A COMPREHENSIVE GUIDE TO

RADIOGRAPHIC SCIENCES AND TECHNOLOGY

EUCLID SEERAM

WILEY Blackwell

A Comprehensive Guide to Radiographic Sciences and Technology

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Dedication

This book is dedicated with love to my Family; my lovely wife, Trish; our son David and daughter-in-law Priscilla; and our two very smart, cute, and witty granddaughters, Claire and Charlotte

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Foreword

Dr Euclid Seeram is a recognized educator in the field of radiographic sciences, including computed tomography (CT) physics and instrumentation for radiologic technologists/radiographers. He has published over 22 textbooks on various topics related to these two subjects. His textbooks can be found in universities and colleges around the world that offer medical imaging and radiographic science programs. He has a very well-developed approach in all his textbooks that allows the reader to understand complex topics.

Dr Seeram has decades of experience in the teaching radiographic sciences and CT. Euclid is also a highly regarded researcher in this field, gaining a PhD in digital radiography and radiation dose management strategies. He has continued to work and research in this area. Euclid is also a highly sought-after speaker and provides highly engaging talks and presentations on radiographic sciences and CT. The impact of Euclid's texts, journal articles, and presentations has had on radiologic technologists/radiographers, other related individuals, and medical physicists in their understanding of radiographic sciences and CT, cannot be understated.

The development of the technologies that underpin radiological science continues to grow rapidly and at an increasing rate. Students need to understand these technologies and the implications of these technologies in clinical practice. The approach undertaken by Dr Seeram in this text, *A Comprehensive Guide to Radiographic Sciences and Technology*, is to provide readers with clearly defined chapters on several related topics. The chapters and sections of this book are logically structured so the readers/learners can progress their understanding. Of growing importance in radiographic sciences, and often misunderstood, is the understanding of the radiation dose/image quality relationship of digital radiography. This area has a strong focus in this textbook. Furthermore, the knowledge gained from studying the subject matter covered in this book will benefit technologists/radiographers in clinical practice in order to provide tangible benefits to their patients.

I have been fortunate to know Dr Seeram for over 20 years, initially as his PhD supervisor, and now as a coresearcher, colleague, and friend/mate. Euclid continues to amaze me on his dedication and passion to educate radiologic technologists/radiographers and his drive to continue writing. Euclid must be commended for his continued efforts in making radiographic sciences, and CT knowledge easy to understand by students and practitioners.

Dr Robert Davidson, PhD, MAppSc (MI), BBus, FASMIRT
Professor of Medical Imaging, Faculty of Health,
University of Canberra, ACT, Australia

Preface

Radiographic sciences and technology include a wide range of topics essential for radiography/radiological technology curriculum offered by educational institutions (colleges, universities, and institutes of technology) around the world. Additionally, radiography/radiological technology/medical imaging professional organizations for radiographer/technologist education and training, such as, for example, the American Association of Radiologic Technologists (ASRT) and the Canadian Association of Medical Radiation Technologists (CAMRT) offer curriculum guidelines for educational institutions to use as guiding principles for core clinical competencies. More details of related activities are highlighted in Chapter 1.

This book includes 13 chapters organized into 6 sections as follows:

- *Section 1*: Chapters 1 and 2
- *Section 2*: Basic Radiographic Sciences and Technology
- *Section 3*: Computed Tomography: Basic Physics and Technology
- *Section 4:* Continuous Quality Improvement
- *Section 5*: Picture Archiving and Communications Systems (PACS) and Imaging Informatics
- *Section 6:* Radiation Protection

PURPOSE

The purpose of this book, *A Comprehensive Guide to Radiographic Sciences and Technology*, is to provide an essential and practical guide for students and technologists engaged in the study and practice of radiography/radiological technology. One of its primary goals is to provide a resource that is brief, clear, and a concise coverage of the subject in preparation for final examinations as well as professional certification examinations. This book is not a textbook as such, and it is not intended to replace the vast resources on radiographic sciences and technology. Rather, it provides a précis of the extensive coverage of radiographic sciences and technical system components for students and technologists.

CORE OBJECTIVES

On the successful completion of the chapters in this book, the reader will be able to:

