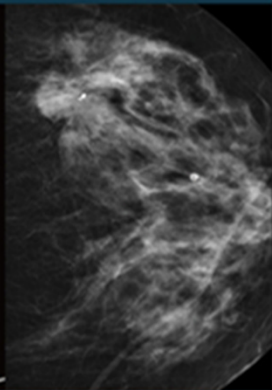
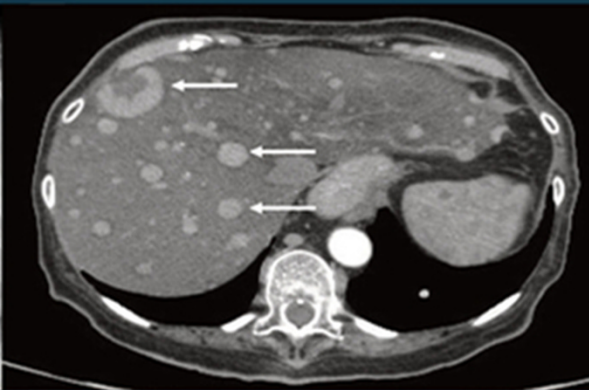


# Medical Imaging for Health Professionals

Technologies  
and Clinical Applications

Edited by  
Raymond M. Reilly, Ph.D



WILEY



## **Medical Imaging for Health Professionals**



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Technologies and Clinical Applications

*Edited by*

*Raymond M. Reilly, PhD  
University of Toronto  
Toronto, Ontario, Canada*

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*To my students who provided the inspiration for this book. There is no more joyful aspect of being a professor than to teach young people to better understand the world.*





# Contents

**Contributors** *xix*  
**Preface** *xxi*  
**Acknowledgments** *xxiii*

**1 Introduction to Medical Imaging** 2  
*Raymond M. Reilly*

1.1 Medical Imaging Procedures 2  
1.1.1 Procedures Involving Ionizing vs. Nonionizing Radiation 3  
1.2 Radiation Doses from Medical Imaging Procedures 4  
1.2.1 Estimating Radiation Doses from Medical Imaging 5  
1.2.2 Radiation Doses and Increased Use of Medical Imaging 8  
1.3 Summary 8  
References 9

**2 X-Ray, CT, and Mammography Technology** 11  
*Raymond M. Reilly*

2.1 Introduction 11  
2.2 X-Rays 11  
2.2.1 X-Ray Tube 13  
2.2.2 X-Ray Machine 14  
2.3 Radiography 15  
2.4 Computed Tomography 16  
2.4.1 Image Acquisition 18  
2.4.2 Image Reconstruction 20  
2.4.3 CT Contrast Agents 21  
2.5 Mammography 23  
2.5.1 Mammography System 23  
2.5.2 Tomosynthesis 25  
2.6 Summary 25  
References 26  
Additional Reading 26

<b>3</b>	<b>Nuclear Medicine Imaging Technology</b>	<b>27</b>
	<i>Raymond M. Reilly</i>	
3.1	Introduction	27
3.2	Scintillation Detectors	28
3.2.1	Conversion of Light to an Electronic Signal	30
3.2.2	Amplification and Analysis of the Electronic Signal	30
3.3	The Gamma Camera	31
3.3.1	Collimator Designs	34
3.3.2	Image Acquisition, Display, and Analysis	34
3.4	Single Photon Emission Computed Tomography	37
3.5	Positron Emission Tomography	38
3.5.1	Design of the PET Tomograph	40
3.5.2	Time-of-Flight PET	40
3.6	Multimodality Imaging – SPECT/CT, PET/CT, and PET/MR	41
3.7	Summary	42
	References	42
<b>4</b>	<b>Radionuclide Production and Radiopharmaceuticals</b>	<b>46</b>
	<i>Noor Al-saden and Raymond M. Reilly</i>	
4.1	Introduction	46
4.2	Production of Radionuclides	47
4.2.1	Reactor Production	48
4.2.2	Cyclotron Production	50
4.2.3	Generator Production	52
4.2.3.1	$^{99}\text{Mo}/^{99\text{m}}\text{Tc}$ Generator	54
4.2.3.2	$^{68}\text{Ge}/^{68}\text{Ga}$ and $^{82}\text{Sr}/^{82}\text{Rb}$ Generators	56
4.3	Radiopharmaceutical Preparation and Supply	57
4.4	Radiopharmaceuticals for Cardiac Imaging	58
4.4.1	$^{99\text{m}}\text{Tc}$ -Sestamibi	60
4.4.2	$^{99\text{m}}\text{Tc}$ -Tetrofosmin	60
4.4.3	$^{201}\text{Tl}$ Thallous Chloride	61
4.4.4	$^{82}\text{Rb}$ Rubidium Chloride	62
4.4.5	$^{15}\text{O}$ Water ( $\text{H}_2^{15}\text{O}$ )	62
4.4.6	$^{13}\text{N}$ Ammonia ( $^{13}\text{NH}_3$ )	62
4.4.7	$^{99\text{m}}\text{Tc}$ Red Blood Cells	62
4.4.8	$^{18}\text{F}$ -2-Fluorodeoxyglucose ( $^{18}\text{F}$ -FDG)	63
4.4.9	$^{123}\text{I}$ -Metaiodobenzylguanidine ( $^{123}\text{I}$ -MIBG)	63
4.5	Radiopharmaceuticals for Tumor Imaging	63
4.5.1	$^{18}\text{F}$ -Fluoro-L-Thymidine ( $^{18}\text{F}$ -FLT)	64
4.5.2	$^{18}\text{F}$ -Fluorodeoxyglucose ( $^{18}\text{F}$ -FDG)	64
4.5.3	$^{18}\text{F}$ - and $^{11}\text{C}$ -Choline	67
4.5.4	$^{18}\text{F}$ -FAZA	67

