

Digital Radiography

Review Questions

Euclid Seeram

 Springer

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This book is dedicated with love and affection to my son, Dave, a brilliant, hard-working, caring, and loving individual who has devoted his efforts into achieving his goals.

Preface

Digital radiography has replaced film-based radiography (FBR) and is now current practice in most medical imaging departments in the world. The American Association of Physicists in Medicine (AAPM) has offered a definition of digital radiography as “radiographic imaging technology producing digital projection images such as those using photostimulable storage phosphor (computed radiography, or CR), amorphous selenium, amorphous silicon, charge-coupled device (CCD), or metal oxide semiconductor-field effect transistor (MOSFET) technology.” These technologies can produce acceptable image quality over a wider range of exposure techniques compared to film screen radiography.

To the best of the author’s knowledge, this is the first book of its kind and the review questions are based on the textbook:

- *Digital Radiography: Physical Principles and Quality Control* by Euclid Seeram, PhD, FCAMRT Second Edition. Springer 2019

The questions provided in this book cover a wide range of topics to address the needs of members of various professional radiologic technology associations including the *American Society of Radiologic Technologists* (ASRT), the *American Registry of Radiologic Technologists* (ARRT), the *Canadian Association of Medical Radiation Technologists* (CAMRT), and the *College of Radiographers* in the UK, as well as those professional medical imaging organizations in Africa, Asia, Australia, and continental Europe. Additionally, this book may serve as a resource for Biomedical Engineering Technology programs that include digital radiography systems in their curriculum.

Review questions are based on the chapters covered in the textbook as follows: Chapter 1 provides an overview of digital radiography systems and sets the framework for the remaining chapters. Whereas Chap. 2 deals with digital image processing, Chap. 3 outlines in detail the elements of computed radiography (CR). Chapter 4 covers in detail the fundamentals of flat-panel digital radiography (FPDR) systems. Chapter 5 describes the characteristics of the standardized exposure indicator (EI). Chapters 6 and 7 address the technical aspects of digital fluoroscopy (DF) and full-field digital mammography (FFDM), respectively. Additionally, Chap. 8 introduces a new technique digital tomosynthesis. Chapters 9 and 10 provide a coverage of picture archiving and communication systems (PACS) and medical imaging

informatics, respectively. Finally, quality assurance (QA) and quality control (QC) and dose optimization in digital radiography are covered in Chaps. 11 and 12, respectively. These chapters are described in a little more detail in the Introduction section of this book.

The format of the questions includes true/false, multiple choice, and short answers, and they are further elaborated in the Introduction.

Enjoy the questions that follow and best wishes in any examination you have to write, and remember—your patients will benefit from your wisdom.

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Acknowledgments

The single most important and satisfying task in writing a book of this nature is to acknowledge the help and encouragement of those individuals who perceive the value of its contribution to the medical imaging sciences literature. It is indeed a pleasure to express sincere thanks to several individuals whose time and efforts have contributed tremendously to this first edition of *Digital Radiography: Review Questions*.

The content on which the questions in this book are based is centered around the published works and expertise of several noted medical physicists, radiologists, computer scientists, and biomedical engineers who have done the original research. In reality, they are the tacit authors of this text, and I am truly grateful to all of them, in particular to Dr. Charles Willis, PhD, of the University of Texas, MD Anderson Cancer Center, and Dr. Anthony Siebert, PhD, of the University of California at Davis and two expert physicists in digital radiography and from whom I have learned the physics and technical aspects of digital radiography through their seminars and workshops that I have attended. Furthermore, I owe a good deal of thanks to my good friend and colleague Dr. Rob Davidson, PhD, MAppSc (MI), BBus, FASMIRT, Professor of Medical Imaging, University of Canberra, Australia. Dr. Davidson is considered another authority on digital radiography in the medical radiation sciences arena. Dr. Davidson has shared examples of his questions on digital radiography with me, in an effort for me to assess the value and similarity of the questions included in this book. Thanks mate.

The people at Springer Nature, SPi Global, deserve special thanks for their hard work, encouragement, and support of this project. They are Ms. Jagjeet Kaur Saini, Editor (Books), Medicine and Life Sciences Springer Nature, and Mr. Kumar Athiappan, Project Coordinator (Books) Springer Nature, who provided support and maintained continued communication to bring this work to fruition. I must also thank the individuals in the production department at Springer for doing a wonderful job on the manuscript to bring it to its final form. In particular, I am grateful to members of the production team, who have worked exceptionally hard during the production of this book, especially in the page-proof stage.

Finally, my family deserves a special mention for their love, support, and encouragement, while I worked into the evenings on the manuscript. In particular, I appreciate the efforts of my lovely wife, Trish, a warm, smart, caring, and overall a very special person in my life. Thanks babes.

Last but not least, I must thank my students who have diligently completed my courses on digital imaging modalities, PACS, and digital image processing in radiology, at both the diploma and degree levels. Thanks for all the challenging questions.

Keep on learning and have fun with the questions that follow.

British Columbia, Canada

Euclid Seeram

Introduction

The review questions in this book are based on the technical materials covered in the following textbook:

- *Digital Radiography: Physical Principles and Quality Control* by Euclid Seeram, PhD, FCAMRT Second Edition. Springer 2019

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<https://www.springer.com/in/book/9789811565212>

This is the *second edition* of a well-received book that enriches the understanding of radiographers and radiologic technologists across the globe and is designed to meet the needs of courses (units) on radiographic imaging equipment, procedures, production, and exposure. The book also serves as a supplement for courses that address digital imaging techniques, such as radiologic physics, radiographic equipment, and quality control. In a broader sense, the purpose of the book is to meet readers' needs in connection with the change from film-based imaging to filmless or digital imaging; today, all radiographic imaging worldwide is based on digital imaging technologies.

The chapters in this book have been updated to address the continued technical evolution and major technology trends in digital radiographic imaging. Furthermore, a set of updated articles have been cited to support the inclusion of major new technical areas of current interest in clinical practice such as the following: the standardized exposure indicator, digital tomosynthesis, and enterprise imaging, including vendor neutral archives (VNAs), cloud computing, big data (BG), and artificial intelligence (AI) including subsets of AI such as machine learning and deep learning. The addition of numerous new images illustrates the fundamental principles of these new technologies, and new line drawings serve to enhance and provide important concepts in the text. Last but not least, a reasonable effort has been made to keep the cited literature current.

Overview of Chapters

The following chapters are covered in this textbook:

Chapter 1: Digital Radiography: An Overview

This chapter presents an *overview of the technologies* that constitute the subject matter of this book including a discussion of the limitations of film-based radiography and the major structural components of digital radiography imaging systems as well as a brief description of the image acquisition detectors, PACS, and imaging informatics.

Chapter 2: Digital Image Processing Concepts

This chapter provides a detailed description of the topic of *digital image processing*, a topic that is of particular importance in today's digital clinical imaging practice.

Chapter 3: Computed Radiography-Physics and Technology

This chapter deals with the basic physics and technology of *computed radiography* (CR) and describes, specifically, the physics of photostimulable luminescence, CR technical components, image processing, exposure control in CR, and image quality descriptors for CR and presents an overview of artifacts. Finally, the chapter concludes with a brief introduction of selected quality control tests for CR, using quality criteria for assessment.

Chapter 4: Flat-Panel Digital Radiography

This chapter is devoted to *flat-panel digital radiography* imaging systems and includes a description of the different types of flat-panel digital imaging systems, design characteristics, operating principles, image processing, and imaging performance characteristics such as spatial resolution, modulation transfer function, dynamic range, detective quantum efficiency, image lag, and image artifacts. Wireless digital detectors are briefly introduced.

Chapter 5: The Standardized Exposure Indicator

This chapter focuses on details of the *standardized exposure indicator* (EI) through a description of the conditions for the IEC standardized EI, various definitions, determination of the standardized EI, interpretation of deviation index (DI) values, factors affecting EI values, responsibilities, and an objective approach for establishing target EI values.

Chapter 6: Digital Fluoroscopy

This chapter provides a description of the technical aspects and image processing for *digital fluoroscopy systems*, based on image intensifiers and flat-panel digital detectors, as well as the fundamental physical principles of digital subtraction angiography.

Chapter 7: Full-Field Digital Mammography

This chapter describes the essential technological aspects of *digital mammography*. Topics include types of detectors, digital image processing, and various applications such as digital tomosynthesis and computer-aided detection and diagnosis.

Chapter 8: Digital Tomosynthesis

This chapter deals with *digital tomosynthesis*. Topics include definition and principles (image acquisition and system components, image acquisition parameters, image reconstruction, image display, and communication), radiation dose considerations, synthesized 2D digital mammography, and clinical applications.

Chapter 9: Picture Archiving and Communication Systems

This chapter examines the major components, and *core technologies of PACS* are described in detail followed by an outline of the bare essentials of information systems and communication standards for digital radiology, including DICOM (Digital Imaging and Communications in Medicine), HL-7 (Health Level-7), and the technical framework of IHE (Integrating the Healthcare Enterprise). Furthermore, the concepts relating to vendor neutral archives (VNAs) and enterprise imaging (EI), including a definition of EI and the major elements of an enterprise imaging system, are presented.

Chapter 10: Medical Imaging Informatics: An Overview

This chapter outlines the major components of medical *imaging informatics*, an evolving field for the digital radiography community. Examples of these components include the health information systems, electronic health record, systems integration, information technology (IT) security fundamentals, and skills and certification of a PACS technologist. Additionally, *new topics* that are considered emerging topics in imaging informatics are introduced in this chapter. In particular, these topics include *cloud computing, big data, artificial intelligence, machine learning, and deep learning*.

Chapter 11: Continuous Quality Improvement in Digital Radiography

This chapter presents a detailed description of the elements of *continuous quality improvement in digital radiography*. Major topics described include significant elements of continuous quality improvement (CQI) such as definitions of quality assurance (QA) and quality control (QC), dose optimization, parameters for QC monitoring in digital radiography, and tolerance limits or acceptance criteria. The next important section of this chapter reviews the processes and errors in digital radiography, responsibilities for digital radiography QC, and an overview of digital mammography QC (topics that were addressed in detail in the first edition of this book and written by Dr. Charles Willis, PhD, as mentioned above, under the topics of “Content and Organization”). In addition, four QC tests for digital radiography have been described in a manner that students can conduct them in a radiography laboratory.

Chapter 12: Dose Optimization in Digital Radiography

This chapter is the final chapter in this book. It deals primarily with *dose optimization in digital radiography*, through a description of topics such as dose optimization approaches (optimization of kVp, optimization of mAs, and optimization of the exposure indicator (EI)) and dose optimization tools and methods for image quality assessment. Finally, the chapter concludes with an overview of the method of visual grading of normal anatomy and optimization of the EI as a dose management strategy

The American Registry of Radiologic Technologists® (ARRT)® sets the questions for the Radiologic Technology Certification examination. The questions are intended to test the knowledge and cognitive skills required for successful performance in the clinical environment. The technical and physics component of the examination related to the questions covered in this book is partly covered in the ARRT® topics on radiations physics, image production, image acquisition and technical evaluation, and equipment operation and quality assurance, totaling about 50 multiple-choice questions. Other related organizations such as the Canadian Association of Medical Radiation Technologists (CAMRT) also use the multiple-choice format for their certification examination in radiography. Furthermore, organizations outside North America may use other question formats such as true-false and more importantly short answer type questions, as well as identification of equipment components through labeling.

The formats of the questions in this book are based mainly on the multiple-choice format, true-false format, and the short answer type format. Answers will be provided at the end of each chapter.

Question Formats: Examples

True–False

At the heart of a digital radiography imaging system is a computer which processes all attenuation data from the patient in order to create digital radiographic images for diagnostic interpretation

Multiple Choice

Which of the following digital radiography imaging systems is based on the physical phenomenon of photostimulable luminescence?

- A. Flat-panel digital radiography system
- B. Computed radiography
- C. Digital fluoroscopy
- D. Computed tomography

Short Answers

Describe how a computed radiography (CR) system works in creating an image.

Answers to Example Questions

1. True
2. B
3. CR uses a photostimulable phosphor such as barium-fluoro-halide coated on an imaging plate (IP). The basic steps in the production of a CR image include exposing the IP to x-rays which causes electrons in the phosphor to move to another energy level, where they remain trapped to create a latent image. The IP is taken to the CR reader/processor (digital image processor) where it is scanned by a laser beam which causes the trapped electrons to return to their original orbit, and in the process, light is emitted. This light is collected by a light guide and sent to a photomultiplier tube (PMT). The output electrical signal from the PMT is subsequently converted into digital data to produce a CR image using a digital processor. The IP is exposed to a bright light to erase it (remove residual latent image) so that it can be used again.

References

The references used to validate the answers to all questions in this book are provided at the end of each of the chapters covered in the textbook by Seeram, shown above. For example, the references for Chap. 3: Computed Radiography: Physics and Technology are as follows:

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About the Author

Euclid Seeram is a full member of the Health Physics Society. He is currently an Honorary Senior Lecturer at the Faculty of Health Sciences, University of Sydney; Adjunct Associate Professor of Medical Imaging and Radiation Sciences at Monash University, Australia; Adjunct Professor at the Faculty of Science, Charles Sturt University, Australia; and Adjunct Associate Professor of Medical Radiation Sciences at the University of Canberra. His current research interests are focused on radiation dose optimization in CT and digital radiography imaging systems, topics on which he has published over 55 papers in professional and peer-reviewed radiologic technology journals. He has published numerous books on CT, computers in radiology, radiographic instrumentation, digital radiography, and radiation protection. Presently, he serves on the editorial boards of the *Biomedical Imaging and Intervention Journal*, *Radiography*, *International Journal of Radiology and Medical Imaging*, *Open Journal of Radiology*, and the *Journal of Allied Health*. He is on the international advisory panel for the *Journal of Medical Radiation Sciences* and serves as an invited peer reviewer for the *Journal of Medical Imaging and Radiation Sciences*.



1.1 Learning Activities

Before attempting to answer these review questions, read the following:

Chapter 1: Digital Radiography-An Overview. From *Digital Radiography: Physical Principles and Quality Control* by Euclid Seeram, PhD., FCAMRT Second Edition. Springer 2019

1.2 Summary of the Main Points in this Chapter

This chapter provides general overview questions on the elements of digital radiography (DR). First, a definition of digital radiography is presented followed by a brief review of the essential underlying principles of film-screen radiography (F-SR) including its limitations. Second, the major components of digital radiography imaging systems are briefly outlined. The third topic covered a comprehensive explanation of digital imaging modalities such as computed radiography (CR), flat-panel digital radiography (FPDR), digital fluoroscopy, and digital mammography. Furthermore, the elements of picture archiving and communication systems and quality control are introduced. Finally, the chapter concludes with an introduction to topics such as enterprise imaging, cloud computing, big data, machine learning and deep learning as well as artificial intelligence that are considered the next era of imaging informatics.

1.3 Review Questions Will Be Based On Each of the Following Key Terms

- Definition of digital radiography
- Film-screen radiography (FSR)
- Limitations of FSR

- Digital imaging modalities
 - Picture archiving and communication systems (PACS)
 - Quality control
 - Imaging informatics
-

1.4 Challenge Questions

Answer the following questions to check your understanding of the materials studied:

1.4.1 True (T)/False (F)

1. DR is based on the use of a computer to process attenuation data from the patient into a digital format for subsequent display generally as greyscale images on a computer monitor for viewing and interpretation by an observer.
2. DR does not use photostimulable phosphors but only amorphous selenium, amorphous silicon and a charge-coupled device (CCD).
3. Film-based radiography makes use of a film characteristic curve to indicate the degree of contrast or different densities that a film can display using a range of radiation exposures.
4. The film characteristic curve is also known as the Hurter-Driffield (H and D) curve.
5. The H and D curve is a plot of the film optical density (OD) to the logarithm of the relative exposure.
6. The film characteristic curve shows that the useful range of densities is best described by the toe and shoulder regions of the curve
7. Image quality factors include spatial resolution, contrast resolution and noise.
8. While humans use the binary number system for counting, computers use the decimal number system for solving problems
9. *Integrating the Healthcare Enterprise* is a model for ensuring that the standards for communication such as DICOM and HL-7 work effectively to facilitate integration.
10. Enterprise imaging, big data, cloud computing, machine learning and deep learning and artificial intelligence are all topics that comprise the next era in medical imaging informatics.

1.4.2 Multiple Choice

1. Of the digital radiographic detectors currently available, which is based on the use of photostimulable phosphors for image production?
 - (a) Computed radiography detectors
 - (b) Indirect flat-panel detectors
 - (c) Direct flat-panel detectors
 - (d) Charge coupled device

2. Which region of the film characteristic curve indicates that the acceptable exposure has been used for the examination?
 - (a) Toe region
 - (b) Slope
 - (c) Shoulder
 - (d) Both a and c are correct

3. The penetrating power of the X-ray beam depends on the:
 - (a) Milliampere (mA) during the exposure
 - (b) Time in seconds (s) of the exposure
 - (c) mAs
 - (d) Kilovolts (kV) applied across the X-ray tube during the exposure

4. The grainy appearance of an image is described by which of the following:
 - (a) Spatial resolution
 - (b) Contrast resolution
 - (c) The kV and mAs used
 - (d) Noise

5. Acquiring attenuation data or X-ray transmission readings through the patient is referred to as:
 - (a) Data acquisition
 - (b) Image processing
 - (c) Image management
 - (d) Data communication

6. An operation that converts a low contrast image into a high contrast image is called:
 - (a) Analog-to-digital conversion
 - (b) Digital-to-analog conversion
 - (c) Greyscale mapping
 - (d) Bit operation

7. Which of the following is used to store, archive and send images to remote locations?
 - (a) HIS
 - (b) PACS
 - (c) RIS
 - (d) DICOM

8. The imaging modality that uses amorphous selenium to create images is:
 - (a) Computed radiography
 - (b) Flat-panel digital radiography
 - (c) CCD
 - (d) Film radiography

9. Which of the following is defined by the Society of Imaging Informatics in Medicine (SIIM) as "... the study and application of processes of information and communications technology for the acquisition, manipulation, analysis and distribution of image data"?
 - (a) Image processing
 - (b) PACS
 - (c) Information technology
 - (d) Imaging informatics

10. The computer-based technology that is not a part of artificial intelligence is:
 - (a) Machine learning
 - (b) Deep learning
 - (c) Big data
 - (d) Natural language processing

1.4.3 Short Answers

1. What is the definition of "Digital Radiography" as offered by the American Association of Physicists in Medicine (AAPM)?
2. What is the film characteristic curve and describe its major three features?
3. Identify three image quality parameters and briefly describe the meaning of each.
4. What are the major technical components of a digital radiography system?
5. What is the difference between a Picture archiving and Communication System (PACS) and an Information System?
6. What is image compression? Explain the basic difference between irreversible and reversible image compression.
7. What is the fundamental difference between Computed Radiography (CR) and Flat-Panel Digital Radiography (FPDR)?
8. Explain briefly, the response of a digital detector to radiation exposure.
9. Provide examples of topics that are considered the "next era of imaging informatics"
10. What is Big Data and its characteristics?

1.5 Answers to Challenge Questions

1.5.1 True/False

1. T
2. T
3. T
4. T
5. T
6. F
7. T
8. F
9. T
10. T

1.5.2 Multiple Choice

1. a
2. b
3. d
4. d
5. a
6. e
7. b
8. b
9. d
10. c

1.5.3 Short Answers

1. The AAPM defines Digital Radiography as “radiographic imaging technology producing digital projection images such as those using photostimulable storage phosphor (computed radiography or CR), amorphous selenium, amorphous silicon, charge-coupled device (CCD) or metal oxide semiconductor-field effect transistor (MOSFET) technology”.
2. Film contrast characteristics can be described by the characteristic curve or what is also known as the Hurter and Driffield (H and D) curve. 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 purpose of the curve is to indicate the degree of contrast or different densities that a film can display using a range of exposures. The curve has three distinct regions, the toe, the slope and the shoulder regions. While the toe and shoulder indicate underexposure and overexposure, respectively, the slope represents the

useful portion of the curve and reflects acceptable exposure or a range of useful densities.

3. In general, there are three image quality parameters, namely, spatial resolution, contrast and noise. While spatial resolution describes the sharpness or detail of an image measured in line pairs per millimeter (lp/mm), contrast is the density differences on a radiographic image. A high-contrast image is characterised by regions of high density (dark) and low density (light). *Noise* on an image appears as mottle, and the image has a grainy appearance (quantum mottle or quantum noise). This occurs when few photons are used to create an image on the image detector.
4. The major technical components of a digital radiography system include the data acquisition system, the computer data processing system, image display and post processing system, image storage and the image and data communication system (see Figure 1–5 in the textbook by Seeram, 2019).
5. While a Picture Archiving and Communication System (PACS) is being used for storing/archiving and communicating images in the digital radiology department. Information systems, such as the radiology information systems (RIS) and the hospital information systems (HIS), are now being integrated with the PACS via computer networks, using communication standards such as DICOM (Digital Imaging and Communications in Medicine) and HL-7 (Health Level-7), for effective management of patient information.
6. Image compression is intended to reduce storage space (and hence costs) and decrease the image transmission time. Two popular compression methods for use in digital radiology are lossless or reversible compression and lossy or irreversible compression. With reversible compression, there is no loss of information when the image is decompressed. With irreversible compression, there is some loss of information.
7. CR imaging technology is based on the use of a photostimulable phosphor such as barium fluorohalide, which is coated on the plate referred to as an imaging plate (IP). This IP is housed in a cassette (similar in appearance to a film-screen cassette) to protect it from damage and exposure to foreign materials. The IP is then considered the digital detector in CR. X-ray passing through the patient falls on the IP to create a latent image that is stored on the photostimulable phosphor. The IP is subsequently processed by what is referred to as the image reader (image digitiser) using a scanning laser beam to render the latent image on the IP visible. This principle is referred to as photostimulable luminescence.

FPDR imaging technology does not use photostimulable phosphors. The technology used is based on the conversion of X-rays to electrical signals which are digitised to create images. Two types of FPDR systems are available: an indirect conversion (IC) system and a direct conversion (DC) system. The basic

difference between the two types is illustrated in Figure 1–9 of the textbook by Seeram. In a DC system, X-rays fall upon the photoconductor (e.g., selenium), which is coupled to a matrix array of electronic elements to produce electrical signals. These signals are digitised and processed by a digital computer to produce an image. An indirect flat-panel digital detector is based on an indirect conversion process and uses several physical components to convert X-rays first into light that is subsequently converted into electrical charges. These components include an X-ray scintillator (X-ray conversion layer), followed by an amorphous silicon (a-Si) photodiode flat-panel layer, with a thin-film transistor (TFT) array for readout of the electrical charges by the photodiode array. The output electrical signal is then digitised to create an image.