1. Outline the core subject matter content of radiographic imaging modalities.
2. Identify and describe briefly the major technical components of digital radiographic imaging systems.
3. Outline the basic physics necessary for understanding essential concepts and principles for x-ray generation, production, x-ray emission, x-ray interaction with matter, and radiation attenuation in the production of diagnostic images in clinical practice.
4. Describe the major components of the x-ray generator and x-ray tube including heat capacity and heat dissipation and x-ray beam filtration and collimation.
5. Explain the core principles of digital image processing, including the characteristics of the digital image and common image processing operations applied in practice.
6. Identify and explain the fundamental physics principles and technology of the following digital imaging modalities: computed radiography (CR), flat-panel digital radiography (FPDR), and digital fluoroscopy.
7. Identify image quality metrics and explain each of them with a focus on how dose is linked to image quality.
8. Describe the basic physics of computed tomography (CT) and explain the major technological considerations of multislice CT (MSCT), including image post processing, image quality metrics, and radiation protection considerations in CT.
9. Identify the essential elements of quality control (QC), including the principles of a repeat analysis, and describe the performance criteria for common QC tests for radiography, fluoroscopy, and CT.
10. Describe the core technical components of PACS, and explain briefly the general subject matter comprising imaging informatics, including artificial intelligence and its subsets: machine learning and deep learning.
11. Outline the major principles of radiobiology, with a specific focus on relevant physical processes, dose–response models, stochastic and deterministic effects, as well as radiation effects on the conceptus.
12. Explain the technical factors affecting the dose in radiography, fluoroscopy, and CT.
13. Identify and discuss the major components of radiation protection including radiation protection philosophy of the International Commission on Radiological Protection (ICRP), radiation quantities and units, personnel dosimetry, optimization of radiation protection, and the current state of gonadal shielding.

USE OF THESE OBJECTIVES AND CONTENT

These objectives and content covered in this book may be used in the following subjects covered in standard radiography/radiological technology programs:

1. Physics of Radiography
2. Digital Radiography Equipment Including Digital Fluoroscopy
3. Image Quality
4. PACS and Imaging Informatics
5. Quality Control in Radiography and Fluoroscopy

6. Computed Tomography Physics and Instrumentation for Entry to Practice
7. Radiobiology for Diagnostic Radiography
8. Radiation Protection in Diagnostic Radiography

Chapter 1 introduces the nature and scope of radiographic sciences and technology and sets the general framework for the remaining chapters. Whereas Chapter 2 presents a description of the major technical components of digital radiographic imaging modalities, such as computed radiography (CR), FPDR, digital fluoroscopy, and digital mammography, Chapter 3 describes the essential physics of radiography, including principles for x-ray generation, production, x-ray emission, x-ray interaction with matter, and radiation attenuation in the production of diagnostic images in clinical practice. Chapter 4 examines the major technical components of the x-ray generator and x-ray tube, describing core technologies such as the x-ray circuit, x-ray generators, the structure and function of the x-ray tube, heat capacity and dissipation, as well as the nature of x-ray beam filtration and collimation. Chapter 5 reviews the fundamental elements of digital image processing beginning with a definition, followed by a review of image formation and representation, processing operations, characteristics of digital images, and gray-scale processing, most notably the nature of windowing. Chapters 6 and 7 address the principles and technology of digital radiographic imaging modalities, identified in Chapter 2, and image quality and dose, respectively. Chapter 8 covers the essential technical aspects of CT, at a depth needed for entry-to-practice, including the basic physics and technology of CT. Specifically, the major technical system components of MSCT are described. Furthermore, image processing, image quality, and radiation dose and radiation protection are described. Chapter 9 provides a discussion of quality control and focusses on the performance criteria/tolerance limits for common QC tests for radiography, fluoroscopy, and CT tests that are in the domain of the technologist. Finally, the chapter reviews the elements of repeat image analysis. The nature of imaging informatics including major topics as picture archiving and communication systems (PACS), and specific imaging topics such as enterprise imaging, cloud computing, Big Data, and artificial intelligence, and its subsets, machine learning and deep learning, are reviewed in Chapter 10. Finally, Section 6 covers topics in radiation protection. In particular, while Chapter 11 provides a discussion of basic concepts of radiobiology, Chapter 12 deals with the technical dose factors in radiography, fluoroscopy, and CT. Finally, the book concludes with Chapter 13, which addresses the essential principles of radiation protection, focusing on topics such as a rationale for radiation protection, objectives of radiation protection, radiation protection philosophy of the International Commission on Radiological Protection (ICRP), radiation quantities and units, personnel dosimetry, optimization of radiation protection, and the current state of gonadal shielding.

Enjoy the pages that follow and remember – your patients will benefit from your wisdom.

Euclid Seeram, PhD., MSc., BSc., FCAMRT
British Columbia, Canada

Acknowledgments

It is always a pleasure to acknowledge the contributions of experts in the field of radiographic sciences including radiologic physics, equipment, image quality, quality control, radiobiology and radiation protection from whom I have learned a great deal that allows me to write this book.

First, I am indeed grateful to all those who have dedicated their energies in providing several comprehensive volumes on radiologic physics and instrumentation for the radiologic community. I would like to acknowledge the notable medical physicist, Dr. Stewart Bushong ScD, FAAPM, FACR and experimental radiobiologist, Dr. Elizabeth Travis, PhD. I have learned a great deal on radiologic science from the works of Dr. Bushong, a professor of radiologic science in the Department of Radiology, Baylor College of Medicine, Houston, TX. In addition, I have gained further insight into the nature, scope, and depth of radiobiology and particularly its significance in radiology, from Dr. Travis, a researcher in the Department of Experimental Radiotherapy, University of Texas, MD Anderson Cancer Center, Houston, TX.