4.5.5	$^{18}\text{F}$ -Fluoroethyltyrosine ( $^{18}\text{F}$ -FET)	67
4.5.6	$^{111}\text{In}$ -Pentetreotide and $^{68}\text{Ga}$ -DOTATOC/DOTATATE	67
4.5.7	$^{123}\text{I}$ -Metaiodobenzylguanidine ( $^{123}\text{I}$ -MIBG)	68
4.5.8	$^{123}\text{I}$ and $^{131}\text{I}$ Sodium Iodide	68
4.5.9	$^{67}\text{Ga}$ Gallium Citrate	69
4.5.10	$^{111}\text{In}$ -Ibritumomab Tiuxetan	69
4.5.11	$^{111}\text{In}$ -Capromab Pendetide	69
4.6	Radiopharmaceuticals for Brain/CNS Imaging	70
4.6.1	$^{18}\text{F}$ -Fluorodeoxyglucose ( $^{18}\text{F}$ -FDG)	70
4.6.2	$^{99\text{m}}\text{Tc}$ -HMPAO ( $^{99\text{m}}\text{Tc}$ -Exametazime)	70
4.6.3	$^{99\text{m}}\text{Tc}$ -ECD ( $^{99\text{m}}\text{Tc}$ -Bicisate)	72
4.6.4	$^{15}\text{O}$ Water ( $\text{H}_2^{15}\text{O}$ ) and $^{13}\text{N}$ Ammonia ( $^{13}\text{NH}_3$ )	72
4.6.5	$^{123}\text{I}$ -Iodobenzamide ( $^{123}\text{I}$ -IBZM) and $^{11}\text{C}$ -Raclopride	72
4.6.6	$^{11}\text{C}$ -Methylspiperone	73
4.6.7	$^{18}\text{F}$ -Fluorodopa ( $^{18}\text{F}$ -FDOPA)	73
4.6.8	$^{11}\text{C}$ -Flumazenil and $^{123}\text{I}$ -Iomazenil	74
4.6.9	$^{111}\text{In}$ -Diethylenetriaminepentaacetic Acid ( $^{111}\text{In}$ -DTPA)	74
4.7	Radiopharmaceuticals for Renal Imaging	74
4.7.1	$^{99\text{m}}\text{Tc}$ -Diethylenetriaminepentaacetic Acid ( $^{99\text{m}}\text{Tc}$ -DTPA)	74
4.7.2	$^{99\text{m}}\text{Tc}$ -MAG <sub>3</sub> ( $^{99\text{m}}\text{Tc}$ -Mertiatide)	76
4.7.3	$^{99\text{m}}\text{Tc}$ -Glucoheptonate	76
4.7.4	$^{99\text{m}}\text{Tc}$ -DMSA ( $^{99\text{m}}\text{Tc}$ -Succimer)	76
4.8	Radiopharmaceuticals for Hepatobiliary Imaging	76
4.8.1	$^{99\text{m}}\text{Tc}$ Sulfur Colloid	77
4.8.2	$^{99\text{m}}\text{Tc}$ -Iminodiacetic Acid Derivatives	77
4.9	Radiopharmaceuticals for Bone Imaging	77
4.9.1	$^{99\text{m}}\text{Tc}$ -Bisphosphonates	78
4.9.2	$^{18}\text{F}$ -Sodium Fluoride ( $\text{Na}^{18}\text{F}$ )	79
4.10	Radiopharmaceuticals for Lung Imaging	79
4.10.1	$^{99\text{m}}\text{Tc}$ -Macroaggregated Albumin ( $^{99\text{m}}\text{Tc}$ -MAA)	79
4.10.2	$^{99\text{m}}\text{Tc}$ -Aerosols	80
4.11	Radiopharmaceuticals for Thyroid/Parathyroid Imaging	80
4.11.1	$^{123}\text{I}$ - and $^{131}\text{I}$ Sodium Iodide ( $\text{Na}^{123}\text{I}$ and $\text{Na}^{131}\text{I}$ )	81
4.11.2	$^{99\text{m}}\text{Tc}$ Sodium Pertechnetate ( $^{99\text{m}}\text{TcO}_4^-$ )	82
4.11.3	Other Thyroid Imaging Agents	82
4.11.4	Parathyroid Gland Imaging Agents	82
4.12	Radiopharmaceuticals for Imaging Infection/Inflammation	83
4.12.1	$^{67}\text{Ga}$ Gallium Citrate	83
4.12.2	$^{111}\text{In}$ - or $^{99\text{m}}\text{Tc}$ -Labeled Leukocytes ( $^{111}\text{In}$ - or $^{99\text{m}}\text{Tc}$ -WBC)	83
4.12.3	$^{99\text{m}}\text{Tc}$ -Sulesomab Fab'	84
4.13	Therapeutic Radiopharmaceuticals	84
4.14	Summary	85
	Reference	85
	Additional Reading	85

