, 2]. Some main sources of generating low-frequency MFs (frequency of 50–60 Hz) are devices such as television, domestic LCDs, hairdryers, wireless communication systems, electric engines, electric transport systems, electric heated mattress, beds, etc. [3–6].

The first survey about biological effects of MFs was carried out in 1976 in which Dumanshii demonstrated

the possibility of chronic diseases risk due to the MF exposure [7]. Recently, this issue has attracted the attention of researchers and there are some evidences based on biological effects of MFs with extremely low frequency (ELF) [8–10], for instance, its effects on causing leukemia [10–13], increased risk of breast cancer, and kidney cancer [14]. In addition, its harmful effects on sex hormones and fertility [4, 5, 13], bone-healing process [15, 16], wound-healing process [10], pain relief [17], hematological and biochemical parameters [9], uterus and ovaries [18], and some factors of the immune system [11–13, 19] had been investigated. These studies were

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almost conducted on animals, biological effects of MFs, and on human samples in accordance with the clinical trials [8]. However, in spite of evidences that there is no relation between MF intensity and biological and pathological manifestations, related studies are still running [3–5, 8, 11].

Different types of electrical and electronic systems are used in operating room environment. These systems produce various (ELF) electromagnetic waves [20, 21]. Therefore, operating room personnel and specialists are exposed to these non-ionizing radiations.

The first study on harmful effects of electromagnetic waves was carried out in 1979 by Wetheimer–Leeper. Since then, many studies were conducted on measuring the intensity of electromagnetic radiations in different parts and their harmful effects. The hazards of electromagnetic radiation to health, such as its adverse effect on the hematopoietic system, the immune system, genital organs, etc., have been proven in various studies. In addition, there are evidences of harmful effects of ELF MFs on permeability of the blood–brain barrier, calcium metabolism changes, increased risk of brain tumors, and neurotransmitter effects [20, 22, 23].

Increased use of electrical systems in operating rooms and evidences on radiation hazards provide researchers to more investigate about the issue.

Although there are several studies about the evaluation of electromagnetic waves intensity around electrical and electronic systems, there are few studies about the evaluation of electromagnetic waves intensity in hospital environments especially in operating rooms [20, 21].

Few studies such as the studies of Riminesi et al. [24], Hanada et al. [25], and Ho Roh et al. [26] showed that electromagnetic waves intensity of some systems in operating rooms were more than the standard rate recommended by international organizations like International Commission of Non Ionizing Radiation Protection (ICNIRP) and personnel who worked many hours next to these systems would be overexposed to the radiation [24, 26].

According to Faraday's law, variable external electrical fields will induce MF, so the personnel of ICNIRP and National Radiation Research Institute strictly emphasize on the hazards of electromagnetic fields that threaten the public health as a major environmental risk. ICNIRP has announced the standard limit of occupational exposure and non-occupational residential exposure levels, which are 500 and 100 micro tesla, respectively [20].

Operating rooms personnel are now widely exposed to MFs with ever-increasing intensity, due to the proliferation of MFs-generating apparatuses [27]. The steep increase in MFs exposure has renewed concerns about the potential health effects of this invisible, man-made environmental exposure [28]. A recent National Institute of Environmental Health Sciences multi-year project conducted by the National Toxicology Program has revealed an increased risk of cancer associated with MF

non-ionizing radiation exposure [29, 30]. This finding has made it more difficult to continue to dismiss possible biological effects of MFs exposure and also the WHO has recommended to be further studied in the context of MFs health effects [31]. In Iran, no comprehensive study has been conducted on evaluation of the occupational exposure of operating rooms personnel and comparison of MFs intensity with international standard levels. Therefore, the lack of data about the level of MF in operating rooms of the hospitals affiliated with Hamadan Medical Sciences University based on their electrical and electronic systems and their geometry accompanied by personnel's working hours made us to perform this research. Therefore, in the first phase of this study, we evaluate the intensity of magnetic and electrical fields in different parts of operating rooms and during different operating procedures; and in the second phase, an estimation of occupational exposure is presented.

Materials and Methods

This cross-sectional study is carried out in educational hospitals of Hamadan University of Medical Sciences (located in Hamadan city including Farshchian Hospital, Ekbatan Hospital, Shahid Beheshti Hospital, Be'sat Hospital, and Fatemieh Hospital) in Iran. The intensity of both electric and MFs in different parts of operating rooms, during the operating procedure, was evaluated using teslameter, while all equipments were working (Holaday Industries HI-3603, Eden Prairie, MN, USA).

All operating rooms of hospitals affiliated with Hamadan University of Medical Sciences (in Hamadan city) were studied. In order to measure electric and MF intensity in different parts of operating rooms, each operating room was divided into 16 equal parts. In each part, the measuring was done at a height of 120 cm from the floor with various orientation of active screen. Measurements were performed based on the study of Ho Roh et al. [26]. Moreover, for more certainty, extra measuring was done at the standing position of specialists and personnel. Then, MF intensity was recorded in different orientations of 0.1, 0.2, 0.5, and 1 m far from the device while just one of electrical and electronic systems was on and the others were off (for instance, when just cautery machine was on and other electric systems were off, e.g., the lights, LCDs, suction machine, pump, fluoroscopy, etc.).

