Neuroendocrinology Letters ISSN 0172–780X

REVIEW ARTICLE

Melatonin And Magnetic Fields

Michal Karasek[1,2] & Alexander Lerchl[3]
1. Laboratory of Electron Microscopy, Chair of Pathomorphology, Medical University of Lodz
2. Clinic of Endocrinology, Polish Mother's Memorial Hospital – Research Institute, Lodz, Poland
3. School of Engineering and Science, International University of Bremen, Bremen FRG

Correspondence to:
Prof. Dr. Michal Karasek,
Laboratory of Electron Microscopy,
Chair of Pathomorphology,
Medical University of Lodz,
92-216 Lodz, Czechoslowacka 8/10, Poland
TEL/FAX: +48 42 675 7613
e-mail: karasek@csk.am.lodz.pl

Submitted: *October 5, 2001*
Accepted: *October 25, 2001*

Key words: **melatonin; pineal gland; magnetic fields**

*Neuroendocrinology Letters 2002; **23**(suppl 1):84–87 pii: NEL230702R11*

Abstract

There is public health concern raised by epidemiological studies indicating that extremely low frequency electric and magnetic fields generated by electric power distribution systems in the environment may be hazardous. Possible carcinogenic effects of magnetic field in combination with suggested oncostatic action of melatonin lead to the hypothesis that the primary effects of electric and magnetic fields exposure is a reduction of melatonin synthesis which, in turn, may promote cancer growth.

In this review the data on the influence of magnetic fields on melatonin synthesis, both in the animals and humans, are briefly presented and discussed.

Introduction

Extremely low frequency electric (ELF-EF) and magnetic fields (ELF-MF), e.g. generated by high-voltage transmission lines and household appliances, are present worldwide and receive increasing attention because of their potential consequences for human health [1-3], especially associated with increased risk for cancer and childhood leukemia [2]. Additionally some attention has also been paid to other possible health hazards, such as interference with cardiac pacemakers [4], Alzheimer's disease [5], and adverse pregnancy outcome [6]. Working Group organized by National Institute of Environmental Health Services concluded in the report published in 1998, on the basis of almost 900 publications, that "ELF-EMF are possibly carcinogenic to humans". This conclusion is based on limited evidence that residential exposure to ELF-MF is carcinogenic to children it terms of childhood leukemia, and occupational exposure to ELF-MF is carcinogenic to humans in terms of chronic lymphocytic leukemia [4]. It has been also concluded that there is inadequate evidence for an association between occupational exposure to EFL-MF and risk for other cancer [4]. Moreover, the same report states: "None of the evidence for adverse health effects seen after exposure to ELF EMF achieved a degree of evidence exceeding 'inadequate' (for humans) or 'weak" (for experimental animals)" [3]. In humans it concerns adverse birth outcomes, reproductive effects, Alzheimer's disease, amyotrophic lateral sclerosis, suicide or depression, cardiovascular disease [3].

Possible carcinogenic effects of EMF in combination with suggested oncostatic action of melatonin [see 7, 8] lead to the hypothesis that the primary effects of EMF exposure is a reduction of melatonin synthesis which, in turn, may promote cancer growth [9].

In this review the data on the influence of EMF on melatonin synthesis, both in the animals and humans, are briefly presented and discussed.

Animal studies

There is substantial evidence that exposure to ELF-MF may alter melatonin secretion in animals. The results of the studies on the influence of ELF-MF on melatonin concentrations in the animals are presented in Table 1.

It can be seen that in majority of studies ELF-MF decreased melatonin secretion, especially in rats and hamsters. However, large variations exist when studies are repeated [34, 35, 39]. Among other explanations [48], one reason may be the age of the animals since young rats seem to be more sensitive against magnetic fields than old ones [49]. Recently, an investigation on isolated hamster pineal organs has shown variable results when the experiments were repeated under identical conditions at 16 2/3 and 50 Hz. However, exposure was found to suppress melatonin synthesis highly significantly when the results were pooled [42].

Human studies

In contrast to animal studies, the data on the influence of magnetic fields on human melatonin concentrations are scarce and contradictory. Conversely to the animal studies, although ELF-MF-induced suppression on nocturnal melatonin secretion in humans has been reported in occupational and residential studies [50-55] in the majority of laboratory-based exposure studies ELF-MF no change in melatonin or 6-hydroxymelatonin concentrations has been observed (Table 2).