8. The response of a digital detector to input radiation exposure is linear. This linear response produces wider exposure latitudes compared to the film characteristic curve, which has limited exposure latitudes (defined by their slopes). This is the most significant advantage of the digital detector. The wide exposure latitude of the digital detector will produce acceptable images even when the input exposure is low or high. Recall that for film-screen radiography, while a low exposure will produce a light image, a high exposure will produce a dark image. These images would have to be repeated to produce acceptable film density, thus increasing the radiation dose to the patient.
9. The next era in medical imaging informatics includes at least six major topics that have received increasing attention in the literature. These include enterprise imaging, Big Data, cloud computing, machine learning and deep learning and artificial intelligence.
10. According to Kansagra AP, Yu J-PJ, Chatterjee AR, Lenchik L, Chow DS, Prater AB, et al. in their paper Big data and the future of radiology informatics, published in *Academic Radiology* 2016;23:30–42, “*Big Data* refers to extremely complex data sets characterised by the four Vs: *Volume*, which refers to the sheer number of data elements within these extremely large data sets; *Variety*, which describes the aggregation of data from multiple sources; *Velocity*, which refers to the high speed at which data is generated; and *Veracity*, which describes the inherent uncertainty in some data elements”.

1.6 Knowledge Lacks Identification

- A. Make a list of topics and/or questions that are still not clear to you after studying this chapter
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-

- B. See the instructor for clarification and/or consolidation of the materials

1.7 Student Comments



2.1 Learning Activities

Before attempting to answer these review questions, read the following:

Chapter 2: Digital Image Processing Concepts. From *Digital Radiography: Physical Principles and Quality Control* by Euclid Seeram, PhD., FCAMRT Second Edition. Springer 2019

2.2 Summary of the Main Points in this Chapter

The topics covered in this Chapter address a definition of digital image processing, followed by a brief historical development leading to its use in medical imaging. Image formation and representation are reviewed through a description of the nature of analogue and digital images, as well as image domains. Additionally, five classes of image processing operations are identified. Furthermore, the characteristics of the digital image are described including matrix, pixels, voxels, bit depth and image appearance. The three steps in digitising an image, namely scanning, sampling and quantisation, are briefly outlined. Finally, a brief overview of four image processing operations, namely, point, local, global and geometric operations, is given.

2.3 Review Questions Will Be Based On Each of the Following Key Terms

- Definition of digital image processing
- Brief history
- Image formation and representation
- Classes of image processing operations
- Characteristics of the digital image

- Steps in digitising and image
 - General concepts of digital image processing operations
-

2.4 Challenge Questions

Answer the following questions to check your understanding of the materials studied:

2.4.1 True/False

1. Digital image processing simply means the processing of images using a digital computer.
2. Images are classified according to their form and method used to produce them.
3. A digital image is a numerical representation of the patient.
4. Digital image processing is defined as subjecting analogue representations of objects to a series of operations in order to obtain the desired result.
5. Improving the quality of images that have distortions or degradations is an example of image enhancement operation.
6. 3-Dimensional (3-D) imaging is an example of image analysis.
7. A typical matrix size and bit depth for Flat-Panel digital radiography systems is $512 \times 512 \times 12$.
8. The bit depth of a digital image determines how many shades of grey a pixel can have.
9. Quantisation is a process whereby the brightness levels obtained from sampling are assigned an integer (zero, a negative or a positive number) called a grey level.
10. Windowing is a digital image processing operation used to change the contrast and brightness of an image displayed for viewing on a display monitor.

2.4.2 Multiple Choice

1. The logical steps in digitising an image are:
 - (a) Scanning, sampling and quantisation
 - (b) Sampling, scanning and quantisation
 - (c) Quantisation, sampling and scanning
 - (d) Sampling, quantisation and scanning
2. Which of the following digital image processing operations include contrast enhancement, edge enhancement, spatial and frequency filtering, image combining and noise reduction?
 - (a) Image analysis
 - (b) Image compression

-
- (c) Image enhancement
 - (d) Image restoration
3. The pixel size can be calculated using the following relationship:
- (a) Pixel size = Field-of-View (FOV) – Matrix size
 - (b) Pixel size = FOV × Matrix size
 - (c) Pixel size = Matrix size/FOV
 - (d) Pixel size = FOV/Matrix size
4. How many shades of grey are possible in a digital image with a bit depth of 10?
- (a) 10
 - (b) 20
 - (c) 256
 - (d) 1024
5. The most frequently used (and least complicated) image processing in digital radiographic imaging is:
- (a) Windowing
 - (b) Edge enhancement
 - (c) Image smoothing
 - (d) Image restoration
6. In digital radiography operations, which of the following describes a histogram?
- (a) Graph of the number of pixels versus the number of grey levels in an image
 - (b) An image processing technique
 - (c) An algorithm for edge enhancement
 - (d) A radiograph taken with a CR imaging system
7. For contrast enhancement in digital radiography, the Look-Up Table (LUT):
- (a) Blurs the original image or make it sharper
 - (b) Adjusts the laser beam intensity so that the final image has better contrast
 - (c) Digitises the signal from the PMT
 - (d) Changes the values of the grey levels (numbers) in the original image to generate a new image with better contrast
8. The use of a high pass filter for image processing will:
- (a) Blur the original image displayed on the viewing monitor
 - (b) Smooth the original image displayed on the monitor
 - (c) Improve the sharpness of the original image displayed on the monitor
 - (d) Change the contrast of the original image displayed on the monitor
9. The digital image processing operation of unsharp masking will:
- (a) Create a sharper final output image than the original image
 - (b) Make the original image appear brighter

- (c) Improve the contrast of the original image
 - (d) Create a blurred final output image than the original image
10. In digital image processing using spatial frequency filtering, a high pass filter:
- (a) Suppresses low frequencies and uses only high frequencies to make the image appear sharper
 - (b) Suppresses high frequencies and uses only the low frequencies to make the image appear sharper
 - (c) Uses both low and high frequencies
 - (d) Does not utilise frequencies but rather the pixel values of the image

2.4.3 Short Answers

1. What is digital image processing and which digital imaging modalities use its characteristic operations?
2. Explain how Castleman (as cited in Seeram's Digital Radiography Textbook) classify images.
3. List five classes of digital image processing operations and briefly explain the purpose of image enhancement.
4. Identify four characteristic features of a digital image and briefly describe each of them.
5. Explain briefly, the general three steps to digitising an image (since similar steps apply to any digital imaging modality).
6. What is windowing and explain how it works?

2.5 Answers to Challenge Questions

2.5.1 True/False

1. T
2. T
3. T
4. F
5. F
6. F
7. F
8. T
9. T
10. T

2.5.2 Multiple Choice

1. a
2. c

3. c
4. d
5. a
6. a
7. d
8. c
9. a
10. a

2.5.3 Short Answers

1. As described in several digital image processing textbooks, digital image processing simply means the processing of images using a digital computer. In digital imaging, patient attenuation x-ray readings are converted into electrical signals and subsequently converted into digital data (numerical data) for processing by a computer. These numerical data can be changed in several ways, to suit the viewing needs of the radiologist, in an effort to improve and enhance diagnostic interpretation and management of patients. In addition, Castleman (cited in Seeram's Digital Radiography Textbook, 2019) offers a formal definition of digital image processing as "subjecting numerical representations of objects to a series of operations in order to obtain the desired result." All digital imaging modalities, such as computed radiography, flat-panel digital radiography, digital fluoroscopy, digital angiography, digital mammography, digital tomosynthesis, computed tomography, magnetic resonance imaging, nuclear medicine and diagnostic sonography, utilise some form of digital image processing to enhance visualisation and interpretation of images of patients.
2. Castleman, a digital image processing expert has classified images on the basis of their form or method of generation. He used set theory to explain image types. According to this theory, images are a subset of all objects. Within the set of images, there are other subsets such as visible images (e.g., paintings, drawings or photographs), optical images (e.g., holograms), nonvisible physical images (e.g., temperature, pressure or elevation maps) and mathematical images (e.g., continuous functions and discrete functions). The sine wave is an example of a continuous function (analogue signal), whereas a discrete function represents a digital image. Castleman notes that "only the digital images can be processed by computer."
3. The five classes of digital image processing operations include image enhancement, image restoration, image analysis, image compression and image synthesis. The purpose of image enhancement, the most commonly used operation in digital radiography, computed tomography and magnetic resonance imaging is to generate images that are more visually pleasing to the observer. Certain characteristics such as contours and shapes can be enhanced to improve the overall quality of the image. The operations include contrast enhancement, edge enhancement, spatial and frequency filtering, image combining and noise reduction.

4. Four characteristics of a digital image include the matrix, the pixel, the voxel and the bit depth. The matrix is a two-dimensional array of numbers consisting of columns (M) and rows (N) that define small square regions called picture elements or pixels. The dimension of the image can be described by M and N, and the size of the image is given by the relationship $M \times N \times \text{kbits}$. During an imaging examination, the operator selects the matrix size, sometimes referred to as the field of view (FOV). Pixels that make up the matrix are generally square. Each pixel contains a number (discrete value) that represents a brightness level. The numbers represent tissue characteristics being imaged. The pixel size can be calculated using the relationship: $\text{Pixel size} = \text{FOV}/\text{matrix size}$. For digital imaging modalities, the larger the matrix size, the smaller the pixel size (for the same FOV) and the better the spatial resolution. A voxel (contraction for volume element) on the other hand represents a volume of tissue in the patient. Tissue voxel information is converted into numerical values and expressed in the pixels, and these numbers are assigned brightness levels. Finally, the bit depth is the number of bits per pixel. An image that is described as having a bit depth of say 10 will have 1024 (2^{10}) shades of grey.
5. There are three steps to digitising an image, namely, scanning, sampling and quantisation. While scanning divides the image into small square regions called pixels, sampling measures the brightness level of each of the pixels in the image. Quantisation, on the other hand, assigns an integer (zero, a negative or a positive number) to the brightness values of each pixel, called a grey level. The image is now made up of a range of grey levels. The total number of grey levels is called the greyscale.
6. Windowing is the most often used image processing operation in digital radiology. It is also called greyscale mapping (also referred to as “contrast stretching,” “contrast enhancement,” “histogram modification,” “histogram stretching,” or simply “windowing”) It is used to change the contrast and brightness of an image displayed for viewing on a display monitor. Image contrast and brightness transformations can be done using a variety of processing techniques. Methods used to change these two image characteristics are the look-up table (LUT) and windowing. Essentially, the LUT changes input pixel numerical values to the corresponding output pixel values, resulting in an image with different contrast and brightness (than the input image).

Digital radiographic imaging systems (such as CR and FPDR) utilise a wide range of LUTs stored in the system, for different types of clinical examinations (e.g., chest, spine, pelvis and extremities). The operator should therefore select the appropriate LUT to match the part being imaged. An important point to note here is the following: since digital radiographic detectors have a wide exposure latitude and a linear response, the image displayed without processing will appear as a low contrast image. Windowing involves the manipulation of two parameters, namely, the window width (WW) and the window level (WL). Since a digital image consists of a matrix of numbers, the range of the numbers displayed on an image is the WW and the centre of the range of numbers displayed on the same image is the

WL. These numbers are subsequently converted into a greyscale image ranging from black to white and shades of grey in between. While the WW controls the contrast of the image, the WL changes the brightness of the image.

2.6 Knowledge Lacks Identification

- A. Make a list of topics and/or questions that are still not clear to you after studying this chapter

- B. See the instructor for clarification and/or consolidation of the materials

2.7 Student Comments



Computed Radiography: Physics and Technology

3

3.1 Learning Activities

Before attempting to answer these review questions, read the following:

Chapter 3: Computed Radiography: Physics and Technology. From *Digital Radiography: Physical Principles and Quality Control* by Euclid Seeram, PhD., FCAMRT Second Edition. Springer 2019

3.2 Summary of the Main Points in this Chapter

The essential physics and technical considerations of Computed Radiography (CR) are described in this chapter. After a brief review of the history of CR, terms synonymous with CR are provided followed by a description of image acquisition, image processing, and image display, storage and communication. The basic physics of CR is described focusing on the nature of Photostimulable Storage Phosphor (PSP), latent image formation and Photostimulable Luminescence (PSL) and PSL characteristics. Furthermore, the technological aspects of CR are described including the structure of CR Imaging Plate (IP), the IP imaging cycle, CR reader types and scanning technologies, features of the CR workstation and computer networking and CR. Additionally, image processing is elaborated and described in terms of pre-processing and post-processing operations. Radiation exposure control in CR is explained in terms of the IP response to exposure, exposure indicators and exposure indicator guidelines. Other topics described in this chapter deals with image quality descriptors including spatial resolution, density resolution, noise and detective quantum efficiency, and an overview of the nature of CR image artefacts is briefly reviewed. Finally, Continuous Quality Improvement (CQI) including Quality Assurance (QA) and Quality Control (QC), parameters for QC monitoring in CR as well as tolerance limits, is reviewed.

3.3 Review Questions Will Be Based on Each of the Following Key Terms

- Terms synonymous with CR
- Brief history
- Basic physics
- CR technology
- Digital image processing in CR
- Exposure indicator
- Continuous quality improvement

3.4 Challenge Questions

Answer the following questions to check your understanding of the materials studied:

3.4.1 True (T)/False (F)

1. CR is based on the phenomenon of photostimulable luminescence that is exhibited by photostimulable phosphors.
2. FUJI-patented process in which photostimulable phosphor was used to record the image by absorbing radiation and then releasing stored images when stimulated by a helium-neon laser.
3. The phosphors used on the CR IP by several manufacturers are, in general, barium fluorohalide: europium (BaFX: Eu²⁺), where X can be chlorine (Cl), bromine (Br), or iodine (I) or a mixture of them.
4. Another phosphor used in CR is the rare-earth phosphor gadolinium oxysulfide (Gd₂O₂S).
5. When the phosphor coating on the CR IP is exposed to X-rays, electrons move from the valence band (ground state) to the conduction band (higher energy). Electrons in the conduction band are free to travel to a so-called F-centre. F comes from the German word *Farbe* meaning colour.
6. High-resolution IPs have thicker phosphor layers and provide sharper images compared to thinner phosphor layers.
7. The Analog-to-Digital Converter (ADC) used in a CR image reader (image processor) will produce 8–16 bits of quantisation per pixel, providing discrete grey levels ranging from 2⁸ to 2¹⁶.
8. In CR imaging, pre-processing is essential to correct the raw digital data collected from the IP and the CR reader that may have imperfections.
9. Exposure field recognition in CR is intended to identify the appropriate raw data values (minimum and maximum values) to be used for image greyscale rendition and to provide an indication of the average radiation exposure to the IP CR detector.

10. The CR imaging system will compensate for underexposure or overexposure by matching the measured histogram with the appropriate known histogram using anatomy-specific template matching algorithm.

3.4.2 Multiple Choice

1. When X-rays strike the CR IP:
 - (a) Electrons return to their original level (valence band).
 - (b) Electrons are raised to a higher energy level (conduction band) and remain trapped in so-called “F-centres.”
 - (c) The IP phosphor is ionised and the ejected electrons are used to create the CR digital image.
 - (d) All trapped electrons return to their valence band.

2. When a CR Imaging Plate (IP) is being scanned in the IP Reader by the laser beam, the phenomenon of light emission is referred to as:
 - (a) Photostimulable luminescence.
 - (b) Photoemission.
 - (c) X-ray stimulated phosphorescence.
 - (d) Fluorescence.

3. When the Imaging Plate (IP) of a CR imaging system is exposed to the laser beam scan, in the CR image reader unit:
 - (a) Electrons of the conduction band (higher energy level) are returned to a lower energy level (valence band) and, in the process, emit light.
 - (b) Electrons from the valence band are raised to a higher energy level (conduction band)
 - (c) Light emitted from the IP is sent directly to the analog-to-digital converter (ADC)
 - (d) Electrons still trapped in the conduction band (the higher energy state) are returned to their valence band (the lower energy state) so that the IP can be used again.

4. The purpose of erasure of the IP in the Image Reader is to:
 - (a) Ensure that all trapped electrons return to their normal state and that the plate can be used for another exposure.
 - (b) Remove any residual dirt particles on the IP.
 - (c) Ensure that the technologist does not have to clean the IP for the next exposure.
 - (d) Remove any X-ray photons trapped on the IP so that they do not create a residual image.

5. In CR, which signal *has to be digitised* and contains the patient information to create the CR image?
 - (a) The laser beam
 - (b) The light emitted by the IP as it is scanned by the laser beam
 - (c) The signal from the photomultiplier tube (PMT)
 - (d) The signal from the analog-to-digital converter (ADC)
6. The exposure indicator in CR is derived from which of the following?
 - (a) The quantity of exposure (radiation) falling on the patient
 - (b) The quantity of exposure falling on the Imaging Plate (IP)
 - (c) The exposure factors (mAs and kV) set by the technologist
 - (d) The type of examination being done
7. The exposure indicator of the FUJI CR imaging system is:
 - (a) Directly proportional to the exposure.
 - (b) Inversely proportional to the exposure.
 - (c) Inversely proportional to the kV.
 - (d) Dependent on entrance skin dose and the collimated area on the patient.
8. The term “exposure creep” in CR refers to the routine use of:
 - (a) Optimum exposure factors for examinations.
 - (b) Higher than required exposure factors.
 - (c) Lower than required exposure factors.
 - (d) Lower S-numbers recommended by the manufacturer.
9. The purpose of the image pre-processing in CR is to:
 - (a) Sharpen the image displayed on the monitor.
 - (b) Adjust the scanned histogram to match it with the stored histogram.
 - (c) Adjust the stored histogram to match the body part and view.
 - (d) Ensure that the Imaging Plate has been properly erased.
10. The purpose of the Look-Up Table (LUT) in CR (diagram above) is to:
 - (a) Change the values of the grey levels (numbers) in the original image (pre-processed) to generate a new image with better contrast.
 - (b) Adjust the laser beam intensity.
 - (c) Digitise the signal from the PMT.
 - (d) Blur the original image or make it sharper.
11. In CR, the purpose of post-processing is to:
 - (a) Correct artefacts arising from the raw data.
 - (b) Ensure that the “S” number is correct.
 - (c) Change the “S” number for the examination.
 - (d) Change the image contrast, brightness and detail of the image displayed on the monitor, to suit the viewing needs of the observer.

12. The Exposure indicator for the Agfa CR Imaging System is:
 - (a) The “S” number.
 - (b) The LgM (log of the median of the histogram).
 - (c) Exposure index
 - (d) Dose area product (DAP)

13. In CR, the ADC divides up the analog signal into equal parts for input into the computer that processes the data to create an image. How many parts will be produced by an 8-bit ADC?
 - (a) 2 parts
 - (b) 8 parts
 - (c) 16 parts
 - (d) 256 parts

14. In CR, the image presented to the observer always appears to be acceptable regardless of the magnitude of the exposure (low or high) used. This feature of the CR system is basically performed by which of the following:
 - (a) The LUT which converts the raw image data (scanned histogram) to match the stored histogram that is the acceptable “film look-alike” (good image).
 - (b) The laser beam that scans the IP when it is placed in the Image Reader.
 - (c) The analog-to-digital converter (ADC) which produces digital data.
 - (d) The photomultiplier tube (PMT) that receives all the light from the light guide.

15. What is the main source of noise in a CR image?
 - (a) The number of X-ray photons at the imaging plate (IP)
 - (b) The number of light photons collected in the image reader
 - (c) The number of electrons in the imaging phosphor before the IP is exposed to radiation
 - (d) The number of X-ray photons at the entrance surface of the patient

3.4.3 Short Answers

1. Identify the three-step cycle in CR imaging and explain briefly each of them.
2. Explain the mechanism of latent image creation and photostimulable luminescence (PSL) in CR imaging.
3. What is the fundamental difference between a standard-resolution IP and a high-resolution IP?
4. What is the purpose of pre-processing in CR? Explain the important pre-processing method in CR called exposure field recognition also referred to as exposure data recognition.
5. Briefly explain the meaning of the term “exposure indicator”
6. List several parameters for quality control (QC) monitoring in CR.

3.5 Answers to Challenge Questions

3.5.1 True/False

1. T
2. T
3. T
4. F
5. T
6. F
7. T
8. T
9. T
10. T

3.5.2 Multiple Choice

1. b
2. a
3. a
4. a
5. c
6. b
7. b
8. b
9. b
10. a
11. d
12. b
13. d
14. a
15. d

3.5.3 Short Answers

1. The three-step cycle in the CR imaging process includes X-ray exposure of the IP, laser scanning and erasure of the IP. While X-ray exposure of the IP that is coated with a photostimulable phosphor (PSP) creates a latent image; laser scanning of the IP renders the latent image visible using a laser beam of a specific wavelength. Laser scanning produces luminescence (light) that is proportional to the stored latent image. This luminescence is referred to as photostimulable luminescence (PSL).

Finally, the IP erasure process is intended to remove any residual image on the IP by exposing it to high-intensity light so that it can be used again for another exposure.