**5 Magnetic Resonance Imaging (MRI) Technology 87**

*Raymond M. Reilly*

- 5.1 Introduction 87
- 5.2 Principles of MRI 87
  - 5.2.1 Precession 88
  - 5.2.2 Resonance and Phase 90
  - 5.2.3 The Magnetic Resonance Signal 91
  - 5.2.4 RF Pulse Sequences 92
  - 5.2.5 T1- and T2-Times 94
  - 5.2.6 T1- and T2-Weighted MRI 94
  - 5.2.7 Signal Encoding Using Magnetic Gradients 95
  - 5.2.8 *K*-Space and Image Formation 97
- 5.3 Components of the MRI System 98
  - 5.3.1 Superconducting Magnet 99
  - 5.3.2 Gradient Coils 99
  - 5.3.3 RF Coils 100
  - 5.3.4 Computer and Image Storage System 100
- 5.4 MRI Safety Considerations 100
- 5.5 MRI Contrast Agents 102
- 5.6 Summary 104
  - References 105
  - Additional Reading 105

**6 Ultrasound Imaging Technology 107**

*Raymond M. Reilly*

- 6.1 Principles of Ultrasound Imaging 107
  - 6.1.1 US Transducer 109
  - 6.1.2 Image Acquisition and Display Modes 110
- 6.2 Doppler US 111
- 6.3 US Contrast Agents 112
- 6.4 Summary 113
  - References 113
  - Additional Reading 113

**7 Cardiac Imaging 117**

*Laura Jimenez-Juan, Shaheeda Ahmed, and Katherine Zukotynski*

- 7.1 Introduction 117
- 7.2 Cardiovascular Magnetic Resonance Imaging (CMR) 117
- 7.3 Cardiovascular MRI Techniques 118
  - 7.3.1 Cardiac Anatomy 118
  - 7.3.2 Cardiac Function 118
  - 7.3.3 Myocardial Tissue Characterization 119
  - 7.3.4 Clinical Importance of the Assessment of Myocardial Viability 124

7.3.5	Prognostic Value of LGE Imaging After Myocardial Infarction	125
7.3.6	Other Imaging Modalities for Assessment of Myocardial Viability	126
7.4	Echocardiography	129
7.4.1	Clinical Applications of Echocardiography	130
7.4.1.1	The Cardiac Chambers	130
7.4.1.2	Cardiac Valves	133
7.4.1.3	Pericardial Disease and the Great Vessels	133
7.5	Nuclear Cardiology	133
7.5.1	Myocardial Perfusion Imaging	134
7.5.2	PET Myocardial Viability Imaging	136
7.5.3	MUGA Scans	139
7.6	Summary	140
	References	140
<b>8</b>	<b>Lung Imaging</b>	<b>146</b>
	<i>Anastasia Oikonomou</i>	
8.1	Introduction	146
8.2	Chest Radiograph – Projections	146
8.3	Normal Findings in a Chest X-Ray	148
8.3.1	Airways – Pulmonary Lobes and Segments	148
8.3.2	Pulmonary Arteries and Veins	151
8.3.2.1	Pulmonary Hila	151
8.3.2.2	Radiographic Density and Pulmonary Markings	153
8.3.3	Pleura – Fissures	153
8.3.4	Mediastinum	154
8.3.5	Heart	154
8.3.6	Diaphragm	155
8.3.7	Chest Wall	155
8.4	Normal Findings in a Chest CT	155
8.5	Pneumonia	158
8.6	Tuberculosis	159
8.7	Chronic Obstructive Pulmonary Disease	163
8.7.1	Emphysema	163
8.7.2	Chronic Bronchitis	164
8.7.3	Bronchiectasis	165
8.7.4	Asthma	166
8.8	Pleural Effusion	167
8.9	Pneumothorax	169
8.10	Pulmonary Embolism	170
8.11	Solitary Pulmonary Nodule	172
8.12	Lung Cancer	176
8.13	Summary	178
	References	180

