Hindawi Publishing Corporation
BioMed Research International
Volume 2014, Article ID 169459, 13 pages
http://dx.doi.org/10.1155/2014/169459

Review Article

Influence of Electric, Magnetic, and Electromagnetic Fields on the Circadian System: Current Stage of Knowledge

Bogdan Lewczuk,[1] Grzegorz Redlarski,[2,3] Arkadiusz Żak,[2] Natalia Ziółkowska,[1] Barbara Przybylska-Gornowicz,[1] and Marek Krawczuk[2]

[1] *Department of Histology and Embryology, Faculty of Veterinary Medicine, University of Warmia and Mazury, Oczapowskiego Street 13, 10-719 Olsztyn, Poland*
[2] *Department of Mechatronics and High Voltage Engineering, Gdansk University of Technology, Własna Strzecha Street 18A, 80-233 Gdansk, Poland*
[3] *Department of Electrical Engineering, Power Engineering, Electronics, and Control Engineering, University of Warmia and Mazury, Oczapowskiego Street 11, 10-736 Olsztyn, Poland*

Correspondence should be addressed to Bogdan Lewczuk; lewczukb@uwm.edu.pl

Received 5 April 2014; Revised 26 May 2014; Accepted 3 June 2014; Published 22 July 2014

Academic Editor: You-Lin Tain

One of the side effects of each electrical device work is the electromagnetic field generated near its workplace. All organisms, including humans, are exposed daily to the influence of different types of this field, characterized by various physical parameters. Therefore, it is important to accurately determine the effects of an electromagnetic field on the physiological and pathological processes occurring in cells, tissues, and organs. Numerous epidemiological and experimental data suggest that the extremely low frequency magnetic field generated by electrical transmission lines and electrically powered devices and the high frequencies electromagnetic radiation emitted by electronic devices have a potentially negative impact on the circadian system. On the other hand, several studies have found no influence of these fields on chronobiological parameters. According to the current state of knowledge, some previously proposed hypotheses, including one concerning the key role of melatonin secretion disruption in pathogenesis of electromagnetic field induced diseases, need to be revised. This paper reviews the data on the effect of electric, magnetic, and electromagnetic fields on melatonin and cortisol rhythms—two major markers of the circadian system as well as on sleep. It also provides the basic information about the nature, classification, parameters, and sources of these fields.

1. Introduction

One of the side effects of each electrical device work is the electromagnetic field generated near its workplace. All organisms, including humans, are exposed daily to the influence of different types of this field, characterized by distinct physical parameters. Therefore, it is important to accurately determine the effects of electromagnetic field on organisms. All electrically powered devices and transmission lines generate the low frequency (usually 50 or 60 Hz) field, which has a quasi-stationary character and its two components—the electric and magnetic field—can be analysed separately. This field is considered as having a potentially negative impact on organisms, although the mechanism of its biological action remains unknown. On the other hand, electronic devices, such as mobile phones, television sets or radio transmitters, emit electromagnetic radiation with high frequencies (from 300 MHz to 300 GHz). High energy radiation of this type causes a thermal effect that may increase the temperature of tissues and organs and also cause serious damage to cells. The international agency for research on cancer (IARC) in 2002 classified the extremely low frequency magnetic field generated by electrical devices as possibly carcinogenic to humans [1]. In 2011, the radio frequencies of electromagnetic fields were qualified by IARC and WHO as possibly increasing the risk of malignant brain tumour development [2].

The visible part of electromagnetic radiation, with a relatively narrow frequency band from 389 to 789 THz, plays a key role in the regulation of the diurnal rhythms by having influence on the activity of the suprachiasmatic nucleus via melanopsin-positive ganglion cells of the retina [3]. However, several reports have provided evidence that electric and magnetic fields also influence the circadian system. It has been suggested that a deficiency in melatonin secretion may be responsible for the oncogenic action of the electromagnetic field [4].

The aim of the paper was to review the data on the effects of electric, magnetic, and electromagnetic fields on melatonin and cortisol rhythms, two major markers of the circadian system as well as on sleep. We also included information on the nature, physical parameters, classification, and sources of fields, which may be useful for biologists and medical doctors.

2. Nature of Electric, Magnetic, and Electromagnetic Forces

In physical sciences, the electromagnetic field is the state of space characterised by electrodynamic nature of forces acting on electrically charged objects. In that context, the electromagnetic field can be thought of as consisting of two independent components [5]:

(i) electric—represented by a state of space, known as an electric field, in which Coulomb forces act on stationary electrically charged objects,

(ii) magnetic—represented by a state of space, known as a magnetic field, in which Lorenz forces act on nonstationary (moving) electrically charged objects (representing electric currents).

It may be interesting to note that according to the special theory of relativity, electric and magnetic fields are two aspects of the same phenomenon depending on a chosen reference frame of observation—an electrical field in one reference frame may be perceived as a magnetic field in a different reference frame.

Within the range of their influence, the electromagnetic fields may affect physical objects, including living organisms. The effects of this influence depend on many factors. Among these, the most important are [5]

(i) field intensity—in the case of the electric field, its intensity E is expressed in volts per metre (V/m), while in the case of the magnetic field (MF) its intensity H is expressed in amperes per metre (A/m),

(ii) distance R from an object expressed in metres (m),

(iii) frequency f of radiated energy—in the case of time dependent fields it is expressed in hertz (Hz), while for time independent fields their frequency f equals 0,

(iv) surface power density P (specific power) representing the intensity of radiated energy (power) with the area throughout this energy being radiated, expressed in watts per square metre (W/m^2).

It is worth mentioning at this point that the intensity of a magnetic field H is expressed in amperes per metre (A/m) according to the SI standards. However, in the literature and scientific practice, very often, the induction of a magnetic field B is used instead, which is expressed in tesla (T). These quantities—H and B—are interrelated through the medium magnetic permeability μ.

3. Electromagnetic Fields in the Habitat of Living Organisms

Electromagnetic radiation and fields have been accompanying living organisms since the dawn of life on Earth. However, their current intensity and omnipresence should be attributed, first of all, to human activity—technological advances in modern engineering related to the development and practical use of electrical power transmission systems, electrical equipment, and telecommunications.

The sources of electromagnetic radiation and fields can be divided into natural and nonnatural ones. The natural sources include celestial bodies such as stars and magnetars, Earth and biological processes involving the flow of electrical impulses in living organisms (Figure 1). The electromagnetic radiation that reaches the Earth's surface from space as microwave background radiation is a consequence of the big bang and the evolution of the universe in the very first seconds of its existence. This type of radiation is characterised by its thermal energy distribution as the most perfect black body in nature and has a nearly ideal Planck spectrum at a temperature around 2.7 K, while the maximum of its surface power density corresponds to the wavelength of 272 GHz [6]. The solar radiation that reaches the Earth's surface has relatively small surface power density around 3 μW/m^2 [6] and comprised of distinctive frequency bands, so-called atmospheric windows, representing those frequency bands that are not absorbed by the Earth atmosphere. They can be listed as

(i) radio window—represented by electromagnetic wavelengths starting from 15 MHz up to 300 GHz,

(ii) optical window—represented by electromagnetic wavelengths starting from 150 THz up to 1000 THz,

(iii) microwave window—represented by electromagnetic wavelengths starting from 23.1 THz up to 37.5 THz.

The magnetic field of Earth is another natural field originating from the planet core that extends to a vast space surrounding Earth, known as the magnetosphere. An important source of strong electromagnetic fields is atmospheric discharges, known as lightning. Rapid radiation releases, which accompany these natural phenomena, are characterised by high power densities and high frequencies. In living organisms, electromagnetic fields originate from the transmission of signals in the nervous system and from structures autonomously generating electrical impulses (like the heart).

The history of nonnatural sources of electromagnetic radiation and fields is relatively short and covers only the last hundred years. Nonnatural sources of electromagnetic radiation or fields are attributed to two groups. The first group includes ionising radiation, characterised by a relatively high energy that may result in the ionisation of matter particles. The presence of this kind of radiation has primarily natural

Table 1: A list of various sources of electromagnetic fields/radiation influencing living organisms [7].

Level	Frequency range	Radiation source
Static	0 Hz	Earth, video screens, magnetic resonance imaging, and other diagnostic/scientific equipment, electrolysis, welding
Extremely low frequency fields	0–300 Hz	Power transmission lines, home wiring, car electric engines, electric trains and trams, welding devices
Intermediate frequency	300 Hz–100 kHz	Video screens, antitheft devices used in cars, homes, shops, card readers, metal detectors, magnetic resonance imaging, welding devices
Radio frequency	100 kHz–300 GHz	Radio, television, mobile phones, microwave ovens, radar and radio transmitters, magnetic resonance imaging

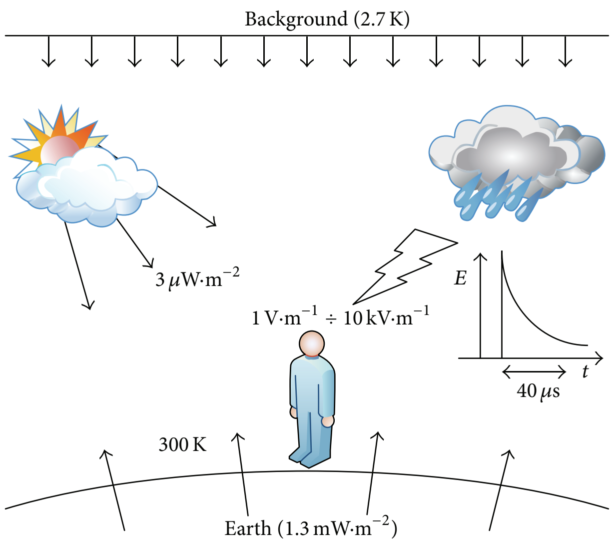

Figure 1: Natural radiation sources present on Earth (based on [6]).

reasons (the statistical annual exposure dose is around 2.4 mSv). However, nonnatural sources of ionising radiation, such as technical devices, in which various radioactive isotopes are used, are currently considered to be the most important problems in public health protection. The second group comprises nonionising radiation of energy, which is too low to ionise matter particles. The common sources of this kind of radiation are all means used for electrical power production, transmission, and utilisation (high-voltage power lines, substations, motors, generators, industrial and domestic appliances, home wiring, etc.). Very important sources of electromagnetic radiation include telecommunication systems (radio, television, internet, and Wi-Fi) as well as medical devices used for diagnosis or therapy.