2. The mechanics of how PSPs is thought to be as follows:
 - When X-rays fall upon the PSPIP, the europium atoms are ionised by radiation, and the electrons move from the valence band (ground state) to the conduction band (higher energy). Electrons in the conduction band are free to travel to a so-called F-centre. F comes from the German word *Farbe* meaning colour
 - The number of trapped electrons is proportional to the absorbed radiation. It is at the point in the process where the electrons are spatially distributed to create the latent image. In addition to this mechanism, X-ray exposure of the PSPIP causes it to fluoresce (emits light when it is exposed to X-rays) for a very brief duration.
 - To render the latent image visible, the PSPIP is taken to the CR reader/processor to be scanned by a laser beam, and this process is referred to as photostimulable excitation Fuji, while in the CR reader, the PSPIP is scanned systematically. The laser light used must be capable of being absorbed by the “F-centres.”
 - This absorption causes the trapped electrons to move up to the conduction band, where they are free to return to the valence band, thus causing the Eu^{3+} to return to the Eu^{2+} state. This transition of the electrons from a higher energy state to a lower energy state (ground state) results in emission of bluish-purple light (~415 nm wavelength). This is referred to as photostimulable luminescence (PSL) in the PSPIP.
 - The lasers used today for PSL in CR units are semiconductor lasers that produce light with a 680 nm wavelength compared to He–Ne lasers that produce light with a 633 nm wavelength used in earlier CR units.
 - The PSL from the IP is collected by a special light collection device and sent to a photomultiplier tube that produces an electrical signal. This signal is subsequently digitised and sent to a digital computer for processing and CR image creation.
3. Standard-resolution IPs are characterised by thick phosphor layers and absorb more radiation. High-resolution IPs on the other hand have thinner phosphor layers and provide sharper images compared to thick phosphors. The sharpness is due to the fact that thinner phosphors reduce the lateral spread of the laser light. In terms of radiographic speed, thick phosphor IPs have faster speeds than high-resolution IPs (slow speeds), similar to the cassettes used in conventional radiography. Of course, the high-resolution IPs will be used for extremity imaging and other small parts where detail (sharpness) is critical.
4. Pre-processing in CR is intended to correct the raw digital data collected from the IP and the CR reader that may have imperfections. For example, the IP may

have scratches and other marks, and the CR reader may have dirt on the light channelling guide, all of which will lead to image artefacts. Furthermore, the raw data is scaled to ensure that only the useful anatomic signals are used in the digitisation process to improve image quality.

One pre-processing method in CR is *exposure field recognition* also referred to as exposure data recognition (Fujifilm Medical Systems) and segmentation (Carestream). The basic steps of exposure recognition include exposure field recognition, histogram analysis and greyscale rendition. The purpose of exposure recognition is to identify the appropriate raw data values (minimum and maximum values) to be used for image greyscale rendition and to provide an indication of the average radiation exposure to the IP CR detector. There are two steps involved in exposure field recognition:

- In step 1, the collimation edges or boundaries are detected, and anatomical structures that should be displayed in the image are identified using specific algorithms, such as the “shift and subtract” method where “the image is subtracted from an identical copy of itself and then shifted onto horizontal and vertical directions by two or more pixels”
 - In step 2, a *histogram* of the information on the IP (including the anatomy and the collimated and opened regions of the image) is created. This is referred to as the *measured histogram* or scanned histogram, to distinguish it from what is referred to as known or *stored histograms*, that is, the identical copy of the images of the anatomy under study stored previously in the machine. The CR imaging system will compensate for underexposure or overexposure by matching the measured histogram with the appropriate known histogram using anatomy-specific template matching algorithm
 - The final step in exposure recognition is *greyscale rendition* of the image. Greyscale rendition is a procedure that “maps the raw image values for the least penetrated anatomic region to the largest presentation value for display at maximum luminance.
 - Exposure recognition performs another task, and that is to provide an indication as to the amount of radiation falling upon the detector as a result of the exposure technique used by the technologist. This *exposure indicator*, or *exposure index* as it is sometimes referred to as, appears on the displayed image and serves to provide the technologist with a visual cue as to whether correct or incorrect exposure technique was used.
5. An exposure indicator (EI) is a numerical parameter used to monitor the radiation exposure to the IP in CR imaging. CR vendors in the past offered different EIs and had different methods of computing the EI. For example, Fujifilm Medical Systems refers to their exposure indicator as a sensitivity number (*S*-number), Carestream uses the term exposure index (EI). Agfa Healthcare, on the other hand, uses the term log of the median of the image histogram (lgM, log of median values). For Fuji, *S* is inversely proportional to exposure; hence a low exposure will result in a high *S*-number, and a high exposure will result in a low *S*-number. Carestream’s EI on the other hand is directly proportional to the expo-

sure; hence, a high exposure will result in a high EI and a low exposure will generate in a low EI. These differences in EI described above have created not only confusion but also frustration among users and hence provided the motivation for the development of a standardised EI, championed most notably by the International Electrotechnical Commission (IEC) and the AAPM. The nature and characteristics of the international standardised EI for digital radiography, through a description of standardisation efforts, deviation index (DI), and the target EI (EI_T), and responsibilities of both the manufacturers and users. The standardised EI is the subject of Chapter 5 in the Digital Radiography textbook by Seeram (2019)

6. The AAPM has recommended several parameters for QC monitoring in CR and they include:
- Physical inspection of the IP,
 - Dark noise
 - Uniformity,
 - Exposure indicator calibration,
 - Laser beam function,
 - Spatial accuracy,
 - Erasure thoroughness,
 - Aliasing/grid response,
 - Positioning, and collimation errors

3.6 Knowledge Lacks Identification

- A. Make a list of topics and/or questions that are still not clear to you after studying this chapter

- B. See the instructor for clarification and/or consolidation of the materials

3.7 Student Comments



4.1 Learning Activities

Before attempting to answer these review questions, read the following:

Chapter 4: Flat-Panel Digital Radiography. From *Digital Radiography: Physical Principles and Quality Control* by Euclid Seeram, PhD., FCAMRT Second Edition. Springer 2019

4.2 Summary of the Main Points in this Chapter

The essential characteristic features of Flat-Panel Digital Radiography (FPDR) Systems are described in detail in the chapter. First, a definition of FPDR is provided, followed by an identification of system components, design characteristics, operational principles, image processing and imaging performance characteristics, as well as image artefacts, and basic features of wireless digital detectors. Systems based on the use of amorphous silicon (a-Si) and amorphous Selenium (a-Se) to produce digital images using a set of electrical components specifically designed to produce digital radiographic images in a manner different from how Computed Radiography (CR) technology is reviewed. Indirect and direct digital detector technologies are described. While the former produces images using an X-ray scintillator (X-ray conversion layer), followed by an amorphous silicon (a-Si) photodiode flat-panel layer, with a thin-film transistor (TFT) array for readout of the electrical charges by the photodiode array, the latter is based on the use of a photoconductor such as amorphous selenium (a-Se) to detect X-ray photons from the patient and convert them directly into electrical charges. a TFT array and associated electronics are also used to collect and store the charges for subsequent readout. The EI is also characteristic of FPDR systems and provides a visual cue as to the amount of exposure used for a particular examination, and whether the exposure falls within guidelines suggested by the manufacturer. In addition, pre-processing and post-processing present the raw data “for processing” and “for presentation” respectively. Finally,

the chapter concludes with a description of imaging performance characteristics (such as spatial resolution, modulation transfer function, dynamic range, detective quantum efficiency, image lag and artefacts) and wireless digital radiography detectors.

4.3 Review Questions Will Be Based on Each of the Following Key Terms

- Limitations of CR
- What is FPDR?
- Types of FPDR Systems
- Design Characteristics of FPDR
- Exposure Indicator (EI)
- Operational Principles
- Image Processing Elements
- Image Performance Characteristics

4.4 Challenge Questions

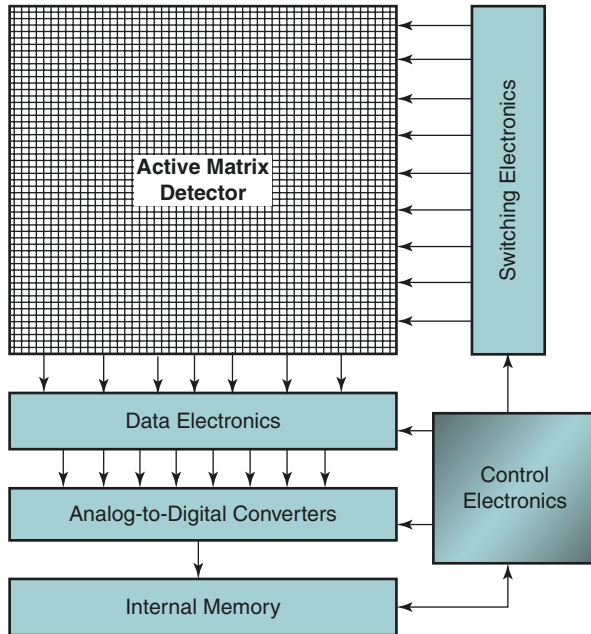
Answer the following questions to check your understanding of the materials studied:

4.4.1 True (T)/False (F)

1. One of the limitations of CR is that its X-ray detection efficiency is inefficient, and this affects the image quality and dose.
2. The flat-panel digital detector is a single unit (a thin flat-panel device) that contains not only the flat-panel X-ray detection array but also the associated electronics as well, all encased in one flat panel.
3. The only type of FPDR system available is the one that is based on the use of a scintillator coupled to an amorphous silicon (a-Si) and a thin film transistor (TFT)
4. The terms indirect conversion and direct conversion have been used synonymously to refer to indirect detectors and direct detectors, respectively.
5. The X-ray scintillator layer used in the indirect flat-panel digital detector is usually caesium iodide (CsI) or gadolinium oxysulfide (Gd_2O_2S).
6. The purpose of the a-Si photodiode layer is to convert the light from the X-ray detection scintillator into electrical charges.
7. The photoconductor in a direct conversion FPDR detector is a-Si.
8. The fill factor of an FPDR detector is defined as the ratio of sensing area of the pixel to the area of the pixel itself

9. A fill factor of 80% means that 20% of the pixel area is the sensing area with 80% of the pixel area occupied by the detector electronics
10. The EI is a numerical value usually displayed on the digital image to indicate the exposure to the digital detector, and it provides a visual cue as to the amount of exposure used for a particular examination

4.4.2 Multiple Choice



1. In the above diagram, which of the following is responsible for digitisation of the electronic signal from the active matrix array?
 - (a) The active matrix detector
 - (b) The control electronics
 - (c) The Analog-to-Digital Converter (ADC)
 - (d) The switching electronics

2. The structured phosphor arrangement in an FPDR indirect conversion detector:
 - (a) Degrades the image contrast because light is scattered in the phosphor
 - (b) Improves the spatial resolution since the lateral spread of light is reduced
 - (c) Increases the dose to the patient thus resulting in a better image
 - (d) Improves the Detective Quantum Efficiency (DQE) of the detector

3. The turbid phosphor arrangement in an FPDR indirect conversion detector:
 - (a) Decreases spatial resolution
 - (b) Decreases contrast resolution
 - (c) Decreases image noise
 - (d) Decreases DQE

4. Which of the following X-ray scintillator phosphor is used in the indirect conversion FPDR detector?
 - (a) Caesium Iodide
 - (b) Gadolinium oxysulfide
 - (c) Calcium Tungstate
 - (d) a and b are correct

5. In the indirect FPDR detector, the conversion of light produced by the scintillator phosphor into electrical charges is performed by the:
 - (a) a-silicon (a-Si) photodiode
 - (b) Thin Film Transistor (TFT)
 - (c) Caesium Iodide phosphor
 - (d) ADCs

6. In the direct conversion FPDR detector, the conversion of X-rays to electrical charges is performed by the:
 - (a) TFT
 - (b) Storage capacitors
 - (c) a-selenium (a-Se) layer
 - (d) ADCs

7. The fill factor of a direct conversion FPDR detector is equal to:
 - (a) Area of a single pixel in the matrix
 - (b) The sensing area of the pixel
 - (c) Area occupied by the capacitors
 - (d) The ratio of the sensing area of the pixel to the area of the pixel

8. The exposure indicator (EI) or exposure index is a useful tool to:
 - (a) Address the problem of “exposure creep”
 - (b) Solve the guess work in the selection of the correct exposure technique factors for the examination
 - (c) Indicate the dose to the patient
 - (d) Enable vendors to derive correct exposures for different examinations

9. The purpose of digital pre-processing of the raw data collected during FPDR imaging is:
 - (a) Display the image with the appropriate contrast for viewing by an observer
 - (b) Display the image with the appropriate brightness to satisfy the visual needs of the observer

- (c) Correct the raw data obtained from “bad” detector elements (pixels) for example.
 - (d) Provide the opportunity for calculating the EI
10. Which of the following will smooth (blur) the original image in an effort to enhance the interpretation of the image features?
- (a) Creating a histogram of the raw data
 - (b) Using a low pass digital filter to suppress high frequencies
 - (c) Using a high pass digital filter to suppress low frequencies
 - (d) Contrast enhancement
11. The response of a digital detector to different levels of radiation exposure to as the:
- (a) Modulation Transfer Function (MTF)
 - (b) Dynamic range of the detector
 - (c) Detective Quantum Efficiency (DQE)
 - (d) Signal-to-Noise ratio (SNR)
12. Which term below also referred to as the “memory effect” refers to the persistence of the image, that is charge is still being produced after the radiation beam from the X-ray tube has been turned off?
- (a) DQE
 - (b) MTF
 - (c) SNR
 - (d) Image lag

4.4.3 Short Answers

1. What are the limitations of CR which provides the motivation for the development of FPDR systems?
2. What are the main components of an FPDR detector?
3. FPDR detectors are categorised into two types. What is the fundamental basis for this classification?
4. Describe the structural elements of an indirect FPDR detector based on a scintillation phosphor coupled to a photoconductor.
5. Describe the structural elements of an indirect FPDR detector based on the use of only a photoconductor instead of a scintillation phosphor characteristic of an indirect FPDR detector
6. What is the fill factor of a flat-panel TFT digital detector?
7. FPDR detectors have a wide exposure latitude. What is the major advantage and disadvantage of such a wide exposure latitude?
8. What are the two essential reasons for image processing in digital radiography?
9. What is meant by a flat-field correction in FPDR systems?
10. Explain briefly the detective quantum efficiency (DQE) of an FPDR detector.

4.5 Answers to Challenge Questions

4.5.1 True/False

1. T
2. T
3. F
4. T
5. T
6. T
7. F
8. T
9. F
10. T

4.5.2 Multiple Choice

1. c
2. b
3. a
4. d
5. a
6. c
7. d
8. a
9. c
10. b
11. b
12. d

4.5.3 Short Answers

1. There are several limitations of CR, such as poor X-ray detection efficiency which affects image quality, poor spatial resolution compared to film-screen radiography (FSR) (about 6 line pairs/mm for CR compared to 8 line pairs/mm for FSR, the IPs can easily be damaged when dropped and they are susceptible to scratches and cracking, and finally, CR IPs must be carried physically by the technologist to a separate image processor (image reader) for image data extraction
2. The flat-panel digital detector is a single unit (a thin flat-panel device) that contains not only the flat-panel X-ray detection array but also the associated electronics as well. These include the preamplifiers, switching control, the central

logic circuits, the ADCs, and internal memory. It is important to note that X-ray detection and digitisation of the X-ray signal take place within the flat-panel detector. There is no need to take the flat-panel detector to a separate unit for signal readout as it is a characteristic feature in CR.

3. The two categories of flat-panel FPDR detectors are indirect detectors and direct detectors based on the type of X-ray absorber used. While indirect detectors use a phosphor, *direct detectors* use a photoconductor,
4. An *indirect flat-panel* digital detector is based on an indirect conversion process and uses several physical components to convert X-rays first, into light that is subsequently converted into electrical charges. These components include:
 - An X-ray scintillator (X-ray conversion layer), followed by an amorphous silicon (a-Si) photodiode flat-panel layer, with a thin-film transistor (TFT) array for readout of the electrical charges by the photodiode array (Fig. 4.5 in the textbook by Seeram (2019))
 - The X-ray scintillator layer is usually *caesium iodide* (CsI) or gadolinium oxysulfide (Gd_2O_2S).
 - The CsI crystals are deposited in a needle-like fashion (structured phosphor) and run in the direction of the X-ray beam, as opposed to crystals deposited as powdered particles (turbid phosphor).
 - While powdered phosphors produce lateral spreading of light, which destroys the spatial resolution of the image, structured phosphors like the CsI needles on the other hand reduce the lateral dispersion of light, thus improving the spatial resolution of the image. This effect is clearly illustrated in Fig. 4.6 in the textbook by Seeram (2019)
 - The purpose of the a-Si photodiode layer is to convert the light from the X-ray detection scintillator into electrical charges.
 - Adjacent to the a-Si photodiode layer is a thin-film transistor (TFT) array, as well as storage capacitors and associated electronics. The capacitors collect and store the electrical charge produced in the a-Si photodiode array.
5. The direct flat-panel TFT digital detector consists of several components such as a source of high voltage, top electrode, dielectric layer, photoconductor, collection electrode, TFT, storage capacitor and the glass substrate.
 - The photoconductor is amorphous selenium (a-Se) although other photoconductors. a-Se offers excellent X-ray photon detection properties and provides images with very high spatial resolution.
 - The photoconductor captures X-ray photons from the patient and converts them directly into electrical charges.
 - The TFT and associated electronics (e.g., capacitors) collect and store the changes for subsequent readout.
6. The pixel of an FPDR detector contains generally three components: the TFT, the capacitor, and the sensing area. The sensing area of the pixel receives the data

from the layer above it that captures X-rays that are converted to light (indirect flat-panel detectors) or electrical charges (direct flat-panel detectors). The fill factor then is defined as the ratio of the sensing area of the pixel to the area of the pixel itself [1] and can be expressed as:

$$\text{Fill factor} = \text{Sensing area of the pixel} / \text{Area of the pixel}$$

- The fill factor is also expressed as a percentage, where a fill factor of 80% means that 20% of the pixel area is occupied by the detector electronics with 80% representing the sensing area.
 - The fill factor affects both the spatial resolution and contrast resolution (signal-to-noise ratio) characteristics of the detector.
 - Detectors with high fill factors (large sensing areas) will provide better spatial and contrast resolution than detectors with low fill factors (small sensing area).
7. The exposure latitude for digital detectors (CR and DR detectors) is much wider (0.1–1000 μGy) compared to the screen-film detectors.
 - The major advantage of such a wide dynamic range is that the detector can respond to different levels of exposure (low to high) and still provide an image that appears acceptable to the observer
 - A significant disadvantage of this response to radiation exposure is that while higher doses provide excellent image quality, the patient dose increases. Furthermore, since operators and observers always tend to favour excellent image quality, operators may often use a higher exposure than is normally required for a particular examination. This situation is referred to as “exposure creep” or simply “dose creep”.
 8. Image processing in digital radiography systems accomplishes two tasks:
 - To provide corrections to the raw digital data obtained from the detector, in an effort to reduce artefacts in image post-processing
 - To optimise the display of the image that is presented to the radiologist for diagnostic interpretation, such that contrast and sharpness are enhanced, while noise can be reduced.
 9. The image obtained initially from the detector is referred to as a flat-field image. This image may contain artefacts due to the bad detector elements and other problems with the pixels on the detector array, such as dead or bad pixels, bad column of pixels, and so forth. These artefacts can be corrected by a pre-processing technique referred to as flat-fielding, a process is popularly referred to as system calibration. This correction procedure is an essential requirement to ensure detector performance integrity.

10. The DQE deals with how efficient a detector is at converting radiation falling upon it into a useful image signal. The DQE provides information about the signal-to-noise ratio (SNR). In general, the signal and the detector must provide the maximum signal possible. On the other hand, noise is also present in the signal due to few photons (quantum noise) striking the detector as well as electronic noise. These two parameters can be put together to create the SNR concept. In imaging applications, since contrast resolution (the ability to resolve small differences in tissue contrast) is mandatory for diagnostic interpretation, it is important to have a high SNR. This means that the signal is high and the noise is low.

- The $DQE = SNR_{out}^2 / DQE_{in}^2$. A perfect digital detector would have a DQE of 1.
- In clinical practice, the DQE for the indirect conversion CsI a-Si TFT flat-panel detectors offers the highest DQE at low frequencies. As the spatial frequencies increase, the DQE decreases rapidly.
- Since the DQE also depends on the photon energy (kV), under controlled conditions, it has been shown that the quantum efficiencies (based on the X-ray absorption properties of the detector converter materials) at 70 kV is about 67% for a-Se and 77% for the CsI phosphor. At 120 kV, efficiencies are 37% for a-Se and 52% for CsI. In lower kV applications such as mammography, a-Se performs better than CsI and has a higher DQE.

4.6 Knowledge Lacks Identification

A. Make a list of topics and/or questions that are still not clear to you after studying this chapter

B. See the instructor for clarification and/or consolidation of the materials

4.7 Student Comments



The Standardised Exposure Indicator

5

5.1 Learning Activities

Before attempting to answer these review questions, read the following:

Chapter 5: The Standardized Exposure Indicator. From *Digital Radiography: Physical Principles and Quality Control* by Euclid Seeram, PhD., FCAMRT Second Edition. Springer 2019

5.2 Summary of the Main Points in this Chapter

This chapter addressed the essential features of the international standardised EI for DR imaging systems. First, two “old” propriety scales for the EI, the inverse scale and the proportional scale, were reviewed briefly followed by an outline of a generalised method for determining the EI. The next topic described is three conditions for the IEC standardised EI that must be met: (a) the standardised EI is related to the detector exposure, the standardised EI be obtained from the pixel values in the region of interest; (b) the standardised EI uses a linear proportional scale related to the detector exposure/signal (i.e., doubling the detector dose, doubles the standardised EI value); and (c) consideration of the radiation beam quality (kVp, half-value layer and added filtration) used for the calibration of the EI and the precision of the scale. Third, selected terminology of the IEC standardised EI was defined and includes the Exposure Index (EI), the Target EI (EI_T), Deviation Index (DI) and the value of interest (VOI). The IEC standardised EI is now proportional to the detector exposure and requires the user to establish EI_T values for all examinations in order to ensure optimisation of the dose to the patient without compromising the image quality. These values (EI and EI_T) can now be used to calculate the DI. The DI provides immediate feedback to the technologist as to whether the correct exposure was used for the examination. The chapter concludes with an example of a dose-image quality optimisation study for the purpose of providing insights as to how a department may go about establishing EI_T values objectively.

5.3 Questions Will Be Based on Each of the Following Key Terms

- Propriety EI Scales
 - Determination of the EI
 - The Standardised EI: Characteristics
 - The Standardised EI: Responsibilities
-

5.4 Challenge Questions

Answer the following questions to check your understanding of the materials studied:

5.4.1 True/False

1. The characteristic curve for film-screen radiography (FSR) shows how the optical density of the film responds to the log of the relative exposure.
2. The characteristic curve in FSR has two regions only, a toe region which shows that low exposures produce underexposed images and a shoulder region which shows that high exposures produce overexposed images.
3. A major problem with FS radiography is the narrow exposure latitude, which means that careful attention must be paid in the selection of the correct exposure technique factors (mAs and kV).
4. DR systems have a linear response to the exposure; the advantage is that of wide exposure latitude that is 100 times that of FS radiography. Furthermore, DR image processing operations render consistent appearance of images that are overexposed and underexposed.
5. The problem of this operation (in 4 above) is that the user now has difficulty in identifying images that have been underexposed and overexposed. In attempting to produce acceptable images, users appear to increase exposure technique factors which ultimately result in what has been referred to as “exposure creep” or simply “dose creep”.
6. DR systems use the exposure indicator (EI), sometimes called an exposure index, to indicate the dose to the patient.
7. Various DR vendors in the past used different EIs with specific names and this has caused confusion in clinical practice, since departments may have different DR systems.
8. A standardised EI has been established to solve the problems identified in 7 above.
9. In the standardised EI paradigm, the EI is directly proportional to the radiation exposure.
10. In the standardised EI paradigm, a deviation index (DI) of 0 indicates that the exposure is very high.