<b>9</b>	<b>Breast Imaging</b>	<b>186</b>
	<i>Hemi Dua and Jagbir Khinda</i>	
9.1	Introduction	186
9.2	Risk Factors for Breast Cancer	186
9.3	Guidelines for Breast Cancer Screening	187
9.3.1	Screening in Average Risk Women	188
9.3.2	High-risk Screening	188
9.4	Breast Anatomy	189
9.5	Imaging Techniques	191
9.6	Mammography	191
9.6.1	Mammography System	191
9.6.2	Image Review and Mammography Views	192
9.6.2.1	Craniocaudal (CC) View	193
9.6.2.2	Mediolateral Oblique (MLO) View	193
9.6.3	Normal Mammogram	193
9.6.4	Screening vs. Diagnostic Mammogram	195
9.6.5	Mammographic BI-RADS Lexicon	196
9.6.6	Breast Tomosynthesis	197
9.7	Ultrasound Imaging	197
9.7.1	Ultrasound Technique	198
9.7.2	Ultrasound BI-RADS Lexicon	198
9.8	Breast MRI	198
9.8.1	Indications	200
9.8.2	Enhancement Kinetics	201
9.8.3	Breast MRI BI-RADS	201
9.9	PEM and Breast-Specific Gamma Camera Imaging	202
9.10	Contrast-Enhanced Spectral Mammography	202
9.11	The ABCs of Breast Imaging – Image Interpretation	203
9.11.1	Benign vs. Malignant Imaging Features	203
9.11.2	Breast Masses	203
9.11.2.1	Fat-containing Breast Masses	203
9.11.2.2	Circumscribed Solid Masses	203
9.11.2.3	Cystic Breast Masses	207
9.11.2.4	Malignant Masses	207
9.11.2.5	Axillary Masses	207
9.11.2.6	Breast Calcifications	207
9.11.2.7	Breast Asymmetries	207
9.12	BI-RADS Assessment Categories	209
9.13	Image-Guided Breast Intervention	209
9.13.1	Ultrasound-Guided Core Needle Biopsy	216
9.13.2	Ultrasound-Guided Needle Aspiration	216
9.13.3	Stereotactic-Vacuum-Assisted Core Needle Biopsy	217
9.13.4	MR-Guided Vacuum-Assisted Core Biopsy	218

- 9.13.5 Radiopaque Markers 218
- 9.13.6 Pre-Operative Image-Guided Wire Localization and Specimen Imaging 218
- 9.14 Extramammary Staging 219
- 9.15 Breast Lymphoscintigraphy 220
- 9.16 Summary 220
- References 220
  
- 10 Endocrine Gland Imaging 225**  
*Katerina Mastrocostas, Kim May Lam, Shereen Ezzat, and Sangeet Ghai*
- 10.1 Introduction 225
- 10.2 The Thyroid Gland 225
- 10.3 Thyroid Hormone Diseases 227
  - 10.3.1 Increased Production of Thyroid Hormones 227
  - 10.3.2 Graves Disease 229
  - 10.3.3 Hyperfunctional “Toxic” Thyroid Adenoma 230
  - 10.3.4 Hyperfunctional “Toxic” Multinodular Goiter 232
  - 10.3.5 Granulomatous (de Quervain) Thyroiditis 234
  - 10.3.6 Subacute Lymphocytic Thyroiditis 234
  - 10.3.7 Struma Ovarii 235
  - 10.3.8 Radioactive Iodine Treatment of Hyperthyroidism 236
  - 10.3.9 Decreased Production of Thyroid Hormones 237
  - 10.3.10 Primary Hypothyroidism 237
  - 10.3.11 Secondary Hypothyroidism 238
  - 10.3.12 Use of Iodinated Contrast in Thyroid Disease 239
  - 10.3.13 Mass Lesions in the Thyroid Gland 239
- 10.4 Thyroid Cancer 240
  - 10.4.1 Thyroid Cancer Metastasis 241
  - 10.4.2 Imaging Thyroid Cancer Metastases 243
  - 10.4.3 Radioactive Iodine Treatment of Thyroid Cancer 243
- 10.5 The Parathyroid Glands 244
  - 10.5.1 Altered Production of PTH 244
  - 10.5.2 Primary Hyperparathyroidism 245
  - 10.5.3 Parathyroid Adenoma 246
  - 10.5.4 Parathyroid Hyperplasia 247
  - 10.5.5 Parathyroid Carcinoma 248
  - 10.5.6 Parathyroid 4D CT Imaging 248
  - 10.5.7 Secondary and Tertiary Hyperparathyroidism 248
- 10.6 The Adrenal Glands 249
  - 10.7 Mass Lesions of the Adrenal Cortex 250
    - 10.7.1 Adrenocortical Adenoma 250
    - 10.7.2 Adrenocortical Carcinoma 252
    - 10.7.3 Adrenal Myelolipoma 253