It should be stressed that various parameters of magnetic fields have been employed in the experiments. Therefore, discrepancies in the results may depend on different experimental paradigms, including differences in certain characteristics of the applied magnetic fields, such as field intensity, frequency, duration of exposure, timing of exposure, applied vector, etc. The results of our studies seem to support the hypothesis that the response of the human pineal to magnetic fields may depend on the field parameters because chronic exposure to 2.9 mT, 40 Hz magnetic field caused a significant decrease in nocturnal melatonin concentrations [63], whereas chronic exposure to 25-80 μT, 200 Hz mag-

Table 1. Effects of magnetic fields on melatonin concentrations in the animals

Exposure parameters	Exposure duration	Effect	[Ref.]
Rat			
52–123 μT	15 min 5 h 24 h	⬇ (p) ⊗ (p) ⬇ (p) ⬇ (s) ⊗ (p)	[10]
50 μT	2 h	⬇ (p)	[11]
50–100 μT	30 min 30 min	⬇ (p) – sighted ⊗ (p) – blind	[12]
35 μT	30 min	⬇ (p)	[13]
2.5 μT	30 min	⊗ (p)	[14]
30 μT	30 min	⬇ (p)	[15]
40 μT	60 min	⊗ (p, s)	[16]
80 μT (inter, auto) 80 μT (inter, man)	60 min	⬇ (p) ⊗ (p)	[17]
44 μT, 33.7 Hz	2.5 h (*in vitro*)	⬇ (p, m)	[18]
5.2 mT, 50 Hz	30 min for 15 days	⬇ (s)	[19]
44 μT (inter)	60 min (*in vitro*)	⬇ (p) ⊗ (m)	[20]
1, 5, 50, 250 μT, 50 Hz (CP)	6 weeks	⬇ (p, pl)	[21]
44 μT (inter, man, not inverted) 44 μT (inter, man, inverted)	30 min, 60 min 30 min, 60 min	⊗ (p) ⬇ (p)	[22]
0.03 mT, 10 Hz	10–30 min	⊗ (s, night) ⬇ (s, day)	[23]
25 μT (pulsed, static)	45 min	⬇ (p) – nighttime exposure ⊗ (p) – daytime exposure	[24]
1 μT, 50 Hz (CP)	6 weeks	⬇ (p)	[25]
1 μT, 50 Hz (HP) 1 μT, 50 Hz (VP)	6 weeks	⊗ (p, pl) ⊗ (p, pl)	[26]
0.3–1 μT, 50 Hz	8–9 weeks	⬇ (s)	[27]
100 μT, 50 Hz 10–100 μT, 50 Hz	12 h 18 h for 30 days	⬇ (s)	[28]
5, 500 μT, 50 Hz	24 h	⊗ (u)	[29]
50 μT, 50 Hz	9 or 12 weeks	⊗ (s)	[30]
10 μT, 50 Hz	91 days	⊗ (p) ⬇ (s)	[31]
1, 100 μT, 50 Hz	24 h	⬆ (u)	[32]
900 MHz (continuous or pulsed with 217 Hz)	15 to 60 min	⊗ (s)	[33]
100 μT, 50 Hz	1 day to 13 weeks	inconsistent	[34]
50 to 500 μT (majority 100 μT)	15 to 120 min (15 experiments)	inconsistent	[35]
0.06 μT, 0.05 mT	12 h (*in vitro*)	⬇ (46%)	[36]
1 mT, 60 Hz (inter) 1 mT, 60 Hz	1 h 20 h for 10 or 42 days	⊗ (u) ⊗ (u)	[37]
Golden hamster			
35 μT	30 min	⊗ (p)	[13]
Djungarian hamster			
100 μT, 60 Hz	15 min	⬇ (p, s)	[38]
100 μT, 60 Hz	Exp. 1–15 min for 9 days (lp) Exp. 1–15 min for 9 days (sp) Exp. 2–15 min for 9 days (lp) Exp. 2–15 min for 9 days (sp)	⬇ (p, s) ⬆ (p) ⬇ (s) ⊗ (p, s) ⊗ (p, s)	[39]
10, 100 μT, 60 Hz 10, 100 μT, 60 Hz (inter)	15 min, 60 min	⊗ (p, s)	[40]
900 MHz (continuous or pulsed with 217 Hz)	15 min to 60 min	⊗ (s)	[33]
300 μT, 50 Hz	24 h for 56 days	⊗ (s)	[41]
86 μT, $16^{2/3}$ Hz or 50 Hz	8 h (*in vitro*)	⬇ (m)	[42]
Gerbil			
30 μT	30 min	⊗ (p) – pigmented ⬇ (p, female) ⊗ (p, male) – albino	[15]
Mouse			
0.5–77 (average 2.75) μT, 50 Hz	2 to 4 months (from conception)	(pl)	[43]
Sheep			
4 μT, 60 Hz	24 h for 8 months	⊗ (s)	[44]
3.77 μT, 60 Hz	24 h for 8 months	⊗ (s)	[45]
Baboon			
50, 100 μT, 60 Hz (irregular, slow onset/offset)	12 h for 6 weeks	⊗ (s)	[46]
50, 100 μT, 60 Hz (irregular, rapid onset/offset)	9 or 21 days	⬇ (p)	[47]