According to the European Commission, nonionizing radiation can be divided into several levels [7]:

(i) static fields,

(ii) extremely low frequency fields (ELF fields),

(iii) intermediate frequency fields (IF fields),

(iv) radio frequency fields (RF fields).

In order to illustrate the authors' considerations, typical sources of electromagnetic fields/radiation influencing living organisms and mentioned above are listed and described in Table 1.

4. Effects of Electric, Magnetic, and Electromagnetic Fields on the Diurnal Rhythm of Melatonin Secretion

Melatonin is the main hormone of the circadian timing system in all vertebrates including the human [8]. The diurnal rhythm of its secretion in the mammalian pineal gland is driven by the suprachiasmatic nucleus—the central endogenous oscillator, directly connected with the retina [8–10]. Under physiological condition, the regulatory mechanisms ensure that this rhythm is properly entrained to the light-dark cycle and, therefore, the elevated night-time melatonin secretion can serve for all cells of the body as a clock and a calendar [8, 11, 12]. Melatonin plays a key role in the control of many physiological processes occurring in daily or seasonal rhythms, like sleep, metabolism, and reproduction [13]. Moreover, melatonin is also involved in the regulation of immune system [14], cardiovascular system [15], and cancer development [13, 16, 17]. It is also a very potent free radical scavenger [18].

It is worth to note that the level of melatonin secretion differs markedly between individuals, in both humans [19, 20] and animals [21, 22]. Based on urinary melatonin measurements, the human population could be divided into low and high melatonin excretors [19, 20]. The study on the sheep demonstrated that interindividual variability in a plasma melatonin level is under strong genetic control and it is related to the pineal gland weight and melatonin secretion, but not to the hormone catabolism [21]. The individual diurnal profiles of plasma melatonin are highly repeatable on consecutive days, weeks, and months, in both humans and animals [20, 22]. The level of nocturnal melatonin secretion decreases with age [23].

Several factors, like light pollution during night or moving across time zones, may lead to the disruption of the melatonin secretion rhythm and circadian disorganization, which undoubtedly has a negative impact on various aspects of health [13, 14, 16, 24, 25].

The melatonin secretion by the pineal gland is generally regarded as particularly sensitive to electric, magnetic, and electromagnetic field influences. The effects of these fields on pineal activity have been analyzed in epidemiological studies [26–41] and experimental investigations carried out using different *in vivo* [42–94] and *in vitro* models [95–100].

4.1. Epidemiological Studies. The epidemiological studies provided interesting and very important data on the influence of electromagnetic fields on melatonin and its metabolite—6-sulfatoxymelatonin—in humans. Many of these investigations concerned the effects of an extremely low frequency magnetic field (ELF-MF), which is generated by outdoor high- and medium-voltage electricity power lines, indoor electrical power supply, and electrical appliances [25].

The relations between exposure to the magnetic fields with a frequency of 16.7 Hz and human health have been intensively studied in railway workers [26, 101, 102]. Pfluger and Minder [26] compared, using a repeated measures design, the urinary excretion of 6-sulfatoxymelatonin in 108 male Swiss railway workers between leisure periods and days following the start of service on electrically powered engines or doing other tasks. The study demonstrated that the urinary excretion of 6-sulfatoxymelatonin was lower on work days than leisure days among engine drivers exposed to a 16.7 Hz magnetic field with an average strength of 20 μT, but not among other workers. It should be noted that epidemiological studies of Swiss railway workers demonstrated significantly increased (0.9% per μT-year of cumulative exposure) leukemia mortality [101]. The statistical data also suggest a link between occupational exposition to a magnetic field with a frequency of 16.7 Hz and the risk of Alzheimer's disease [102].

Humans are widely exposed to magnetic fields with a frequency of 50 Hz (in Europe) or 60 Hz (in North America) generated by the electrical power supply and electrical devices, commonly used in homes and workplaces. The decreased excretion of 6-sulfatoxymelatonin in urine was observed in electrical utility workers, who were exposed to magnetic fields with a frequency of 60 Hz [27–29]. Significant changes were noted after the second day of the working week and the effect of the magnetic field exposition was the most prominent in subjects with low workplace light exposures [28]. Further, it was demonstrated that a decrease in excretion of 6-sulfatoxymelatonin occurred in workers exposed for more than two hours and in a 3-phase environment [29]. No change was found in people working in a 1-phase environment. A weak effect of occupational exposure to low-intensity magnetic field on 6-sulfatoxymelatonin excretion was also observed in female workers [30].

Davis et al. [31] suggested that domestic exposure to a 60 Hz magnetic field decreased pineal activity in women, primarily those using medications. The level of 6-sulfatoxymelatonin excretion was lower in infants kept in incubators and rose when they were moved to a place free from electrical devices [103]. The analysis performed by Juutilainen and Kumlin [32] suggests that exposure to a magnetic field with a frequency of 50 Hz may enhance the effects of night-time light exposure on melatonin production; however, the study was performed on a relatively small group of subjects.

It should be underlined that a moderate number of epidemiological studies showed no effect of the exposure to ELF-MF on melatonin secretion [33–37]. Gobba et al. [33] noted similar levels of 6-sulfatoxymelatonin excretion in two groups of workers exposed to fields ≤0.2 μT and >0.2 μT. No association between residential exposure to a 60 Hz magnetic field and 6-sulfatoxymelatonin excretion was observed in adults aged 50–81 years [34]. Touitou et al. [35] showed that the long-term exposure to ELF-MF did not change the level and diurnal secretion of melatonin. These data suggest that magnetic fields do not have cumulative effects on melatonin secretion in humans.

In contrast to ELF-MF, much less attention has been paid in epidemiological studies to the effects of intermediate frequency range (300 Hz to <10 MHz) and radio frequency range (10 MHz to 300 GHz) electromagnetic fields. No changes in urinary 6-sulfatoxymelatonin excretion were found in women residing near radio and television broadcasting transmitters [38]. The use of a mobile phone for more than 25 minutes a day decreased the level of melatonin secretion [39]. Broadcast transmitters with short-wave electromagnetic fields (6–22 MHz) reduced melatonin secretion by 10% [40]. A study carried out on 50 electronic equipment service technicians, exposed to different kinds of fields, found significantly decreased levels of serum melatonin compared to the control group [41].

4.2. Experimental Studies on Volunteers. In contrast to the epidemiological studies, the majority of investigations performed on volunteers found no effect of ELF-MF on melatonin or/and 6-sulfatoxymelatonin levels [42–51]. In a study by Warman et al. [42], 2-hour-long exposure to a 50 Hz field at an intensity of 200–300 μT did not induce significant changes in the nocturnal melatonin rise. Similarly, the exposure of volunteers for one night to 50 Hz field at an intensity of 20 μT had no effect on plasma melatonin level [43]. Selmaoui et al. [44] demonstrated that nocturnal acute exposure to either continuous or intermittent 50 Hz linearly polarized magnetic fields of 10 μT does not affect melatonin secretion in humans. In a series of experiments performed by Graham et al. [45–49], the nocturnal secretion and metabolism of melatonin were not altered in humans by the exposure to ELF-MF at intensities within the occupational-exposure range for one or more nights. No changes in salivary melatonin were found after exposing volunteers to a 16.7 Hz electromagnetic field [50, 51]. In contrast to the data presented above, Davis et al. [52] demonstrated that the exposure to a magnetic field of 0.5 to 1 μT greater than the ambient levels for 5 consecutive nights reduced the excretion of 6-sulfatoxymelatonin in women.

4.3. Experimental Studies on Animals. The majority of *in vivo* experiments concerning the influence of magnetic field exposure on pineal activity have been conducted on laboratory rodents [53–85].

Highly variable results were obtained in the studies on the effects of ELF-MF. The continuous exposition of Sprague-Dawley rats to a 10 μT 50 Hz magnetic field for 91 days decreased the blood melatonin level [53]. However, another study from the same group failed to demonstrate a consistent effect of a 100 μT 50 Hz magnetic field exposure on melatonin levels in rats, as a decline or no changes were observed [54]. A decrease in the pineal activity in response to ELF-MF was also noted in several other experiments performed on laboratory rats [55–63] and Djungarian hamsters [64, 65]. On the other hand, an increased excretion of 6-sulfatoxymelatonin was observed in Sprague-Dawley rats exposed to a magnetic field with a frequency of 50 Hz and an intensity of 100 μT for 24 hours [66]. Similarly, Dyche et al. [67] demonstrated that male rats, exposed to the 100 μT magnetic field for 1 month, have a slightly elevated excretion of 6-sulfatoxymelatonin. Increased melatonin secretion after exposure to a weak magnetic field was also reported in the Djungarian hamster by Niehaus et al. [68]. In other studies performed on rats and hamsters, no changes in melatonin secretion were observed in response to a magnetic field with a frequency of 50/60 Hz [69–77]. The lack of influence of ELF-MF on pineal activity was also reported for mice [78].

