

Masamichi Kato (Editor)

Electromagnetics in Biology

With 80 Figures

 Springer

Contents

Part I Overview, Endpoints, and Methodologies

1	Introduction	3
	Kato M., Shigemitsu T.	
1.1	A Brief History of Research on Electromagnetic Field Effects on Organisms	3
1.1.1	Basic neurophysiologic research	4
1.1.2	Biological research with microwave energy	5
1.1.3	ELF electric fields and bone healing	5
1.1.4	Public concern about exposure to electromagnetic fields	5
1.1.5	The Bioelectromagnetics Society	6
1.1.6	Models used and topics investigated	6
1.2	Bioelectricity and Biomagnetism	7
1.2.1	Bioelectricity	7
1.2.1.1	Membrane potential	7
1.2.1.2	Origin of the membrane potential	7
1.2.1.3	The action potential	8
1.2.1.4	Synaptic transmission	9
1.2.1.5	Structural elements of chemical synapses	10
1.2.1.6	Excitatory synapses	10
1.2.1.7	Inhibitory synapses	10
1.2.1.8	Synaptic receptors	10
1.2.1.9	Electrical synapses	12
1.2.2	Biomagnetism	12
1.3	Environmental Electromagnetic Fields and Biosystems	12
1.3.1	Natural background fields	12
1.3.2	ELF electromagnetic fields and biological systems	16
1.3.2.1	Circadian rhythms	16
1.3.2.2	Similarity between EEG rhythms and Schumann resonance	20

1.3.2.3	Influences of natural electromagnetic processes on humans	20
1.3.2.4	Geomagnetic fields and biological systems	20
1.3.3	Anthropogenic electromagnetic fields	23
1.3.3.1	Power-frequency electric fields in the environment	24
1.3.3.2	Power-frequency magnetic fields in the environment	25
1.4	Summary	26
1.5	References	28
2	Endpoints and Methodologies	31
	Fujiwara O., Wang J., Kato M., Miyakoshi J.	
2.1	Definition and Equations of Electric and Magnetic Fields	31
2.1.1	Electric field	31
2.1.2	Magnetic field	31
2.1.3	Electromagnetic wave	32
2.2	Endpoints and Methodologies for <i>In vivo</i> Research	32
2.2.1	Nervous system	33
2.2.1.1	Nervous system and behavior	33
2.2.1.1.1	Outline of behavioral science	33
2.2.1.1.2	Activity and attention, learning and memory, and task performance	35
2.2.1.1.3	Behavioral methodologies employed in bioelectromagnetics	36
2.2.1.2	Electroencephalogram	38
2.2.1.3	Evoked potentials	39
2.2.1.3.1	Sensory-evoked potential	40
2.2.1.3.2	Event-related potential	40
2.2.1.4	Neurotransmitters	40
2.2.1.5	Receptors for neurotransmitters	41
2.2.1.6	Opioid system	42
2.2.2	Endocrine system	43
2.2.2.1	Pineal gland	43
2.2.2.1.1	Measurement of melatonin	46
2.2.2.1.2	Melatonin effects on the endocrine system	46
2.2.2.1.3	Oncostatic action of melatonin	46
2.2.2.1.4	Melatonin effects on immune function	46
2.2.2.1.5	Analgesic action of melatonin	46
2.2.2.1.6	Other actions of melatonin	47
2.2.2.1.7	Melatonin in humans	47
2.2.3	Immune system	47
2.2.3.1	Acquired and innate immunity	48
2.2.3.2	Types of immune cells	49
2.2.3.3	Immune modulators	50
2.2.4	Summary	51

2.3	Endpoints and Methodologies for <i>In vitro</i> Research	51
2.3.1	Cell growth	51
2.3.1.1	Basic characteristics of cell growth <i>in vitro</i>	51
2.3.1.2	Cell cycle and DNA synthesis	52
2.3.2	Genotoxicity	52
2.3.2.1	Chromosomal aberration	52
2.3.2.2	DNA strand breaks	53
2.3.2.3	Micronucleus formation	54
2.3.2.4	Mutation	55
2.3.3	Gene expression	56
2.3.4	Transformation	57
2.3.5	Summary	57
2.4	References	58