⬇– inhibition; ⬆– stimulation; ⊗ – no effect; p – pineal, s – serum, pl – plasma, u – urinary 6–hydroxymelatonin sulfate, m – culture medium; inter – intermittent exposure, auto – automatic switching, man – manual switching; CP – circular polarity, HP – horizontal polarity, VP – vertical polarity; Exp. – experiment; lp – long photoperiod, sp – short photoperiod.

netic field did not influence melatonin levels [64].

Concluding remarks

Summarizing, it seems that there is substantial evidence that exposure to ELF-MF decreases melatonin secretion in some animals. However, presently there are no convincing data showing a distinct effect of magnetic fields on melatonin secretion in humans, and more studies are needed to identify the specific circumstances under which such effects may occur.

Acknowledgements

This paper was supported by Medical University of Lodz (503-129-0)

Table 2. Effects of magnetic fields on serum (SE), plasma (PL), salivary (SA) and urinary (U) melatonin concentrations or 6-hydroxymelatonin sulfate (6-OHMS) urinary concentrations in humans

Exposure parameters	Exposure duration	Outcome	[Ref.]
150 mT (MRI)	40.5 min	no effect (SE)	[56]
0.057 µT, 60 Hz 0.66 µT, 60 Hz 0.46 µT, 60 Hz	4 weeks 4 weeks 7 weeks	no effect (6-OHMS)	[57]
1.5 T (MRI)	60 min	no effect (PL)	[58]
10 µT, 50 Hz 10 µT, 50 Hz	9 h (continuous) 9 h (intermittent)	no effect (SE, 6-OHMS)	[59]
1 µT, 60 Hz 20 µT, 60 Hz	8 h (intermittent) 8 h (continuous)	no effect (PL) (reduction in men with low baseline melatonin)	[60]
20 µT, 50 Hz	8 h (continuous)	no effect (PL)	[61]
20 µT, 50 Hz	1.5 to 4 h	no effect (PL) (delayed rise)	[62]
2.9 mT, 40 Hz	3 weeks (20 min per day, 5 days a weeks)	decrease (SE)	[63]
25–80 µT, 200 Hz	3 weeks (16 min per day, 5 days per weeks)	no effect (SE)	[64]
2–7 mT	9 h	no effect (6-OHMS)	[65]
28.3 µT, 60 Hz	8 h	no effect (U, 6-OHMS)	[66]
100 µT, 50 Hz continuous or intermittent	30 min	no effect (PL, 6-OHMS)	[67]
0.7–9.1 µT, 50 Hz	overnight for 11 weeks	no effect (6-OHMS)	[68]
GSM-standard: 900 MHz, pulsed with 217 Hz, pulse width of 577 µs	8 h	no effect (SE)	[69]
GSM-standard: 900 MHz, pulsed with 217 Hz, pulse width of 576 µs	4 weeks (2 h per day, 5 days a week)	no effect (SE)	[70]
DCS-standard: 1800 MHz, pulsed with 217 Hz, pulse width of 576 µs	4 weeks (2 h per day, 5 days a week)	no effect (SE)	[70]
GSM-standard: 900 MHz, pulsed with 217 Hz, pulse width of 577 µs	20 randomly allotted 4 h sessions	no effect (SA)	[71]
GSM-standard: 900 MHz, pulsed with 217 Hz, pulse width of 576 µs	60 min	no effect (6-OHMS)	[72]

