Euclid Seeram

X-Ray Imaging Systems for Biomedical Engineering Technology

An Essential Guide

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This book is dedicated to my two smart and beautiful granddaughters
Claire and Charlotte
With love and blessings to you both forever.

Preface

Biomedical Engineering Technology (BMET) students may have to complete laboratory hands-on exercises in the x-ray imaging laboratory as part of their educational requirements. Additionally, biomedical engineering technologists often service x-ray imaging equipment in the radiology department of their hospitals. X-Ray Imaging Systems include Digital Radiography (DR) and Digital Fluoroscopy (DF) Digital Mammography and Computed Tomography (CT). The imaging modalities are based on physics, engineering, and computer science principles that make them useful clinical tools for imaging the patient. These modalities have experienced several technical innovations in recent years that have not only reduced the radiation dose to the patient but improve the image quality needed for diagnostic interpretation. For example, the fundamental concepts of the wide exposure latitude of DR systems and the standardized exposure indicator established by the International Electrotechnical Commission (IEC) have provided researchers with the motivation to operate DR systems with the goal of optimization of the dose and image quality. Additionally, CT technical innovations, such as new detector technology, Iterative Reconstruction (IR) algorithms, and Artificial Intelligence-based image reconstruction are now offered by several CT vendors, play a significant role in dose reduction and optimization in CT. Furthermore, the introduction of Photon Counting Detectors (PCDs) has solved the major problem of image noise during low-dose CT imaging.

This book *X-Ray Imaging Systems for Biomedical Engineering Technology: An Essential Guide* provides a useful resource to meet the x-ray imaging educational requirements of biomedical engineering students and provide a continuing education resource for practicing technologists. This book is intended to meet fundamental requirements for x-ray imaging systems in the BMET curriculum, in the United States, Canada, South America, Africa, Asia, Australia, and continental Europe.

The contents in this book are described in 11 chapters as follows:

Chapter 1 introduces the nature and scope of X-Ray Imaging Systems and sets the general framework for the remaining chapters. Whereas Chap. 2 presents a description of the essential Radiation Physics needed for a good understanding of how these systems work and how x-rays interact with the patient to generate images used for diagnosis. Chapter 3 describes the major technical components of Computed Radiography (CR). Chapter 4 deals with the physical principles and technical components of Flat-Panel Digital Radiography (FPDR). The principles and technology of Digital Fluoroscopy are discussed in Chap. 5. Chapter 6 identifies and outlines Digital Image Quality Descriptors and Performance Characteristics, such as spatial resolution, contrast resolution, and noise as well as the detective quantum efficiency (DQE) which describes the noise characteristics of a digital detector. In Chap. 7, the physical principles and technology of Computed Tomography (CT) at a depth needed for entry-to-practice, specifically the major technical system components of Multi-Slice CT (MSCT), are described. Furthermore, image processing, image quality, and radiation dose and radiation protection are described. Chapter 8 introduces the ideas and major concepts of Imaging Informatics including major topics, such as Medical Image Management and Processing System (MIMPS) formerly referred to as Picture Archiving and Communication Systems (PACS), and related topics, such as Health Information Systems, The Electronic Health Record, Other Concepts in Imaging Informatics, and Enterprise Imaging. Artificial Intelligence (AI) and its subsets, Machine Learning and Deep Learning, as well as applications of AI in medical imaging; AI in Diagnosis of Diseases; AI in Computed Tomography; and Ethics of AI in Medical Imaging are reviewed in Chap. 9. Chapter 10 deals with the major elements of Quality Control in Diagnostic X-Ray Imaging focusing on steps in conducting a QC, tolerance limits or acceptance criteria, reject/retake analysis, visual assessment of the electronic display monitors, and describes briefly four examples of QC Tests for CR using qualitative criteria. These include dark noise, CR Imaging Plate (IP)test for uniformity, spatial accuracy, and erasure thoroughness of the IP. Finally, Chap. 11 presents an overview of Radiation Protection for Diagnostic X-Ray Imaging, including biological effects of exposure to ionizing radiation; goals of radiation protection; regulatory radiation protection guidance recommendations; and personnel dosimetry.

Enjoy the pages that follow and remember—your wisdom of ensuring that x-ray imaging equipment performs efficiently, effectively and is absolutely safe for imaging patients.

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Acknowledgments

An important satisfying task in writing a book of this nature is to thank those medical physicists, biomedical engineers, computer scientists, and manufacturers who have done the original work in conceptualizing and developing x-ray systems for imaging patients. This book deals with x-ray imaging systems as outlined in the Preface, and in this respect, it is indeed a pleasure to express sincere thanks to all of the scientific and clinical experts.

I am most grateful to Dr. Rob Davidson, PhD, MAppSc (MI), BBus, FASMIRT, Professor of Medical Imaging, University of Canberra, Australia. Thanks mate.

Furthermore, two medical physicists to whom I am truly grateful for my Digital Radiography (DR) education are Dr. Anthony Siebert, PhD, of the University of California at Davis, and Dr. Charles Willis, PhD, formerly of the University of Texas, MD Anderson Cancer Center, from whom I have learned the physics and technical aspects of digital radiography through their seminars and workshops that I have attended. My X-Ray Imaging education (including CT physics and instrumentation) has its roots in not only attending courses, conferences and workshops, but personal communications with a number of notable medical physicists.

Two other notable medical physicists to whom I am particularly grateful are 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) and Dr. Anthony Wolbarst, PhD, Medical Physics Department, University of Kentucky (Retired) from whose published works in medical physics I have learned a great deal.