Part II Extremely Low Frequency

3	Experimental Results: <i>In vivo</i>	63
	Kato M.	
3.1	Behavioral Science Research	63
3.1.1	Experiments with rodents	63
3.1.2	Experiments with non-human primates	64
3.1.3	Experiments with humans	65
3.1.4	Summary	66
3.2	Central Nervous System	66
3.2.1	Neurophysiology and clinical neurology	66
3.2.2	Neurotransmitters	69
3.2.2.1	Magnetic field exposure and transmitter release	69
3.2.2.2	Magnetic field exposure and transmitter receptors	69
3.2.3	Pain	73
3.2.4	Electroencephalogram	75
3.2.5	Evoked potentials	75
3.2.5.1	Sensory-evoked potentials	75
3.2.5.2	Event-related potentials	75
3.2.6	Perception of electric and magnetic fields.	76
3.2.7	Kindling.	77
3.3	Development and Regulation of the Cell Axis, Neurite Growth, and Nerve Regeneration	78
3.3.1	Regulation of the cell axis	78
3.3.2	Neurite growth	79
3.3.3	Nerve regeneration	79
3.4	Endocrine System	81
3.4.1	Field exposure and endocrine functions	81
3.4.1.1	Melatonin	81

3.4.1.1.1	Effects of manipulation of geomagnetic field on melatonin	81
3.4.1.1.2	Effects of 60 Hz electric fields on melatonin in rodents.	81
3.4.1.1.2.1	Assessment of melatonin concentration	82
3.4.1.1.2.2	Morphological studies . . .	87
3.4.1.1.3	Experiments with farm animals.	88
3.4.1.1.4	Experiments with non-human primates	88
3.4.1.1.5	Experiments with humans	89
3.4.1.1.5.1	Laboratory experiments with healthy humans	89
3.4.1.1.5.2	Laboratory measurement on patients	91
3.4.1.1.5.3	Occupational exposure studies with humans	92
3.4.1.1.6	Mechanism of magnetic field effects on pineal gland.	95
3.4.1.2	Effects of electric and magnetic field exposure on sex hormones	97
3.5	Bone Repair	98
3.5.1	Clinical studies	98
3.5.2	Animal studies	100
3.6	Immune Responses	102
3.6.1	Lymphocyte proliferation	102
3.6.2	T lymphocyte activity	104
3.6.3	Natural killer cell activity	104
3.6.4	Cytokines	104
3.7	References	105
4	Experimental Results: <i>In vitro</i>	115
	Miyakoshi J.	
4.1	Genotoxic Effects	115
4.1.1	Chromosomal aberrations	116
4.1.2	DNA strand breaks	117
4.1.2.1	Induction of strand breakage	118
4.1.3	Micronucleus formation.	119
4.1.4	Mutation	119
4.2	Cellular Proliferation	121
4.2.1	Cell proliferation and survival	121
4.2.2	Melatonin and cell proliferation	122
4.2.3	DNA synthesis	123
4.3	Gene Expression	123
4.3.1	<i>c-myc</i>	123
4.3.2	<i>c-fos</i> and <i>c-jun</i>	124