REFERENCES

1 Repacholi MH, Greenebaum B. Interaction of static and extremely low frequency electric and magnetic fields with living systems: health effects and research needs. Bioelectromagnetics 1999; **20**:133-60.
2 Moulder JE. Power-frequency fields and cancer. Critical Rev Biomed Engineering 1998; **26**:1-116.
3 Portier CJ, Wolfe MS (editors). Assessment of health effects from exposure to power-line frequency electric and magnetic fields. Working group report. NIEHS, Research Triangle Park, 1998.
4 Hayes DL, Vlietstra RE. Pacemaker malfunction. Ann Intern Med 1993; **119**:828-35.
5 Sobel E, Dunn M, Davanipour Z, Qian Z, Chui H. Elevated risk of Alzheimer's disease among workers with likely electromagnetic exposure. Neurology 1996; **47**:1477-81.
6 Robert E. Teratogen update: electromagnetic fields. Teratology, 1996; **54**:305-31.
7 Pawlikowski M, Winczyk K, Karasek M. Oncostatic action of melatonin: facts and question marks. Neuroendocrinol Lett, 2002; **23** (suppl 1):24–29.
8 Bartsch H, Bartsch C, Karasek M. Melatonin in clinical oncology. Neuroendocrinol Lett, 2002; **23**(suppl 1):30–38.
9 Stevens RG, Davis S. The melatonin hypothesis: electric power and breast cancer. Environ Health Perspect 1996; **104**(suppl 1):135-40.
10 Welker HA, Semm P, Willig RP, Commentz JC, Wiltschko W, Vollrath L. Effects of an artificial magnetic field on serotonin N-acetyltransferase activity and melatonin content in the rat pineal gland. Exp Brain Res 1983; **50**:426-32.
11 Semm P. Neurobiological investigations on the magnetic sensitivity of the pineal gland of rodents and pigeons. Comp Biochem Physion [A] 1983; **76A**:683-9.
12 Olcese J, Reuss S, Volltath L. Evidence for the involvement of the visual system mediating magnetic field effects on pineal melatoninsynthesis in the rat. Brain Res 1985; **333**:382-4.
13 Olcese J, Reuss S. Magnetic field effects on pineal gland melatonin synthesis: comparative studies on albino rat and pigmented rodents. Brain Res 1986; **369**:365-8.
14 Khoory R. Compensation of the natural magnetic field does not alter N-acetyltransferase activity and melatonin content of rat pineal gland. Neurosci Lett 1987; **76**:215-20.
15 Stehle J, Reuss S, Schroder H, Herschel M, Vollrath L. Magnetic field effects on pineal N-acetyltransferase activity and melatonin content in the gerbil – role of pigmentation and sex. Physiol Behav 1988; **44**:91-4.
16 Lerchl A, Nonaka KO, Stokkan KA, Reiter RJ. Marked rapid alteration in nocturnal pineal serotonin metabolism in mice and rats exposed to weak intermittent magnetic fields. Biochem Biophys Res Commun 1990; **169**:102-8.
17 Lerchl A, Nonaka KO, Reiter RJ. Pineal gland 'magnetosensitivity' to static magnetic fields is a consequence of induced electric currents (eddy currents). J Pineal Rea 1991; **10**:109-16.
18 Lerchl A, Reiter RJ, Howes KA, Nonaka KO, Stokkan KA. Evidence that low frequency Ca^{2+}-cyclotron resonance depresses pineal melatonin synthesis in vitro. Neurosci Res 1991; **124**:213-5.
19 Martinez Soriano F, Gimenez Gonzales M, Armanazas E, Riuz Turner A. Pineal 'synaptic ribbons' and serum melatonin levels in the rat following the pulse action of 52-Gs (50 Hz) magnetic fields: an evaluative analysis over 21 days. Acta Anat 1992; **143**:289-93.
20 Richardson BA, Yaga K, Reiter RJ, Morton DJ. Pulsed static magnetic field effects on in vitro pineal indoleamine metabolism. Biochim Biophys Acta 1992; **1137**:59-64.
21 Kato M, Honma K, Shigemitsu T, Shiga Y. Effects of exposure to a circularly polarized 50-Hz magnetic field on plasma and pineal melatonin levels in rats. Bioelectromagnetics 1993; **14**:97-106.
22 Richardson BA, Yaga K, Reiter RJ, Hoover P. Suppression of nocturnal pineal N-acetyltransferase activity and melatonin content by inverted magnetic fields and induced eddy currents. Int J Neurosci 1993; **69**:149-55.
23 Jentsch A, Lehmann M, Schöne E, Thoss F, Zimmermann G. Weak magnetic fields change extinction of a conditional reaction and daytime melatonin levels in the rat. Neurisci Lett 1993; **157**:79-82.
24 Yaga K, Reiter RJ, Manchester LC, Nieves H, Sun JH, Chen LD. Pineal sensitivity to pulsed static magnetic field changes during the photoperiod. Brain Res Bull 1993; **30**:153-6.
25 Kato M, Honma K, Shigemitsu T, Shiga Y. Circularly polarized 50 Hz magnetic field exposure reduces pineal gland and blood melatonin concentrations of Long-Evans rats. Neurosci Lett 1994; **166**:59-62.
26 Kato M, Honma K, Shigemitsu T, Shiga Y. Horizontal or vertical 50-Hz, 1-micro T magnetic fields have no effect on pineal gland or plasma melatonin concentration of albino rat. Neurosci Lett 1994; **168**:201-8.