Alongside, to evaluate the underlying intensity of electric and MFs in operating rooms, the measuring of electric and MFs intensity was done for all the systems when they were off.

Similar measuring was done in each operating room during three different operating procedures. In order to increase the accuracy, measurements repeated for each operating room in three separate days. For each operating

room, nine measurements (three times in three different days) were done (average six active systems were located in each operating room).

Therefore, for each operating room, there were nine measurements for different parts, six measurements for electric systems, and one measurement for background waves, while all electric systems were off. Definition of the 8-h time weighted average (TWA) is used for evaluating the exposure of personnel during the working time. It is calculated by the following formula:

$$V_{(TWA)} = \frac{VaTa + VhTh + L + ViTi + \dots}{8}$$

In this formula, Vi is the induced voltage into the personnel's body during a specific time, which is Ti. The time period of personnel's presence in each part was observed and recorded. The calculation of personnel's exposure in each part was carried out using MATLAB

software. Finally, all data were imported to SPSS software and the analysis was carried out using descriptive statistics and related statistical tests. Then, all data were compared to the standard statistics of ICNIRP.

Results

The average of MFs intensity [in milligauss (mG)] in the closest position to patient and the average at the standing position of operating room personnel (except physicians) are shown in *Table I*.

Table I demonstrated that the maximum rates of MF intensities are respectively in cataract surgery, cesarean, laparotomy, and artery repair surgery. Similarly, the maximum intensity rates at the standing position of personnel are in endoscopic dacryocystorhinostomy (DCR) and percutaneous nephrolithotomy (PCNL) endoscopy that are 5.9 and 5.6 mG, respectively. Statistical

Table I | Magnetic fields intensity (mG) in the nearest distance to patient and the standing position of personnel in various operations

Row	Operation	Magnetic field intensity (mean ± standard deviation)	
		In the nearest distance to patient	At the standing position of personnel
1	Orthopedic (DHS)	1.15 ± 0.68	0.45 ± 0.19
2	Finger rapture	0.60 ± 0.26	0.85 ± 0.32
3	Artery repair	1.41 ± 0.76	0.79 ± 0.31
4	Laparoscopy	0.39 ± 0.28	0.79 ± 0.25
5	Harelip	0.28 ± 0.19	0.22 ± 0.17
6	Parotid	0.31 ± 0.15	0.28 ± 0.21
7	Hydrocele	0.53 ± 0.33	0.15 ± 0.10
8	Shoulder arthroscopy	0.46 ± 0.29	0.24 ± 0.19
9	Gastrostomy	0.23 ± 0.19	0.15 ± 0.09
10	Ileus	0.21 ± 0.18	0.16 ± 0.11
11	Endoscopy DCR	0.61 ± 0.37	5.94 ± 1.99
12	SCC	0.25 ± 0.22	0.24 ± 0.18
13	Locking plate	0.86 ± 0.24	0.50 ± 0.31
14	Laparotomy	1.41 ± 0.82	0.79 ± 0.31
15	Knee arthroscopy	0.66 ± 0.37	0.24 ± 0.14
16	TUL	0.83 ± 0.52	0.39 ± 0.25
17	PCNL	0.59 ± 0.39	5.64 ± 2.13
18	Tracheostomy	0.49 ± 0.26	0.59 ± 0.34
19	Prostate biopsy	0.19 ± 0.13	0.14 ± 0.06
20	Cesarean	1.58 ± 0.79	1.53 ± 0.91
21	CABG	1.08 ± 0.66	0.65 ± 0.31
22	Cataract	1.75 ± 0.83	1.38 ± 0.83
23	Removal of abdominal mass	0.63 ± 0.29	0.68 ± 0.26
24	Pterygium	0.40 ± 0.36	0.64 ± 0.32

mG: milligauss; DCR: dacryocystorhinostomy; PCNL: percutaneous nephrolithotomy; CABG: coronary artery bypass grafting; DHS: dynamic hip screw; TUL: transureteral lithotripsy; SCC: squamous cell carcinoma

test of one-way analysis of variance indicates that there is no significant relation between the number of active electrical systems and the intensity of electromagnetic field at the standing position of personnel ($p = 0.0198$). The intensity average of MFs in different distances from each active system is shown in *Table II*.

As it is shown in *Table II* among all active systems in operating room, the maximum rate of MF intensity is seen around voltage booster systems. In the distance of 10 cm far from these systems, the calculated intensity is about 46.7500 mG. The intensity of other systems, such as laparoscopy (17.6125 mG) and anesthesia LCD monitor (10.6034 mG), was in the next ranking.