4.3.3	Heat shock protein	125
4.3.4	Neuron-derived orphan receptor-1	125
4.4	Signal Transduction	126
4.4.1	Calcium ion	127
4.4.2	Protein kinase C	128
4.5	Ornithine Decarboxylase	128
4.5.1	Interleukin-2	129
4.5.2	Gap junctions	129
4.6	Cell Transformation	130
4.7	Summary	131
4.7.1	Summary of findings	131
4.7.2	Commentary	132
4.8	References	132
5	Dosimetry Related to ELF Electromagnetic Field Exposure	
	Experiments	137
	Shigemitsu T.	
5.1	ELF EMF Coupling and Dosimetry with Biological Systems	137
5.2	Macroscopic Dosimetry	138
5.2.1	Electric field <i>in vivo</i> exposure systems	139
5.2.2	Magnetic field <i>in vivo</i> exposure systems	141
5.2.3	<i>In vitro</i> exposure systems	142
5.2.4	Issues related to insufficient consideration of electrical engineering	149
5.3	Induced Electric Fields and Currents	151
5.3.1	ELF electric and magnetic fields into biological systems and need for scaling	151
5.3.1.1	Coupling	151
5.3.1.2	Scaling	153
5.3.2	Models for analysis of induced current inside biological systems	154
5.4	Summary	156
5.5	References	157
6	What Magnetic Field Parameters are Biologically Effective?	159
	Shigemitsu T., Kato M.	
6.1	Overview	159
6.2	Polarization of Magnetic Fields	160
6.3	Orientation of Magnetic Fields	166
6.4	Exposure Intensity of Magnetic Fields	167
6.5	Exposure Duration of Magnetic Fields	168
6.6	Time-weighted Average and Dose	170
6.7	Intermittency or Irregularity of Magnetic Fields	172
6.8	Transients of Magnetic Fields	174
6.9	Conclusion	175

6.10	References	176
7	Induced Current as the Candidate Mechanism for Explanation of Biological Effects	179
	Yamazaki K.	
7.1	Background	179
7.2	Methods for Estimating the Induced Current Inside the Human Body	180
7.2.1	Direct measurement with a miniature probe	180
7.2.2	Analytical formulae describing induced current in a spherical model	180
7.2.3	Numerical calculation of induced current	181
7.2.3.1	Finite element method	181
7.2.3.2	Impedance method	181
7.2.3.3	Scalar-potential, finite-difference method	181
7.2.3.4	Finite-difference, time-domain method	182
7.2.3.5	Boundary element method	182
7.2.3.6	Calculation method for an electrostatic problem ..	182
7.3	Human Models, Field Uniformity, and Frequency Domain	182
7.3.1	Human models	183
7.3.2	Field uniformity	184
7.3.3	Expansion of frequency range studied	186
7.4	Challenges to Interpretation of Biological Outcomes	186
7.5	Inter-laboratory Comparison Studies	187
7.6	Summary	188
7.7	References	189
8	Electromagnetic Fields, Biophysical Processes, and Proposed Biophysical Mechanisms	193
	Shigemitsu T.	
8.1	Electromagnetic Fields and Electromagnetic Waves	193
8.2	Electrical Characteristics of Organisms	195
8.2.1	Fundamental units and properties	195
8.2.2	Cells and tissues	196
8.3	Electromagnetic Fields and Organisms	198
8.3.1	Fundamental	198
8.3.2	Non-thermal effect	199
8.3.3	Thermal effect	200
8.4	Proposed Biophysical Mechanisms	201
8.4.1	A framework for understanding bioeffects	202
8.4.1.1	Background	202
8.4.1.2	Some early examples of potential mechanism	203
8.4.2	Forces acting on ions and molecules	205
8.4.2.1	External field	205
8.4.2.2	Electrical noise	206
8.4.3	Resonance models	208

8.4.3.1	Ion cyclotron resonance model	208
8.4.3.2	Parametric resonance model	210
8.4.3.3	Ion parametric resonance model	211
8.4.3.4	Stochastic resonance model	212
8.4.4	Biogenic magnetite	213
8.4.5	Free radical reaction	214
8.4.5.1	Background	214
8.4.5.2	Free radical interaction	215
8.5	Discussion	216
8.6	References	219