5.4.2 Multiple Choice

1. The EI in digital radiography indicates:
 - (a) The dose to the patient
 - (b) The dose to the detector
 - (c) Whether the correct exposure techniques have been used
 - (d) Both b and c are correct

2. Detectors for DR have a linear response to radiation exposure providing an advantage of a wide exposure latitude which is:
 - (a) 50 times that of FSR
 - (b) 20 times that of FSR
 - (c) 100 times that of FSR
 - (d) Equal to that of FSR

3. Which of the following addresses the problem of “exposure creep”?
 - (a) Exposure Indicators
 - (b) Exposure technique factors
 - (c) Technologists
 - (d) Radiologists

4. A measure of the detector response to radiation in the relevant region of an image is the International Electrotechnical Commission (IEC) definition of:
 - (a) The Detective Quantum Efficiency (DQE)
 - (b) The Exposure Indicator
 - (c) The Volume of Interest (VOI)
 - (d) The Region of Interest (ROI)

5. The scale which expresses the EI as increasing proportionally as the dose increases is called the:
 - (a) Proportional scale
 - (b) Inverse scale
 - (c) Logarithmic scale
 - (d) Nominal scale

6. The old exposure indicator of the FUJI CR imaging system is is:
 - (a) Directly proportional to the exposure
 - (b) Inversely proportional to the exposure
 - (c) Inversely proportional to the kV
 - (d) Dependent on the entrance skin dose and the collimated area on the patient

7. In determination of the EI, the method that uses the mean value of the relevant range of pixel values is called the:
 - (a) Histogram method
 - (b) ROI method

- (c) VOI method
(d) Both b and c are correct
8. Which of the following is defined by the IEC as the “expected value of the exposure index when exposing the x-ray image receptor properly”?
- (a) EI
(b) Target EI (EI_T)
(c) Deviation Index (DI)
(d) VOI
9. Which of the following is defined by the IEC as a “number quantifying the deviation of the actual exposure index from a target exposure index”?
- (a) EI
(b) Target EI (EI_T)
(c) Deviation Index (DI)
(d) VOI
10. Which of the following is defined by the IEC as the “central tendency of the original data in the relevant image region? The central tendency is a statistical term depicting generally the center of a distribution. It may refer to a variety of measures such as the mean, median, or the mode.”
- (a) EI
(b) Target EI (EI_T)
(c) Deviation Index (DI)
(d) VOI
11. In general, the essential steps to determine the standardised EI are:
- (a) Detector calibration to ensure a direct proportional relationship between the EI and the exposure at the detector
(b) The EI_T should be determined by the department (not the vendor) using objective approaches
(c) The DI values can be computed using the following mathematical relationship: $DI = 10 \log_{10} (EI/EI_T)$
(d) All of the above are correct
12. DI values ranging from -1 to -3 indicate:
- (a) Correct exposure
(b) Acceptable range of DI values used in practice
(c) Underexposure
(d) Overexposure

5.4.3 Short Answers

1. What provided the motivation for the development of the standardised EI?
2. What two approaches or scales are used to express the EI?

3. What are the two popular methods for calculating the EI?
 4. What are the definitions of the IEC for each of the following parameters?
 - Exposure index (EI),
 - The target exposure index (EI_T),
 - The deviation index (DI) and
 - The value of interest (VOI).
 5. What are the major steps in determining the standardised EI?
 6. What value of the DI indicates that a perfect exposure was used? What range of DI values indicates acceptable exposures?
 7. What are the major responsibilities of both the vendor and the user in the Standardised EI paradigm?
-

5.5 Answers to Challenge Questions

5.5.1 True/False

1. T
2. F
3. T
4. T
5. T
6. F
7. T
8. T
9. T
10. F

5.5.2 Multiple Choice

1. d
2. c
3. a
4. b
5. a
6. b
7. a
8. b
9. c
10. d
11. d
12. d

5.5.3 Short Answers

1. The fact that during the early days of DR, various vendors had different scales for their EIs. For example, while Fuji and Philips offered an inverse scale, others such as Carestream and Siemens offered a proportional scale. These scales caused confusion among users and therefore a Standardised EI would remove this confusion. The IEC developed the Standardised EI, which is a proportional scale in which case as the dose increases, the EI increases proportionally.
2. Two different approaches (or scales) to express the EI as a function of the radiation dose. While the first is an inverse scale which explains that as the dose increases, the EI decreases, the second is a proportional scale which shows that as the dose increases, the EI increases proportionally.
3. The EI is obtained from the image information using one of the two popular methods: the histogram method and the ROI method. The latter uses a procedure referred to as the VOI (pixel value of interest) segments, the anatomy under study and an average value is obtained from at least 25% of the central region of the image. The histogram method on the other hand is based on the use of the mean value of the relevant range of pixel values in calculating the EI.
4. The IEC definitions are as follows:
 - The EI is a “measure of the detector response to radiation in the relevant image region of an image acquired with a digital X-ray imaging system”.
 - The EI_T is the “expected value of the exposure index when exposing the X-ray image receptor properly”.
 - The DI is a “number quantifying the deviation of the actual exposure index from a target exposure index”.
 - The VOI is the “central tendency of the original data in the relevant image region. The central tendency is a statistical term depicting generally the centre of a distribution. It may refer to a variety of measures such as the mean, median, or the mode.” The VOI is important for the calculation of the EI.
5. Both the IEC and the AAPM suggest the following steps to obtain the standardised EI:
 - First, the detector must be calibrated such that there is a direct proportional relationship between the EI and the exposure at the detector, that is, if the detector exposure is doubled, the EI value doubles. For example, detector exposures of 2 μGy , 4 μGy , 8 μGy and 10 μGy produce EI values of 200, 400, 800 and 1300, respectively.
 - Second, the EI_T should be determined by the department (not the vendor) using objective approaches.
 - The third essential task, the DI values can be computed using the following mathematical relationship: $DI = 10 \log_{10} (EI/EI_T)$.

-
6. While a DI value of 0 indicates a perfect exposure technique, the DI value range of -1 to $+1$ indicates an acceptable range of exposure techniques.
 7. The DR vendor's major responsibilities are calibration of the response of the detector such that a directly proportional scale is used (as the dose increases, the EI increases proportionally), image processing operations, as well as establishing EI_T values for different examinations. Users on the other hand must establish their own EI_T values based on the exposure technique factors used in their departments for different body parts, etc., using objective measures. Other responsibilities require the IEC standardised EI implementation when purchasing new imaging equipment. Furthermore, the department has an important responsibility to also train users on the use of the DI, its acceptable limits and how to adjust techniques when the DI is beyond the acceptable range.

5.6 Knowledge Lack Identification

- A. Make a list of topics and/or questions that are still not clear to you after studying this chapter

- B. See the instructor for clarification and/or consolidation of the materials

5.7 Student Comments



6.1 Learning Activities

Before attempting to answer these review questions, read the following:

Chapter 6: Digital Fluoroscopy. From *Digital Radiography: Physical Principles and Quality Control* by Euclid Seeram, PhD., FCAMRT Second Edition. Springer 2019

6.2 Summary of the Main Points in this Chapter

Fluoroscopy is an imaging modality that shows anatomical structures and the motion of organs, and the movement of contrast media in blood vessels and organs with the goal of obtaining functional information. It has evolved from conventional fluoroscopy recording images on film to current digital fluoroscopy (DF) in which digital dynamic images are obtained and stored in a computer. There are two modes of DF, one that is based on using an image intensifier coupled to a digital imaging chain, and one that is based on the use of digital flat-panel detectors (FPDs). The former is being replaced by the latter, which is capable of producing dynamic images that can be displayed and viewed in real time. For this reason, these detectors are sometimes referred to as dynamic FPDs. Two types of dynamic FPDs are currently available for digital fluoroscopy, namely, the Caesium Iodide amorphous-Silicon (CsI a-Si) TFT indirect digital detector and the a-Selenium TFT direct digital detector. An important characteristic of these detectors is that they must have high frame rates and fast data transfer rates. Frame rates of 15 to 30 frames per second (fps) or greater are possible at readout speeds of 30 to 50 msec. Additionally, dynamic FPDs can operate in at least two readout modes; the fps in continuous X-ray mode and the fps in the pulsed X-ray mode. The overall goal of the latter is to reduce the dose to the patient during the examination.

FPD DF systems offer two approaches to image magnification: (a) electronic magnification (zoom) and (b) binning. With the former approach, there is no increase

in spatial resolution and both original and magnified images have the same signal-to-noise ratio (SNR). Binning has the disadvantage of less spatial resolution because the effective area of each image pixel is four times larger, and it has the advantage of lower data rates and less image mottle than ungrouped pixels. Advantages of FPD DF include distortion-free images, improved contrast resolution, high detective quantum efficiency (DQE) and uniform image quality over the whole displayed rectangular image. The chapter concludes with a brief description of several image post-processing operations specifically for digital fluoroscopy, such as greyscale image manipulation, temporal frame averaging, last image hold and edge enhancement; and a brief overview of Digital Subtraction Angiography (DSA).

6.3 Questions Will Be Based on Each of the Following Key Terms

- Conventional Fluoroscopy Principles
- Digital Fluoroscopy with Image Intensifiers
- Digital Fluoroscopy with Flat-Panel Detectors
- Digital Image Post-Processing
- Digital Subtraction Angiography

6.4 Challenge Questions

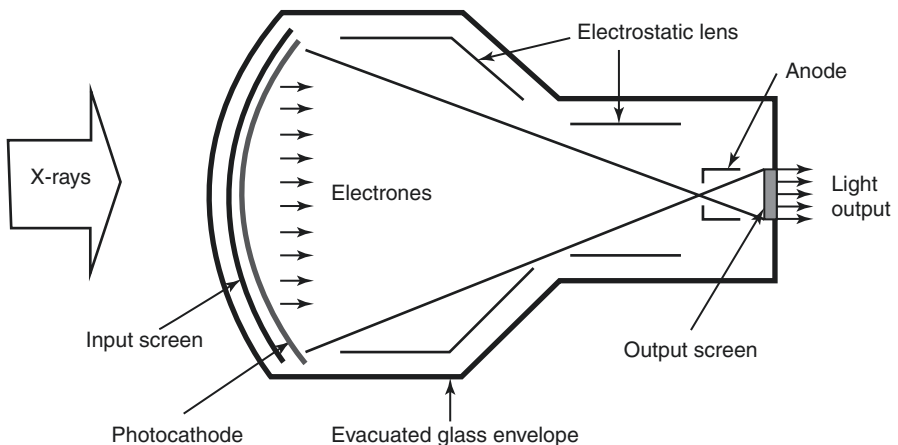
6.4.1 True (T)/False (F)

1. Conventional fluoroscopy refers to the use of an image intensifier coupled to a video camera that converts the image from the output screen of the image intensifier into a video signal (analogue data).
2. Image intensifier-based digital fluoroscopy system, and it consists of an X-ray tube and generator, the image intensifier, the video camera, the analog-to-digital converter (ADC), the digital computer, a digital-to-analog converter (DAC) and finally the television monitor.
3. Digital fluoroscopy (DF) using Flat-Panel Detectors (FPD) has replaced Image Intensifier-based DF.
4. For the effect of motion in fluoroscopy, frame rates must be at least 30 frames per second (fps).
5. Pulsed fluoroscopy systems require the use of a grid-controlled X-ray tube and will reduce the dose to the patient by as much as 90% compared to non-pulsed systems.
6. Magnification fluoroscopy does not increase the dose to the patient.

7. Pincushion and “S” distortions are not considered artefacts in conventional and image intensifier-based fluoroscopy.
8. Digital fluoroscopy systems operate in the radiographic mode and therefore the mA is sometimes 100 times that of the low mA (3–5 mA) used in conventional fluoroscopy systems.
9. Only one type of dynamic FPD is currently available for digital fluoroscopy, namely, the CsI a-Si TFT indirect digital detector.
10. Dynamic FPDs can operate in at least two readout modes: the frame rate (fps) in continuous X-ray mode and the fps in the pulsed X-ray mode.

6.4.2 Multiple Choice

1. Major problems of the early fluoroscopes which allowed direct observation of a fluorescent screen are:
 - (a) Lack of brightness of the image
 - (b) Poor image detail and contrast
 - (c) Only (a) above
 - (d) Both a and b are correct



2. The component of the image intensifier tube (shown above) that converts X-rays into light is the:
 - (a) Photocathode
 - (b) Input screen phosphor
 - (c) Output phosphor
 - (d) Anode

3. Which of the following emits light photons?
 - (1) Input Phosphor
 - (2) Output Phosphor
 - (3) Photocathode
 - (4) Electrostatic Lens
 - (a) (1) only
 - (b) (1) and (2)
 - (c) (1), (2) and (3)
 - (d) (1), (2), (3) and (4)

4. Which of the following emits electrons?
 - (1) Input Phosphor
 - (2) Output Phosphor
 - (3) Photocathode
 - (4) Electrostatic Lens
 - (a) (1) only
 - (b) (1) and (2)
 - (c) (3) only
 - (d) (3) and (4)

5. The input screen phosphor for a modern image intensifier tube is:
 - (a) Gadolinium Oxysulfide
 - (b) Caesium Iodide
 - (c) Zinc Cadmium Sulfide
 - (d) Calcium Tungstate

6. What is the approximate potential difference (voltage) across the image intensifier tube from the input screen to the output screen?
 - (a) 10–15 kV
 - (b) 25–30 volts
 - (c) 200–3000 volts
 - (d) 25–30 kV

7. In an image intensifier-based DF system, which component is responsible for digitising the signal received from the video camera?
 - (a) The computer
 - (b) The photocathode
 - (c) The analog-to-digital converter
 - (d) The digital-to-analog converter

8. Which of the following types of dynamic FPDs are currently available for digital fluoroscopy?
 - (a) The Caesium Iodide (CsI) amorphous-Silicon (a-Si) Thin Film Transistor (TFT) indirect digital detector
 - (b) The a-Se TFT direct digital detector.
 - (c) a only
 - (d) a and b are used

9. The advantages of dynamic FPD fluoroscopy compared with image intensifier-based digital fluoroscopy are:
 - (a) Distortion-free images
 - (b) Improved contrast resolution, high detective quantum efficiency (DQE)
 - (c) Uniform image quality over the whole displayed rectangular image
 - (d) All are correct

10. In dynamic FPD fluoroscopy, which magnification mode of operation results is no increase in spatial resolution, and both original and magnified images have the same signal-to-noise ratio (SNR)?
 - (a) Electronic magnification (zoom)
 - (b) Binning

6.4.3 Short Answers

1. What are the shortcomings of conventional fluoroscopy that have been overcome by DF systems?
2. Explain how an image intensifier tube works.
3. Describe briefly how magnification is accomplished in an image intensifier tube and identify the advantages and disadvantages of magnification.
4. Identify the components of an image intensifier-based DF system and state the role of the analog-to-digital converter.
5. Outline the limitations of an intensifier-based digital fluoroscopy system.
6. State the types and characteristics of digital flat-panel detectors used in a digital fluoroscopy.
7. List the advantages of dynamic FPDs in digital fluoroscopy.
8. Briefly outline the role of digital image post-processing in digital fluoroscopy.

6.5 Answers to Challenge Questions

6.5.1 True/False

1. T
2. T
3. T
4. T
5. T
6. F
7. F
8. T
9. F
10. T

6.5.2 Multiple Choice

1. d
2. b
3. b
4. c
5. b
6. d
7. c
8. d
9. d
10. a

6.5.3 Short Answers

1. The shortcomings of a conventional fluoroscopy imaging system are its lack of brightness of the image, poor image detail and poor image contrast. These are overcome by image intensifier-based fluoroscopy systems, including an image intensifier-based digital fluoroscopy system.
2. The major system components of the image intensifier tube are shown in the diagram for multiple-choice questions above. These include the input screen, the photocathode, the electrostatic lens and an output screen, all enclosed in an evacuated glass envelope. The input screen is coated with CsI phosphor packed in a needle-like fashion (structured phosphor to reduce the lateral spread of light in an effort to improve the spatial resolution compared with powdered CsI phosphors). The light from the input screen (phosphor) strikes the photocathode which is made of antimony caesium (SbCs) and which emits photoelectrons. The

electrostatic lens or electron optics as it is often referred to consists of a series of electrodes that accelerate and focus the photoelectrons from the photocathode to the output screen. This requires a voltage of about 25–30 kV applied between the photocathode and the output screen. The output screen is coated with ZnCdS phosphor that converts the photoelectrons into light. The diameter of the output screen is about one-tenth the diameter of the input screen. Due to the acceleration of the photoelectrons and the small size of the output screen, the image at the output screen is extremely bright. This increase in brightness is conveniently referred to as the brightness gain.

3. Magnification on fluoroscopy with image intensifiers is intended to enhance the image in order to facilitate diagnostic interpretation. Magnification fluoroscopy is only possible with multi-field image intensifiers. These include the popular dual-field and the triple-field intensifiers that use a technique referred to as electron optical magnification. This technique changes the voltage on specific electrodes of the electrostatic lens system in the image intensifier tube, to cause the electron beam crossover point to increase its distance from the output screen. A dual-field intensifier (25 cm/17 cm) can operate in the full-field mode (25 cm) and in the magnification mode (17 cm). When the magnification mode is used, the X-ray beam is automatically collimated to fall upon the central portion of the input screen to cover a diameter of 17 cm. On the other hand, a triple-field intensifier (25 cm/17 cm/12 cm) can operate in two magnification modes, 17 cm and 12 cm modes. The 12 cm mode provides greater magnification than the 17 cm mode. Magnification provides increased spatial resolution but at the expense of increased dose to the patient. In general, the increase is about 2.2 times that used in the full-field mode of operation for the 17 cm and 12 cm modes, respectively.

¶The approximate dose can be computed by using the ratio of the two fields as follows:

$$\text{Dose Full – field diameter}^2 / \text{Magnification mode}$$

4. An image intensifier-based digital fluoroscopy system consists of an X-ray tube and generator, the image intensifier, the video camera, the ADC, the digital computer, a digital-to-analog converter (DAC) and finally the television monitor. While the X-ray tube is a high-capacity tube and is pulsed in operation, the generator on it is a high-frequency generator and can provide high mA values to be used in digital fluoroscopy, compared with low mA values typical of conventional fluoroscopy (the mA is sometimes 100 times higher). The CCD camera is now used in digital fluoroscopy systems using image intensifiers. The ADC receives the output video signal (analog signal) from the video camera, samples it and digitises it according to the bit size of the ADC. A 10 bit ADC will divide the signal into 1024 (2^{10}) parts. At the heart of a digital fluoroscopy imaging system is a digital host computer which is a minicomputer system capable of receiving dynamic digital data from the ADC and processing it quickly for image display and subsequent storage.

5. The shortcomings of using image intensifier tube for fluoroscopic imaging are veiling glare, vignetting, image lag and pincushion and “S” distortions. Furthermore, light and electron scattering within the tube degrade the image contrast (veiling glare), and image magnification results increased the dose to the patient.
6. The components of a flat-panel digital fluoroscopy system include the X-ray tube and generator, patient table, the grid, the dynamic FPD, the host computer and the television display monitor. Two types of dynamic FPDs are used for digital fluoroscopy, namely, the CsI a-Si TFT indirect digital detector and the a-Se TFT direct digital detector. Several characteristics are the detector dimensions, matrix sizes, pixel considerations and the zoom feature. While typical dimensions of these detectors vary, 31 cm × 31 cm, 35 cm × 35 cm, 30 cm × 40 cm and 41 cm × 41 cm are not uncommon. Generally, larger detectors have larger matrix sizes, and typical sizes include 1024 × 1024, 2304 × 2304 and 2048 × 2048. The pixel size is larger than the pixel size used in digital radiography detectors. Another characteristic feature of the dynamic FPD is that they offer “zoom” modes. In this respect, the operator can zoom into the survey image and examine the details of smaller structures. Magnification can be accomplished via (a) electronic magnification (zoom) and (b) binning. With electronic magnification, there is no increase in spatial resolution, and both original and magnified images have the same signal-to-noise ratio (SNR). Binning involves a grouping of several pixels in the input to create one pixel in the output image; however, the disadvantage is less spatial resolution because the effective area of each image pixel is four times larger, and it has the advantage of lower data rates and less image mottle than ungrouped pixels.
7. The advantages of dynamic FPDs in digital fluoroscopy include distortion-free images, improved contrast resolution, high detective quantum efficiency (DQE) and uniform image quality over the whole displayed rectangular image (a format that makes efficient use of the rectangular display of television monitors), while it is circular for intensifier-based systems.
8. Image post-processing operations in digital fluoroscopy include greyscale image manipulation, temporal frame averaging, last image hold (lih), edge enhancement, temporal and energy subtraction. While greyscale image manipulation changes the contrast and brightness of an image displayed on the monitor, lih displays the last frame continuously when the X-ray beam is turned off. The process repeats itself when the beam is turned on once again. Temporal frame averaging reduces the noise present in an image by continuously displaying an image that is created by averaging the current frame with one or more previous frames of digital fluoroscopic image data. Edge enhancement is an image-sharpening post-processing operation. Finally, while temporal digital subtraction subtracts of images in time, energy subtraction subtracts images taken with different kVs. These operations are all intended to enhance diagnostic image interpretation.