- 10.8 Mass Lesions of the Adrenal Medulla 253
- 10.8.1 Pheochromocytoma and Extra-adrenal Paraganglioma 253
- 10.9 Other Neuroendocrine Diseases 255
- 10.9.1 Pancreatic Neuroendocrine Tumors (PanNET) 255
- 10.9.2 Carcinoid Tumor 258
- 10.10 Summary 259
- Additional Reading 260
  
- 11 Abdominal Imaging 264**  
*Vivek Singh and Chirag Patel*
- 11.1 Introduction 264
- 11.2 Surgical Sieve 265
- 11.3 Peritoneum/Mesentery 265
- 11.4 Acute Peritoneal Pathologies 266
- 11.4.1 Pneumoperitoneum 266
- 11.4.2 Hemoperitoneum 267
- 11.4.3 Ascites 268
- 11.4.4 Peritoneal Carcinomatosis 269
- 11.5 Gastrointestinal Tract 270
- 11.5.1 Bowel Obstruction 271
- 11.5.2 Diverticulitis 274
- 11.5.3 Appendicitis 277
- 11.6 Inflammatory Bowel Disease 279
- 11.6.1 Crohn's Disease 279
- 11.6.2 Ulcerative Colitis 280
- 11.7 Colorectal Adenocarcinoma 282
- 11.7.1 Screening 282
- 11.7.2 Imaging 285
- 11.8 Hepatic System 287
- 11.9 Diffuse Hepatic Disease 289
- 11.9.1 Fatty Infiltration 289
- 11.9.2 Hepatic Cirrhosis 290
- 11.10 Focal Hepatic Disease 292
- 11.10.1 Hepatic Abscess 292
- 11.10.2 Cavernous Hemangioma 293
- 11.10.3 Cysts 294
- 11.10.4 Focal Nodular Hyperplasia 295
- 11.10.5 Hepatic Metastases 296
- 11.10.6 Hepatocellular Carcinoma 299
- 11.11 Biliary Tract 300
- 11.12 Gallbladder 301
- 11.12.1 Cholelithiasis 301
- 11.12.2 Acute Cholecystitis 302



- 11.12.3 Neoplasms 302
- 11.13 Bile Ducts 304
- 11.13.1 Biliary Dilation 304
- 11.13.2 Neoplasms 305
- 11.14 Pancreas 306
- 11.14.1 Acute Pancreatitis 306
- 11.14.2 Pancreatic Trauma 309
- 11.14.3 Chronic Pancreatitis 310
- 11.14.4 Pancreatic Neoplasms 310
- 11.14.5 Pancreatic Ductal Adenocarcinoma 311
- 11.15 Spleen/Lymph Nodes 313
- 11.15.1 Splenic Trauma 315
- 11.15.2 Splenomegaly/Splenic Masses 316
- 11.15.3 Lymphadenopathy 316
- 11.16 Summary 316
- Reference 317
- Additional Reading 317

## **12 Genitourinary Tract Imaging 320**

*Sarah Johnson*

- 12.1 Introduction 320
- 12.2 GU System Imaging Modalities 321
- 12.2.1 Ultrasound 321
- 12.2.2 Computed Tomography 326
- 12.2.3 Magnetic Resonance Imaging 326
- 12.2.4 Nuclear Scintigraphy 326
- 12.3 Evaluation of the Kidneys and Collecting Systems 328
- 12.3.1 Urinary Tract Calculi (Nephroureterolithiasis) 328
- 12.3.2 Renal Infection and Inflammation 329
- 12.3.3 Renal Vascular Anomalies 332
- 12.3.4 Renal Lesions 333
- 12.3.5 Renal Transplants 336
- 12.3.6 Renal Function and Dysfunction 337
- 12.3.7 Ureteric Neoplasms 339
- 12.4 Bladder and Urethra 343
- 12.4.1 Bladder Cancer 343
- 12.4.2 Lower Urinary Tract Trauma 343
- 12.5 Testicles 345
- 12.5.1 Testicular Cancer 345
- 12.5.2 Testicular Pain 346
- 12.6 Prostate 348
- 12.7 Female Genitourinary Tract 350
- 12.7.1 Abnormal Vaginal Bleeding 350