27 Löscher W, Wahnschaffe U, Mevisse M, Lerchl A, Stamm A. Effects of weak alternating magnetic fields on nocturnal melatonin production and mammary carcinogenesis in rats. Oncology 1994; **51**:288-95.

28 Selmaoui B, Touitou Y. Sinusoidal 50-Hz magnetic fields depress rat pineal NAT activity and serum melatonin. Role of duration and intensity of exposure. Life Sci 1995; **57**:1351-8.

29 Bakos J, Nagy N, Thuroczy G, Szabo L. Sinusoidal 50 Hz, 500 μT magnetic field has no acute effect on urinary 6-sulphatoxymelatonin in wistar rats. Bioelectromagnetics 1995; **16**:377-80.

30 Mevissen M, Lerchl A, Szamel M, Löscher W. 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 1996; **17**:903-10.

31 Mevissen M, Lerchl A, Löscher W. Study on pineal function and DMBA-induced breast cancer formation in rats during the exposure to a 100 mG, 50 Hz magnetic field. J Toxicol Environ Health 1996; **48**:169-85.

32 Bakos J, Nagy N, Thyroczy G, Szabo L. Urinary 6-sulphatoxymelatonin excretion is increased in rats after 24 hours exposure to vertical 50 Hz, 100 μT magnetic field. Bioelectromagnetics 1997; **18**:190-2.

33 Vollrath L, Spessert R, Kratzsch T, Keiner M, Hollmann H. No short-term effects of high-frequency electromagnetic fields on the mammalian pineal gland. Bioelectromagnetics 1998; **18**:376-87.

34 Löscher W, Mevissen M, Lerchl A. Exposure of female rats to a 100-microT, 50 Hz magnetic field does not induce consistent changes in nocturnal levels of melatonin. Radiat Res 1998; **150**:557-67.

35 Reiter RJ, Tan DX, Poeggeler B, Kavet R. Inconsistent suppression of nocturnal pineal melatonin synthesis and serum melatonin levels in rats exposed to pulsed DC magnetic fields. Bioelectromagnetics 1998; **19**:318-29.

36 Rosen LA, Barber I, Lyle DB. A 0.5 G, 60 Hz magnetic field suppresses melatonin production in pinealocytes. Bioelectromagnetics 1998; **19**:123-7.

37 John TM, Liu GY, Brown GM. 60 Hz magnetic field exposure and urinary 6-sulphatoxymelatonin in the rat. Bioelectromagnetics 1998; **19**:172-80.

38 Yellon SM. Acute 60 Hz magnetic field exposure effects on the melatonin rhythm in the pineal gland and circulation of the adult Djungarian hamster. J Pineal Res 1994; **16**:136-44.