Studies on rodents have provided interesting data concerning the effect of radio frequency range of electromagnetic field on pineal activity. The exposure of rats to an electromagnetic field of 900 MHz frequency and a specific adsorption of 0.9 $W{\cdot}kg^{-1}$ (mobile phone) lasting 2 hours a day and repeated for 45 days resulted in a statistically significant decrease in pineal melatonin content [81]. Moreover, a field of 1800 MHz frequency and a power of 200 $W{\cdot}cm^{-2}$ (2 hours per day for 32 days; 0.5762 $W{\cdot}kg^{-1}$) disturbed the rhythm of melatonin secretion in rats [82]. However, in another experiment, the animals were subjected to a similar field for 30 minutes a day, 5 days a week for 4 weeks and no changes in the level of melatonin in rat serum were noted [83]. Similarly, the exposure of Djungarian hamsters to an electromagnetic field with frequencies of 383, 900, and 1800 MHz (80 m $W{\cdot}kg^{-1}$) for 60 days (24 hours a day) did not result in alternations of the melatonin secretion [84].

Studies on the effects of electric and magnetic fields on nonrodent species have been conducted only occasionally [86–94]. The exposure of dairy cattle to a vertical electric field of 10 kV/m and a uniform horizontal magnetic field of 30 μT for 28 days did not change the nocturnal blood melatonin level [86]. Similarly, no changes in melatonin secretion were observed in other experiments performed on dairy cows [87, 88] and on lambs [89, 90]. The studies of American kestrels reveled that a long-term exposure to electromagnetic fields (60 Hz, 30 μT, 10 $kV{\cdot}m^{-1}$) caused changes in melatonin secretion [91]. The magnetic field increased the level of melatonin in the pineal gland and blood serum of trout during the night [92].

4.4. In Vitro Studies. In vitro studies concerning the effect of electromagnetic fields on melatonin secretion were conducted on the pineal glands of Djungarian hamsters [95, 100] and rats [96–99]. The results of experiments with hamster pineals in the superfusion organ culture demonstrated that ELF-MF with an intensity of 86 μT and a frequency of 16.67 or 50 Hz caused a decrease in melatonin secretion, activated by isoproterenol [95]. A reduction in isoproterenol-stimulated melatonin secretion and activity of arylalkylamine N-acetyltransferase has also been found in studies of rat pinealocytes after exposure to ELF-MF [96, 97]. On the contrary, Lewy et al. [98] noted increased activity of melatonin-synthetizing enzymes, while Tripp et al. [99] found no changes in melatonin secretion in rat pinealocytes in response to ELF-MF.

The effect of exposure to an electromagnetic field with a frequency of 1800 MHz on melatonin secretion from the Djungarian hamster pineal gland was investigated [100] in the same experimental setup which had been used in experiments with ELF-MF [95]. This study demonstrated that both continuous and pulse signals at a specific adsorption level of 800 $mW{\cdot}kg^{-1}$, lasting seven hours, increased the level of isoproterenol-stimulated melatonin secretion [100].

5. Effects of Electric, Magnetic, and Electromagnetic Fields on the Diurnal Rhythm of Cortisol Secretion

Cortisol is an essential steroid hormone produced by the adrenal gland. Like melatonin, it exhibits a constant and reproducible diurnal rhythm under physiological conditions [104–107]. Debono et al. [105] in a study of 33 healthy individuals with 20-minute-interval cortisol profiling over 24 hours showed that the cortisol concentration reached the lowest levels at around midnight. It then started to rise at 02:00–03:00 and the peak occurred at around 08:30. Next, the cortisol level slowly decreased back to the nadir. The peak cortisol level in the human blood was approximately 399 nmol/L, while the nadir cortisol level was <50 nmol/L. Like many other physiological processes in the body occurring in daily cycles, the rhythm of cortisol secretion is regulated by the suprachiasmatic nucleus, located in the hypothalamus.

Cortisol governs hunger and appetite, stress, inflammatory response, and many other functions [108–110]. The importance of cortisol is especially evident when it becomes deficient in a state known as adrenal insufficiency [111]. It has been suggested that cortisol acts as a secondary messenger between central and peripheral clocks and may be an important factor in the synchronization of body circadian rhythms [111]. Alterations in the rhythmic production and level of the cortisol lead to significant adverse effects [108, 112]. Children with autism frequently show a large variation in day-time patterns of cortisol and significant elevations in salivary cortisol in response to a nonsocial stressor [113].

Both people and animals live in environments with electromagnetic fields of different origins. They are exposed to electromagnetic field of natural origin, like the magnetic force of Earth and artificial origins, which results from human activities. Variations in the Earth's magnetic field are consequential to all living beings of the planet. In addition, electric and magnetic fields, which exist wherever electricity is generated or transmitted, seem to be very important to exposed organisms.

5.1. Experimental Studies on Animals. The results of studies on the effects of electromagnetic field on the secretion of cortisol in animals are very diverse. In Guinea pigs, ELF-MF caused changes in cortisol levels, which depended on the field frequency and intensity [114]. Exposure of animals for 2 h and 4 h per day, over a period of 5 days, to a field of 50 Hz and 0.207 μT showed a significant decrease in cortisol levels [114]. However, in the groups subjected to a field of 5 Hz and 0.013 μT, no significant changes in cortisol were observed after 2 h or 4 h of exposure [114]. In Swiss mice continuously exposed to a low frequency (50 Hz) field for 350 days, a decrease in cortisol value was observed on day 190 of the experiment [115]. No significant differences were noted on days 90 and 350 of the exposure [115]. An increase in the cortisol level was observed in rats exposed to uniform magnetic fields of 10^{-3} T and 10^{-2} T, 1 hour each day for a period of ten days [116]. The exposure of female hamsters to mobile phones working at 950 MHz for short (10 days, 3 h daily) and long (60 days, 3 h daily) periods caused a significant increase in cortisol in comparison with the control group [117].

A lack of electromagnetic field effect on cortisol concentration was also reported. Burchard et al. [118] showed no variation in cortisol concentration, which could be attributed to the exposure of dairy cows to electric and magnetic fields (vertical electric field 10 kV and horizontal magnetic field of 30 mT). In ewe lambs, no effect of the exposition to a 60 Hz magnetic field for 43 weeks on serum cortisol was also reported [119]. A lack of electromagnetic field effect on corticosterone concentration, irrespective of the exposure characteristics and period, was also found in experiments on rats [120, 121].

5.2. Studies in Humans. The studies concerning the influence of the Earth's magnetic force on the human body demonstrated that the serum cortisol values were dependent on the direction of the head during sleep in relation to the North and South Magnetic Poles [122]. The biological effect of exposure to man-made electromagnetic fields on humans was the subject of several studies [123–127]. Dentistry is one of the job categories with high exposure to elevated levels of ELF-MF. Exposure of dentists to the fields emitted by cavitrons caused a decrease in the serum cortisol level in comparison with a control group [123]. Low frequency magnetic fields are applied in physiotherapy (magnetotherapy and magnetostimulation). Studies of the long-term application of these procedures suggest a regulating influence of magnetic fields on cortisol concentration [124]. However, it should be stressed that numerous studies found no effect of the magnetic fields 50/60 Hz (1–20 μT) and the radio frequency electromagnetic fields on a level of cortisol, irrespective of the experiment time, age, or sex of individuals or sampling time [125–127].

6. Effects of Electric, Magnetic, and Electromagnetic Fields on Sleep

The diurnal rhythms are generated by an internal biological clock system that is synchronized to a 24-hour day by environmental factors, primarily the light-dark cycle. Many rhythms are overt and easy to recognize, such as the sleep-wake cycle, locomotor activity, and feeding behavior.

The sleep-wake cycle is likely the primary output rhythm of the circadian clock, because the regulation of many behavior and physiological activities depends on whether the organism is asleep or awake. Sleep disorders—frequently occurring clinical symptoms—have been hypothesized to be partially related to electromagnetic field exposure. In recent years, there has been an increasing amount of experimental and epidemiological data on the influence of nonionizing electromagnetic fields on brain physiology and sleep [40, 128–144].

Sleep is an endogenous, self-sustained cerebral process. It is possible to measure defined and distinguishable phases of sleep. The low frequency activity (<10 Hz) and the sleep spindle frequency activity (approximately 12–15 Hz) are two silent features of nonrapid eye movement (NREM) sleep that can be quantified and used as markers of sleep regulating processes [145]. Several experiments have shown that electroencephalographic (EEG) spectral power in the alpha (8–12 Hz) and spindle (12–14 Hz) frequencies is enhanced both during and following pulsed-modulated radio frequency field exposure [128–133]. Recently, an increase in delta power (<4.5 Hz) has also been observed [129]. Mann and Röschke [134] reported a reduction of rapid eye movement (REM) sleep and changes in spectral power of EEG during REM sleep in response to a high frequency electromagnetic field emitted by digital mobile radio telephones. Regel et al. [130] performed a study on the influence of radio frequency electromagnetic field exposure by varying the signal intensity in three experimental sessions. The analysis of the sleep EEG revealed a dose-dependent increase of power in the spindle frequency range in NREM sleep. This provided the first indications of a dose-dependent relation between the field intensity and its effect on brain physiology. Huber et al. [137] also demonstrated a power increase in the fast spindle frequency range of EEG during pulse-modulating radio frequency field exposure but not in a dose-dependent manner. It should be also stressed that many studies [135, 139–141] failed to show any effects of the radio frequency field exposure on sleep or sleep EEG.

Despite several reports showing an influence of pulsed-modulated radio frequency electromagnetic field on sleep EEG, the mechanism behind these exposure-induced changes is still unclear. Additionally, there is no supporting evidence that this effect is related to health consequences such as alterations in sleep quality [128–130, 136].