Part III Radiofrequency Fields

9	Radiofrequency Dosimetry and Exposure Systems	223
	Fujiwara O., Wang J.	
9.1	Computational Techniques	223
9.1.1	Anatomically based biological models	223
9.1.2	Finite difference time domain method	226
9.1.2.1	FDTD formulation	226
9.1.2.2	Absorbing boundary conditions	229
9.1.2.3	Field excitation	231
9.1.2.4	Finite difference time domain flow chart	232
9.1.3	Bio-heat equation and temperature calculation	232
9.2	Measurement Techniques	234
9.2.1	Tissue-simulating phantoms	234
9.2.1.1	Liquid phantoms	234
9.2.1.2	Solid phantoms	234
9.2.1.3	Gel phantoms	236
9.2.2	Electric field measurement	236
9.2.3	Thermal measurement	238
9.3	<i>In vivo</i> Exposure Systems	238
9.3.1	Near-field exposure	238
9.3.1.1	Linear antennas	240
9.3.1.2	Improvement with high-permittivity material	241
9.3.1.3	Loop antennas	242
9.3.2	Far-field exposure	243
9.3.2.1	Resonant waveguide structure	243
9.3.2.2	TEM cells	244
9.4	<i>In vitro</i> Exposure Systems	245
9.5	References	248

10 Radiofrequency Biology: <i>In vivo</i>	251
Kato M.	
10.1 Carcinogenesis	251
10.2 Central Nervous System	253
10.2.1 Morphology	253
10.2.2 Blood-brain barrier	254
10.2.3 Electroencephalogram	258
10.2.3.1 Animal studies	258
10.2.3.2 Human studies during waking state	259
10.2.3.3 Human studies during sleep	260
10.2.3.4 Preparatory potentials	261
10.2.3.5 Event-related magnetic fields	262
10.2.3.6 Summary	262
10.2.4 Cognitive function	262
10.2.4.1 Cognitive studies with animals	263
10.2.4.2 Cognitive studies with humans	265
10.2.4.3 Human attention	266
10.2.5 Hippocampal slice preparation	266
10.2.6 Detection of RF electromagnetic fields	268
10.2.6.1 Perception	268
10.2.6.2 Electromagnetic hypersensitivity	268
10.2.7 Neurotransmitters	272
10.2.7.1 Microwave exposure alone	272
10.2.7.2 Microwaves and drug effects	274
10.2.7.3 Summary	275
10.3 Peripheral Nervous System	275
10.3.1 Intact nerves	275
10.3.2 Regenerating nerves	277
10.4 Endocrinology	277
10.4.1 Pituitary gland and its axes	277
10.4.1.1 Corticosteroids in animals	277
10.4.1.2 Studies with humans	279
10.4.2 Pineal gland and melatonin	280
10.4.2.1 Experiments with animals	280
10.4.2.2 Experiments with humans	281
10.4.2.3 Summary	283
10.5 Cardiovascular System	283
10.5.1 Experiments with animals	283
10.5.2 Experiments with humans	284
10.6 Ocular Responses	285
10.6.1 Experiments with rabbits	285
10.6.2 Experiments with monkeys	287
10.6.3 Magnetic resonance imaging	288
10.7 Auditory Responses	289
10.7.1 Sensation and perception	289

10.7.2	RF hearing	290
10.7.2.1	Basic phenomenon	290
10.7.2.2	Mechanisms for RF hearing	290
10.7.3	Effects on auditory pathway	291
10.7.3.1	Experimental data	291
10.8	Thermoregulatory Responses	292
10.8.1	Regulation of body temperature	292
10.8.2	Experiments with animals	294
10.8.3	Experiments with humans	295
10.8.4	Magnetic resonance imaging	297
10.8.5	Conclusions	297
10.9	References	298
11	Radiofrequency Biology: <i>In vitro</i>	305
	Miyakoshi J.	
11.1	Cell Growth	305
11.2	Genotoxic Effects	305
11.2.1	Chromosomal aberration	306
11.2.1.1	Studies reporting negative results	306
11.2.1.2	Studies reporting positive results	307
11.2.1.3	Summary	307
11.2.2	DNA strand breaks	308
11.2.2.1	Studies reporting negative results	308
11.2.2.2	Studies reporting positive results	309
11.2.2.3	Summary	310
11.2.3	Micronucleus formation	310
11.2.3.1	Experimental data	310
11.2.3.2	Summary	312
11.2.4	Mutation	312
11.3	Gene Expression	312
11.3.1	Heat shock proteins	312
11.3.2	Oncogenes	314
11.4	Signal Transduction	314
11.5	Cell Transformation	314
11.6	References	316
12	Summary and Conclusion	319
	Kato M.	
	Index	321