The 8-h TWA of personnel in operating room was calculated by MATLAB software. The results conveyed

Table II The mean of magnetic fields intensity in different distances from each active system in operating room

System	Mean of magnetic field intensity (mG)			
	100 cm	50 cm	20 cm	10 cm
Surgical light	0.22	0.32	0.64	2.68
Cautery	0.35	1.07	2.90	8.46
Anesthesia LCD monitor	0.51	1.11	1.77	10.60
Emergency light	0.29	0.74	1.48	11.18
Dry-heat sterilizer	0.33	0.38	0.92	1.73
Phacoemulsification machine	0.28	0.35	2.01	3.58
Microscope	0.44	0.91	1.65	2.91
Warmer	0.44	0.64	3.03	9.51
Anesthesia machine	0.45	0.74	1.90	5.49
Photo warmer	0.19	0.33	0.74	1.55
Suction	0.22	0.32	2.48	4.90
Defibrillator	0.24	0.24	0.26	0.29
Pump	0.35	0.39	0.55	0.80
Laparoscope	0.30	0.66	2.31	17.61
Hysteroscope	0.68	1.67	4.30	4.54
High-voltage power supply	5.40	12.03	13.30	46.75
Eter cooler	0.45	0.87	1.68	4.53
Negatoscope	0.30	0.80	2.14	39.00
Cooler	0.26	0.32	0.48	0.88
Ventilator	0.22	0.74	0.81	1.09
Fluoroscopy	0.35	1.04	1.22	1.66
Anesthesia pump	0.51	3.26	8.40	17.90
Oximeter pulse	0.29	0.18	0.20	0.30

mG: milligauss

that the maximum rate of TWA in an 8-h period of working was about 18.8 micro tesla (188 mG), which was much lower than the standard rate of NICRP for the general public (100 micro tesla), while NICRP announced the standard rate of occupational exposure as about 500 micro teslas.

Discussion

The first study about hazards of electromagnetic waves was conducted in 1979 by Wetheimer–Leeper. Since then, several studies were conducted about the intensity of electromagnetic waves in various parts. In addition, the harmful effects of electromagnetic waves on health [32] and various body systems (such as the hematopoietic system, the immune system, genital organs, etc.) are proven in many studies [20, 22, 24, 25, 33, 34].

The nature of occupational exposure from electromagnetic waves is completely different in various occupations [35], so it is needed to do separate surveys on each occupation. At present, there are some ongoing projects on studying the occupational exposure from electromagnetic waves in different jobs [20, 22, 36].

The results of this study represent that the highest rates of MF intensity were in cataract surgery, cesarean, laparotomy, and artery repair surgery, which were 1.75, 1.69, 1.41, and 1.41 mG, respectively. In addition, the highest rates of MF intensity at the standing position of personnel belonged to DCR and PCNL endoscopy, which were 5.9 and 5.6 mG, respectively. Besides, the highest rate of TWA was about 18.8 micro tesla (188 mG), which was much lower than the standard rate suggested by NICRP for the public health.

Moreover, the results of this study are in accordance with results of Ho Roh et al. [26] and Macca et al. [37]. In the study of Ho Roh et al., which was conducted in South Korea, the MF intensity at the standing position of personnel was about 5.23 ± 5.83 mG. Ho Roh et al. determined that their rate of MF intensity was lower than the standard rate. In addition, Macca et al. in Italy showed that over 4-m distances of magnotherapy systems, the MF intensity was lower than 10 mG. However, the study of Farag et al. [38] in Saudi Arabia demonstrated the high rate of electromagnetic field intensity around high-voltage systems in power plants. Ozen et al. [39] in Turkey showed that the occupational exposure of personnel in high-voltage power stations was about 0.5–0.8 micro tesla, which was more than the standard rate. This could be due to the use of high voltage [40] and too much current density in voltage booster stations [41]. It should be noted that in the voltage booster generators of operating room systems, the current density is much less than voltage booster power stations. The study of Martin et al. [42] in England showed that

in the operating rooms, the intensity of MFs up to 0.5 m and sometimes 1 m far from high-voltage systems was more than the standard rate of ICNIRP. Park et al. [43] showed the mean MFs exposures of the surgeons in the laparoscopic and robotic surgeries were lower than the mean MF exposure level of 1.1 mG in homes of North America. Therefore, it can be considered safe for patients who spend a considerably short time in the operating room.

The limitation of this study is the exposure classification, because different types of electronic systems produce harmful electromagnetic waves in operating rooms; also, a general lack of standardization of the procedures and technologies adopted for exposure assessment has emerged, which makes it difficult to perform a direct comparison of results from different studies carried out by applying different assessment strategies [28]. Another limitation is that the source publications did not provide sufficient information to assess the impact of measurement uncertainty when comparing the measured values with the action levels.

Conclusions

According to the results, it does not seem that the occupational exposure of personnel in the operating rooms is more than the standard rate, so there is no considerable risk and no need to be worried about the personnel who are overexposed to non-ionizing radiation. Electromagnetic exposure is a significant concern for surgeons and operative room staff, the most worrisome being the development of malignancy. As such, magnetic safety must be a priority in the operative setting.

It is suggested to the personnel to keep the safe distance from high-voltage supplies and in order to reduce the intensity of electric and MFs of operating rooms, it is better to install electric system power supplies out of the operating rooms. All practitioners, irrespective of their practice setting, can and should employ the safety principles of shielding, distance, and dose reduction. Furthermore, practitioners should also consider the use of new navigation systems with alternative modalities.

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