7.1 Learning Activities

Before attempting to answer these review questions, read the following:

Chapter 7: Full-Field Digital Mammography. From *Digital Radiography: Physical Principles and Quality Control* by Euclid Seeram, PhD., FCAMRT Second Edition. Springer 2019

7.2 Summary of the Main Points in this Chapter

Mammography is defined as radiography of the breast. Digital mammography (DM) or full-field digital mammography (FFDM) has become commonplace in medical imaging departments. FFDM overcomes the limitations of film-screen mammography (FSM). Two major limitations include a limited dynamic range, and that the display characteristics such as brightness and contrast are fixed due to the chemical processing of the film. FFDM is radiography of the breast using a digital detector coupled to a digital computer that makes use of digital image processing techniques to enhance the visibility of detail and contrast of the image, in an effort to improve the detectability of breast lesions. FFDM consists of five steps which include data acquisition; analog-to-digital conversion (ADC); digital image processing; image display, image storage, archiving; and communications via the picture archiving and communications system (PACS). Four types of digital detector systems are used for FFDM: flat-panel phosphor system, charge-coupled device (CCD) system, Flat-Panel amorphous Selenium (a-Se) System and a computed radiography (CR) FFDM system. Detectors for FFDM must be capable of providing a spatial resolution of at least 10 line pairs/mm (lp/mm) to improve lesion detectability. Another performance characteristic of an FFDM detector is the detective quantum efficiency (DQE), which provides an indication of how well the FFDM imaging system can efficiently transfer the input signal-to-noise ratio (SNR) (at the detector) to the output SNR (image displayed on the monitor) so that it is useful to

the observer in making a diagnosis. Digital image processing is an essential feature of FFDM and included operations such as windowing, measurement and annotation tools, as well as various sophisticated digital post-processing techniques, such as frequency processing for enhancing the sharpness of an image as well as manual intensity windowing (MIW), histogram-based intensity windowing (HIW), mixture-model intensity windowing (HMIW), contrast-limited adaptive histogram equalisation (CLAHE), unsharp masking and peripheral equalisation. Applications of FFDM include computer-aided detection and diagnosis, digital breast tomosynthesis (DBT) and contrast-enhanced digital mammography. DBT is also referred to as three-dimensional (3D) mammography and is a relatively new technique which has increased attention in the literature.

7.3 Questions Will Be Based On Each of the Following Key Terms

- Screen-Film Mammography Review
- What is FFDM?
- Technical Requirements for FFDM
- Detector Types for FFDM
- Digital Image Processing Techniques
- Applications of FFDM

7.4 Challenge Questions

7.4.1 True (T)/False (F)

1. Mammography is defined as radiography of the breast, and it is a prime example of soft tissue radiography.
2. Screen-Film Mammography (SFM) uses a computer to render the latent image on the detector, visible for viewing and interpretation.
3. The problem of a narrow dynamic range of SFM has been overcome by Digital Mammography (DM).
4. Full-field digital mammography (FFDM) is radiography of the breast using a digital detector and a digital computer, and various image processing techniques to enhance the visibility of detail and contrast of the image, in an effort to improve the detectability of breast lesions.
5. Two important advantages of FFDM are that it offers Computer-aided detection (CAD) and Diagnosis and Digital breast tomosynthesis (DBT).
6. Analog-to-digital conversion (ADC) is the first step of FFDM imaging procedure.
7. Whereas the DQE for a SFM system is about 45%, the DQE for a perfect FFDM system is 1 (100%).
8. FFDM systems may use 12 to 14-bit ADCs.
9. There are at least four types of detectors used including the Flat-Panel Scintillator/amorphous Silicon (a-Si) System, the charge-coupled device (CCD)

system, the computed radiography (CR) FFDM system and the Flat-Panel amorphous Selenium (a-Se) System.

10. The physical basis for imaging using a CR FFDM system is photostimulable luminescence.

7.4.2 Multiple Choice

1. SFM offers the following advantages:
 - (a) High image contrast
 - (b) Spatial resolution of about 15–20 line pairs/mm
 - (c) Only a is correct
 - (d) a and b are correct

2. SFM offers the following disadvantages:
 - (a) Narrow exposure latitude
 - (b) Brightness and contrast of film images are fixed
 - (c) Film serves the role of data acquisition, image display and image storage
 - (d) All of the above are correct

3. FFDM uses a digital detector and computer processing to generate images, as opposed to chemical processing of film characteristic of SFM. These imaging components offer the following advantages of FFDM over SFM:
 - (1) Wider dynamic range (wider exposure latitude)
 - (2) Greater contrast resolution
 - (3) Digital image processing
 - (4) Computer-Aided Detection (CAD), Digital Tomosynthesis and Contrast-enhanced DM
 - (a) (1) only
 - (b) (1) and (2)
 - (c) (3) and (4)
 - (d) (1), (2), (3) and (4) are correct

4. Which of the following detectors used in FFDM system is based on the principle of photostimulable luminescence?
 - (a) Flat-panel phosphor system,
 - (b) Charge-coupled device (CCD) system,
 - (c) Flat-Panel amorphous Selenium (a-Se) System,
 - (d) Computed radiography (CR) system

5. The measure of the FFDM detector performance that addresses how the detector converts the input exposure to the output exposure is the:
 - (a) Detective Quantum Efficiency (DQE)
 - (b) Signal-to-Noise Ratio (SNR)
 - (c) Spatial resolution
 - (d) Area (size) of the detector

-
6. The bit size of the analog-to-digital converter (ADC) for FFDM should be at least:
- (a) 6–8
 - (b) 10–12
 - (c) 12–14
 - (d) 20 bits
7. In FFDM, which detector type converts radiation into light and subsequently converts the light into electrical signals for digitisation by the ADC?
- (1) Amorphous-Selenium (a-Se) system
 - (2) Scintillator/a-Silicon (a-Si) system
 - (3) Photostimulable phosphor system
 - (4) Charge-Coupled Device (CCD) system
- (a) (1) and (2)
 - (b) (2) only
 - (c) (2) and (3)
 - (d) (2), (3) and (4)
8. Which of the following detector types makes use of Caesium Iodide?
- (1) Amorphous-Selenium (a-Se) system
 - (2) Scintillator/a-Silicon (a-Si) system
 - (3) Photostimulable phosphor system
 - (4) Charge-Coupled Device (CCD) system
- (a) (1) and (2)
 - (b) (3) only
 - (c) (2) and (4)
 - (d) (2) and (4)
9. In a computer-aided detection and diagnosis (CAD) system, which of the following operations finds unique features that can be readily distinguished reliably between a lesion and other normal anatomical structures?
- (a) Quantitation
 - (b) Data processing
 - (c) Image post -processing
 - (d) All of the above
10. In which of the following imaging methods does the X-ray tube sweeps across the patient, through various angles, while the image detector remains stationary using image reconstruction to generate images for diagnosis?
- (a) Digital tomosynthesis (DT)
 - (b) Conventional tomography
 - (c) Digital mammography (DM)
 - (d) Contrast-enhanced DM

7.4.3 Short Answers

1. What are the shortcomings of SFM that are overcome by FFDM?
2. Describe the major system components of an FFDM system
3. Outline the advantages of FFDM
4. List the four types of detector systems used in FFDM and describe the various measures of detector performance in FFDM
5. Compare the differences between the Flat-Panel Scintillator/amorphous Silicon (a-Si) and the Flat-Panel amorphous Selenium (a-Se) FFDM Systems
6. Outline the application areas of FFDM
7. Describe the fundamental principles of Digital Tomosynthesis

7.5 Answers to Challenge Questions

7.5.1 True/False

1. T
2. F
3. T
4. T
5. T
6. F
7. T
8. T
9. T
10. T

7.5.2 Multiple Choice

1. d
2. d
3. d
4. d
5. a
6. c
7. d
8. c
9. a
10. a

7.5.3 Short Answers

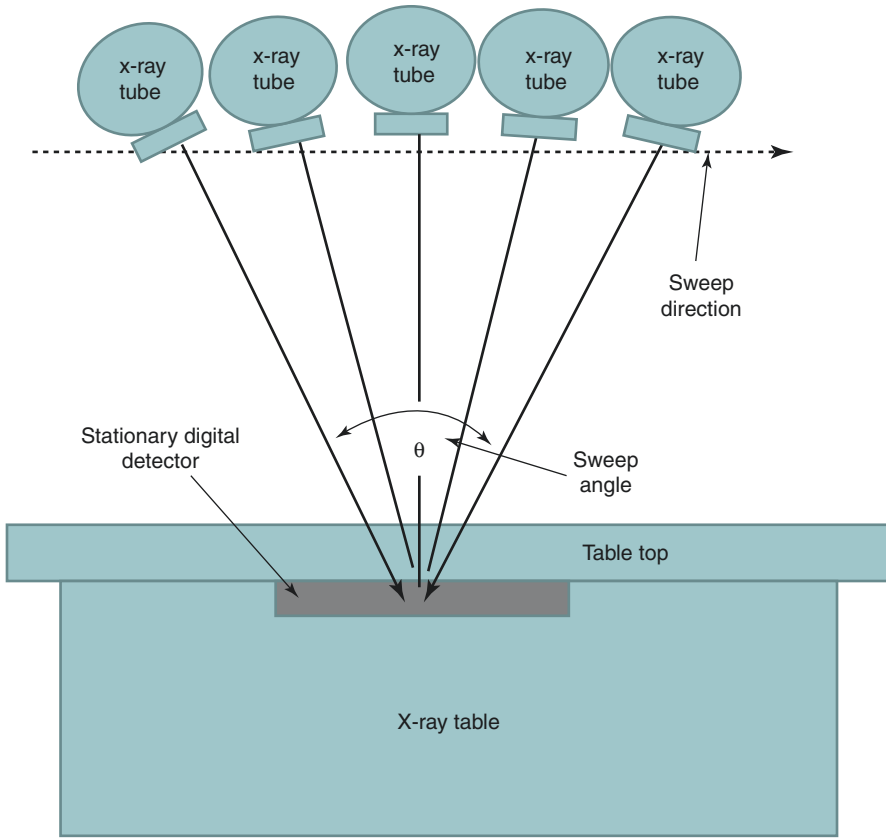
1. The shortcomings of SFM that have been overcome by FFDM imaging are: the limited dynamic range (narrow exposure latitude) of the film. SFM uses the characteristic curve to describe the response of the film to radiation exposure. The film will only respond to a narrow range of exposures, and therefore the technologist must be extremely careful in selection of the optimum exposure factors to provide the best image contrast. Such contrast falls on the slope of the characteristic curve. In addition, the display characteristics of film (brightness and contrast) are fixed once the film is developed in the chemical processor. Another limitation of SFM is that the film serves three roles: acquisition, display and storage.
2. FFDM is digital radiography of the breast. A computer makes use of digital image processing techniques to enhance the visibility of detail and contrast of the image, in an effort to improve the detectability of breast lesions. Major system components include a digital detector, analog-to-digital converter (ADC), computer, the digital-to-analog converter (DAC) and finally a display monitor. Currently, there are four types of digital detector systems used for FFDM: flat-panel phosphor system, charge-coupled device (CCD) system, Flat-Panel amorphous Selenium (a-Se) System and a computed radiography (CR) FFDM system. Digital image post-processing is a vital component system and includes a number of processing operations to enhance the visibility of structures and enhance diagnostic interpretation.
3. The advantages of FFDM over SFM include:
 - The digital detector offers a wider dynamic range. While SFM offers a dynamic range of about 40:1, it is 1000:1 for FFDM.
 - Greater contrast resolution especially for dense breast tissue.
 - Use of digital image post-processing operations to enhance image quality.
 - The ability to communicate with a picture archiving and communication system (PACS).
 - Computer-aided detection (CAD) diagnosis
 - Digital breast tomosynthesis (DBT) and
 - Contrast-enhanced DM.
4. There are currently four types of detector systems available such as the Flat-Panel Scintillator/amorphous Silicon (a-Si) System, the charge-coupled device (CCD) system, the computed radiography (CR) FFDM system and the Flat-Panel amorphous Selenium (a-Se) System. Detectors for FFDM must be capable of providing a high spatial resolution of at least 10 lp/mm to improve lesion detectability, a high-intensity signal is required with low-intensity noise, a good

Signal-to-Noise Ratio (SNR) and the detective quantum efficiency (DQE) that is much higher than FSR which has a DQE of about 45%. The DQE for a perfect imaging system is 1 (100%).

5. There are several differences between the Flat-Panel Scintillator/amorphous Silicon (a-Si) and the Flat-Panel amorphous Selenium (a-Se) FFDM Systems. The most significant difference is the structure and function of the digital detector itself. The former system consists of three major components: a CsI-based scintillator, deposited on top of an a-Si TFT array and a glass support. This detector system is sometimes referred to as an indirect conversion system. The detector first converts X-ray photons falling upon it into light photons, which is then converted into electricity by the a-Si TFT. An important consideration in the design of this detector is that the CsI phosphor is deposited on top of the a-Si TFT array in a needle-like fashion (to reduce lateral dispersion of light in an effort to improve image detail). Furthermore, the light falls upon the a-Si TFT array that is constructed as a matrix of photodiodes and is subsequently converted into electrical signals. These signals are sent to a digitiser (ADC) and are converted into digital data for input into a digital computer. The computer performs the appropriate digital processing to produce a digital image of the breast.

The major difference between the Flat-panel a-Si detector and the a-Se detector system is that the components of this system allow for a direct conversion of X-rays to electrical signals eliminating the light conversion process. This type of FFDM system is referred to as direct conversion system. The detector system consists of a thin layer of a-Se deposited onto a readout layer of electronics. This layer (laid down upon a glass support) is a-Si similar to the phosphor flat-panel system described above. When X-rays fall upon the a-Se layer, an electric charge is released and readout using an electric field. The electrical signal generated is then digitised, and the digital data are sent to a digital computer for processing. The result of processing is a digital image of the breast.

6. FFDM has found applications in the areas of Computer-Aided Detection and Diagnosis (CAD), a technology which includes image processing, quantitation of image features and data processing; Digital Tomosynthesis (DT), a technique based on the principles of conventional tomography to produce tomographic images that are intended to enhance the conspicuity of lesions by blurring out structures above and below the layer of interest; and Contrast-enhanced DM which includes two methods, Temporal contrast-enhanced DM (CEDM) and Dual-energy CEDM.



7. The basic principles of digital tomosynthesis are illustrated in the Figure above. Data acquisition involves movement of the X-ray tube through various angles (sweep angles), while the digital detector remains stationary. Subsequently, image reconstruction algorithms (filtered back projection or iterative reconstruction algorithms) and digital image processing are used not only to create digital tomosynthesis images but to enhance the visualisation of image features, respectively. FFDM has found clinical applications in breast {digital breast tomosynthesis (DBT)} chest, head and neck imaging as well as in orthopaedic, emergency and abdominal imaging.



8.1 Learning Activities

Before attempting to answer these review questions, read the following:

Chapter 8: Digital Tomosynthesis. From *Digital Radiography: Physical Principles and Quality Control* by Euclid Seeram, PhD., FCAMRT Second Edition. Springer 2019

8.2 Summary of the Main Points in this Chapter

The purpose of this chapter is to present a brief description of digital tomosynthesis, a three-dimensional (3D) imaging technique that overcomes the problems of conventional two-dimensional (2D) tomography. The technique involves image acquisition, image reconstruction and image display and communication. While image acquisition is such that the X-ray tube rotates through a limited angle about the detector which is often stationary, to obtain a number of projection data taken from different angles. These data are subsequently reconstructed to produce individual slices of the volume of tissue scanned, using algorithms specially developed for tomosynthesis. There are two types of designs for image acquisition in digital tomosynthesis: step-and-shoot system and continuous scan system. While, in the former method, the X-ray tube that moves to every angular position stops, an exposure is taken and the tube then moves to the next angular position; in the latter system, the X-ray tube moves during the scanning of the object. Digital tomosynthesis (DT) is being applied to general radiographic imaging and to digital breast imaging referred to as digital breast tomosynthesis (DBT). Major imaging system components include the X-ray tube and housing designed to rotate during the data acquisition, collimation and filtration, breast support, breast compression device, and either a full-field indirect flat-panel digital detector {amorphous silicon (a-Si) caesium iodide (CsI)} or a full-field direct flat-panel digital detector (a-Selenium).

Furthermore, DT is characterised by several parameters such as the sweep angle, sweep direction, patient barrier–object distance, number of projections and total radiation dose. Additionally, an overview of image reconstruction methods of DT, image display and communication and radiation dose considerations is presented. Finally, this chapter concludes with an outline of synthesised 2D digital mammography (DM) and clinical applications of DT.

8.3 Questions Will Be Based On Each of the Following Key Terms

- Digital Tomosynthesis-Definition and Principles
 - Radiation Dose Considerations
 - Synthesised 2D Digital Mammography
 - Clinical Applications
-

8.4 Challenge Questions

8.4.1 True (T)/False (F)

1. The word “tomography” is derived from the Greek language “tomos”, meaning “section”.
2. The word “tomosynthesis” is derived from the Greek language “tomos” meaning a slice or a section and “synthesis” meaning a process to combine or blend ideas to produce a new system.
3. While conventional mammography produces two-dimensional (2D) images (produced by superimposed structures) that make it difficult to clearly visualise specific pathologies, Digital Tomosynthesis (DT), a three-dimensional (3D) imaging technique solves this problem by separating out the superimposed tissues.
4. A more complete definition of DT is that it is a three-dimensional imaging technique based on the reconstruction of several planar radiographs.
5. Digital Breast Tomosynthesis (DBT) is “an extension of digital mammography that produces quasi three-dimensional reconstructed images from a set of low-dose X-ray projections acquired over a limited angular range”.
6. DBT systems are based on digital detectors characteristic of full-field indirect flat-panel digital detector, that is the CSI-a-Si detector or a full-field direct flat-panel digital detector based on a-Se.
7. Two important acquisition parameters in DBT are the sweep angle and the sweep direction.
8. Iterative reconstruction (IR) algorithms are used to reconstruct images in DBT systems.
9. Studies on the dose from all DBT systems are equal, and comparable to DM.
10. A synthesised 2D mammography image can be created from the DBT 3D image data set.

8.4.2 Multiple Choice

1. Which specific problem of conventional mammography is solved by digital breast tomosynthesis (DBT), a three-dimensional imaging technique?
 - (a) Superimposed breast structures
 - (b) Patient discomfort from compression
 - (c) Loss of tissue contrast due to the open beam geometry
 - (d) All of the above

2. In DBT imaging:
 - (1) The X-ray tube rotates during the exposure
 - (2) The detector moves in the opposite direction of the tube
 - (3) The detector is often stationary
 - (4) Image reconstruction algorithm is used to create images
 - (a) (1)
 - (b) (1) and (2)
 - (c) (3)
 - (d) (3) and (4)

3. In DBT imaging, which of the following parameters refers to the total arc from the first to the final projection in the tomosynthesis acquisition?
 - (a) Sweep direction
 - (b) Sweep angle
 - (c) Angle of swing
 - (d) Tomographic angle

4. The radiation dose from DBT is:
 - (a) The dose from one projection
 - (b) Cumulative sum of dose from all projections
 - (c) Distance from the patient to the detector
 - (d) Dependent upon the sweep angle

5. Which of the following image quality factors generated by the filtered back projection (FBP) algorithm can be improved through the use of IR algorithm used in DBT imaging?
 - (a) Noise
 - (b) Steak artefacts
 - (c) Image sharpness
 - (d) All are correct

6. What are the main characteristics of common DT systems from DBT vendors?
 - (1) Sweep angle and the number of projections
 - (2) Detector technology

- (3) Pixel pitch and scan time
 - (4) Reconstruction algorithm (FBP or IR)
 - (a) (1) only
 - (b) (1) and (2)
 - (c) (1), (2) and (3)
 - (d) (1), (2), (3) and (4)
7. The characteristic features of display monitors used in DBT imaging include:
- (1) Food and Drug Administration (FDA) approval
 - (2) Mandatory calibration
 - (3) At least five million pixels
 - (4) Meeting the luminance standards of the American College of Radiology (ACR)
 - (a) (1) only
 - (b) (1) and (2)
 - (c) (1), (2), (3)
 - (d) (1), (2), (3), (4).
8. The dose quantity (metric) used in breast imaging dose studies is the:
- (a) Entrance skin exposure
 - (b) Absorbed dose
 - (c) Mean glandular dose
 - (d) Effective dose
9. Which of the following digital detector system is used in DBT?
- (a) Photostimulable Phosphor Type
 - (b) a-Si TFT type
 - (c) a-Se TFT type
 - (d) b and c are correct
10. The process of generating a synthesised 2D image from a DBT image data set includes:
- (1) DBT data acquisition
 - (2) Reconstruction of DBT 3D images
 - (3) Stack all DBT 3D images
 - (4) Apply a 2D algorithm to the DBT 3D images
 - (a) (1) and (2)
 - (b) (1) and (3)
 - (c) (1), (2), (3)
 - (d) (1), (2), (3), (4).

8.4.3 Short Answers

1. What is the overall goal of conventional tomography and state the limitations of this technique?

2. State the definition of Digital Tomosynthesis (DT) and describe how a DT imaging system works.
 3. Identify and explain each of five parameters that characterise DT.
 4. What metric is used in breast imaging dose studies? Summarise the results of a few studies reporting the dose from Digital Breast Tomosynthesis (DBT).
 5. What is meant by synthesised 2D digital mammography, and how is a synthesised 2D image from the DBT image data?
-

8.5 Answers to Challenge Questions

8.5.1 True/False

1. T
2. T
3. T
4. T
5. T
6. T
7. T
8. T
9. F
10. T

8.5.2 Multiple Choice

1. a
2. d
3. b
4. b
5. d
6. d
7. d
8. c
9. d
10. d

8.5.3 Short Answers

1. Conventional tomography produces an image of a section of the patient that is oriented parallel to the film, by moving the X-ray tube and the image receptor (film) simultaneously in opposite directions. Using this technique, unwanted sections can be blurred, while the desired layer or section is kept in focus. The immediate goal of tomography is to eliminate structures above and below the

focused section or the focal plane. However, this is difficult to achieve and, under no circumstances, can all unwanted planes be removed. The limitations of tomography include persistent image blurring that cannot be completely removed, degradation of image contrast because of the presence of scattered radiation created by the open geometry of the X-ray beam and other problems resulting from film-screen combinations.

2. DT is defined as a three-dimensional imaging technique based on the reconstruction of several planar radiographs. The essential elements of DT include at least three steps, namely, data acquisition, image reconstruction and image display on a workstation monitor. During image acquisition, the X-ray tube moves through various positions which describe an angle θ , called the sweep angle. Subsequently, a number of projection images are taken from different angles while the detector is stationary. There are two types of designs for image acquisition in digital tomosynthesis: (1) step-and-shoot system and (2) continuous scan system. While in the former system, the X-ray tube moves to each angular position, then stops and takes an exposure, then moves to the next location, in the latter system, the X-ray tube moves in a generally uniform velocity throughout the scan. The detectors may be a full-field indirect flat-panel digital detector a-Si CsI or a full-field direct flat-panel a-Se detector.