Another individual to whom I owe a good deal of thanks is Valentina Al Hamouche, MRT(R), MSc, who is the CEO/Founder of VCA Education Solutions for Health Professionals based in Toronto, Canada. Valentina has provided me with recurring opportunities to provide Radiographic Imaging Sciences and CT Physics and Technology in-house lectures and webinars to further educate technologists and students across Canada and internationally as well. Thanks Valentina.

I am particularly grateful to Jochen Boehm, MEng, and Dr. Anthony Chan, PhD, both Biomedical Engineers and Faculty in the Biomedical Engineering Technology

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I humbly acknowledge the support from my beautiful family; first my lovely wife, Trish, a warm, smart, caring, and a very special person in my life, thanks babes. Secondly, my caring and very brilliant son David, the best Dad on the planet, to his two most precious daughters, my granddaughters, to whom this book is dedicated. Thanks for your enduring love, support, and encouragement.

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Contents

Chapter 1
X-Ray Imaging Systems: An Overview

1.1 Introduction

The Canadian Medical and Biological Engineering Society (CMBES) defines a biomedical engineering technologist as one who works "in large health care facilities providing comprehensive service and support of medical devices and equipment. Activities include inspection, installation, repair, and preventive maintenance of medical devices and complex medical systems. They also provide advice and training on the safe and effective use of medical devices and systems" [1].

An example of such a "complex medical system" is the X-ray imaging system commonly found in medical imaging departments (radiology) worldwide. X-ray imaging systems produce ionizing X-rays to generate patient images. Given that these systems expose patients to radiation, it is mandatory that the biomedical engineering technologist to comprehend the workings of these systems for the safety of patients and related personnel.

X-ray imaging systems include film-screen imaging (now obsolete); digital X-ray imaging systems such as computed radiography, flat-panel digital radiography, digital fluoroscopy, digital mammography, and computed tomography (Fig. 1.1). These systems are based on radiation physics which explains how they work. The biomedical engineering technologist ensures the proper and safe functioning of these systems in the care and management of the patient. Additionally, two important considerations that are also essential to the skill set of the biomedical engineering technologist are equipment quality control and radiation protection.

The objective of this chapter is to present a comprehensive overview of X-ray imaging systems, including the nature of quality assurance and quality control. Additionally, it will provide a summary of radiation physics and radiation protection.

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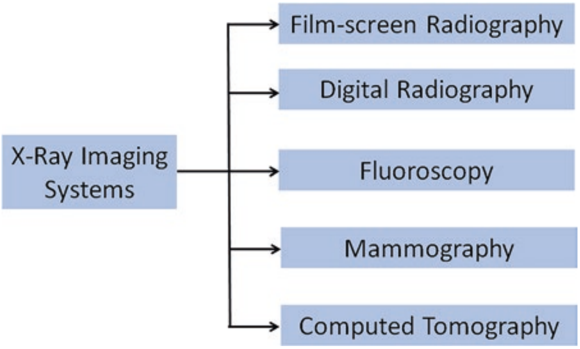

Fig. 1.1 X-Ray imaging systems include film-screen imaging (now obsolete), digital X-ray imaging systems such as computed radiography, flat-panel digital radiography, digital fluoroscopy, digital mammography, and computed tomography

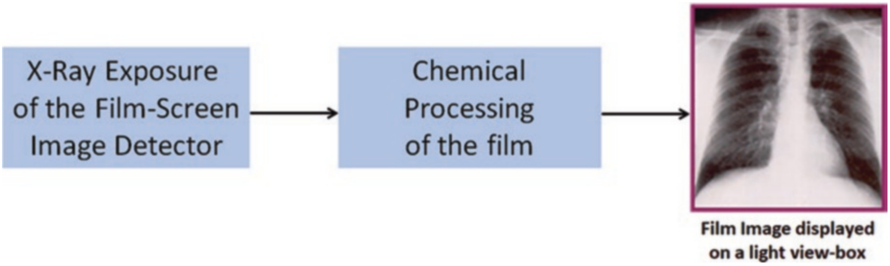

Fig. 1.2 The basic steps in the production of a film-screen radiographic image. See text for further explanation

1.2 Film-Screen Radiography

Film-Screen Radiography (FSR) served as the primary X-ray imaging system for clinical applications for several years following the discovery of X-rays. In FSR, the detector consists of a film sandwiched between two intensifying screens made of certain phosphors, such as calcium tungstate ($CaWO_4$), and later rare earth phosphors such as gadolinium oxysulfide and lanthanum oxysulfide replaced $CaWO_4$ screens with the goal of reducing the dose to the patient without compromising image quality needed for diagnosis [3, 2].

The basic steps in the production of a film-screen radiographic image are illustrated in Fig. 1.2. X-rays pass through the patient and fall upon the film to form a latent image. The latent image is then rendered visible using *chemical processing* and subsequently displayed on a light view-box for interpretation by a radiologist.

The *response of the film to x-ray exposure* can be described by what is referred to as the film *characteristic curve* as illustrated in Fig. 1.3. The curve is a plot of the optical density (OD) to the radiation exposure (or more accurately, the logarithm of the relative exposure) used in the imaging process. The curve shows the degree of contrast or different densities that a film can display using a range of exposures. It has three elements that are significant: the toe, the slope (straight line portion), and the shoulder. While the toe and shoulder indicate underexposure and overexposure,