

---

# Contents

<b>About the Series</b>	<b>xi</b>
<b>Foreword</b>	<b>xv</b>
<b>List of Contributors</b>	<b>xix</b>
<b>1 Introduction</b>	<b>1</b>
<i>Klaus P. Schäfers</i>	
1.1 Introduction . . . . .	1
1.2 Principle of emission tomography . . . . .	2
1.3 Electromagnetic spectrum . . . . .	4
1.4 Need for correction techniques . . . . .	4
References . . . . .	7
<b>I Background</b>	<b>9</b>
<b>2 Biomedical Applications of Emission Tomography</b>	<b>11</b>
<i>Michael Schäfers, Sven Hermann, Sonja Schäfers, Thomas Viel, Marilyn Law, and Andreas H. Jacobs</i>	
2.1 The role of imaging in biomedical research and applications . . . . .	11
2.2 Functional and molecular imaging by emission tomography enables high sensitivity and spatial resolution . . . . .	13
2.3 Biomedical applications of emission tomography depend on tracers . . . . .	14
2.4 Applications . . . . .	16
2.4.1 Preclinical applications . . . . .	16
2.4.2 Clinical applications . . . . .	17
2.4.3 Examples of biomedical applications of emission tomography . . . . .	18
2.4.3.1 Bioluminescence imaging of tumor growth . .	18
2.4.3.2 Dynamic PET in pharmacodynamic studies .	19
2.4.3.3 From mice to men—Non-invasive translational imaging of inflammatory activity in graft- versus-host disease . . . . .	20

2.4.3.4	PET to quantify catecholamine recycling and receptor density in patients with arrhythmias	22
2.4.3.5	Multiparametric imaging of brain tumors . . .	23
References	. . . . .	26
<b>3</b>	<b>PET Image Reconstruction</b>	<b>31</b>
	<i>Frank Wübbeling</i>	
3.1	Introduction . . . . .	31
3.2	Analytical algorithms . . . . .	32
3.2.1	Mathematical basis . . . . .	32
3.2.2	Filtered backprojection . . . . .	35
3.2.3	Implementation: Resolution and complexity . . . . .	37
3.2.4	Implementation and rebinning . . . . .	38
3.2.4.1	2D Rebinning . . . . .	39
3.2.4.2	3D filtered backprojection . . . . .	40
3.2.5	Limitations . . . . .	40
3.3	Discrete algorithms . . . . .	40
3.3.1	ART—Algebraic reconstruction technique . . . . .	41
3.3.2	EM . . . . .	42
3.3.3	Computing the system matrix . . . . .	44
3.3.4	List mode . . . . .	45
3.4	Summary . . . . .	47
References	. . . . .	47
<b>II</b>	<b>Correction Techniques in PET and SPECT</b>	<b>49</b>
<b>4</b>	<b>Basics of PET and SPECT Imaging</b>	<b>51</b>
	<i>Ralph A. Bundschuh and Sibylle I. Ziegler</i>	
4.1	Introduction . . . . .	51
4.1.1	Interaction of photons with matter . . . . .	52
4.1.1.1	Photoelectric effect . . . . .	52
4.1.1.2	Compton scattering . . . . .	52
4.1.2	Photon attenuation . . . . .	54
4.1.3	Scatter . . . . .	57
4.1.4	Variation in detector efficiency, normalization . . . . .	58
4.1.5	Dead time effects (loss of count rate) (PET and SPECT) . . . . .	59
4.1.6	Partial volume effects (PET and SPECT) . . . . .	59
4.1.6.1	Spill out . . . . .	60
4.1.6.2	Spill in . . . . .	60
4.1.7	Time resolution and randoms (PET only) . . . . .	61
4.1.8	Collimator effects—Distance dependent spatial resolution (SPECT only) . . . . .	62
4.1.9	Positron range and annihilation (PET only) . . . . .	63
References	. . . . .	64

<b>5</b>	<b>Corrections for Physical Factors</b>	<b>67</b>
	<i>Florian Büther</i>	
5.1	Introduction . . . . .	67
5.2	Decay correction . . . . .	69
5.3	Randoms correction . . . . .	71
	5.3.1 Singles-based correction . . . . .	72
	5.3.2 Delayed window correction . . . . .	72
5.4	Attenuation correction . . . . .	73
	5.4.1 Stand-alone emission tomography systems . . . . .	77
	5.4.2 PET/CT and SPECT/CT systems . . . . .	80
	5.4.3 Attenuation correction artifacts . . . . .	82
5.5	Scatter correction . . . . .	90
	5.5.1 Energy windowing methods . . . . .	91
	5.5.2 Analytical methods . . . . .	92
	5.5.3 Direct calculation methods . . . . .	94
	5.5.4 Iterative reconstruction methods . . . . .	95
5.6	Concluding remarks . . . . .	95
	References . . . . .	95
<b>6</b>	<b>Corrections for Scanner-Related Factors</b>	<b>105</b>
	<i>Marc Huismann</i>	
6.1	Positron emission tomography . . . . .	105
	6.1.1 Introduction . . . . .	105
	6.1.2 Data normalization . . . . .	107
	6.1.3 Noise equivalent count rates . . . . .	108
	6.1.4 System dead time . . . . .	108
	6.1.5 Partial volume . . . . .	110
6.2	Single photon emission computed tomography . . . . .	112
	6.2.1 Linearity, center of rotation, and whole body imaging	112
	6.2.2 Motion correction . . . . .	114
	References . . . . .	115
<b>7</b>	<b>Image Processing Techniques in Emission Tomography</b>	<b>119</b>
	<i>Fabian Gigengack, Michael Fieseler, Daniel Tenbrinck, and Xiaoyi Jiang</i>	
7.1	Introduction . . . . .	119
7.2	Denoising . . . . .	121
	7.2.1 Image domain . . . . .	122
	7.2.2 Fourier transform domain . . . . .	123
	7.2.3 Wavelet transform domain . . . . .	124
7.3	Interpolation . . . . .	126
7.4	Registration . . . . .	129
	7.4.1 Categorization . . . . .	130
	7.4.1.1 Nature of transformation . . . . .	132
	7.4.1.2 Similarity measure . . . . .	133
	7.4.2 Validation . . . . .	135