To date, there have been few controlled laboratory studies on sleep EEG under low frequency electric and magnetic fields. Åkerstedt et al. [143] carried out a double-blind, placebo-controlled study on 18 healthy subjects to examine the effects of a 50 Hz magnetic field on sleep. The results showed that sleep efficiency, slow wave sleep, and slow activity as well as subjective depth of sleep were significantly reduced under ELF-MF exposure. Although these results suggest an interference of the low frequency field, the authors emphasize that these alterations are still within a normal range. In a double-blind laboratory study, Graham et al. [144]

investigated the effect of a 60 Hz magnetic field on sleep during continuous, intermittent, or sham exposures. They demonstrated that intermittent exposure resulted in clear distortion of sleep and altered sleep architecture compared to sham conditions and continuous exposure. It should be emphasized that field strengths in both cited studies [143, 144] were below those used for medical diagnostic purposes such as magnetic resonance imaging.

The analysis of epidemiological data concerning the sleep quality and melatonin cycle, collected during ten years in the area surrounding a short-wave (6–22 MHz) broadcasting station, provided the evidence that electromagnetic field exposure only affects poor sleepers and that might be a group of people who are sensitive to such exposure [40]. This phenomenon has been described as electromagnetic hypersensitivity, EHS. It was also observed in several other reports [146, 147].

Although a biological explanation for an association between exposure to radio frequency electromagnetic field and impaired sleep quality has not been identified, it is hypothesized that the suppression of night-time melatonin secretion may be involved in this process [148]. Two relatively recent studies suggest an association between the decreased secretion of melatonin during the night and increasing use of mobile phones emitting a radio frequency field [39, 149]. However, four cross-over trials [127, 141, 150, 151] have found no correlation between the exposure to mobile phone handset and the melatonin secretion. The hypothesis of an association between melatonin cycle and electromagnetic field exposure requires further investigation [152].

7. Conclusions

The results of studies on the effects of electric, magnetic, and electromagnetic fields on melatonin and cortisol secretion as well as on sleep are largely contradictory. The adverse data related to the influence of these physical factors on secretion of both "circadian" hormones were obtained in all groups of investigations including the epidemiological studies, the studies on volunteers, and the studies on animals. Moreover, *in vitro* investigations on rodent pineals have also brought inconsistent results. The sources of discrepancies remain unknown; however such factors as an inappropriate estimation of exposure level, interferences with other factors like light and medication, differences in a phase of the circadian rhythm during exposure, and interindividual variability in the sensitivity to electromagnetic fields seem to be particularly worth of attention. The idea that some individuals are more sensitive to the electromagnetic field than others, due to genetic background or/and current health status, appears very attractive and should be a subject of further studies. It is worth to note that inconsistent results have been also obtained in the studies dealing with other effects of electrical, magnetic, and electromagnetic fields on organism, including their tumor-promoting action [153–157].

Despite divergences in the reported results, ELF-MF and radio frequency electromagnetic field have to be considered as factors possibly influencing the circadian system function, because a substantial number of studies demonstrated the changes in melatonin and cortisol secretion as well as in sleep after exposition to these fields. Due to widespread exposure of humans and animals to ELF-MF and radio frequency electromagnetic field, the studies on their biological effects should be continued. An important and still unsolved issue is relationships between physical characteristics and biological effects of the fields as well as the mechanisms of field action on the circadian system.

In light of the existing literature, the hypothesis pointing to the disruption of melatonin secretion, as one of the main factors responsible for cancerogenic effects of electrical, magnetic, or electromagnetic fields [158, 159], is not supported by the epidemiological and experimental data. Therefore, it should be currently considered as negatively verified.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

References

[1] International Agency for Research on Cancer, "Non-ionizing radiation, part 1: static and extremely low-frequency (ELF) electric and magnetic fields," *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans*, vol. 80, pp. 1–395, 2002.

[2] International Agency for Research on Cancer, "IARRC classifies radiofrequency electromagnetic fields as possibly carcinogenic to humans," Press Release No 2008, 2011.

[3] F. G. Amaral, A. M. Castrucci, J. Cipolla-Neto et al., "Environmental control of biological rhythms: effects on development, fertility and metabolism," *Journal of Neuroendocrinology*, 2014.

[4] R. G. Stevens and S. Davis, "The melatonin hypothesis: electric power and breast cancer," *Environmental Health Perspectives*, vol. 104, no. 1, pp. 135–140, 1996.

[5] D. Halliday, R. Resnick, and J. Walker, *Fundamentals of Physics, Part 3*, John Wiley & Sons, New York, NY, USA, 2001.

[6] "Exposure to high frequency electromagnetic fields, biological effects and health consequences (100 kHz-300 GHz)," in *Review of the Scientific Evidence on Dosimetry, Biological Effects, Epidemiological Observations, and Health Consequences Concerning Exposure to High Frequency Electromagnetic Fields (100 kHz to 300 GHz)*, P. Vecchia, R. Matthes, G. Ziegelberger James Lin, R. Saunders, and A. Swerdlow, Eds., International Commission on Non-Ionizing Radiation Protection ICNIRP, 2009.

[7] *Possible Effects of Electromagnetic Fields (EMF) on Human Health*, European Commission, Health & Consumer Protection D, Directorate C: Public Health and Risk Assessment, 2007.

[8] P. Pévet, "Melatonin and biological rhythms," *Biological Signals and Receptors*, vol. 9, no. 3-4, pp. 203–212, 2000.

[9] H. Okamura, S. Yamaguchi, and K. Yagita, "Molecular machinery of the circadian clock in mammals," *Cell and Tissue Research*, vol. 309, no. 1, pp. 47–56, 2002.

[10] M. Münch and A. Kawasaki, "Intrinsically photosensitive retinal ganglion cells: classification, function and clinical implications," *Current Opinion in Neurology*, vol. 26, no. 1, pp. 45–51, 2013.

[11] R. J. Reiter, "The melatonin rhythm: both a clock and a calendar," *Experientia*, vol. 49, no. 8, pp. 654–664, 1993.

[12] V. Simonneaux and C. Ribelayga, "Generation of the melatonin endocrine message in mammals: a review of the complex regulation of melatonin synthesis by norepinephrine, peptides, and other pineal transmitters," *Pharmacological Reviews*, vol. 55, no. 2, pp. 325–395, 2003.

[13] M. Singh and H. R. Jadhav, "Melatonin: functions and ligands," *Drug Discovery Today*, 2014.

[14] D. P. Cardinali, L. I. Brusco, R. A. Cutrera, P. Castrillon, and A. I. Esquifino, "Melatonin as a time-meaningful signal in circadian organization of immune response," *Biological Signals and Receptors*, vol. 8, no. 1-2, pp. 41–48, 1999.

[15] F. Simko, R. J. Reiter, O. Pechanova, and L. Paulis, "Experimental models of melatonin-deficient hypertension," *Frontiers in Bioscience*, vol. 18, no. 2, pp. 616–625, 2013.

[16] F. C. Kelleher, A. Rao, and A. Maguire, "Circadian molecular clocks and cancer," *Cancer Letters*, vol. 342, no. 1, pp. 9–18, 2014.

[17] B. V. Jardim-Perassi, A. S. Arbab, L. C. Ferreira et al., "Effect of melatonin on tumor growth and angiogenesis in xenograft model of breast cancer," *PLoS ONE*, vol. 9, no. 4, Article ID e85311, 2014.

[18] J. J. García, L. López-Pingarrón, P. Almeida-Souza et al., "Protective effects of melatonin in reducing oxidative stress and in preserving the fluidity of biological membranes: a review," *Journal of Pineal Research*, vol. 56, no. 3, pp. 225–237, 2014.

[19] J. D. Bergiannaki, C. R. Soldatos, T. J. Paparrigopoulos, M. Syrengelas, and C. N. Stefanis, "Low and high melatonin excretors among healthy individuals," *Journal of Pineal Research*, vol. 18, no. 3, pp. 159–164, 1995.

[20] L. Wetterberg, J. D. Bergiannaki, T. Paparrigopoulos et al., "Normative melatonin excretion: a multinational study," *Psychoneuroendocrinology*, vol. 24, no. 2, pp. 209–226, 1999.

[21] P. Chemineau, A. Daveau, L. Bodin, L. Zarazaga, A. Gomez-Brunet, and B. Malpaux, "Sheep as a mammalian model of genetic variability in melatonin," *Reproduction*, vol. 59, supplement, pp. 181–190, 2002.

[22] A. Rapacz, B. Lewczuk, M. Prusik, and A. Raś, "Diurnal rhythm of plasma melatonin level in mares from spring equinox to summer solstice," *Bulletin of the Veterinary Institute in Pulawy*, vol. 54, no. 4, pp. 693–699, 2010.

[23] R. Hardeland, "Melatonin and the theories of aging: a critical appraisal of melatonin's role in antiaging mechanisms," *Journal of Pineal Research*, vol. 55, no. 4, pp. 325–356, 2013.

[24] Y. Touitou, O. Coste, G. Dispersyn, and L. Pain, "Disruption of the circadian system by environmental factors: effects of hypoxia, magnetic fields and general anesthetics agents," *Advanced Drug Delivery Reviews*, vol. 62, no. 9-10, pp. 928–945, 2010.

[25] Y. Touitou and B. Selmaoui, "The effects of extremely low-frequency magnetic fields on melatonin and cortisol, two marker rhythms of the circadian system," *Dialogues in Clinical Neuroscience*, vol. 14, no. 4, pp. 381–399, 2012.

