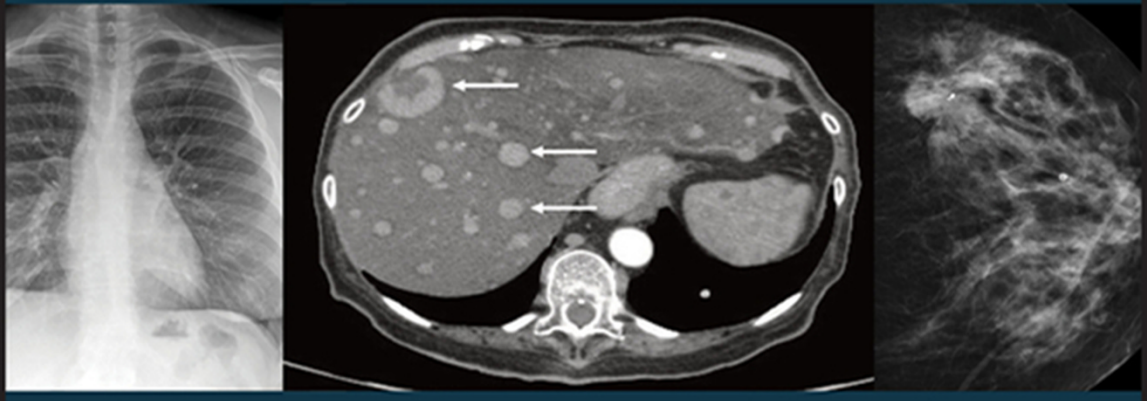
Medical Imaging for Health Professionals

Technologies and Clinical Applications

Edited by
Raymond M. Reilly, Ph.D



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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.

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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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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.

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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.

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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 ($HO^{\bullet}$) and hydronium ions (H_3O^+). 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 γ-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 ($8–40 \times 10^{-9}$ 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	<0.000 000 04
Radiofrequency	MRI	<0.001
X-rays	X-ray and CT	1000–10 000
γ-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 ($J\,kg^{-1}$). An older unit still in use in the United States is the rad, which is defined as 100 ergs g^{-1} of tissue (0.01 $J\,kg^{-1}$). 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 γ-rays is 1, thus in medical imaging, 1 Sv = 1 Gy and 1 rem = 1 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.[a]

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 (^{99m}Tc-MDP)	SPECT	4.2
V/*Q* lung scan (^{99m}Tc-MAA/^{99m}Tc aerosol)	SPECT	2.0
Renal scan (^{99m}Tc-MAG_3)	SPECT	3.6–5.2
Myocardial perfusion scan (^{99m}Tc-sestamibi/^{99m}Tc-tetrofosmin)	SPECT	11.2
Whole body scan (^{18}FDG)	PET	14.0

[a] Whole-body dose.
Source: Data from https://hps.org/documents/meddiagimaging.pdf.