Image reconstruction algorithms used in DT and DBT fall into two categories, namely, iterative reconstruction (IR) algorithms and the filtered back projection (FBP) algorithm. The major problems of the FBP algorithm are image noise in the image and streak artefacts, to improve the sharpness and contrast of images. These problems are overcome with IR algorithms. IR algorithms generally make use of FBP to create simulated data which are then compared with the actual measured projection data to determine differences in image noise. Once this difference is determined, it is applied to the simulated projection to correct for inconsistencies. The system reconstructs a new image, and the process repeats until the difference between the measured and simulated projections is minor enough to be acceptable.

Finally, images are displayed on a monitor for viewing and interpretation. These monitors should be approved by the Food and Drug Administration (FDA) and must be calibrated, and have at least five million pixels, and meet luminance standards of the American College of Radiology (ACR).

3. DT is characterised by several parameters. These include the sweep angle, sweep direction, patient barrier-object distance, number of projections and total radiation dose.

The formal definitions are as follows:

- *Sweep angle*: “The term sweep angle refers to the total arc about the centre of the detector as defined by the focal spot position from the first to the final projection in the tomosynthesis acquisition or sweep. A sweep angle of 40° signifies a -20° to $+20^\circ$ sweep. The sweep angle can be varied between 20° and 40° on our flat-panel detector system.”

- *Sweep direction*: “The direction of X-ray tube movement relative to the object or body part of interest during a sweep. Sweep direction can be arbitrarily determined by altering the position or direction of the object or body part.”
 - *Patient barrier–object distance*: “Is the minimum distance between the surface of the patient barrier and the object of interest. Detector-object distance should be used for more accurate geometric analysis, but patient barrier-object distance is convenient because it can be determined more easily and accurately.”
 - *Number of projections and projection density*: “The number of projections is simply the number of X-ray projection images acquired during a single sweep. The projections are acquired at approximately constant angle intervals. For example, with a 40° sweep with 40 projections, a projection is acquired every 1°. As mentioned earlier, any number of projections from 25 to 60 can be selected on our flat-panel detector system. Projection density (number of projections divided by sweep angle) is used as an important conceptual parameter in the minimization of ripple artifact.”
 - *Total radiation dose*: “Is the cumulative sum of the doses for all projections.”
4. The site of carcinogenesis for the breast is the glandular tissue, and therefore the mean glandular dose (MGD) is the metric used in breast imaging dose studies. Examples of various studies on dose from DBT have demonstrated the following:
- a modest increase of radiation dose to the breast by tomosynthesis compared to FFDM
 - DBT dose was 13% higher than DM, but this differential is highly dependent on thickness
 - Contrast-Enhanced Spectral Mammography (CESM) was found to increase AGD at a mean breast thickness of 63 mm by approximately 0.9 mGy and 0.5 mGy compared with 2D FFDM and 3D tomosynthesis, respectively.
 - Adding DBT to FFDM more than doubles the radiation dose, a woman would receive in routine breast screening.
 - Stand-alone DBT operated at lower to slightly higher radiation doses in comparison with FFDM.
5. The production of a synthetic 2D image which can be generated from the DBT data set. This operation is referred to as synthesised 2D digital mammography. Additionally, the process for generating a synthesised 2D image from the DBT image data are:
- DBT data acquisition is performed followed by the reconstruction of DBT 3D images.
 - Next, the DBT 3D images are stacked and subsequently subjected to a synthesised 2D algorithm (C-View™ algorithm for example) to generate synthesised 2D images.

8.6 Knowledge Lack Identification

- A. Make a list of topics and/or questions that are still not clear to you after studying this chapter

- B. See the instructor for clarification and/or consolidation of the materials

8.7 Student Comments



Picture Archiving and Communication Systems

9

9.1 Learning Activities

Before attempting to answer these review questions, read the following:

Chapter 9: Picture Archiving and Communication Systems. From *Digital Radiography: Physical Principles and Quality Control* by Euclid Seeram, PhD., FCAMRT Second Edition. Springer 2019

9.2 Summary of the Main Points in this Chapter

This chapter described the major system components and technologies related to picture archiving and communication systems (PACS) used in medical imaging. First a definition of PACS is provided followed by a brief description of the major components of a PACS. Several definitions have been cited in the chapter. One such definition is that PACS is fundamentally a highly sophisticated storage system that stores data and images from the image acquisition equipment and uses computer networks and application software not only to display images for viewing and interpretation but to transmit the data and images to remote locations, and as a result, PACS has become an enterprise image management system. Major components include image acquisition modalities, computer networks, the PACS main computer, image storage characteristics, image compression, display and analysis workstations, the radiology information system (RIS), the PACS broker and finally the webserver. PACS is also characterised by the use of two communication standards, Digital Imaging and Communications in Medicine (DICOM[®]) and Health Level-7 (HL-7). While HL-7 deals with the flow of textual information between the hospital information system (HIS) and the RIS and other information systems in the hospital, DICOM[®] deals primarily with the exchange of images in the radiology department and facilitates communication among manufacturer-specific imaging equipment. DICOM[®] is an international standard to transmit, store, retrieve, print, process and display medical imaging information. An essential feature of PACS is that in order to facilitate communications between various computer-based healthcare

information systems and imaging modalities and PACS vendors through the integrated use of DICOM® and HL-7 requires an initiative referred to as Integrating the Healthcare Enterprise (IHE). IHE provides a *process flowchart* that illustrates the resources and tools such as standards, technical specifications, integration profiles and technical frameworks, for example, for the purpose of helping users not only to integrate systems but also to share information in an efficient and effective manner. Two other significant features gaining widespread attention in the PACS environment is the vendor neutral archive (VNA) and more recently enterprise imaging. A VNA is an archive that “can be easily migrated, ported to interface with another vendor’s viewing, acquisition, and workflow engine to manage medical images and related information”; enterprise imaging is a technology that offers improved efficiencies in data archiving and management and creates a comprehensive program that can combine data from different departments into one system. An enterprise imaging system should consist of elements such as governance, enterprise imaging strategy, enterprise imaging platform (infrastructure), clinical images and multimedia content, electronic health record (EHR) enterprise viewer, image exchange services and image analytics, in order to be successful.

Finally, the chapter outlines briefly important characteristics of the PACS administrator and the evolving role of the medical imaging technologist as an informaticist.

9.3 Questions Will Be Based On Each of the Following Key Terms

- PACS-A Definition
- Major Components
- Core Technologies
- Workflow
- PACS and Information Systems
- DICOM and HL-7
- Integrating the Healthcare Enterprise
- Enterprise-Wide Image Distribution and Viewing
- PACS and Regulatory Approval
- Vendor Neutral Archives
- Integrating the Healthcare Enterprise (IHE)

9.4 Challenge Questions

9.4.1 True (T)/False (F)

1. A rationale for developing Picture Archiving and Communication Systems (PACS) for radiology is that the number of images from digital imaging modalities is increasing rapidly every year.
2. PACS is a popular term used to describe a medical device where images are acquired from the patient, displayed on monitors for viewing and subsequent digital image post-processing, stored and archived in electronic form and transmitted to other locations via computer communication networks.

3. Health Level-7 (HL-7) is a standard that essentially addresses the communication of images (image data).
4. Digital Imaging and Communications in Medicine (DICOM) is a communication standard configured for information systems and addresses the communication of textual data, such as patient demographics, admission and discharge transfer and the type of imaging examinations and radiology reports.
5. A mini-PACS system is one whereby a single imaging modality such as a digital radiography unit is connected to a storage server and viewing workstations via a local area network.
6. Computer networks are radiology information systems (RIS) and hospital information systems (HIS).
7. The data transfer rate of computer networks is called the bandwidth which varies depending on the physical connection between computers. The unit of bandwidth in this case is in megabits per second ($1 \text{ Mbps} = 10^6 \text{ bps}$) or in gigabits per second ($1 \text{ Gbps} = 10^9 \text{ bps}$).
8. One type of storage technology used in PACS is the redundant array of independent disks (RAIDs) which can contain several magnetic or optical disks that can perform as a single large disk drive.
9. Information systems in a digital radiology department include PACS, RIS, HIS, voice recognition system and an electronic teaching/research file system.
10. The major role of Integrating the Healthcare Enterprise (IHE) is to facilitate communications between various computer-based healthcare information systems and imaging modalities and PACS vendors through the integrated use of DICOM and HL-7.

9.4.2 Multiple Choice

1. PACS is a computer system that:
 - (1) Captures medical images from imaging modalities
 - (2) Stores medical images
 - (3) Displays medical images
 - (4) Communicates medical images
 - (a) (1) only
 - (b) (1) and (2)
 - (c) (2) and (3)
 - (d) (1), (2), (3) and (4)
2. Which of the following represents the first point of entry of images to a PACS?
 - (a) Interface
 - (b) PACS controller
 - (c) Imaging modalities
 - (d) Hospital information system
3. The transfer and sharing of information among several computers are a function carried out by:
 - (a) Storage devices

- (b) Display work stations
 - (c) Servers and routers
 - (d) LANs and WANs
4. The rate at which data are transferred over a computer network is referred to as the:
- (a) Bandwidth
 - (b) Node
 - (c) Bus rate
 - (d) Transmission control protocol
5. Which of the following is the main communication protocol used in a PACS environment?
- (a) TCP/IP
 - (b) DICOM
 - (c) HL-7
 - (d) All are correct
6. Which of the following storage devices has limited storage capacity?
- (a) Magnetic disks
 - (b) Magnetic tapes
 - (c) Optical disks
 - (d) Random Access Memory (RAM)
7. What is RAID?
- (1) Redundant Array of Inexpensive Disks
 - (2) Redundant Array of Independent Disks
 - (3) A system of magnetic or optical disks that can act as a large disk drive
 - (4) An automated library system or “jukebox”
- (a) (1) only
 - (b) (2) only
 - (c) (2), (3) and (4)
 - (d) (1), (3) and (4)
8. Compression of images in a PACS environment:
- (1) Speeds up transmission
 - (2) Reduces storage requirements
 - (3) Can be lossless or lossy
 - (4) Can be of the wavelet method
- (a) (1) only
 - (b) (1) and (2)
 - (c) (1), (2) and (3)
 - (d) (1), (2), (3) and (4)
9. Which type of PACS display workstation must be used for primary diagnosis?
- (a) High-resolution workstation
 - (b) Medium-resolution workstation

- (c) Desktop workstation
 - (d) Hardcopy workstation for image printing
10. The following are considered information systems except:
- (a) Image acquisition
 - (b) PACS
 - (c) RIS/HIS
 - (d) Voice-recognition dictation system
11. Which of the following information systems support the medical and administrative activities of the imaging department in a hospital?
- (a) PACS
 - (b) HIS
 - (c) RIS
 - (d) Image acquisition modalities
12. Integrating the Healthcare Enterprise (IHE) deals with efforts to:
- (1) Foster communications between information systems and PACS vendors to integrate the use of standards such as DICOM and HL-7.
 - (2) Enhance access to clinical patient information and to facilitate integrity of this information.
 - (3) Eliminate data redundancy between information systems and PACS.
 - (4) Increase the pace of health care enterprise integration.
- (a) (1) only
 - (b) (1) and (2)
 - (c) (1), (2) and (3)
 - (d) (1), (2), (3) and (4)
13. Which of the following is an archive that “can be easily migrated, ported to interface with another vendor’s viewing, acquisition, and workflow engine manage medical images and related information”?
- (a) Vendor Neutral Archive (VNA)
 - (b) RAID
 - (c) Optical disks
 - (d) Random Access Memory (RAM)

9.4.3 Short Answer Questions

1. Dr Huang, PhD, a professor of Radiology and Biomedical Engineering at the University of Southern California, Los Angeles, has categorised PACS into five models based on how they are implemented. Summarise the basic notion of each of the models.
2. What are the major system components of a PACS and state two communication protocols that are at the heart of the system?
3. What is the difference between a local area network (LAN) and a wide area network (WAN)? Describe briefly the basic characteristics of three network topologies for LANs.

4. Explain briefly the differences between the current storage technologies for PACS.
 5. What is the purpose of image compression in a PACS system and why is the compression ratio important?
 6. What are the types of display workstations used in a PACS environment? State two types of image display format used on PACS workstations and identify the major difference between them.
 7. Describe briefly how windowing or greyscale manipulation is accomplished on an image in terms of its purpose and basic features.
 8. What is an information system and state the difference between a Radiology Information System (RIS) and a Hospital Information System (HIS)?
 9. What is DICOM and what does it specify? Identify the basic configuration components of DICOM.
 10. What is meant by the term Integrating the Healthcare Enterprise (IHE)? State its major role and briefly describe its technical framework.
-

9.5 Answers to Challenge Questions

9.5.1 True/False

1. T
2. T
3. F
4. F
5. T
6. F
7. T
8. T
9. T
10. T

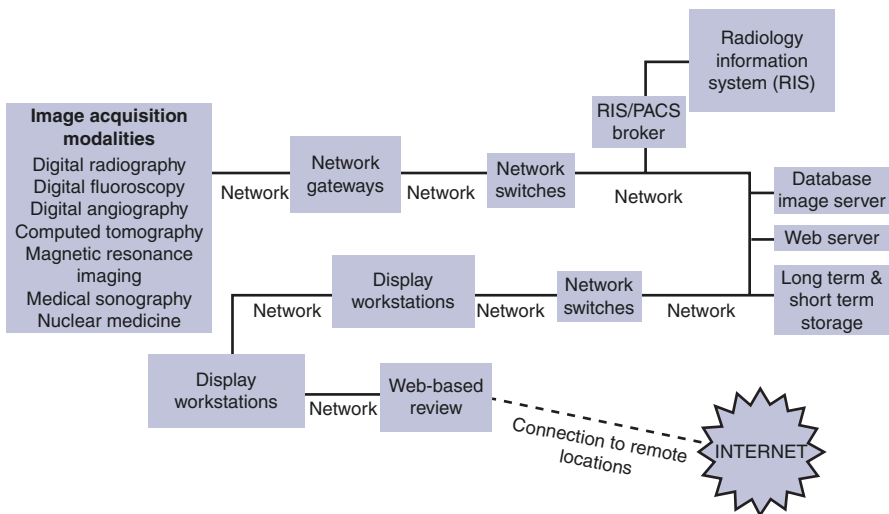
9.5.2 Multiple Choice

1. d
2. c
3. d
4. a
5. b
6. d
7. c
8. d
9. a
10. c
11. c
12. d
13. a

9.5.3 Short Answers

1. The five models of PACS as described by Dr Huang, PhD are:
 - (a) The Home-Grown Model: This is a PACS developed by the radiology department and hospital using technical components from various manufacturers to suit the needs of the hospital.
 - (b) The Two-Team Effort Model: This model is based on collaboration of individuals from both outside and inside the hospital to address PACS specifications and a manufacturer to address implementation issues related to the PACS.
 - (c) The Turnkey Model: In this model, the PACS is developed by a manufacturer who sells it to a hospital and accepts full responsibility for implementing the system for use by technologists, radiologists, biomedical engineers, medical physicists and other related personnel such as information technology (IT) staff.
 - (d) The Partnership Model: In this model, the manufacturer and the hospital work together to ensure the optimum performance and integrity of the system, via training for personnel, upgrading and general system maintenance.
 - (e) The Application Service Provider (ASP) Model: In this model, “a system integrator provides all PACS-related service to a client, which can be the entire hospital or a practice group. No IT requirements are required by the client”.

2. The major components of a PACS and their functional relationships are shown in figure below (Figure 9-1 in the textbook by Seeram).



These include *digital image acquisition modalities, database/image server, web server, archive server, short-term and long-term archive and image display subsystems*, all connected via *computer networks*, using various gateways and switches. In

order to extend its functionality and usefulness, the PACS is integrated with the RIS (and HIS as well). Furthermore, the system can serve to connect to remote locations via the Internet. Communication and integration of all of these components require the use of communication protocol standards. Essentially there are two main standards: The Digital Imaging and Communications in Medicine (DICOM) standard that essentially addresses the communication of images (image data) and Health Level-7 (HL-7) is a communication standard configured for information systems and addresses the communication of textual data, such as patient demographics, admission and discharge transfer and the type of imaging examinations and radiology reports.

3. Two computer networks are local area networks (LANs) and wide area networks (WANs). The basis for this classification is the distance covered by the network. A LAN, for example, connects computers that are separated by short distances such as in a radiology department, a building or two or more buildings. A WAN, on the other hand, connects computers that are separated by large distances, such as in another province or country. The Internet is a perfect example of a WAN. Three network topologies for LANs include bus, star and ring. While the bus configuration is characterised by computers (nodes) connected via a single cable; in the star configuration, all computers are connected to a central or host computer called a hub. Finally, in the ring topology, a computer is connected to two adjacent computers, and all computer connections form a ring.
4. Current storage technologies for PACS include solid-state memory (RAM), magnetic data carriers (disk and tapes) and optical disks. While RAM and magnetic disks are expensive, optical and magnetic tape storage is inexpensive. RAM resides in the PACS host computer itself, and has limited storage capacities (the same for magnetic disks); storage capacity is large for optical disks and magnetic tapes. One popular storage technology used in PACS is the redundant array of independent disks (RAIDs) which can contain several magnetic or optical disks that can perform as a single large disk drive. The result is an automated library system (ALS) or a "jukebox." RAIDs are used primarily for short-term storage. Digital linear tape (DLT) is usually 0.5 in. magnetic tape that is intended for long-term storage of images. Multiple DLT drives can be arranged to create a "jukebox" similar to the RAID situation. It is important to note here that these image storage components can be connected by a sub-network called a storage area network (SAN), a fibre-optic high-speed network (up to about 100 megabits/s) sometimes referred to as fibre channel. SAN has been designed solely for image. Furthermore, storage can be online, near-line and offline. While online storage cannot be removed and provides immediate access to images (e.g., RAM) within seconds, near-line storage is removable (e.g., RAIDs) with longer image retrieval times. Offline storage, on the other hand, refers to storage devices that must be retrieved by an individual and loaded into a drive for access to images. Offline storage is of course cheap and provides the largest storage capacity.

5. In general, the goal of image of compression in a PACS system is to speed up transmission of information (textual data and images) and to reduce storage requirements.

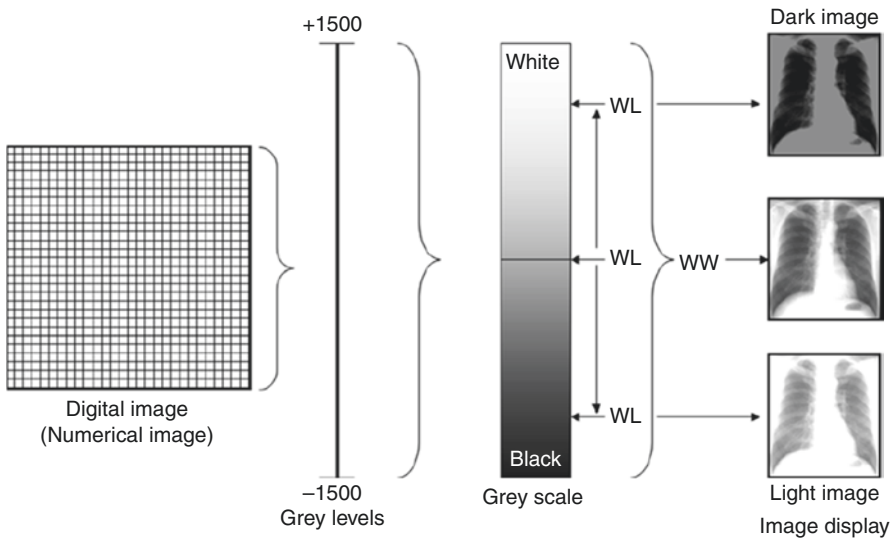
Image compression can be either lossless or lossy. While lossless compression or reversible compression, where no information is lost in the process; lossy compression or irreversible compression, where some information is lost in the process, JPEG (Joint Photographic Experts Group) image compression, for example, features both lossy and lossless compression methods. For medical images, JPEG is DICOM's present compression method. Furthermore, JPEG 2000 uses something referred to as wavelets (wavelet compression) in an effort to decrease the compressed image size and enhance image quality.

The compression ratio is important in the PACS system because it reduces the size of the image file, and therefore it is a very important variable in studies examining the effects of image compression on image quality. Dr Huang, PhD, states that "the compression ratio between the original image and the compressed image file is the ratio between computer storage required to save the original image and that of the compressed data. Thus a 4:1 compression on a $512 \times 8 = 2,097,152$ bit image, requires only 524,288 bit storage, 25% of the original image storage required.....". The size of the compressed image is influenced by the compression ratio (see definition of terms), with lossless compression methods yielding ratios of 2:1 to 3:1 and lossy or irreversible compression having ratios ranging from 10:1 to 50:1 or more. It is well known that as the compression ratio increases, less storage space is required and faster transmission speeds are possible, but at the expense of image quality degradation. It is also well established that the quality of digital images plays an important role in helping the radiologist to provide an accurate diagnosis. At low compression ratios (8,1 or less), the loss of image quality is such that the image is still "visually acceptable". Different modalities and different image types based on the patient's anatomy under imaging have different compression ratios depending on the type of compression used.

6. Three types of display workstations are generally used in a PACS environment, namely, a high-resolution display workstation, a medium-resolution display workstation and a desktop workstation. High-resolution display workstations are used by radiologists for primary diagnosis since their viewing tasks are fundamentally different than other physicians, medical physicists and technologists. These are the most expensive of workstations. Medium-resolution display workstations are used mainly for secondary diagnosis, that is, review function that can be done by radiologists. Finally, *desktop workstations* are intended for use by technologists and physicians, other than radiologists.

Two types of image display formats are available for these workstations: a landscape display and a portrait display. While the former displays more pixels in the horizontal than vertical direction, the latter displays more pixels in the vertical than in the horizontal direction.

7. Windowing (greyscale manipulation) can be used to manipulate the image brightness and contrast to suit the needs of the observer. Windowing makes use of two major functions to manipulate the brightness and contrast of the displayed image. These two include the window width (WW = the range of the digital numbers making up the image) and the window level (WL = the centre of the range of digital numbers) can be used to alter the image contrast and brightness, respectively. While increasing the WL (for a fixed WW) makes the image darker because more of the lower digital numbers are displayed, decreasing the WL (for a fixed WW) makes the image lighter, since more of the higher digital numbers are displayed. The concept of windowing is illustrated below.