[26] D. H. Pfluger and C. E. Minder, "Effects of exposure to 16.7 Hz magnetic fields on urinary 6-hydroxymelatonin sulfate excretion of Swiss railway workers," *Journal of Pineal Research*, vol. 21, no. 2, pp. 91–100, 1996.

[27] J. B. Burch, J. S. Reif, M. G. Yost, T. J. Keefe, and C. A. Pitrat, "Nocturnal excretion of a urinary melatonin metabolite among electric utility workers," *Scandinavian Journal of Work, Environment and Health*, vol. 24, no. 3, pp. 183–189, 1998.

[28] J. B. Burch, J. S. Reif, M. G. Yost, T. J. Keefe, and C. A. Pitrat, "Reduced excretion of a melatonin metabolite in workers exposed to 60 Hz magnetic fields," *American Journal of Epidemiology*, vol. 150, no. 1, pp. 27–36, 1999.

[29] J. B. Burch, J. S. Reif, C. W. Noonan, and M. G. Yost, "Melatonin metabolite levels in workers exposed to 60-Hz magnetic fields: work in substations and with 3-phase conductors," *Journal of Occupational and Environmental Medicine*, vol. 42, no. 2, pp. 136–142, 2000.

[30] J. Juutilainen, R. G. Stevens, L. E. Anderson et al., "Nocturnal 6-hydroxymelatonin sulfate excretion in female workers exposed to magnetic fields," *Journal of Pineal Research*, vol. 28, no. 2, pp. 97–104, 2000.

[31] S. Davis, W. T. Kaune, D. K. Mirick, C. Chen, and R. G. Stevens, "Residential magnetic fields, light-at-night, and nocturnal urinary 6-sulfatoxymelatonin concentration in women," *American Journal of Epidemiology*, vol. 154, no. 7, pp. 591–600, 2001.

[32] J. Juutilainen and T. Kumlin, "Occupational magnetic field exposure and melatonin: interaction with light-at-night," *Bioelectromagnetics*, vol. 27, no. 5, pp. 423–426, 2006.

[33] F. Gobba, G. Bravo, M. Scaringi, and L. Roccatto, "No association between occupational exposure to ELF magnetic field and urinary 6-sulfatoximelatonin in workers," *Bioelectromagnetics*, vol. 27, no. 8, pp. 667–673, 2006.

[34] S. D. Youngstedt, D. F. Kripke, J. A. Elliott, and J. D. Assmus, "No association of 6-sulfatoxymelatonin with in-bed 60-Hz magnetic field exposure or illumination level among older adults," *Environmental Research*, vol. 89, no. 3, pp. 201–209, 2002.

[35] Y. Touitou, J. Lambrozo, F. Camus, and H. Charbuy, "Magnetic fields and the melatonin hypothesis: a study of workers chronically exposed to 50-Hz magnetic fields," *The American Journal of Physiology—Regulatory Integrative and Comparative Physiology*, vol. 284, no. 6, pp. R1529–R1535, 2003.

[36] P. Levallois, M. Dumont, Y. Touitou et al., "Effects of electric and magnetic fields from high-power lines on female urinary excretion of 6-sulfatoxymelatonin," *American Journal of Epidemiology*, vol. 154, no. 7, pp. 601–609, 2001.

[37] P. Cocco, M. E. Cocco, L. Paghi et al., "Urinary 6-sulfatoxymelatonin excretion in humans during domestic exposure to 50 hertz electromagnetic fields," *Neuroendocrinology Letters*, vol. 26, no. 2, pp. 136–142, 2005.

[38] M. L. Clark, J. B. Burch, M. G. Yost et al., "Biomonitoring of estrogen and melatonin metabolites among women residing near radio and television broadcasting transmitters," *Journal of Occupational and Environmental Medicine*, vol. 49, no. 10, pp. 1149–1156, 2007.

[39] J. B. Burch, J. S. Reif, C. W. Noonan et al., "Melatonin metabolite excretion among cellular telephone users," *International Journal of Radiation Biology*, vol. 78, no. 11, pp. 1029–1036, 2002.

[40] E. Altpeter, M. Röösli, M. Battaglia, D. Pfluger, C. E. Minder, and T. Abelin, "Effect of short-wave (6-22 MHz) magnetic fields on sleep quality and melatonin cycle in humans: the Schwarzenburg shut-down study," *Bioelectromagnetics*, vol. 27, no. 2, pp. 142–150, 2006.

[41] M. El-Helaly and E. Abu-Hashem, "Oxidative stress, melatonin level, and sleep insufficiency among electronic equipment repairers," *Indian Journal of Occupational and Environmental Medicine*, vol. 14, no. 3, pp. 66–70, 2010.

[42] G. R. Warman, H. Tripp, V. L. Warman, and J. Arendt, "Acute exposure to circularly polarized 50-Hz magnetic fields of 200-300 microT does not affect the pattern of melatonin secretion in young men," *Journal of Clinical Endocrinology and Metabolism*, vol. 88, no. 12, pp. 5668–5673, 2003.

[43] Y. Kurokawa, H. Nitta, H. Imal, and M. Kabuto, "Acute exposure to 50 Hz magnetic fields with harmonics and transient components: lack of effects on nighttime hormonal secretion in men," *Bioelectromagnetics*, vol. 24, no. 1, pp. 12–20, 2003.

[44] B. Selmaoui, J. Lambrozo, and Y. Touitou, "Magnetic fields and pineal function in humans: evaluation of nocturnal acute exposure to extremely low frequency magnetic fields on serum melatonin and urinary 6-sulfatoxymelatonin circadian rhythms," *Life Sciences*, vol. 58, no. 18, pp. 1539–1549, 1996.

[45] C. Graham, M. R. Cook, D. W. Riffle, M. M. Gerkovich, and H. D. Cohen, "Nocturnal melatonin levels in human volunteers exposed to intermittent 60 Hz magnetic fields," *Bioelectromagnetics*, vol. 17, no. 4, pp. 263–273, 1996.

[46] C. Graham, M. R. Cook, and D. W. Riffle, "Human melatonin during continuous magnetic field exposure," *Bioelectromagnetics*, vol. 18, no. 2, pp. 166–171, 1997.

[47] C. Graham, M. R. Cook, A. Sastre, D. W. Riffle, and M. M. Gerkovich, "Multi-night exposure to 60 Hz magnetic fields: effects on melatonin and its enzymatic metabolite," *Journal of Pineal Research*, vol. 28, no. 1, pp. 1–8, 2000.

[48] C. Graham, M. R. Cook, M. M. Gerkovich, and A. Sastre, "Melatonin and 6-OHMS in high-intensity magnetic fields," *Journal of Pineal Research*, vol. 31, no. 1, pp. 85–88, 2001.

[49] C. Graham, A. Sastre, M. R. Cook, and M. M. Gerkovich, "All-night exposure to EMF does not alter urinary melatonin, 6-OHMS or immune measures in older men and women," *Journal of Pineal Research*, vol. 31, no. 2, pp. 109–113, 2001.

[50] B. Griefahn, C. Künemund, M. Blaszkewicz, K. Golka, and G. Degen, "Experiments on effects of an intermittent 16.7-Hz magnetic field on salivaray melatonin concentrations, rectal temperature, and heart rate in humans," *International Archives of Occupational and Environmental Health*, vol. 75, no. 3, pp. 171–178, 2002.

[51] B. Griefahn, C. Künemund, M. Blaszkewicz, K. Golka, P. Mehnert, and G. Degen, "Experiments on the effects of a continuous 16.7 Hz magnetic field on melatonin secretion, core body temperature, and heart rates in humans," *Bioelectromagnetics*, vol. 22, no. 8, pp. 581–588, 2001.

[52] S. Davis, D. K. Mirick, C. Chen, and F. Z. Stanczyk, "Effects of 60-Hz magnetic field exposure on nocturnal 6-sulfatoxymelatonin, estrogens, luteinizing hormone, and follicle-stimulating hormone in healthy reproductive-age women: results of a crossover trial," *Annals of Epidemiology*, vol. 16, no. 8, pp. 622–631, 2006.

[53] W. Löscher, U. Wahnschaffe, M. Mevissen, A. Lerchl, and A. Stamm, "Effects of weak alternating magnetic fields on nocturnal melatonin production and mammary carcinogenesis in rats," *Oncology*, vol. 51, no. 3, pp. 288–295, 1994.

[54] W. Löscher, M. Mevissen, and A. Lerchl, "Exposure of female rats to a 100-μT 50 Hz magnetic field does not induce consistent changes in nocturnal levels of melatonin," *Radiation Research*, vol. 150, no. 5, pp. 557–567, 1998.

[55] B. W. Wilson, L. E. Anderson, D. I. Hilton, and R. D. Phillips, "Chronic exposure to 60-Hz electric fields: effects on pineal function in the rat," *Bioelectromagnetics*, vol. 2, no. 4, pp. 371–380, 1981.

[56] B. W. Wilson, E. K. Chess, and L. E. Anderson, "60-Hz electric-field effects on pineal melatonin rhythms: time course for onset and recovery," *Bioelectromagnetics*, vol. 7, no. 2, pp. 239–242, 1986.

[57] R. J. Reiter, L. E. Anderson, R. L. Buschbom, and B. W. Wilson, "Reduction of the nocturnal rise in pineal melatonin levels in rats exposed to 60-Hz electric fields in utero and for 23 days after birth," *Life Sciences*, vol. 42, no. 22, pp. 2203–2206, 1988.

[58] M. Kato, K. Honma, T. Shigemitsu, and Y. Shiga, "Effects of exposure to a circularly polarized 50-Hz magnetic field on plasma and pineal melatonin levels in rats," *Bioelectromagnetics*, vol. 14, no. 2, pp. 97–106, 1993.