12.7.2	Endometrial Cancer	351
12.7.3	Cervical Cancer	353
12.7.4	Adnexal Masses and Ovarian Cancer	354
12.7.5	Acute Pelvic Pain	355
12.7.6	Pregnancy – First Trimester	356
12.7.7	Obstetrical Evaluation	357
12.7.8	Pregnancy – Second and Third Trimester	358
12.8	Pediatric Genitourinary Tract	360
12.8.1	Congenital Anomalies	360
12.8.2	Cystic Renal Disease	361
12.8.3	Renal Masses	361
12.8.4	Urinary Tract Infections	362
12.8.5	Assessing Pediatric Genitalia	363
12.9	Summary	364
	References	364

### **13 Imaging of the Head, Neck, Spine, and Brain 371**

*Laila Alshafai, Eugene Yu, and Sylvain Houle*

13.1	Introduction	371
13.2	Imaging the Skull and Brain	372
13.2.1	Trauma	372
13.2.2	Vascular Imaging	372
13.2.3	Tumor Imaging	378
13.2.4	Infection Imaging	379
13.2.5	Imaging Inflammatory/Metabolic Lesions	382
13.2.6	Imaging Dementia	382
13.3	Imaging the Spine	383
13.3.1	Trauma	383
13.3.2	Vascular Imaging	385
13.3.3	Tumor Imaging	385
13.3.4	Infection Imaging	385
13.3.5	Imaging Inflammatory/Metabolic Conditions	387
13.4	Imaging the Head and Neck	390
13.4.1	Trauma	390
13.4.2	Vascular Imaging	393
13.4.3	Tumor Imaging	394
13.4.4	Infection Imaging	395
13.4.5	Imaging Inflammatory Conditions	395
13.5	PET and SPECT Neuroimaging	396
13.6	Summary	401
	References	401

- 14 Musculoskeletal Imaging 404**  
*Rakesh Mohankumar and Ali Naraghi*
- 14.1 Introduction 404
- 14.2 Plain Radiography (X-rays) 404
- 14.3 Computed Tomography 408
- 14.4 Magnetic Resonance Imaging 411
- 14.5 Ultrasound 413
- 14.6 Applications of Musculoskeletal Imaging 415
- 14.6.1 Trauma 415
- 14.6.2 Infection 417
- 14.6.3 Arthritis 420
- 14.6.4 Musculoskeletal Tumors 427
- 14.7 Summary 435
- Additional Reading 435
- 15 Molecular Imaging with Positron Emission Tomography 439**  
*Ur Metser, Noam Tau, and Amit Singnurkar*
- 15.1 Introduction 439
- 15.2 PET Probes Including  $^{18}\text{F}$ -FDG 440
- 15.2.1  $^{18}\text{F}$ -FDG PET/CT Protocol 440
- 15.2.2 Technical Considerations in Performing and Interpreting PET 440
- 15.3  $^{18}\text{F}$ -FDG PET in Oncology 442
- 15.3.1  $^{18}\text{F}$ -FDG-PET/CT in the Management of Lung Cancer 442
- 15.3.2 Role of  $^{18}\text{F}$ -FDG PET in Lymphoma 445
- 15.3.2.1 Staging 445
- 15.3.2.2 Therapy Response Assessment 446
- 15.3.3  $^{18}\text{F}$ -FDG PET/CT in Gastrointestinal Malignancies 448
- 15.3.3.1  $^{18}\text{F}$ -FDG-PET/CT in Esophageal Cancer 448
- 15.3.3.2  $^{18}\text{F}$ -FDG-PET/CT in Colorectal Cancer 450
- 15.3.4  $^{18}\text{F}$ -FDG-PET/CT in Head and Neck Cancers 452
- 15.4  $^{18}\text{F}$ -FDG PET in Non-Oncology Indications 453
- 15.4.1 Cardiac PET 453
- 15.4.2 Neurological Applications of PET 455
- 15.4.3  $^{18}\text{F}$ -FDG-PET in Infectious and Inflammatory Disorders 457
- 15.4.3.1 Sarcoidosis 457
- 15.4.3.2 Fever of Unknown Origin 458
- 15.4.3.3 Infected Implanted Medical Devices 459
- 15.5 Overview of Other PET Radiopharmaceuticals 460
- 15.5.1 Other PET Agents for Myocardial Perfusion Imaging 461
- 15.5.2 Agents for Imaging Tumor Proliferation 461
- 15.5.3 Agents for Tumor Receptor Imaging 463
- 15.5.3.1  $^{68}\text{Ga}$ -DOTATATE 463

15.5.3.2	Imaging PSMA in Prostate Cancer	465
15.5.4	Imaging Tumor Hypoxia	466
15.6	Multimodal Imaging – PET/CT Versus PET/MR	468
15.6.1	Technical Challenges in PET/MR	468
15.6.2	Current Status of Clinical PET/MRI	469
15.7	Summary	470
	References	470