Secondly, I am grateful to physicist, Dr. Hans Swan, PhD and digital radiography expert, Dr. Rob Davidson, PhD, who served as my primary supervisors for my PhD dissertation entitled *Optimization of the Exposure Indicator of a Computed Radiography Imaging System as a Radiation Dose Management Strategy*. Furthermore, Dr. Stewart Bushong served as an external examiner for my PhD dissertation. Additionally, two other notable medical physicists from whom I have learned my digital radiography imaging physics and technology are Dr. Charles Willis, PhD (University of Texas; MD Anderson Cancer Center-Retired) and Dr. Anthony Seibert, PhD (University of California at Davis). Dr. Seibert's notable textbook on *The Essential Physics of Medical Imaging* has educated me in the core principles of medical imaging physics. Thanks to you all.

I must acknowledge all others, such as the authors whose papers I have cited and referenced in this book, thank you for your significant contributions to radiographic sciences knowledge base. Additionally, I would like to express my sincere thanks to Dr. Perry Sprawls, PhD, FACR, FAAPM, FIOMP, Distinguished Emeritus Professor, Emory University, Director, Sprawls Educational Foundation, http://www.sprawls.org, Co-Director, College on Medical Physics, ICTP, Trieste, Italy, and Co-Editor, Medical Physics International, http://www.mpijournal.org/.

Dr. Sprawls has always supported my writing and I appreciate his free resources on the World Wide Web (www) from which students, technologists, and educators alike can benefit. I must also mention Dr. Anthony Wolbarst, PhD, Medical Physics Department, University of Kentucky (Retired).

Another individual to whom I owe a good deal of thanks is Valentina Al Hamouche, MRT(R), MSc, who is the CEO/Founder VCA Education Solutions for Health Professionals http://www.VCAeducation.ca. Valentina has provided me with opportunities to provide radiographic sciences and CT physics and Instrumentation in-house lectures and webinars to further educate technologists and students across Canada and internationally. Thanks Valentina.

I must acknowledge James Watson, Commissioning Editor, Wiley, Oxford, UK, who understood and evaluated the need for this book. Additionally, I am grateful to Anupama Sreekanth, former project editor and current managing editor Anne Hunt at Wiley, for the advice and support you both provided to me during the writing stage of this book. Furthermore, I appreciate the work of Sandeep Kumar, Content Refinement Specialist at Wiley, who has done an excellent job in bringing this manuscript to fruition.

Finally, I am very grateful for the warm and wonderful support of my family: my lovely wife, Trish, a very wise and caring person; and my very smart son, David, a very special young man and the best Dad in the universe. Thank you both for your unending love, support, and encouragement.

Last, but not least, I want to express my gratitude to all the students in my radiographic sciences classes – your questions have provided me with a further insight into teaching this important subject. Thank you.

SECTION 1

Introduction

1

Radiographic sciences and technology: an overview

Radiographic Science and Technology have evolved through the years, ever since the discovery and use of x-rays in 1895. This evolution has resulted in the introduction of physical principles and technology with the major goal of improving the care and management of the patient. Furthermore, a significant benefit of these innovations is focused on reducing the radiation dose to the patient without compromising image quality. *Radiographic sciences* deal with the physics of various diagnostic imaging modalities (radiography, fluoroscopy, mammography, and computed tomography [CT]) and include x-ray generation, x-ray production, x-ray emission, and x-ray interaction with tissues. Furthermore, radiographic sciences also address radiation risks and radiation protection. *Radiographic technology,* on the other hand, addresses the equipment components and how they function to produce diagnostic images, image quality characteristics, and quality control (QC) aspects of these imaging modalities.

A Comprehensive Guide to Radiographic Sciences and Technology, First Edition. Euclid Seeram.

The workhorse of radiology has been *film-screen radiography* which is now obsolete and has been replaced globally with *digital imaging*. The scope of digital imaging is extremely wide and now involves a basic understanding of computer sciences, to explain how the new digital imaging modalities work. These modalities include computed radiography (CR), flat-panel digital radiography (FPDR), digital fluoroscopy (DF), digital mammography (DM), digital tomosynthesis, and CT. In addition, the digital imaging environment now demands that operators understand what has been referred to as "imaging informatics," an area of study that involves picture archiving and communication systems (PACS), enterprise imaging, Big Data, machine learning (ML), deep learning (DL), and artificial intelligence (AI).