[59] M. Kato, K. Honma, T. Shigemitsu, and Y. Shiga, "Circularly polarized 50-Hz magnetic field exposure reduces pineal gland and blood melatonin concentrations of Long-Evans rats," *Neuroscience Letters*, vol. 166, no. 1, pp. 59–62, 1994.

[60] M. Kato, K. Honma, T. Shigemitsu, and Y. Shiga, "Recovery of nocturnal melatonin concentration takes place within one week following cessation of 50 Hz circularly polarized magnetic field exposure for six weeks.," *Bioelectromagnetics*, vol. 15, no. 5, pp. 489–492, 1994.

[61] B. Selmaoui and Y. Touitou, "Sinusoidal 50-Hz magnetic fields depress rat pineal nat activity and serum melatonin: role of duration and intensity of exposure," *Life Sciences*, vol. 57, no. 14, pp. 1351–1358, 1995.

[62] B. Selmaoui and Y. Touitou, "Age-related differences in serum melatonin and pineal NAT activity and in the response of rat pineal to a 50-Hz magnetic field," *Life Sciences*, vol. 64, no. 24, pp. 2291–2297, 1999.

[63] M. Mevissen, A. Lerchl, and W. Löscher, "Study on pineal function and DMBA-induced breast cancer formation in rats during exposure to a 100-MG, 50-HZ magnetic field," *Journal of Toxicology and Environmental Health A*, vol. 48, no. 2, pp. 169–185, 1996.

[64] S. M. Yellon and L. Gottfried, "An acute 60 Hz exposure suppresses the nighttime melatonin rhythm in the adult Djungarian hamster in short days," in *Annual Review of Research on Biological Effects of Electric and Magnetic Fields from the Generation, Delivery and Use of Electricity*, US Department of Energy: A-22, San Diego, Calif, USA, 1992.

[65] S. M. Yellon, "Acute 60 Hz magnetic field exposure effects on the melatonin rhythm in the pineal gland and circulation of the adult *Djungarian hamster*," *Journal of Pineal Research*, vol. 16, no. 3, pp. 136–144, 1994.

[66] J. Bakos, N. Nagy, G. Thuróczy, and L. D. Szabó, "Urinary 6-sulphatoxymelatonin excretion is increased in rats after 24 hours of exposure to vertical 50 Hz, 100 μT magnetic field," *Bioelectromagnetics*, vol. 18, no. 2, pp. 190–192, 1997.

[67] J. Dyche, A. M. Anch, K. A. J. Fogler, D. W. Barnett, and C. Thomas, "Effects of power frequency electromagnetic fields on melatonin and sleep in the rat," *Emerging Health Threats Journal*, vol. 5, no. 1, Article ID 10904, 2012.

[68] M. Niehaus, H. Brüggemeyer, H. M. Behre, and A. Lerchl, "Growth retardation, testicular stimulation, and increased melatonin synthesis by weak magnetic fields (50 Hz) in Djungarian hamsters, *Phodopus sungorus*," *Biochemical and Biophysical Research Communications*, vol. 234, no. 3, pp. 707–711, 1997.

[69] M. Kato, K. Honma, T. Shigemitsu, and Y. Shiga, "Horizontal or vertical 50-Hz, 1-μT magnetic fields have no effect on pineal gland or plasma melatonin concentration of albino rats," *Neuroscience Letters*, vol. 168, no. 1-2, pp. 205–208, 1994.

[70] J. Bakos, N. Nagy, G. Thuróczy, and L. D. Szabó, "Sinusoidal 50 Hz, 500 microT magnetic field has no acute effect on urinary 6-sulphatoxymelatonin in Wistar rats," *Bioelectromagnetics*, vol. 16, no. 6, pp. 377–380, 1995.

[71] J. Bakos, N. Nagy, G. Thuróczy, and L. D. Szabó, "One week of exposure to 50 Hz, vertical magnetic field does not reduce urinary 6-sulphatoxymelatonin excretion of male wistar rats," *Bioelectromagnetics*, vol. 23, no. 3, pp. 245–248, 2002.

[72] M. Fedrowitz, J. Westermann, and W. Löscher, "Magnetic field exposure increases cell proliferation but does not affect melatonin levels in the mammary gland of female sprague Dawley rats," *Cancer Research*, vol. 62, no. 5, pp. 1356–1363, 2002.

[73] T. M. John, G. Y. Liu, and G. M. Brown, "60 Hz magnetic field exposure and urinary 6-sulphatoxymelatonin levels in the rat," *Bioelectromagnetics*, vol. 19, no. 3, pp. 172–180, 1998.

[74] M. Mevissen, A. Lerchl, M. Szamel, and W. Löscher, "Exposure of DMBA-treated female rats in a 50-Hz, 50 μTesla magnetic field: effects on mammary tumor growth, melatonin levels, and T lymphocyte activation," *Carcinogenesis*, vol. 17, no. 5, pp. 903–910, 1996.

[75] H. Truong, J. C. Smith, and S. M. Yellon, "Photoperiod control of the melatonin rhythm and reproductive maturation in the juvenile Djungarian hamster: 60-Hz magnetic field exposure effects," *Biology of Reproduction*, vol. 55, no. 2, pp. 455–460, 1996.

[76] S. M. Yellon, "60-Hz magnetic field exposure effects on the melatonin rhythm and photoperiod control of reproduction," *American Journal of Physiology: Endocrinology and Metabolism*, vol. 270, no. 5, part 1, pp. E816–E821, 1996.

[77] S. M. Yellon and H. N. Truong, "Melatonin rhythm onset in the adult Siberian hamster: influence of photoperiod but not 60-Hz magnetic field exposure on melatonin content in the pineal gland and in circulation," *Journal of Biological Rhythms*, vol. 13, no. 1, pp. 52–59, 1998.

[78] L. de Bruyn, L. de Jager, and J. M. Kuyl, "The influence of long-term exposure of mice to randomly varied power frequency magnetic fields on their nocturnal melatonin secretion patterns," *Environmental Research*, vol. 85, no. 2, pp. 115–121, 2001.

[79] L. J. Grota, R. J. Reiter, P. Keng, and S. Michaelson, "Electric field exposure alters serum melatonin but not pineal melatonin synthesis in male rats," *Bioelectromagnetics*, vol. 15, no. 5, pp. 427–437, 1994.

[80] T. Kumlin, P. Heikkinen, J. T. Laitinen, and J. Juutilainen, "Exposure to a 50-Hz magnetic field induces a circadian rhythm in 6-hydroxymelatonin sulfate excretion in mice," *Journal of Radiation Research*, vol. 46, no. 3, pp. 313–318, 2005.

[81] K. K. Kesari, S. Kumar, and J. Behari, "900-MHz microwave radiation promotes oxidation in rat brain," *Electromagnetic Biology and Medicine*, vol. 30, no. 4, pp. 219–234, 2011.

[82] F. Qin, J. Zhang, H. Cao et al., "Effects of 1800-MHz radiofrequency fields on circadian rhythm of plasma melatonin and testosterone in male rats," *Journal of Toxicology and Environmental Health A*, vol. 75, no. 18, pp. 1120–1128, 2012.

[83] A. Koyu, F. Ozguner, G. Cesur et al., "No effects of 900 MHz and 1800 MHz electromagnetic field emitted from cellular phone on nocturnal serum melatonin levels in rats," *Toxicology and Industrial Health*, vol. 21, no. 1-2, pp. 27–31, 2005.

[84] A. Lerchl, H. Krüger, M. Niehaus, J. R. Streckert, A. K. Bitz, and V. Hansen, "Effects of mobile phone electromagnetic fields at nonthermal SAR values on melatonin and body weight of Djungarian hamsters (*Phodopus sungorus*)," *Journal of Pineal Research*, vol. 44, no. 3, pp. 267–272, 2008.

[85] R. J. Reiter, D. X. Tan, B. Poeggeler, and R. Kavet, "Inconsistent suppression of nocturnal pineal melatonin synthesis and serum melatonin levels in rats exposed to pulsed DC magnetic fields," *Bioelectromagnetics*, vol. 19, no. 5, pp. 318–329, 1998.

[86] J. F. Burchard, D. H. Nguyen, and E. Block, "Effects of electric and magnetic fields on nocturnal melatonin concentrations in dairy cows," *Journal of Dairy Science*, vol. 81, no. 3, pp. 722–727, 1998.

[87] J. F. Burchard, D. H. Nguyen, and H. G. Monardes, "Exposure of pregnant dairy heifer to magnetic fields at 60 Hz and 30 μT," *Bioelectromagnetics*, vol. 28, no. 6, pp. 471–476, 2007.

[88] M. Rodriguez, D. Petitclerc, J. F. Burchard, D. H. Nguyen, and E. Block, "Blood melatonin and prolactin concentrations in dairy cows exposed to 60 Hz electric and magnetic fields during 8 h photoperiods," *Bioelectromagnetics*, vol. 25, no. 7, pp. 508–515, 2004.

[89] J. M. Lee Jr., F. Stormshak, J. M. Thompson et al., "Melatonin secretion and puberty in female lambs exposed to environmental electric and magnetic fields," *Biology of Reproduction*, vol. 49, no. 4, pp. 857–864, 1993.

[90] J. M. Lee Jr., F. Stormshak, J. M. Thompson, D. L. Hess, and D. L. Foster, "Melatonin and puberty in female lambs exposed to EMF: a replicate study," *Bioelectromagnetics*, vol. 16, no. 2, pp. 119–123, 1995.