<b>Index</b>	<b>485</b>
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## Preface

Patient care is interdisciplinary and requires a health-care team approach to be most effective. The health-care team includes pharmacists, nurses, physiotherapists, medical technologists, and other allied health-care professionals who interact on a daily basis with physicians who have a wide range of specialties. Appropriate treatment relies on an accurate diagnosis, thus diagnostics and therapeutics are the two pillars of an optimal patient-care plan. Medical imaging is a critical tool in diagnosing disease and in assessing the effectiveness of treatment. Radiologists and nuclear medicine physicians are the experts in medical imaging on the health-care team and treatment decisions rely on their judgement. Non-radiologist professionals on the health-care team need to understand medical imaging in order to appreciate the results of these tests that are communicated by the radiologists and nuclear medicine physicians. This book aims to educate the non-radiologist health professional about medical imaging, including the principles of the imaging technologies as well as the most common clinical applications of medical imaging. The terminology in the book has been carefully edited to make it suitable for a broader health professional readership. The motivation for this book arises from an elective course that I teach on Medical Imaging for Pharmacists, at the University of Toronto. This course has proven to be very popular among the undergraduate pharmacy students. Practicing pharmacists have similarly expressed a strong interest in learning more about medical imaging, and therefore, I hope that this book will provide an important learning tool for students in the health professions as well as practicing health professionals.

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## Acknowledgments

The editor greatly appreciates the contributions of the radiologists to this book in writing the clinical chapters and their understanding of the need to communicate the important role of medical imaging in terminology that is understood by most health professionals. Most of all, the editor thanks all of the contributors for their great patience in awaiting completion of the book. The editor hopes that all authors and readers will be pleased with the book, which is one of the few aimed at a wide range of health professionals who recognize the importance of medical imaging in patient care.





## Raymond M. Reilly

Raymond Reilly is a Full Professor and Director of the Centre for Pharmaceutical Oncology at the Leslie Dan Faculty of Pharmacy, University of Toronto. He is a pharmacist, who obtained his BScPhm and MScPhm degrees in pharmacy and a PhD in Medical Biophysics from the University of Toronto. Dr. Reilly practiced as a nuclear pharmacist in nuclear medicine at the University Health Network in Toronto prior to

his academic position. He teaches undergraduate courses in the PharmD program in the areas of clinical laboratory medicine and medical imaging, and teaches a graduate course on radiopharmaceuticals. Dr. Reilly's research is focused on the development of molecular imaging and radioimmunotherapeutic agents for cancer. He has trained 15 PhD and 12 MSc students. His research is supported by the Canadian Institutes of Health Research, the Canadian Breast Cancer Foundation, the Canadian Cancer Society Research Institute and the Ontario Institute for Cancer Research.

## 1

## Introduction to Medical Imaging

*Raymond M. Reilly*

### 1.1 Medical Imaging Procedures

Medical imaging is widely used in patient care to diagnose disease, to plan treatment, and to monitor response to treatment. Medical imaging includes radiological technologies such as X-ray, computed tomography (CT), mammography, ultrasound (US), and magnetic resonance imaging (MRI) as well as nuclear medicine imaging, which includes single photon computed tomography (SPECT) and positron emission tomography (PET). In the United States (U.S.), there were almost 400 million radiological imaging procedures performed in 2006 (most recent data) including 18 million nuclear medicine studies, a 10-fold increase since 1950 [1]. Worldwide, there were more than 3.6 billion medical imaging procedures performed annually from 1997 to 2007 and 36 million nuclear medicine tests [1]. More recent data from Canada in 2015 show that nine million imaging tests are performed each year, including 1.5 million SPECT/CT studies and almost 80 000 PET procedures (Table 1.1). Statistics in the U.S. are likely more than 10-fold higher, due to the population size differences between Canada and the U.S. PET has been more widely adopted in the U.S. and it is estimated that there are more than 1.5 million PET scans performed in that country each year [2]. Medical imaging procedures are used to diagnose a wide range of disease conditions including infections, cancer, myocardial perfusion and function, abdominal masses, thyroid disorders, renal dysfunction, liver and biliary tract diseases, Alzheimer's and Parkinson's disease, muscle and bone abnormalities, and many others. Chapters 2–6 in this book present the basic principles of medical imaging technologies while Chapters 7–15 discuss the clinical applications of medical imaging. In this chapter, the general considerations of different medical imaging technologies will be discussed.

**Table 1.1** Number of medical imaging procedures in Canada each year.

Technology	Number of imaging systems	Number of procedures each year (million)
CT	538	5.28
MRI	340	1.95
SPECT and SPECT/CT	478	1.48
PET	47	0.077

Source: Data from <https://www.cadth.ca/canadian-medical-imaging-inventory-2015>.