With the above in mind, various professional organizations such as the American Society of Radiologic Technologists (ASRT), the Canadian Association of Medical Radiation Technologists (CAMRT), and other professional medical imaging organizations throughout the world have prescribed curricula for diagnostic imaging programs which provide guiding, principles that assist academic program leaders in designing foundational learning outcomes that are intended to meet the professional standards, and more importantly meet the entry requirements for clinical practice. Institutions offering educational programs in diagnostic imaging should be then able to raise the level of these foundational learning outcomes and content to meet the requirements of degree programs, including graduate degree programs in diagnostic imaging.

A good example of the above is offered by the ASRT curriculum content which is organized around the following subject matter [1]: Introduction to Radiologic Science and Health Care; Ethics and Law in the Radiologic Sciences; Human Anatomy and Physiology; Pharmacology and Venipuncture; Imaging Equipment; Radiation Production and Characteristics; Principles of Exposure and Image Production; Digital Image Acquisition and Display; Image Analysis; Radiation Biology; Radiation Protection; Clinical Practice; Patient Care in Radiologic Sciences; Radiographic Procedures; Radiographic Pathology; Additional Modalities and Radiation Therapy; Basic Principles of Computed Tomography and Sectional Anatomy. Similar content is characteristic of other curricula offered by other medical imaging professional organizations around the world.

Keeping the above ideas in mind, this book will address content that are considered radiographic sciences and technology. Specifically, the chapters included present a summary of the critical knowledge base needed for effective and efficient imaging of the patient, and wise use of the technical factors that play a significant role in optimization of the dose to the patient without compromising the image quality necessary for diagnostic interpretation. Furthermore, the summaries of the technical elements of radiographic sciences and technology will assist the student in preparing to write certification examinations. As such, the major and significant principles and concepts will be reviewed in three sections as follows:

Section 1: Radiographic imaging systems: major modalities and components
Section 2: Radiographic physics and technology
Section 3: Radiation protection and dose optimization

RADIOGRAPHIC IMAGING SYSTEMS: MAJOR MODALITIES AND COMPONENTS

In this book, the following *radiographic imaging systems* will be reviewed. These include x-ray imaging modalities such as digital radiography (DR) which includes CR and FPDR, DF, DM, digital radiographic and breast tomosynthesis, and CT. Furthermore, these systems include imaging informatics which has become commonplace since radiology and more importantly hospitals are now all operating in the digital environment; that is, all data acquired from the patient are now in digital form and are stored and communicated using digital technologies. Informatics topics of importance include that nature and scope of PACS, enterprise imaging, cloud computing, Big Data, and the more recent of computer applications in medical imaging: AI. More details of these major technologies and how they work will be presented in Chapter 6 on Digital Imaging Modalities and Chapter 10 on Imaging Informatics.

RADIOGRAPHIC PHYSICS AND TECHNOLOGY

Radiographic physics and technology subject matter include basic physics concepts, and more specifically the physics of diagnostic imaging; technical aspects of the modalities; radiographic exposure technique; image quality, quality assurance (QA), and QC; CT physical principles; imaging informatics; radiobiology and radiation protection.

Essential physics of diagnostic imaging

The *physics of diagnostic imaging* is an important and vital topic that explains the nature of how these imaging modalities work to produce diagnostic images of the patient. Understanding the fundamental physics will provide the user with the tools not only needed to produce optimum image quality but more importantly to protect the patient from unnecessary radiation. As such, it is now a common characteristic of imaging departments to optimize radiation dose and work within the International Commission on Radiological Protection (ICRP) philosophy of as low as reasonably achievable (ALARA) to reduce the dose to the patient but not compromise the diagnostic quality of the images used to make a diagnosis of the patient's medical condition.

In this book, the topics in physics that will emphasize the imaging modalities are the nature of radiation, x-ray generation, x-ray production, x-ray emission, x-ray attenuation, and x-ray interaction with matter. Furthermore, other physics topics of significance are radiation quantities and their associated units and measurement concepts. These topics and more fall in the domain of *Health Physics*. Three radiation quantities that are important to radiation protection of the patient are exposure, absorbed dose, and effective dose (ED). The units associated with each of these include coulombs per kilogram (C/kg), Grays (Gy), and Sieverts (Sv), respectively. In order to measure radiation, it must first be detected.

Digital radiographic imaging modalities

As listed earlier in this chapter, these modalities include CR, FPDR or DR as it is sometimes referred to, DF, DM, digital radiographic tomosynthesis (DRT), digital breast tomosynthesis (DBT), and last but not least CT. Additionally, since all of the above-mentioned modalities include image processing using computers, the concepts of Digital Image Processing will be reviewed since it has become an essential tool for technologists, radiologists, and medical physicists working in a digital radiology department.

These imaging modalities include specific physics concepts that must be understood for optimum results. For example, CR is based on the use of photostimulable phosphors (PSP) which are based on the physical principle of photostimulable luminescence (PSL). An example