8. There are at least five separate information systems in an electronic radiology department, including the PACS, RIS, HIS, voice recognition system and the electronic teaching and research film system. A HIS is a computer-based information system used to gather not only medical information about a patient but also all activities related to the hospital's administration, such as billing, accounting, statistics, personnel, budgets and material management, to mention only a few. There are usually at least two major components, the hospital business and administrative component and the hospital operation component. These two are linked, and special software is used to allow the HIS to distribute HL-7 data to other systems external to the HIS. A RIS, on the other hand, is a computer-based information system that could be a stand-alone system, or it may be integrated with a HIS. Some of the functions performed by the RIS are patient registration, exam scheduling, patient tracking, report generation, administration and billing, documentation and so on.
9. The acronym DICOM stands for Digital Imaging and Communications in Medicine. It is an international standard to transmit, store, retrieve, print, process and display medical imaging information. It makes medical imaging information interoperable and integrates image acquisition devices. Furthermore, DICOM

specifies not only the type of communications referred to as DICOM service class, but also DICOM objects. The latter refers to the types of data to be moved around the network and the data format. For example, DICOM object called CR is a data format for transmitting CR data. Other DICOM objects include CT, MRI, NM, US and so on.

In its most basic configuration, DICOM communication can involve two devices, one called a user and the other a provider, hence the terms service class user (SCU) and service class provider (SCP). The Internet is a good analogue of this type of communication. When you use your computer to access the Internet from anywhere, you are a service user. Your request to access the Internet is answered by your Internet service provider (ISP). Other DICOM service classes include verification, modality worklist management, performed procedure step, store, storage commit, print and query/retrieve. Furthermore, DICOM uses the term “role” to indicate that a device can be either a “user” (SCU) of a service or a “provider” of a service (SCP). DICOM also specifies information object definitions (IODs) to address what is contained in images (image data and related information) from different imaging modalities. Another element of DICOM is that of a Service-Object Pair (SOP) Class, which includes both service class and an IOD. Last is that of DICOM conformance statements. These are statements that deal with specific ways of implementation using the service classes, information objects and communication protocols that are supported. DICOM conformance is seen as a useful specification and implementation strategy.

10. Integrating the Healthcare Enterprise (IHE) provides action and resources in the health professions and industry whereby healthcare computer systems share information. IHE supports the use of DICOM and HL7 in the enterprise. IHE systems communicate with one another more effectively and efficiently in an effort to facilitate the use of information among healthcare providers more effectively. The major role of IHE is to facilitate communications between various computer-based healthcare information systems and imaging modalities and PACS vendors through the integrated use of DICOM and HL-7.

There are three significant elements in the IHE technical framework, and they include a data model, actors and integration profiles. While the data model is based on communication standards DICOM and HL-7, actors refer to information systems and components of information systems address operational activities in the enterprise. Examples of actors and their roles include the patient registration, image acquisition modality, image archive and display systems, image manager, master patient index (MPI), report creator, report manager, print server, post-processing manager, report repository, system scheduler and order filler, to mention only a few. Furthermore, an essential feature of IHE is integration profiles (outline the roles of actors in DICOM and HL-7). These include scheduled workflow, patient information reconciliation, post-processing workflow, charge posting, presentation of grouped procedures, consistent presentation of images, key image notes, simple image and numeric reports, access to radiology information, reporting workflow, evidence documents and basic security. An important consideration for departments purchasing digital imaging equipment, PACS and RIS systems is to ensure that vendors comply with the IHE profiles.



10.1 Learning Activities

Before attempting to answer these review questions, read the following:

Chapter 10: Medical Imaging Informatics: An Overview. From *Digital Radiography: Physical Principles and Quality Control* by Euclid Seeram, PhD., FCAMRT Second Edition. Springer 2019

10.2 Summary of the Main Points in this Chapter

Imaging Informatics (II) has replaced the term Medical Imaging Informatics (MI) and is now commonplace in the imaging community. The Society of Imaging Informatics in Medicine (SIIM) states that the “science of imaging informatics is the study and application of processes of information and communications technology for the acquisition, manipulation, analysis, and distribution of image data”. This chapter describes the essential technologies such as the fundamentals of computers and communication technologies that are the building blocks for an understanding of II. In addition, relevant elements of Picture Archiving and Communication systems (PACS), the Radiology Information System (RIS) and the Electronic Health Record (HER) are highlighted in terms of definitions and components. Furthermore, an overview of systems integration and information technology security is provided. Finally, emerging topics of II such as Cloud Computing, Big Data, Artificial Intelligence, Machine Learning and Deep Learning are briefly described. Since the latter four topics, Big Data, Artificial Intelligence, Machine Learning and Deep Learning are in their infancy in terms of development and implementation, major definitions of each have been quoted from the experts, so as not to detract from the original meaning.

Big data is characterised by four Vs: Volume, Variety, Velocity and Veracity. While Volume refers to the very large amount of data, Variety deals with a wide array of data from multiple sources. Furthermore, Velocity addresses the very high

speeds at which the data are generated. Finally, Veracity describes the uncertainty of the data such as the authenticity and credibility.

The definitions for AI, Machine Learning and Deep Learning are as follows (see appropriate citations in the text):

- AI is the “effort to automate intellectual tasks normally performed by humans.”
- Machine learning “a set of methods that automatically detect patterns in data, and then utilize the uncovered patterns to predict future data or enable decision making under uncertain conditions”.
- Deep Learning algorithms are “characterized by the use of neural networks with many layers”.

10.3 Questions Will Be Based On Each of the Following Key Terms

- Information Technology Basics
- What is Informatics
- Imaging Informatics
- PACS Technology
- Health Information Systems
- The Electronic Health Record
- IT Security Fundamentals
- Cloud Computing
- Big data
- Artificial Intelligence, Machine Learning and Deep Learning

10.4 Challenge Questions

10.4.1 True(T)/False (F)

1. In the domain of computer science, information refers to useful, meaningful and organised data.
2. One definition of information technology (IT) is “the use of any computers, storage, networking and other physical devices, infrastructure and processes to create, process, store, secure and exchange all forms of electronic data.
3. Informatics refers to the process of changing information to data.
4. Medical Imaging Informatics (MII) of Imaging Informatics (II) is the application of IT to medical imaging.
5. PACS is an example of an electronic system that is based on the use of computers and communication technologies.
6. The Electronic Health Record (HER) is intended to contain only medical images of the patient and is based on the digital imaging and communication in medicine (DICOM) standard.

7. The only category of computer security threats falls in the software attacks.
8. Cloud computing uses the Internet for data storage and retrieval in conjunction with the capacity to act on the data with computational algorithms and software packages.
9. One definition of Big Data is that it is data that are very large and too complex for processing by traditional database management tools.
10. Artificial Intelligence (AI) falls within the domain of computer science and consists of two subsets, machine learning (ML) and deep learning (DL).

10.4.2 Multiple Choice

1. Which of the following are major elements of PACS?
 - (1) Digital imaging modalities
 - (2) Computer network database server
 - (3) Archival system and display workstation
 - (4) Often connected to Radiology Information System (RIS) and a Hospital Information System (HIS)
 - (a) (1) and (2)
 - (b) (1) and (3)
 - (c) (1), (3) and (4)
 - (d) (1), (2), (3) and (4)

2. The following are essential features of RIS except:
 - (a) Order entry and scheduling
 - (b) Report generation and billing
 - (c) Image storage
 - (d) Quality Assurance, inventory monitoring and statistical analysis

3. The Electronic Health Record (HER) contains the following information:
 - (1) Images from diagnostic imaging modalities
 - (2) Order entry
 - (3) Clinical documentation and clinical messaging
 - (4) Data repository, decision support and results reporting
 - (a) (1)
 - (b) (2) and (3)
 - (c) (1), (2) and (3)
 - (d) (1), (2), (3) and (4)

4. Threats to computer security include:
 - (a) Hardware attacks
 - (b) Software attacks
 - (c) Social engineering attacks
 - (d) All are correct

-
5. Which of the following is not an emerging trend in imaging informatics?
 - (a) Big Data
 - (b) Picture Archiving and Communication Systems (PACS)
 - (c) Artificial Intelligence
 - (d) Machine Learning and Deep Learning

 6. A model that allows access to computing resources using the Internet for purposes of data storage, aggregation, synthesis and retrieval, together with the capacity to act on the data with computational algorithms and software packages refers to:
 - (a) Big Data
 - (b) Cloud computing
 - (c) Artificial Intelligence (AI)
 - (d) Machine Learning (ML) and Deep Learning (DL)

 7. With respect to Big Data, which of the following describes the inherent uncertainty in some data elements?
 - (a) Velocity
 - (b) Volume
 - (c) Veracity
 - (d) Variety

 8. In which of the following uses algorithms that are trained to perform tasks by learning patterns from data rather than by explicit programming?
 - (a) AI
 - (b) ML
 - (c) DL
 - (d) Artificial Neural Network (ANN)

 9. Which of the following algorithms are characterised by the use of artificial neural networks with multiple layers?
 - (a) Iterative Reconstruction algorithms
 - (b) ML algorithms
 - (c) DL algorithms
 - (d) Cloud computing algorithms

 10. DL can be used to explore and create quantitative biomarkers from medical Big Data obtained through:
 - (1) Internet of things
 - (2) Genetics and genomics
 - (3) Medical Imaging
 - (4) Mobile monitoring
 - (a) (1)
 - (b) (1) and (2)
 - (c) (1), (2) and (3)
 - (d) (1), (2), (3) and (4)

10.4.3 Short Answer Questions

1. What is the Society of Imaging Informatics in Medicine (SIIM) definition of imaging informatics (II)?
2. What is Information Technology (IT) and what is its central role in the radiology department?
3. Draw a diagram to show the major components of a computer and their functional connection.
4. What are the key elements of communications technology?
5. What is informatics and what are its subspecialties? Differentiate between medical and imaging informatics.
6. Summarise the overall system components of PACS.
7. What is the Electronic Health Record (EHR)?
8. Explain what is meant by the term “information security”. List three categories of threats to security, and list various security methods.
9. What are the so-called “emerging topics” of imaging informatics?
10. Describe briefly the basic elements of cloud computing.
11. What is ‘big data’, and what are its fundamental characteristics?
12. Define each of the following:
 - Artificial Intelligence (AI)
 - Machine Learning (ML)
 - Deep Learning (DL)

What is the fundamental difference between ML and DL?

10.5 Answers to Challenge Questions

10.5.1 True/False

1. T
2. T
3. F
4. T
5. T
6. F
7. F
8. T
9. T
10. T

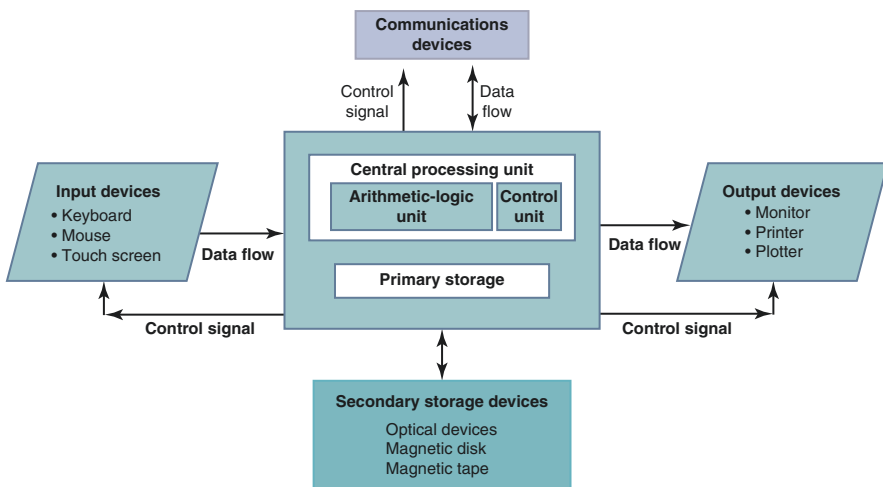
10.5.2 Multiple Choice

1. d
2. c

- 3. d
- 4. d
- 5. b
- 6. b
- 7. c
- 8. b
- 9. c
- 10. d

10.5.3 Short Answers

- 1. SIIM defines II as the “science of imaging informatics is the study and application of processes of information and communications technology for the acquisition, manipulation, analysis, and distribution of image data”.
- 2. A definition offered by one technology company, Tech Target, is that IT is “the use of any computers, storage, networking and other physical devices, infrastructure and processes to create, process, store, secure and exchange all forms of electronic data”. While computer technology deals with the structure and function of a computer and how it can be used to solve problems, computer communication technology, on the other hand, deals with the use of electromagnetic devices and systems for communicating over long distances. The role of IT in a digital radiology department is to facilitate communications with all digital devices including computers in terms of not only image data but also text data.”
- 3. The major components of a computer and their functional connection is shown below taken from Figure 10-1 in the textbook:



Major components include input devices, internal processing components, including Hardware devices such as the CPU to process data entered into the computer. Processing converts data to information. Another major component is storage such as internal storage (or memory), or it can be stored permanently outside the computer (external storage). Furthermore, there are output devices such as monitors, printers and plotters. Finally, communications components are vital to complete the organisation of the major components of a computer. Communications enable computer data and output information (e.g., images) can be transmitted to other individuals anywhere in the world, with the use of the Internet, for example, as the communication vehicle.

4. The key elements of communications technology include the physical components and other related aspects of the system. These include modems, communications media and communication networks. Related components of communications include topics such as cyber-threats, security and safeguard issues.

The term modem is a contraction for *modulate/demodulate*. The modem is used to send and receive signals from computers, by converting a digital signal from the computer (modulate) into an analog signal. This analog signal is transmitted over a communication link (e.g., phone line) to receiving computer. The analog signal must be converted back to a digital signal (demodulate) for processing by a digital computer. Modems can be external or internal to the computer and can transmit data in bits per second (bps). Communications media are responsible for data transmission, for example, the phone line is one such medium. Other communications media include wire pairs (twisted pairs), coaxial cables, fibre optics, microwave and satellite transmission. Wireless transmission is also used to send data using radio frequencies to connect various physical devices. Protocols are essential tools for devices to communicate with each other, such as the Internet Communications Transmission Control Protocol/Internet Protocol (TCP/IP). Standards also help to facilitate communication among different systems. Additionally, the DICOM standard is also an element responsible for the effective communication of diagnostic medical images. Last but not least are the communication networks which allow several devices (e.g., computers) to be connected together in an effort to utilise data and information. Three typical network topologies are the bus, star and ring topologies. While the smallest size of network is the local area network (LAN), the largest is the wide area network (WAN). Finally, wireless communications media such as infrared transmission, broadcast radio, microwave radio and communications satellite have become commonplace.

5. Since informatics is closely linked with IT, its definition is organised around the elements of IT. One such approach outlines informatics as the process of changing data to information, and therefore computers and communication technologies are central elements to the process. Informatics subspecialties include medical informatics, healthcare informatics, biomedical informatics, nursing

informatics, imaging informatics (radiology informatics), cardiology informatics, clinical informatics, etc.

Healthcare Information and Management Systems Society (HIMSS) has formulated a definition merging both medical informatics and healthcare informatics noting that both as “the interdisciplinary study of the design, development, adoption, and application of IT-based innovations in healthcare services delivery, management, and planning”.

The new term for medical imaging informatics is imaging informatics and is the application of IT concepts to medical imaging tasks, which include digital image acquisition, digital image processing and image display, image storage and archiving, computer networking and image transmission.

6. PACS is an information-rich technology consisting of several components including digital image acquisition modalities, a computer network database server, an archival system and a soft-copy display workstation. Furthermore, PACS is often connected to health information systems such as a radiology information system (RIS) and a hospital information system (HIS).

Image acquisition modalities such as Computed Radiography (CR), Digital Radiography (DR), Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and so on are sent to the PACS for storage and archiving and subsequent transmission to remote locations. Image transfer is supported by the international standard for communicating images, the DICOM standard. Images are stored in the database server (image server), using storage devices such as magnetic disks, optical disks, magneto-optical disks and digital video-disks. Additionally, display systems (which are a part of the PACS workstation) in a PACS environment can be cathode ray tubes (CRTs) and liquid crystal displays (LCDs). Finally, access and distribution of images in the PACS to interested parties, not only in the radiology department but to others throughout the healthcare enterprise. While the former is referred to as a traditional radiology-centric PACS model, the latter is called the enterprise-wide image distribution model. Within a PACS environment, it is mandatory that the PACS be integrated with information systems since these systems contain data and information related to the patient whose images are stored in the PACS.

An information system is a computer-based system used to collect and process data generating information needed for problem-solving and decision-making. A healthcare information system and hospital information system (HIS) are systems used within a hospital or enterprise that support and enhance the care and management of patients.

Furthermore, a radiology information system (RIS) is another essential component of a PACS. The RIS can perform a number of tasks such as order entry, scheduling of imaging procedures, report generation, billing and accounting, quality assurance, inventory, monitoring, statistical analysis and so on.

7. The HER replaces the paper-based medical record. As outlined by the Healthcare Information and Management Systems Society (HIMSS), the EHR “is a longitudinal electronic record of patient health information generated by one or more

encounters in any care delivery setting. Included in this information are patient demographics, progress notes, problems, medications, vital signs, past medical history, immunizations, laboratory data and radiology reports. The EHR automates and streamlines the clinician's workflow. The EHR has the ability to generate a complete record of clinical patient-related activities directly or indirectly via interface-including evidence-based decision support, quality management, and outcomes reporting”.

The EHR contains a vast amount of medical information, data about the patient (e.g., demographic information) and of course other related health information, such as images from medical imaging procedures. The EHR contains data and information such as order entry, clinical documentation, data repository, decision support, result reporting, clinical messaging, and e-mail. The EHR provides a wide range of benefits not only to healthcare professionals including physicians but also benefits that are available to the healthcare enterprise. Such benefits, for example, include improved data integrity and quality of care, as well as increased productivity and satisfaction for healthcare providers.

8. Information security (IS) is intended to protect information systems and ensure integrity of the system, namely, to protect confidentiality, integrity and availability of computer data from malicious acts. Security allows authorised users to have access to the information and prevents unauthorised users from accessing such information. There are at least three categories of threats to security including hardware and software attacks and social engineering attacks. While social engineering attacks seek to obtain data and information from authorised users in the form of deception, hardware attacks refer to attacks on hardware components, such as the theft of a computer. Software attacks deal with attacks on operating systems and application software, for example.
9. Emerging topics (topics receiving more and more attention in research and practical use in imaging practice) in imaging informatics are cloud computing, Big Data, artificial intelligence (AI), machine learning (ML) and deep learning (DL).
10. Cloud computing is a term used to refer to the delivery of specific services to users through the use of the Internet. For example, in medical imaging, departments using Picture Archiving and Communication Systems (PACS), Vendor Neutral Archives (VNAs) and enterprising imaging, cloud computing is used to store the data from these local systems and allows such data to be accessed by any user, from anywhere in the world using the Internet. The hardware and software systems used for this specific purpose at the data centres have been referred to as a “cloud”. The National Institute of Standards and Technology (NIST) states that cloud computing is “a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources that can be rapidly provisioned and released with minimal management effort or service provider interaction”. A cloud can be a private cloud, a public cloud or hybrid cloud (both private and public) and offered through a

number of cloud service models or cloud types. With respect to PACS, a cloud-based PACS, sometimes referred to as “Cloud PACS” is a PACS system that is located in the cloud and can be accessed by authorised users through the use of the Internet.

11. The significant growth of digital data from organisations such as the National Aeronautics and Space Administration (NASA), social media platforms (Facebook, Twitter), photographs from cell phones around the world, Internet search engines (Google for example), world governments, global healthcare institutions and medical imaging and radiation therapy have created extensive data sets now referred to as “big data” (BD). BD is characterised by the four Vs, namely; Volume, Variety, Velocity and Veracity. While Volume refers to the number of data elements in these very large data sets, Variety refers to the collection of data from a wide range of different sources; Velocity, on the other hand, refers to the high speed at which data are generated. Finally, Veracity relates to the inherent uncertainty in various data components.

BD can generate new results through data preparation and data analytics, both of which are a part of the subject of data science. The technologies used for BG analytics include data mining tools, cloud computing technologies and Artificial Intelligence (AI) providing the application of BD to many fields including bioinformatics, clinical informatics, imaging informatics (II) and public health and information. In II, specific applications, for example, include treatment and diagnosis processes for the patient, population studies using BD, scheduling of scans, creating patient-specific personalised scanning protocols, radiologist decision support, emergency reporting, virtual quality assurance, medical image analysis, physiological signal processing and genomic data processing.

12. The definitions of AI, ML and DL are as follows:

- AI is a computer-based science and technology that addresses how humans think and solve problems intelligently.
- ML is a subset of AI and is “a set of methods that automatically detect patterns in data, and then utilize the uncovered patterns to predict future data or enable decision making under uncertain conditions.” ML uses “algorithms are trained to perform tasks by learning patterns from data rather than by explicit programming.”
- DL is a subset of ML and uses algorithms that are “characterized by the use of neural networks with many layers” and are “a special type of artificial neural network (ANN) that resembles the multilayered human cognition system.”

The major difference between ML and DL is inherent in the definitions provided above.