### 1.1.1 Procedures Involving Ionizing vs. Nonionizing Radiation

Some medical imaging procedures (X-ray, CT, mammography, SPECT, and PET) employ radiation that has sufficient energy to ionize biological molecules, while other procedures (MRI and US) do not cause such ionizations. Since the body is composed mostly of water molecules, most ionizations result in formation of hydroxyl free radicals (HO•) and hydronium ions (H<sub>3</sub>O<sup>+</sup>). These species have the potential to cause DNA strand breaks that could increase the long-term risk for cancer (see Section 1.2). The minimum energy required to ionize molecules is >5–100 electron volts (eV). An electron volt is defined as the energy acquired by an electron when accelerated across a potential difference of 1 V. The energy of different forms of electromagnetic radiation in electron volts is shown in Table 1.2. X-ray, CT, and mammography, which utilize X-rays for imaging, and SPECT and PET, which employ  $\gamma$ -rays emitted by radiopharmaceuticals, cause ionizations in biological molecules. In contrast, MRI employs radiofrequency (RF) energy, which has insufficient energy to cause ionizations. US imaging employs high-frequency sound waves that have extremely low energy in eV ( $8\text{--}40 \times 10^{-9}$  eV), which is not able to cause ionizations. Thus, sometimes a technology that is nonionizing (e.g. MRI or US) may be preferred over one that is ionizing (e.g. CT, SPECT, or PET) to minimize the risk for long-term effects such as cancer, especially if these technologies are available and provide equivalent diagnostic information. When imaging technologies that use ionizing radiation are required, the radiation dose to the

**Table 1.2** Energy of different forms of radiation in electron volts (eV).

Type of radiation	Imaging procedure	Energy (eV)
Ultrasound waves	US	<0.00000004
Radiofrequency	MRI	<0.001
X-rays	X-ray and CT	1000–10 000
$\gamma$ -Rays	SPECT and PET	100 000–500 000

patient is kept as low as possible to minimize long-term risks (As Low as Reasonably Achievable [ALARA] principle). Nonetheless, these risks from medical imaging procedures are very low (see Section 1.2).

## 1.2 Radiation Doses from Medical Imaging Procedures

The energy deposited per unit mass of tissue by radiation is known as the *radiation dose*. The SI unit of radiation dose is the Gray, which is defined as 1 Joule per kg ( $\text{J kg}^{-1}$ ). An older unit still in use in the United States is the rad, which is defined as  $100 \text{ ergs g}^{-1}$  of tissue ( $0.01 \text{ J kg}^{-1}$ ). Since different types of radiations exhibit different abilities to cause biological damage, this is further incorporated into the term *equivalent dose*, which has units of Sievert (Sv) or rem. The Sv or rem is the Gy or rad multiplied by a radiation weighting factor ( $w_R$ ). The  $w_R$  for X-rays and  $\gamma$ -rays is 1, thus in medical imaging,  $1 \text{ Sv} = 1 \text{ Gy}$  and  $1 \text{ rem} = 1 \text{ rad}$ . Once radiation doses are estimated, a further refinement takes into account the relative radiation sensitivity of tissues by multiplying the dose estimates by a tissue sensitivity factor ( $w_T$ ) to provide the *effective dose*. The units of effective dose remain the Sv or rem. Estimates of radiation doses from medical imaging procedures inform on possible acute effects as well as long-term risks such as the development of cancer. The radiation doses from most medical imaging procedures range from 1 to 14 mSv (Table 1.3) [3].

**Table 1.3** Radiation doses from common medical imaging procedures.<sup>a</sup>

Imaging procedure	Modality	Radiation dose (mSv)
Chest	X-ray	0.02–0.04
Lumbar spine	X-ray	0.7
Mammogram	X-ray	0.7
Abdomen	CT	10.0
Coronary angiogram	CT	4.6–15.8
Bone scan ( $^{99\text{m}}\text{Tc-MDP}$ )	SPECT	4.2
V/Q lung scan ( $^{99\text{m}}\text{Tc-MAA}/^{99\text{m}}\text{Tc aerosol}$ )	SPECT	2.0
Renal scan ( $^{99\text{m}}\text{Tc-MAG}_3$ )	SPECT	3.6–5.2
Myocardial perfusion scan ( $^{99\text{m}}\text{Tc-sestamibi}/^{99\text{m}}\text{Tc-tetrofosmin}$ )	SPECT	11.2
Whole body scan ( $^{18}\text{F}$ FDG)	PET	14.0

<sup>a</sup> Whole-body dose.

Source: Data from <https://hps.org/documents/meddiagimaging.pdf>.