[91] K. J. Fernie, D. M. Bird, and D. Petitclerc, "Effects of electromagnetic fields on photophasic circulating melatonin levels in American kestrels," *Environmental Health Perspectives*, vol. 107, no. 11, pp. 901–904, 1999.

[92] A. Lerchl, A. Zachmann, M. A. Ali, and R. J. Reiter, "The effects of pulsing magnetic fields on pineal melatonin synthesis in a teleost fish (brook trout, *Salvelinus fontinalis*)," *Neuroscience Letters*, vol. 256, no. 3, pp. 171–173, 1998.

[93] W. R. Rogers, R. J. Reiter, L. Barlow-Walden, H. D. Smith, and J. L. Orr, "Regularly scheduled, day-time, slow-onset 60 Hz electric and magnetic field exposure does not depress serum melatonin concentration in nonhuman primates.," *Bioelectromagnetics*, vol. 3, pp. 111–118, 1995.

[94] W. R. Rogers, R. J. Reiter, H. D. Smith, and L. Barlow-Walden, "Rapid-onset/offset, variably scheduled 60 Hz electric and magnetic field exposure reduces nocturnal serum melatonin concentration in nonhuman primates," *Bioelectromagnetics*, supplement 3, pp. 119–122, 1995.

[95] H. Brendel, M. Niehaus, and A. Lerchl, "Direct suppressive effects of weak magnetic fields (50 Hz and 162/3 Hz) on melatonin synthesis in the pineal gland of *Djungarian hamsters* (*Phodopus sungorus*)," *Journal of Pineal Research*, vol. 29, no. 4, pp. 228–233, 2000.

[96] B. A. Richardson, K. Yaga, R. J. Reiter, and D. J. Morton, "Pulsed static magnetic field effects on in-vitro pineal indoleamine metabolism," *Biochimica et Biophysica Acta: Molecular Cell Research*, vol. 1137, no. 1, pp. 59–64, 1992.

[97] L. A. Rosen, I. Barber, and D. B. Lyle, "A 0.5 G, 60 Hz magnetic field suppresses melatonin production in pinealocytes," *Bioelectromagnetics*, vol. 19, no. 2, pp. 123–127, 1998.

[98] H. Lewy, O. Massot, and Y. Touitou, "Magnetic field (50 Hz) increases N-acetyltransferase, hydroxy-indole-O-methyltransferase activity and melatonin release through an indirect pathway," *International Journal of Radiation Biology*, vol. 79, no. 6, pp. 431–435, 2003.

[99] H. M. Tripp, G. R. Warman, and J. Arendt, "Circularly polarised MF (500 micro T 50 Hz) does not acutely suppress melatonin secretion from cultured Wistar rat pineal glands," *Bioelectromagnetics*, vol. 24, no. 2, pp. 118–124, 2003.

[100] I. Sukhotina, J. R. Streckert, A. K. Bitz, V. W. Hansen, and A. Lerchl, “1800 MHz electromagnetic field effects on melatonin release from isolated pineal glands,” *Journal of Pineal Research*, vol. 40, no. 1, pp. 86–91, 2006.

[101] C. E. Minder and D. H. Pfluger, “Leukemia, brain tumors, and exposure to extremely low frequency electromagnetic fields in Swiss railway employees,” *American Journal of Epidemiology*, vol. 153, no. 9, pp. 825–835, 2001.

[102] M. Röösli, M. Lörtscher, M. Egger et al., “Mortality from neurodegenerative disease and exposure to extremely low-frequency magnetic fields: 31 years of observations on Swiss railway employees,” *Neuroepidemiology*, vol. 28, no. 4, pp. 197–206, 2007.

[103] C. V. Bellieni, M. Tei, F. Iacoponi et al., “Is newborn melatonin production influenced by magnetic fields produced by incubators?” *Early Human Development*, vol. 88, no. 8, pp. 707–710, 2012.

[104] J. R. Ingram, J. N. Crockford, and L. R. Matthews, “Ultradian, circadian and seasonal rhythms in cortisol secretion and adrenal responsiveness to ACTH and yarding in unrestrained red deer (*Cervus elaphus*),” *Journal of Endocrinology*, vol. 162, no. 2, pp. 289–300, 1999.

[105] M. Debono, C. Ghobadi, A. Rostami-Hodjegan et al., “Modified-release hydrocortisone to provide circadian cortisol profiles,” *Journal of Clinical Endocrinology and Metabolism*, vol. 94, no. 5, pp. 1548–1554, 2009.

[106] E. D. Weitzman, D. Fukushima, C. Nogeire, H. Roffwarg, T. F. Gallagher, and L. Hellman, “Twenty-four hour pattern of the episodic secretion of cortisol in normal subjects,” *Journal of Clinical Endocrinology and Metabolism*, vol. 33, no. 1, pp. 14–22, 1971.

[107] B. Selmaoui and Y. Touitou, “Reproducibility of the circadian rhythms of serum cortisol and melatonin in healthy subjects: a study of three different 24-h cycles over six weeks,” *Life Sciences*, vol. 73, no. 26, pp. 3339–3349, 2003.

[108] K. Raspopow, A. Abizaid, K. Matheson, and H. Anisman, “Anticipation of a psychosocial stressor differentially influences ghrelin, cortisol and food intake among emotional and non-emotional eaters,” *Appetite*, vol. 74, pp. 35–43, 2014.

[109] M. S. Rea, M. G. Figueiro, K. M. Sharkey, and M. A. Carskadon, “Relationship of morning cortisol to circadian phase and rising time in young adults with delayed sleep times,” *International Journal of Endocrinology*, vol. 2012, Article ID 749460, 6 pages, 2012.

[110] R. H. Straub, “Interaction of the endocrine system with inflammation: a function of energy and volume regulation,” *Arthritis Research and Therapy*, vol. 16, no. 1, p. 203, 2014.

[111] S. Chan and M. Debono, “Replication of cortisol circadian rhythm: new advances in hydrocortisone replacement therapy,” *Therapeutic Advances in Endocrinology and Metabolism*, vol. 1, no. 3, pp. 129–138, 2010.

[112] H. Raff and H. Trivedi, “Circadian rhythm of salivary cortisol, plasma cortisol, and plasma ACTH in end-stage renal disease,” *Endocrine Connections*, vol. 2, no. 1, pp. 23–31, 2012.

[113] B. A. Corbett, S. Mendoza, M. Abdullah, J. A. Wegelin, and S. Levine, “Cortisol circadian rhythms and response to stress in children with autism,” *Psychoneuroendocrinology*, vol. 31, no. 1, pp. 59–68, 2006.

[114] S. Zare, H. Hayatgeibi, S. Alivandi, and A. G. Ebadi, “Effects of whole-body magnetic field on changes of glucose and cortisol hormone in quinea pigs,” *The American Journal of Biochemistry and Biotechnology*, vol. 1, no. 4, pp. 209–211, 2005.

[115] L. Bonhomme-Faivre, A. Macé, Y. Bezie et al., “Alterations of biological parameters in mice chronically exposed to low- frequency (50 Hz) electromagnetic fields,” *Life Sciences*, vol. 62, no. 14, pp. 1271–1280, 1998.

[116] E. Gorczynska and R. Wegrzynowicz, “Glucose homeostasis in rats exposed to magnetic fields,” *Investigative Radiology*, vol. 26, no. 12, pp. 1095–1100, 1991.

[117] R. Seyednour and V. Chekaniazar, “Effects of exposure to cellular phones 950 mhz electromagnetic fields on progesterone, cortisol and glucose level in female hamsters (*Mesocricetus auratus*),” *Asian Journal of Animal and Veterinary Advances*, vol. 6, no. 11, pp. 1084–1088, 2011.

[118] J. F. Burchard, D. H. Nguyen, L. Richard, and E. Block, “Biological effects of electric and magnetic fields on productivity of dairy cows,” *Journal of Dairy Science*, vol. 79, no. 9, pp. 1549–1554, 1996.

[119] J. M. Thompson, F. Stormshak, J. M. Lee Jr., D. L. Hess, and L. Painter, “Cortisol secretion and growth in ewe lambs chronically exposed to electric and magnetic fields of a 60-Hertz 500-kilovolt AC transmission line,” *Journal of Animal Science*, vol. 73, no. 11, pp. 3274–3280, 1995.

[120] R. Szemerszky, D. Zelena, I. Barna, and G. Bárdos, “Stress-related endocrinological and psychopathological effects of short- and long-term 50 Hz electromagnetic field exposure in rats,” *Brain Research Bulletin*, vol. 81, no. 1, pp. 92–99, 2010.

[121] J. Martínez-Sámano, P. V. Torres-Durán, M. A. Juárez-Oropeza, and L. Verdugo-Díaz, “Effect of acute extremely low frequency electromagnetic field exposure on the antioxidant status and lipid levels in rat brain,” *Archives of Medical Research*, vol. 43, no. 3, pp. 183–189, 2012.

[122] A. Shrivastava, K. K. Mahajan, V. Karla, and K. S. Negi, “Effects of electromagnetic forces of Earth on human biological system,” *Indian Journal of Preventive and Social Medicine*, vol. 40, no. 3, pp. 162–167, 2009.

[123] S. M. J. Mortazavi, S. Vazife-Doost, M. Yaghooti, S. Mehdizadeh, and A. Rajaie-Far, “Occupational exposure of dentists to electromagnetic fields produced by magnetostrictive cavitrons alters the serum cortisol level,” *Journal of Natural Science, Biology and Medicine*, vol. 3, no. 1, pp. 60–64, 2012.

[124] M. Woldańska-Okońska, J. Czernicki, and M. Karasek, “The influence of the low-frequency magnetic fields of different parameters on the secretion of cortisol in men,” *International Journal of Occupational Medicine and Environmental Health*, vol. 26, no. 1, pp. 92–101, 2013.