7.4.3	Software . . . . .	137
7.5	Partial volume correction . . . . .	137
7.5.1	The partial volume effect in PET imaging . . . . .	138
7.5.2	Correction methods . . . . .	140
7.6	Super-resolution . . . . .	144
7.7	Validation . . . . .	146
7.7.1	Intensity-based measures . . . . .	146
7.7.2	Phantoms . . . . .	148
7.7.2.1	Hardware . . . . .	148
7.7.2.2	Software . . . . .	149
	References . . . . .	150
<b>8</b>	<b>Motion Correction in Emission Tomography</b>	<b>157</b>
	<i>Mohammad Dawood</i>	
8.1	Introduction . . . . .	157
8.1.1	Magnitude of motion . . . . .	158
8.1.1.1	Patient motion . . . . .	158
8.1.1.2	Respiratory motion . . . . .	158
8.1.1.3	Cardiac motion . . . . .	159
8.2	Motion correction on 3D PET data . . . . .	160
8.2.1	Overview . . . . .	161
8.2.2	Rigid motion correction . . . . .	162
8.2.3	Elastic motion correction . . . . .	163
8.3	Optical flow . . . . .	164
8.3.1	Image constraint equation . . . . .	164
8.3.2	Optical flow methods . . . . .	166
8.3.3	Optical flow in medical imaging . . . . .	167
8.4	Lucas–Kanade optical flow . . . . .	168
8.5	Horn–Schunck optical flow . . . . .	169
8.6	Bruhn optical flow . . . . .	170
8.7	Preserving discontinuities . . . . .	172
8.8	Correcting for motion . . . . .	173
8.9	Mass conservation–based optical flow . . . . .	174
8.9.1	Correcting for motion . . . . .	175
	References . . . . .	177
<b>9</b>	<b>Combined Correction and Reconstruction Methods</b>	<b>185</b>
	<i>Martin Benning, Thomas Kösters, and Frederic Lamare</i>	
9.1	Introduction . . . . .	186
9.2	Parameter identification . . . . .	187
9.2.1	Compartment modeling . . . . .	187
9.2.2	4D methods incorporating linear parameter identification . . . . .	189
9.2.3	4D methods incorporating nonlinear parameter identification . . . . .	190

9.3	Combined reconstruction and motion correction . . . . .	192
9.3.1	The advantages of the list mode format . . . . .	193
9.3.2	Motion correction during an iterative reconstruction algorithm . . . . .	194
9.3.2.1	Approaches based on a rigid or affine motion model . . . . .	194
9.3.2.2	Approaches based on a non-rigid motion model . . . . .	196
9.4	Combination of parameter identification and motion estimation . . . . .	198
	References . . . . .	200

**III Recent Developments 207**

**10 Introduction Hybrid Tomographic Imaging 209**

*Hartwig Newiger*

10.1	Introduction . . . . .	209
10.2	Combining PET and SPECT . . . . .	210
10.3	The combination with MR . . . . .	211
10.4	Combining ultrasound with PET and SPECT . . . . .	214
	References . . . . .	215

**11 MR-based Attenuation Correction for PET/MR 217**

*Matthias Hofmann, Bernd Pichler, and Thomas Beyer*

11.1	Introduction . . . . .	218
11.2	MR-AC for brain applications . . . . .	220
11.2.1	Segmentation approaches . . . . .	220
11.2.2	Atlas approaches . . . . .	221
11.3	Methods for torso imaging . . . . .	224
11.4	Discussion . . . . .	229
11.4.1	The presence of bone . . . . .	230
11.4.2	MR imaging with ultrashort echo time (UTE) . . . . .	231
11.4.3	Required PET accuracy . . . . .	232
11.4.4	Validation of MR-AC methods . . . . .	232
11.4.5	Truncated field-of-view . . . . .	232
11.4.6	MR coils and positioning aids . . . . .	233
11.4.7	User intervention . . . . .	233
11.4.8	Potential benefits of MR-AC . . . . .	234
11.4.9	Additional potential benefits of simultaneous PET/MR acquisition . . . . .	234
11.5	Conclusion . . . . .	234
	References . . . . .	235

<b>12 Optical Imaging</b>	<b>241</b>
<i>Angelique Ale and Vasilis Ntziachristos</i>	
12.1 Introduction . . . . .	241
12.2 Fluorescence molecular tomography (FMT) . . . . .	244
12.2.1 Light propagation model . . . . .	244
12.2.1.1 Photon interaction with biological tissue . . . . .	244
12.2.1.2 The diffusion approximation . . . . .	246
12.2.1.3 Model for a fluorescence heterogeneity . . . . .	248
12.2.2 Reconstruction of the fluorochrome distribution . . . . .	249
12.3 FMT and hybrid FMT systems . . . . .	251
12.3.1 Instrumentation . . . . .	251
12.3.1.1 Illumination . . . . .	251
12.3.1.2 Detection . . . . .	252
12.3.1.3 360° projections . . . . .	252
12.3.2 Multimodal optical imaging . . . . .	253
12.3.2.1 Optical tomography and MRI . . . . .	253
12.3.2.2 FMT-XCT . . . . .	254
References . . . . .	257
<b>Index</b>	<b>263</b>