

Contents

Preface — V

Acknowledgments — VII

Part D: Radiotherapeutical methods

1 Radiobiology basics — 3

- 1.1 Introduction — 3
- 1.2 Life cycle of cells — 4
- 1.3 Tumor cells — 9
 - 1.3.1 General remarks — 9
 - 1.3.2 Cancer cell development — 11
 - 1.3.3 Tumor growth — 12
- 1.4 Radiation response of cells — 14
 - 1.4.1 LQ model — 14
 - 1.4.2 Dose fractionation — 15
 - 1.4.3 Biological effect of radiation — 16
 - 1.4.4 Reaction distance — 17
 - 1.4.5 Relative biological effectiveness (RBE) — 18
 - 1.4.6 Oxygen enhancement ratio — 19
- 1.5 Radiation therapies — 20
 - 1.5.1 Dose control — 20
 - 1.5.2 Hypoxia and chemotherapy — 22
 - 1.5.3 Types of radiotherapies — 23
 - 1.5.4 Radiation treatment planning overview — 23
 - 1.5.5 Staging — 25
- 1.6 Summary — 26
 - Exercises — 28
 - References — 29
 - Further reading — 30
 - Useful websites — 30

2 X-ray radiotherapy — 31

- 2.1 Introduction — 32
- 2.2 Absorbed dose by high-energy photon beam — 33
 - 2.2.1 Percent depth dose for electrons — 34
 - 2.2.2 Percent depth dose for photons — 36
 - 2.2.3 Reference dosimetry and beam quality correction factor — 37
 - 2.2.4 Monte Carlo simulations — 39

2.2.5	Dose to isocenter —	42
2.3	Target volume and collimators —	43
2.3.1	Target volume definition —	43
2.3.2	Multileaf collimator —	45
2.3.3	Intensity-modulated radiotherapy —	48
2.4	Linear accelerators for x-ray generation —	49
2.5	New developments —	52
2.5.1	Cyberknife technology —	52
2.5.2	MR-linac hybrid systems —	54
2.5.3	FLASH-RT —	56
2.6	Gamma knife —	56
2.7	Summary —	57
	Exercises —	60
	References —	60
	Further reading —	62
	Useful websites on cyberknife technology —	62
3	Charged particle radiotherapy —	63
3.1	Introduction —	63
3.2	Proton beam therapy: overview —	64
3.3	Characteristics of proton beams —	68
3.3.1	Interaction channels —	68
3.3.2	Proton beam range —	68
3.3.3	Beam profile —	72
3.3.4	Formation of SOBP —	74
3.3.5	Beam delivery and scanning —	75
3.3.6	Dose requirements —	76
3.3.7	Charge particle fluence —	77
3.4	Positioning and range monitoring —	78
3.4.1	Treatment plan and positioning —	78
3.4.2	PET monitoring —	80
3.4.3	Prompt gamma monitoring —	84
3.4.4	Patient monitoring —	87
3.5	Examples for proton beam therapy —	87
3.5.1	Posterior fossa tumor —	87
3.5.2	Prostate tumor —	88
3.5.3	Uveal melanoma —	89
3.6	Accelerators and gantries for proton beam therapy —	90
3.7	Carbon ion beam therapy —	93
3.7.1	LET and OER —	93
3.7.2	Implementation —	95
3.7.3	Concluding remarks —	96

3.8	Summary — 96
	Exercises — 98
	References — 99
	Useful websites — 101
	Further reading — 101
4	Neutron radiotherapy — 103
4.1	Introduction — 103
4.2	Neutron energies and lifetime — 104
4.3	Fast neutron production by fission — 105
4.4	Accelerator-based neutron sources — 106
4.4.1	$^9\text{Be}(p,n)^9\text{B}$ reaction — 107
4.4.2	$^9\text{Be}(d,n)^{10}\text{B}$ reaction — 108
4.4.3	$^3\text{H}(d,n)^4\text{He}$ reaction — 109
4.5	Accelerator facility — 109
4.6	LET, RBE, and OER of fast neutrons — 110
4.7	Boron neutron capture therapy — 113
4.8	Summary — 116
	Exercises — 117
	References — 117
	Further reading — 118
	Useful website — 118
5	Brachytherapy — 119
5.1	Introduction — 119
5.2	Radioisotope selection for brachytherapy — 120
5.3	Specific radioisotopes for brachytherapy — 124
5.3.1	Radioisotopes ^{137}Cs and ^{131}Cs — 124
5.3.2	Radioisotope ^{60}Co — 125
5.3.3	Radioisotope ^{192}Ir — 126
5.3.4	Radioisotope ^{125}I — 126
5.3.5	Radioisotope ^{103}Pd — 127
5.3.6	Radioisotopes ^{198}Au and ^{106}Ru — 128
5.3.7	Radioisotope ^{90}Sr — 128
5.4	Procedures — 129
5.4.1	Interstitial and contact brachytherapy — 129
5.4.2	Cervical cancer — 131
5.4.3	Prostate cancer — 131
5.4.4	Breast cancer — 132
5.4.5	New developments — 133
5.5	Dosimetry — 133
5.6	Summary — 137