39 Truong H, Smith JC, Yellon SM. Photoperiod control of the melatonin rhythm and reproductive maturation in the juvenile Djungarian hamster – 60-Hz magnetic field exposure effects. Biol Reprod 1996; **55**:455-60.

40 Truong H, Yellon SM. Effect of various acute 60 Hz magnetic field exposures on the nocturnal melatonin rise in the adult Djungarian hamster. J Pineal Res 1997; **22**:177-83.

41 Niehaus M, Bruggemeyer H, Behre HM, Lerchl A. Growth retardation, testicular stimulation, and increased melatonin synthesis by weak magnetic fields (50 Hz) in Djungarian hamster, *Phodopus sungorus*. Biochem Biophys Res Commun 1997; **234**:707-11.

42 Brendel H, Niehaus M, Lerchl A. Direct suppressive effects of weak magnetic fields (50 Hz and $16^{2/3}$ Hz) on melatonin synthesis in the pineal gland of Djungarian hamsters (*Phodopus sungorus*). J Pineal Res 2000; **29**:228-33.

43 de Bruyn L, de Jager L, Kuyl JM. The influence of long-term exposure of mice to randomly varied power frequency magnetic filelds on their nocturnal melatonin secretion patterns. Environ Res 2001; **85**:114-21.

44 Lee JMJ, Stormshak F, Thompson JM, Thinesen P, Painter LJ, Olenchek EG, et al. Melatonin secretion and puberty in female lambs exposed to environmental electric and magnetic fields. Biol Reprod 1993; **49**:857-64.

45 Lee JMJ, Stormshak F, Thompson JM, Hess DL, Foster DL. Melatonin and puberty in female lambs exposed to EMF: a replicable study. Bioelectromagnetics 1995; **16**:119-23.

46 Rogers WR, Reiter RJ, Barlow-Walden L, Smith HD, Orr JL. Regularly scheduled, day-time, slow-onset 60 Hz electric and magnetic field exposure does not depress serum melatonin concentration in nonhuman primates. Bioelectromagnetics 1995 **Suppl 3**:111-8.

47 Rogers WR, Reiter RJ, Smith HD, Barlow-Walden L. Rapid onset/offset, variably scheduled 60 Hz electric and magnetic field exposure reduces nocturnal serum melatonin concentration in nonhuman primates. Bioelectromagnetics 1995 **Suppl 3**:119-22.

48 Anderson LE, Morris JE, Saaaer LB, Loscher W. Effects of 50- or 60-Hertz, 100 microT magnetic field exposure in the DMBA mammary cancer model in Sprague-Dawley rats: possible explanations for different results from two laboratories. Environ Health Perspect 2000; **108**:797-802.

49 Selmaoui B, Touitou Y. Age-related differences in serum melatonin and pineal NAT activity and in the response of rat pineal to a 50-Hz magnetic field. Life Sci 1999; **64**:2291-7.

50 Burch JB, Reif JS, Yost MG, Keefe TJ, Pitrat CA. Nocturnal excretion of a urinary melatonin metabolite among electric utility workers. Scand J Work Environ Health 1998; **24**:183-9.

51 Burch JB, Reif JS, Yost MG, Keefe TJ, Pitrat CA. Reduced excretion of a melatoninmetabolite in workers exposed to 60 Hz magnetic fields. Am J Epidemiol 1999; **150**:27-36.

52 Burch JB, Reif JS, Yost MG. Geomagnetic disturbances are associated with reduced nocturnal excretion of a melatonin metabolite in humans. Neurosci Lett 1999; **266**:209-12.

53 Burch JB, Reif JS, Noonan CW, Yost MG. Melatonin metabolite levels in workers wxposed to 60-Hz magnetic fields: work in substations and with 3-phase conductors. JOEM 2000; **42**:136-42.

54 Davis S, Kaune WT, Mirick DK, Chen C, Stevens RG. Residential magnetic fields, light-at-night, and nocturnal urinary 6-sulfatoxymelatonin concentration in women. Am J Epidemiol; **154**:591-600.

55 Levallois P, Dumont M, Touitou Y, Gingras S, Masse B, Gauvin D, et al. Effects of electric and magnetic fields from high-power lines on female urinary excretion of 6-sulfatoxymelatonin. Am J Epidemiol 2001; **154**:601-9.