[125] C. M. Maresh, M. R. Cook, H. D. Cohen, C. Graham, and W. S. Gunn, “Exercise testing in the evaluation of human responses to powerline frequency fields,” *Aviation Space and Environmental Medicine*, vol. 59, no. 12, pp. 1139–1145, 1988.

[126] B. Selmaoui, J. Lambrozo, and Y. Touitou, “Endocrine functions in young men exposed for one night to a 50-Hz magnetic field. A circadian study of pituitary, thyroid and adrenocortial hormones,” *Life Sciences*, vol. 61, no. 5, pp. 473–486, 1997.

[127] K. Radon, D. Parera, D.-M. Rose, D. Jung, and L. Vollrath, “No effects of pulsed radio frequency electromagnetic fields on melatonin, cortisol, and selected markers of the immune system in man,” *Bioelectromagnetics*, vol. 22, no. 4, pp. 280–287, 2001.

[128] S. P. Loughran, A. W. Wood, J. M. Barton, R. J. Croft, B. Thompson, and C. Stough, “The effect of electromagnetic fields

emitted by mobile phones on human sleep," *NeuroReport*, vol. 16, no. 17, pp. 1973–1976, 2005.

[129] M. R. Schmid, M. Murbach, C. Lustenberger et al., "Sleep EEG alterations: effects of pulsed magnetic fields versus pulse-modulated radio frequency electromagnetic fields," *Journal of Sleep Research*, vol. 21, no. 6, pp. 620–629, 2012.

[130] S. J. Regel, G. Tinguely, J. Schuderer et al., "Pulsed radio-frequency electromagnetic fields: dose-dependent effects on sleep, the sleep EEG and cognitive performance," *Journal of Sleep Research*, vol. 16, no. 3, pp. 253–258, 2007.

[131] K. Mann and J. Röschke, "Sleep under exposure to high-frequency electromagnetic fields," *Sleep Medicine Reviews*, vol. 8, no. 2, pp. 95–107, 2004.

[132] A. A. Borbély, R. Huber, T. Graf, B. Fuchs, E. Gallmann, and P. Achermann, "Pulsed high-frequency electromagnetic field affects human sleep and sleep electroencephalogram," *Neuroscience Letters*, vol. 275, no. 3, pp. 207–210, 1999.

[133] R. Huber, T. Graf, K. A. Cote et al., "Exposure to pulsed high-frequency electromagnetic field during waking affects human sleep EEG," *NeuroReport*, vol. 11, no. 15, pp. 3321–3325, 2000.

[134] K. Mann and J. Röschke, "Effects of pulsed high-frequency electromagnetic fields on human sleep," *Neuropsychobiology*, vol. 33, no. 1, pp. 41–47, 1996.

[135] G. Fritzer, R. Göder, L. Friege et al., "Effects of short- and long-term pulsed radiofrequency electromagnetic fields on night sleep and cognitive functions in healthy subjects," *Bioelectromagnetics*, vol. 28, no. 4, pp. 316–325, 2007.

[136] R. Huber, V. Treyer, A. A. Borbély et al., "Electromagnetic fields, such as those from mobile phones, alter regional cerebral blood flow and sleep and waking EEG," *Journal of Sleep Research*, vol. 11, no. 4, pp. 289–295, 2002.

[137] R. Huber, J. Schuderer, T. Graf et al., "Radio frequency electromagnetic field exposure in humans: Estimation of SAR distribution in the brain, effects on sleep and heart rate," *Bioelectromagnetics*, vol. 24, no. 4, pp. 262–276, 2003.

[138] R. Huber, V. Treyer, J. Schuderer et al., "Exposure to pulse-modulated radio frequency electromagnetic fields affects regional cerebral blood flow," *European Journal of Neuroscience*, vol. 21, no. 4, pp. 1000–1006, 2005.

[139] P. Wagner, J. Röschke, K. Mann, W. Hiller, and C. Frank, "Human sleep under the influence of pulsed radiofrequency electromagnetic fields: a polysomnographic study using standardized conditions," *Bioelectromagnetics*, vol. 19, no. 3, pp. 199–202, 1998.

[140] P. Wagner, J. Röschke, K. Mann et al., "Human sleep EEG under the influence of pulsed radio frequency electromagnetic fields: results from polysomnographies using submaximal high power flux densities," *Neuropsychobiology*, vol. 42, no. 4, pp. 207–212, 2000.

[141] K. Mann, J. Röschke, B. Connemann, and H. Beta, "No effects of pulsed high-frequency electromagnetic fields on heart rate variability during human sleep," *Neuropsychobiology*, vol. 38, no. 4, pp. 251–256, 1998.

[142] A. Lowden, T. Åkerstedt, M. Ingre et al., "Sleep after mobile phone exposure in subjects with mobile phone-related symptoms," *Bioelectromagnetics*, vol. 32, no. 1, pp. 4–14, 2011.

[143] T. Åkerstedt, B. Arnetz, G. Ficca, L. Paulsson, and A. Kallner, "A 50-Hz electromagnetic field impairs sleep," *Journal of Sleep Research*, vol. 8, no. 1, pp. 77–81, 1999.

[144] C. Graham, M. R. Cook, H. D. Cohen, D. W. Riffle, S. Hoffman, and M. M. Gerkovich, "Human exposure to 60-Hz magnetic fields: neurophysiological effects," *International Journal of Psychophysiology*, vol. 33, no. 2, pp. 169–175, 1999.

[145] H. Landolt, J. V. Rétey, K. Tönz et al., "Caffeine attenuates waking and sleep electroencephalographic markers of sleep homeostasis in humans," *Neuropsychopharmacology*, vol. 29, no. 10, pp. 1933–1939, 2004.

[146] L. Hillert, N. Berglind, B. B. Arnetz, and T. Bellander, "Prevalence of self-reported hypersensitivity to electric or magnetic fields in a population-based questionnaire survey," *Scandinavian Journal of Work, Environment and Health*, vol. 28, no. 1, pp. 33–41, 2002.

[147] M. Röösli, M. Moser, Y. Baldinini, M. Meier, and C. Braun-Fahrländer, "Symptoms of ill health ascribed to electromagnetic field exposure—a questionnaire survey," *International Journal of Hygiene and Environmental Health*, vol. 207, no. 2, pp. 141–150, 2004.

[148] R. G. Stevens, "Electric power use and breast cancer: a hypothesis," *American Journal of Epidemiology*, vol. 125, no. 4, pp. 556–561, 1987.

[149] S. Jarupat, A. Kawabata, H. Tokura, and A. Borkiewicz, "Effects of the 1900 MHz electromagnetic field emitted from cellular phone on nocturnal melatonin secretion," *Journal of Physiological Anthropology and Applied Human Science*, vol. 22, no. 1, pp. 61–63, 2003.

[150] R. de Seze, J. Ayoub, P. Peray, L. Miro, and Y. Touitou, "Evaluation in humans of the effects of radiocellular telephones on the circadian patterns of melatonin secretion, a chronobiological rhythm marker," *Journal of Pineal Research*, vol. 27, no. 4, pp. 237–242, 1999.

[151] A. Bortkiewicz, B. Pilacik, E. Gadzicka, and W. Szymczak, "The excretion of 6-hydroxymelatonin sulfate in healthy young men exposed to electromagnetic fields emitted by cellular phone: an experimental study," *Neuroendocrinology Letters*, vol. 23, supplement 1, pp. 88–91, 2002.

[152] G. R. Warman, H. M. Tripp, V. L. Warman, and J. Arendt, "Circadian neuroendocrine physiology and electromagnetic field studies: precautions and complexities," *Radiation Protection Dosimetry*, vol. 106, no. 4, pp. 369–373, 2003.

[153] D. D. Hauri, B. Spycher, A. Huss, F. Zimmermann, M. Grotzer, and N. von der Weid, "Exposure to radio-frequency electromagnetic fields from broadcast transmitters and risk of childhood cancer: a census-based cohort study," *American Journal of Epidemiology*, vol. 179, no. 7, pp. 843–851, 2014.

[154] M. Kabuto, H. Nitta, S. Yamamoto et al., "Childhood leukemia and magnetic fields in Japan: a case-control study of childhood leukemia and residential power-frequency magnetic fields in Japan," *International Journal of Cancer*, vol. 119, no. 3, pp. 643–650, 2006.

[155] L. Hardell and C. Sage, "Biological effects from electromagnetic field exposure and public exposure standards," *Biomedicine and Pharmacotherapy*, vol. 62, no. 2, pp. 104–109, 2008.

[156] B. Selmaoui, A. Bogdan, A. Auzeby, J. Lambrozo, and Y. Touitou, "Acute exposure to 50 Hz magnetic field does not affect hematologic or immunologic functions in healthy young men: a Circadian study," *Bioelectromagnetics*, vol. 17, no. 5, pp. 364–372, 1996.

[157] Y. Djeridane, Y. Touitou, and R. de Seze, "Influence of electromagnetic fields emitted by GSM-900 cellular telephones on the circadian patterns of gonadal, adrenal and pituitary hormones in men," *Radiation Research*, vol. 169, no. 3, pp. 337–343, 2008.

[158] Y. Touitou, A. Bogdan, J. Lambrozo, and B. Selmaoui, “Is melatonin the hormonal missing link between magnetic field effects and human diseases?” *Cancer Causes & Control*, vol. 17, no. 4, pp. 547–552, 2006.

[159] D. L. Henshaw and R. J. Reiter, “Do magnetic fields cause increased risk of childhood leukemia via melatonin disruption?” *Bioelectromagnetics*, vol. 26, supplement 7, pp. S86–S97, 2005.