Exercises —	138
References —	138
Further reading —	139
Useful websites —	139

Part E: Diagnostics and therapeutics beyond radiology

6 Laser applications in medicine — 143

6.1	Introduction —	143
6.2	Laser basics —	146
6.2.1	Two-level system —	146
6.2.2	Three-level system —	147
6.2.3	Basic laser components —	148
6.2.4	YAG laser —	149
6.2.5	Laser types, wavelengths, and units —	150
6.2.6	Laser specifications —	152
6.3	Laser pulsation —	153
6.3.1	Mechanical switching —	154
6.3.2	Q-switch —	154
6.3.3	Mode locking —	156
6.4	Laser interaction with tissue —	159
6.4.1	Laser beam penetration depth —	159
6.4.2	Laser-tissue interaction —	161
6.4.3	Photothermal interaction —	162
6.4.4	Photoablation —	165
6.4.5	Plasma-induced ablation —	166
6.4.6	Photomechanical interaction —	167
6.4.7	Photochemical interaction —	168
6.5	Laser applications in ophthalmology —	170
6.5.1	Photorefractive keratectomy —	170
6.5.2	Diabetic retinopathy —	173
6.5.3	Cataract and glaucoma —	175
6.6	Summary —	176
	Exercises —	178
	References —	179
	Further reading —	180

7 Nanoparticles for nanomedical applications — 181

7.1	Introduction —	181
7.2	Pathway of nanoparticles through the body —	183
7.2.1	Reticuloendothelial system (RES) —	183

7.2.2	Clearance — 184
7.2.3	Enhanced permeation and retention effect (EPR) — 185
7.2.4	Coatings — 185
7.2.5	Antigen-Antibody — 187
7.2.6	Targeting — 188
7.2.7	Size — 188
7.2.8	Biocompatibility — 188
7.3	Magnetic nanoparticles for diagnostics and therapeutics — 189
7.3.1	Magnetic properties of gadolinium — 189
7.3.2	Magnetic properties of magnetite — 191
7.3.3	Superparamagnetism — 192
7.3.4	Blocking temperature — 194
7.4	MR imaging contrast — 196
7.4.1	Basics of MRI contrast — 196
7.4.2	Gd ³⁺ chelates as positive contrast agent for MRI — 198
7.4.3	Fe ₃ O ₄ as negative contrast agent for MRI — 198
7.4.4	Size of magnetic nanoparticles — 199
7.4.5	Coating of magnetic nanoparticles — 200
7.4.6	Alternative magnetic nanoparticles — 200
7.5	Magnetic hyperthermia — 201
7.5.1	Relaxation mechanisms — 201
7.5.2	Relaxation in an AC magnetic field — 202
7.5.3	Power loss density — 204
7.5.4	Magneto-mechanical cell destruction — 206
7.6	Metal nanoparticles for diagnostics and therapeutics — 207
7.6.1	X-ray radiography contrast — 207
7.6.2	K-edge contrast — 209
7.6.3	Bimodal contrast — 209
7.6.4	Alternative concepts — 209
7.7	Plasmon resonance — 210
7.7.1	Mie scattering — 210
7.7.2	Surface plasma resonance — 212
7.7.3	Photothermal therapy — 215
7.8	Imaging and spectroscopy — 217
7.8.1	Dark field imaging — 217
7.8.2	Surface enhanced Raman scattering — 219
7.9	Multimodality of theranostic nanoparticles — 221
7.10	Summary — 223
	Exercises — 225
	References — 225
	Further reading — 227

Part F: Measuring and statistics

- 8 Elements of medical statistics: measurements, population, distribution, reliability — 231**
 - 8.1 Introduction — 231
 - 8.2 Precision and accuracy — 232
 - 8.3 Random errors and systematic errors — 233
 - 8.4 Mean, variance, and confidence interval — 234
 - 8.5 Absolute and relative errors — 236
 - 8.6 Error propagation — 237
 - 8.7 Error of measuring devices and sensitivity — 238
 - 8.8 Population and sampling — 239
 - 8.9 Frequency, histogram, and distribution — 240
 - 8.10 Standard distribution — 242
 - 8.11 Assessing histograms by standard distribution — 243
 - 8.12 Normal probabilities — 246
 - 8.13 Linear regression and correlation — 248
 - 8.14 Risk and odds — 251
 - 8.15 Sensitivity, specificity, predictive values of diagnosis — 252
 - 8.16 Summary — 255
 - Exercises — 257
 - References — 258
 - Further reading — 258
 - Useful website — 258

Appendix

- 9 Answers to questions — 261**
- 10 Solutions to exercises — 269**
- 11 List of acronyms (used in all three volumes) — 283**
- 12 Selection of fundamental physical constants, conversions, and relationships — 286**
- 13 List of scientists named in this volume — 287**
- 14 Glossary — 288**
- 15 Index of terms — 291**