56 Prato FS, Ossenkopp KP, Kavaliers M, Uksik P, Nicholson RL, Drost D, et al. Effects of exposure to magnetic resonance imaging on nocturnal serum melatonin and other hormone levels in adult males. Preliminary findings. J Bioelectricity1989; **7**:169-80.

57 Wilson BW, Wright CW, Morris JE, Buschbom RL, Brown DP, Miller DL, et al. Evidence for an effect of ELF electromagnetic fields on human pineal gland function. J Pineal Res 1990; **9**:259-69.

58 Schiffman JS, Lasch HM, Rollag MD, Flanders AE, Brainard GC, Burk DL. Effect of magnetic resonance imaging on the normal human pineal body: measurements of plasma melatonin levels. J Magn Reson Imaging 1994; **4**:7-11

59 Selmaoui B, Lambrozo J, Touitou Y. Magnetic fields and pineal function in humans: evaluation of nocturnal acute exposure to extremely low frequency magnetic fields on serum melatonin and urinary 6-hydroxymelatonin rhythm. Life Sci 1996; **58**:1539-49.

60 Graham C, Cook MR, Riffle DW, Gerkovich MM, Cohen HD. Nocturnal melatonin levels in human volunteers exposed to intermittent 60 Hz magnetic field. Bioelectromagnetics 1996; **17**:263-73.

61 Graham C, Cook MR, Riffle DW. Human melatonin during continuous magnetic field exposure. Bioelectromagnetics 1997; **18**:166-71.

62 Wood AW, Armstrong SM, Sait ML, Devine L, Martin MJ. Changes in human plasma melatonin profiles in response to 50 Hz magnetic field exposure. J Pineal Res 1998; **25**:116-27.

63 Karasek M, Woldanska-Okonska M, Czernicki J, Zylinska K, Swietoslawski J. Chronic exposure to 2.9 mT, 40 Hz magnetic field reduces melatonin concentrations in humans. J Pineal Res 1998; **25**:240-4.

64 Karasek M, Czernicki J, Woldanska-Okonska M, Zylinska K, Swietoslawski J. Chronic exposure to 25-80 μT, 200 Hz magnetic field does not influence serum melatonin concentrations in patients with low back pain. J Pineal Res 2000; **29**:81-5.

65 Haugsdal B, Tynes T, Rotnes JS, Griffiths D. A single nocturnal exposure to 2-7 militesla static magnetic field does not inhibit the excretion of 6-sulfatoxymelatonin in healthy young men. Bioelectromagnetics 2001; **22**:1-6.

66 Graham C, Sastre A, Cook MR, Gerkovich MM. All-night exposure to EMF does not alter urinary melatonin, 6-OHMS or immune measures in older men and women. J Pineal Res 2001; **31**:109-13.

67 Crasson M, Beckers V, Pequeux Ch, Claustrad B, Legros JJ. Daytime 50 Hz magnetic field exposure and plasma melatonin and urinary concentration profiles in humans. J Pineal Res 2001; **31**:234-41.

68 Hong SC, Kurokawa Y, Kabuto M, Ohtsuka R. Chronic exposure to ELF magnetic fields during night sleep with electric sheet: effects on diurnal melatonin rhythms in men. Bioelectromagnetics 2001; **22**:138-43.

69 Mann K, Wagner P, Brunn G, Hassa F, Hiemke C, Röschke J. Effects of pulsed high-frequency electromagnetic fields on the neuroendocrine system. Neuroendocrinology 1998; **67**:139-44.

70 de Seze R, Ayoub J, Peray P, Miro L, Touitou Y. Evaluation in humans of the effects of radiocellular telephones on the circadian patterns of melatonin secretion, a chronobiological rhythm marker. J Pineal Res 1999; **27**:237-42.

71 Radon K, Parera D, Rose DM, Jung D, Vollrath L. No effects of pulsed radio frequency electromagnetic fields on melatonin, cortisol, and selected markers of the immune system in man. Bioelectromagnetics 2001; **22**:280-7.

72 Bortkiewicz A, Pilacik B, Gadzicka E, Szymczak W. The excretion of 6-hydroxymelatonin sulfate in healthy young men exposed to electromagnetic fields emitted by cellular phone – an experimental study. Neuroendocrinol Lett 2002; (suppl 1):88–91.