Continuous Quality Improvement for Digital Radiography

11

11.1 Learning Activities

Before attempting to answer these review questions, read the following:

Chapter 11: Continuous Quality Improvement for Digital Radiography From *Digital Radiography: Physical Principles and Quality Control* by Euclid Seeram, PhD., FCAMRT Second Edition. Springer 2019

11.2 Summary of the Main Points in this Chapter

Continuous quality improvement (CQI) is a process to ensure that every employee plays a role in ensuring a quality product, and it includes two major elements, quality assurance (QA) and quality control (QC). While QA primarily deals with the administrative aspects of patient care and quality outcomes, QC addresses the more technical aspects of equipment performance. Both QA and QC play major roles in dose optimisation that is a radiation protection principle to keep the dose as low as reasonably achievable (ALARA) without affecting the diagnostic quality of the image. QC is a common activity of technologists, medical physicists and radiologists working in a medical imaging department, and it involves at least three essential tasks: that of acceptance testing, routine performance and error correction. Furthermore, acceptance criteria or tolerance limits for the recommended digital radiography QC tests, in which both qualitative and quantitative criteria may be used to assess image quality, are provided. A quality image is one that makes accurate diagnosis possible. This is known as “diagnostic quality.” The quality of any image can be described in terms of spatial resolution, contrast resolution, noise, detective quantum efficiency (DQE) and artefacts. QA and QC activities demand an understanding of the processes and errors in digital radiography. A process map which is a flowchart of the steps involved in performing a Digital Radiography (DR) exam can be created as a way to understand the interrelationships between activities within the

imaging operation. There are at least 16 steps that begin with the arrival of the patient in the imaging department to the step (step 16) where the images are released to the picture archiving and communication system (PACS). The process map draws attention to errors in the association of demographic and exam information, errors that can be avoided by periodic testing, errors in performing the examination and errors in the delivery of the images. Additionally, reject analysis is an essential element of QC activities, and it is a time-honoured method for assessing and improving the quality of imaging operations. Examples of several QC tests that employ qualitative criteria for acceptance limits have been described briefly and include tests for dark noise, computed radiography imaging plate test for uniformity and spatial accuracy and erasure thoroughness. Furthermore, ongoing QC is an essential element and process of any digital imaging department, and as such the American Association of Physicists in Medicine (AAPM) has provided guidance details of such activities such as reject image analysis, exposure analysis and artefact identification. The AAPM, the American College of Radiology (ACR) and the Society for Imaging Informatics in Medicine (SIIM) identify and describe at least five individuals who should play a significant role in QA/QA programs including the physician, a qualified medical physicist (QMP), registered radiologist assistant, radiologic technologist and the imaging informatics professional. Digital mammography is now an acceptable modality in most imaging departments, and the ACR provides *recommendations for full-field digital mammography quality control* in which they provide a list of 13 QC tests specifically for the technologist and 17 QC tests to be carried out specifically by the qualified medical physicist.

11.3 Questions Will Be Based On Each of the Following Key Terms

- Elements of CQI
- Image Quality: Definition and Descriptors
- Processes and Errors in Digital Radiography
- Qualitative Criteria for Selected QC Tests
- Responsibilities for QC in Digital Radiography
- QC for Digital Mammography

11.4 Challenge Questions

11.4.1 True (T)/False (F)

1. CQI was developed by the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) in 1991, and it ensures that every employee plays a role in ensuring a quality product.
2. Quality Assurance (QA) deals with the administrative aspects of patient care and quality outcomes.

3. Quality Control (QC) deals with the technical aspects (rather than administrative aspects) of equipment performance.
4. CQI, QA and QC are threefold: to ensure optimum image quality for the purpose of enhancing diagnosis, to optimise the radiation dose to patients and reduce the dose to personnel and to reduce costs to the institution.
5. The exposure indicator (EI) calibration is not a parameter for QC monitoring in Digital Radiography (DR).
6. The tolerance limit for the X-ray beam collimation should be $\pm 2\%$ of the source-to-image receptor distance (SID).
7. The detective quantum efficiency (DQE) is the only image quality descriptor in DR.
8. Dark noise, spatial accuracy and erasure thoroughness are the only quality QC tests available for Computed Radiography (CR).
9. In a digital radiology department, the radiologist has the ultimate responsibility for the quality of images.
10. In a QC program for Digital Mammography, noise, spatial linearity and geometric distortion of the detector should only be carried out by a qualified medical physicist (QMP) and not a technologist.

11.4.2 Multiple Choice

1. The benefits of a Quality Assurance (QA) Program are:
 - (a) Cost control to patient and hospital
 - (b) Reduced radiation dose to patients and personnel
 - (c) Improvement of image quality standards
 - (d) All are correct
2. What term is used to describe the process of monitoring equipment in a QA program?
 - (a) Administrative review
 - (b) Continuing education
 - (c) Quality administration
 - (d) Quality control (QC)
3. Which term is used specifically to refer to the people aspect of a QA program?
 - (a) Quality Control
 - (b) Quality Administration
 - (c) Error Correction
 - (d) Acceptance Testing
4. According to the US Food and Drug Administration (FDA) and The Joint Commission (TJC), who has the primary responsibility for the development, implementation and maintenance of a QA program in radiology?
 - (a) The hospital physicist
 - (b) The radiologist in charge of the radiology facility

- (c) The manager of the radiology department
 - (d) The hospital diagnostic services manager
5. The acceptance criteria or tolerance levels in a QC program is based on:
- (1) The results of research studies
 - (2) Objective data
 - (3) Subjective data such as the radiologist preferences
 - (a) (1) only
 - (b) (1) and (2)
 - (c) (2) only
 - (d) (1), (2) and (3)
6. In a QC Program, what term is used to describe the tests which are carried out to ensure that the manufacturer's specifications are met?
- (a) Error correction
 - (b) Routine performance
 - (c) Acceptance testing
 - (d) Continuous quality improvement
7. In a QC Programme, which of the following is used to indicate that the QC results for a particular test have been met?
- (a) Tolerance limit
 - (b) Routine performance
 - (c) Acceptance testing
 - (d) Continuous quality improvement
8. The image quality descriptor that is related to the bit depth of a digital image is the:
- (a) Contrast resolution
 - (b) Spatial resolution
 - (c) Noise
 - (d) Detective Quantum Efficiency (DQE)
9. The image quality descriptor that is related to the size of the pixels in the image matrix is the:
- (a) Contrast resolution
 - (b) Spatial resolution
 - (c) Noise
 - (d) Detective Quantum Efficiency (DQE)
10. The image quality descriptor that describes the number of X-ray photons falling on the detector to create the image is the:
- (a) Contrast resolution
 - (b) Spatial resolution
 - (c) Noise
 - (d) Detective Quantum Efficiency (DQE)

11. The image quality descriptor that explains the efficiency and fidelity with which the detector can convert the input exposure into a useful output image is the:
 - (a) Contrast resolution
 - (b) Spatial resolution
 - (c) Noise
 - (d) Detective Quantum Efficiency (DQE)

12. The steps in conduction of a DR examination can be represented in a flowchart referred to as:
 - (a) Process map
 - (b) Location map
 - (c) Interrelationship map
 - (d) All are correct

13. The electronic file header contains information on patient demographics, examination data and specific information about the image including how it was acquired and processed. This file header is referred to as:
 - (a) Image information
 - (b) Object data
 - (c) Metadata
 - (d) Data facts

14. A characteristic feature that is specifically designed to take advantage of information that already exists in the Radiology Information System (RIS) is:
 - (a) DICOM compliant
 - (b) Modality worklist (MWL)
 - (c) RIS worklist
 - (d) Technologist worklist (TWL)

15. Which of the following QC test can be performed to check for non-uniformity by exposing the digital detector to a uniform field of radiation using a long source-to-image detector distance (SD)?
 - (a) Dark noise test
 - (b) Spatial accuracy test
 - (c) Erasure thoroughness test
 - (d) Flat field test

16. In DR QC testing, a flat filed image acquired according to the manufacturers' conditions can be used to verify:
 - (1) Uniformity
 - (2) Absence of detector defects
 - (3) Gain
 - (4) The Exposure Indicator (EI)
 - (a) (1) only
 - (b) (1) and (2)
 - (c) (1), (2) and (3)
 - (d) (1), (2), (3) and (4)

17. Reject analysis in DR showed that the most frequent cause of repeated examination is:
 - (a) Positioning errors
 - (b) Underexposures
 - (c) Overexposures
 - (d) Patient motion

18. The tendency of using higher than required exposure technique factors in digital radiography is formally referred to as:
 - (a) Exposure factor creep
 - (b) Deficient exposure factor
 - (c) Overexposure creep
 - (d) Radiologist factor

19. Which of the following ensures that the appearance of the image at the QC workstation monitor matches the appearance at the physician's PACS workstation monitor, both displays must be similarly calibrated.
 - (a) Greyscale display function (GSDF)
 - (b) Greyscale processing
 - (c) Exposure indicator function
 - (d) Radiologist requirement for the perception of the number of shades that the image can display

20. Which of the following QC test for DR can be used to assess the level of noise present in the system (intrinsic noise)?
 - (a) Spatial accuracy
 - (b) Uniformity
 - (c) Dark Noise
 - (d) Erasure thoroughness

21. A QC test for DR that should be carried out by a qualified medical physicist (QMP) is:
 - (a) Erasure thoroughness
 - (b) Verification of detector calibrations
 - (c) Dark Noise
 - (d) Detector uniformity

22. A QC test for DR that should be carried out by a clinical engineer is:
 - (a) Erasure thoroughness
 - (b) Verification of detector calibrations
 - (c) Verification of monitor display calibrations
 - (d) Detector uniformity

23. Who has the QC responsibility of compiling and reviewing reject analysis data?
 - (a) Radiologist
 - (b) QC technologist

- (c) QMP
 - (d) QA coordinator
24. Who has the QC responsibility of reporting substandard digital images?
- (a) Radiologist
 - (b) Technologist
 - (c) QMP
 - (d) QA coordinator

11.4.3 Short Answers

1. Explain the difference between QA and QC and state the purpose of CQI.
2. Identify the basic notion of dose optimisation.
3. Identify three important activities of a QC program and explain the meaning of each.
4. List a few parameters and test tools for QC monitoring in digital radiography.
5. State briefly what is meant by the notion of a tolerance limit in QC for DR.
6. Identify four descriptors of digital image quality, briefly explain each of them and describe the factors affecting each descriptor.
7. Outline the fundamental elements of a process map in a QC program for DR.
8. Briefly describe each of the following:
 - Flat field
 - Ghost image
 - Exposure Indicator (EI)
9. What is a reject analysis in DR and summarise the results of studies in the literature?
10. State the reason why departments must pay careful attention to the greyscale display function (GSDF) as specified in DICOM
11. Identify the purpose of the following QC tests for Computed Radiography (CR) and state the qualitative criteria for acceptance of each of the test results.
 - Dark Noise
 - CR imaging plate for Uniformity
 - Spatial accuracy
 - Erasure thoroughness

11.5 Answers to Challenge Questions

11.5.1 True/False

1. T
2. T
3. T
4. T
5. F

6. T
7. F
8. F
9. T
10. T

11.5.2 Multiple Choice

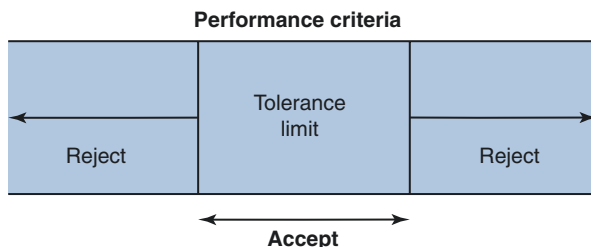
1. d
2. d
3. b
4. b
5. d
6. c
7. a
8. a
9. b
10. c
11. d
12. a
13. c
14. b
15. d
16. d
17. a
18. a
19. a
20. c
21. b
22. c
23. d
24. a

11.5.3 Short Answers

1. QA deals with people and in particular addresses quality assessment, continuing education, the usefulness of quality control procedures and the assessment of outcomes. QA deals with the administrative aspects of patient care and quality outcomes. QC on the other hand is a component of QA and deals with the technical aspects of the equipment. More importantly, QC examines the monitoring of important variables that affect image quality and radiation dose, such as, for example, dark noise, uniformity, exposure indicator calibration, laser beam function, spatial accuracy, erasure thoroughness, aliasing/grid response, positioning,

collimation errors and so on. QA and QC programs are essential not only for optimising the assessment and evaluation of patient care. Both QA and QC fall within the notion of Continuous Quality Improvement (CQI) developed by the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) in 1991. CQI ensures that every employee plays a role in ensuring a quality product and it includes both QA and QC procedures. The purpose of the procedures and techniques of CQI, QA and QC is threefold: to ensure optimum image quality for the purpose of enhancing diagnosis, to optimise the radiation dose to patients and reduce the dose to personnel and to reduce costs to the institution.

2. The International Commission on Radiological Protection (ICRP) first introduced the three principles of radiation protection, namely, justification, optimisation and dose limitation. Dose optimisation therefore is a radiation protection principle and it means working within the as low as reasonably achievable (ALARA) philosophy. This strategy is designed to use very low exposures without affecting the diagnostic quality of the image. The ICRP defines at least two levels of optimisation. While the first deals with the design and function of the X-ray imaging equipment; the second level addresses imaging techniques and imaging protocols used during daily operation. While the former examines the design and function of the equipment to meet current radiation protection standards, the latter deals with the procedural and operational practices during the conduct of the examination. QA/QC programs play significant roles in dose optimisation.
3. Three important and mandatory activities of a QC are acceptance testing, routine performance of QC tests and error correction if any component fails the test. The first step in QC of equipment is acceptance testing which is designed to ensure that the equipment meets the vendor's specifications; routine performance means performing the actual QC test on the equipment with varying degrees of frequency (annually, semi-annually, monthly, weekly or daily). The last step in these activities is error correction and this ensures that equipment not meeting the performance criteria or tolerance limit established for specific QC tests must be replaced or repaired to meet tolerance limits.
4. As recommended by the AAPM, examples of parameters for QC testing in digital radiography include physical inspection of the CR imaging plate (CR IP), dark noise and uniformity, exposure indicator calibration, laser beam function, spatial accuracy, erasure thoroughness, aliasing/grid response, positioning, collimation errors and so forth. Examples of test tools include screen-contact wire mesh pattern, anti-scatter grid, calibrated ion chamber, densitometer for hard copy film evaluation (in cases where film is used), manufacturer-approved cleaning solutions and cloths, two metric-calibrated 30-cm steel rulers and low-contrast phantom to mention only a few.
5. The notion of a tolerance limit is conceptualised in the Figure below and the consequences of exceeding the \pm values that define the limit.



(Figure 11-1 in *Digital Radiography: Physical Principles and Quality Control* by Euclid Seeram, PhD., FCAMRT Second Edition. Springer 2019)

The AAPM has also established acceptance criteria or tolerance limits for the recommended digital radiography QC tests, in which both qualitative and quantitative criteria may be used to assess image quality. For example, a qualitative criterion for the QC test for dark noise (system noise) is that the results of the test show a uniform image without artefacts. A quantitative criterion for collimation of the X-ray beam should be $\pm 2\%$ of the source-to-image receptor distance (SID).

6. Several parameters are used to describe image quality in digital radiography and they include spatial resolution, contrast resolution, noise, detective quantum efficiency (DQE) and artefact.
 - (a) Spatial resolution refers to the sharpness or detail of a digital image. Such sharpness is related to the size of the pixels in the image matrix. The smaller the pixel size, the better the spatial resolution of the image.
 - (b) Contrast resolution can be described by the range of grey levels or greyscale that a pixel in the image can have. Contrast resolution of a digital image is related to the bit depth, which is the range of grey levels per pixel. An image with a bit depth of 10 will have 1024 (2^{10}) shades of grey per pixel. Generally, a greater bit depth results in better contrast resolution.
 - (c) Image noise is linked to the number of photons used to create the image. While few photons result in a noisy or grainy image (quantum noise), more photons reduce the noise. Low-exposure technique factors will produce few photons at the detector (i.e., less signal and more noise), higher exposure technique factors will generate more photons at the detector (i.e., more signal and less noise). The former will result in a noisy, or grainy, image that is generally poor, and the latter will produce a clearer image but at the same time increases the dose to the patient.
 - (d) Another parameter used to describe image quality in digital radiography is that of the detective quantum efficiency (DQE). The DQE is a measure of the efficiency and fidelity with which the detector can perform this task. The DQE considers not only the signal-to-noise ratio (SNR) but also the system noise (electronic noise) and, therefore, includes a measure of the amount of noise added. The DQE for a perfect detector is 1 (100%).

7. A process map is a flowchart that illustrates the steps involved in performing a DR examination and demonstrates the interrelationships involved in the total conduct of the operation. In general, a process map consists of about 18

steps, with each step focussing on a specific detail. For example, step 1 indicates that the patient arrives in the department, step 9 indicates that the patient is being positioned, step 10 indicates that the examination is performed, step 10 will require that images be reviewed on the quality control (QC) workstation monitor, steps 16 and 17 indicate that images are released to the Picture Archiving and Communication System (PACS) and that the complete examination will be sent to the Radiology Information System, respectively. Furthermore, a process map will also feature points at which questions about QC may arise.

It is important to note that apart from addressing one of the QC questions during analysis, other questions concern the readiness of the DR system to acquire and display images. Additionally, errors in the association of demographic and exam information can be identified and other errors (such as errors in performing the exam) can be avoided by periodic testing.

8. Digital radiography (DR) systems require that a uniformity correction is applied to compensate for differences in gain across the receptor. This calibration for non-uniformity, also known as a shading correction, must be repeated on a periodic basis. A QC test for non-uniformity is a flat field correction in which the detector is exposed to a uniform field of radiation called a flat field. This is done by the use of a large SID, such as 180 cm, opening the collimator to cover the receptor, and developing the image.

DR detectors are referred to as reusable image media (RIM). After the digital image is transferred, any signal remaining in the receptor is erased, so that the receptor can be used to acquire another image. If erasure is inadequate, the previous exposure is superimposed as a ghost image on the current image.

The exposure indicator (EI) is a numerical value to indicate that the correct exposure technique factors have been used for the examination. The same flat-field exposure can also be used to check the value of the exposure indicator.

9. A reject analysis program (RAP) is a process for assessing and improving the quality of imaging activities. It involves the following activities: collecting data, data analysis (to find out causes of errors in the conduct of an examination), corrective action, record keeping and standardised reasons for rejection, such as positioning, exposure error, artefact, patient motion, grid problems, etc. The results should be examined by radiologists and supervisors who must consider actions that should be taken to improve departmental operations. Various reject analysis studies in digital radiography (DR) have been conducted and the results proved to be interesting indeed since there was an initial claim by users of DR technology that there were few and no rejected images. These studies showed that positioning errors are by far the most frequent cause of repeated exams, followed by overexposed and underexposed images, artefacts and motion. While some studies reported rejection rates ranging from 4% to 8%, others reported ranges of 12% to 15%. With these results in mind, the American Association of Physicists in Medicine (AAPM) Task Group 151 “recommends that 8% be used as a target for overall rejected image rate, and 10% as a threshold for investigation and possible corrective action”.

10. To enable accuracy, in interpreting images on display monitors in the department, it is mandatory that the monitor greyscale feature be calibrated according to the DICOM Grey Scale Display Function (GSDF) to ensure monitor greyscale uniformity. Observers looking at digital images on any monitor calibrated according to the DICOM GSDF will see the same degree of image greyscale display.

11. The answers are provided in the table below:

QC test	Purpose	Qualitative criteria
Dark noise	To assess the level of noise present in the system (intrinsic noise)	Uniform image without artefacts
Uniformity of CR Imaging plate	To assess the uniformity of the recorded signal from a uniformly exposed imaging plate (a non-uniform response could affect clinical image quality)	Uniform image without artefacts
Spatial accuracy	To check that there is no spatial distortion in the image	The grid pattern spacing of the wire mesh should be uniform without and distortion across the CR image
Erasure thoroughness	To test that minimal residual signal (ghosting) on a CR imaging plate after readout and exposure	The absence of a ghost image of the step wedge from the first exposure in the re-exposed image

11.6 Knowledge Lack Identification

A. Make a list of topics and/or questions that are still not clear to you after studying this chapter

B. See the instructor for clarification and/or consolidation of the materials

11.7 Student Comments



Dose Optimisation in Digital Radiography

12

12.1 Learning Activities

Before attempting to answer these review questions, read the following:

Chapter 12: Dose Optimization in Digital Radiography. From *Digital Radiography: Physical Principles and Quality Control* by Euclid Seeram, PhD., FCAMRT Second Edition. Springer 2019

12.2 Summary of the Main Points in this Chapter

This chapter explored the ICRP's principle of optimisation, optimisation of the exposure technique factors [kilovolts (kV) and milliamperere-seconds (mAs)] used in a digital radiography examination, including the exposure indicator (EI). Secondly, dose optimisation tools for image quality assessment were outlined, specifically the method of visual grading of normal anatomy. Finally, the chapter provides an example of a research study examining the optimisation of the EI as a dose management strategy in digital radiography. The ICRP principle of optimisation is intended to protect the patient from unnecessary radiation by using a dose that is as low as reasonably achievable (ALARA). The ultimate goal of optimisation is to minimise stochastic effects and to prevent deterministic effects. Three dose optimisation approaches were introduced and reviewed. These include optimisation of the exposure techniques factor (kV and mAs) and the EI. The literature review on the use of these approaches in computed radiography (CR) found the EI as a dose-control mechanism and as a "surrogate for dose management," and the use of the EI has been viewed as an opportunity for dose optimisation. Furthermore, optimisation research has focused mainly on optimising the kV in CR imaging as a means of implementing the ALARA philosophy. Generally, these studies have produced "conflicting results." The fourth topic addressed in this chapter is image quality assessment of medical images. These include objective physical measures and observer performance methods such as the use of visual grading of normal

anatomy and the various receiver operating characteristic (ROC) methods. One tool that is well established and makes use of the European Guidelines on Quality Criteria for Diagnostic Radiographic Images is visual grading analysis (VGA) procedure. This procedure is used to evaluate image quality based on the visualisation and reproduction of defined anatomical structures in images and not on lesion detection.

12.3 Questions Will Be Based On Each of the Following Key Terms

- Biological Effects of Radiation Exposure
- Radiation Protection Philosophy
- What is Dose Optimisation?
- Dose Optimisation Approaches
- Dose Optimisation Tools for Image Quality Assessment
- Visual Grading of Normal Anatomy

12.4 Challenge Questions

12.4.1 True (T)/False (F)

1. Exposure creep (dose creep) refers to increasing patient dose, possibly without being aware of it (unintended excessive exposure) or an increase in exposure over time when using manual exposure timing in digital radiography (DR).
2. In DR, the detector response to radiation exposure results in a wide-exposure latitude whereby images created with low and high exposures appear to have acceptable image quality.
3. In DR, the fact is that low exposures result in images with high noise levels and high exposures result in increased radiation doses to patients.
4. There are two classes of biological effects of radiation exposure fall, namely, stochastic effects and deterministic effects.
5. Stochastic effects are effects for which the probability of their occurrence depends on the amount of radiation dose an individual receives, and the probability increases as the dose increases.
6. There is a threshold dose for stochastic effects which occurs years after the exposure and therefore is called late effects.
7. Deterministic effects are those for which the severity of the effect (rather than the probability) increases with radiation dose and for which there is no threshold dose.
8. While examples of stochastic effects include cancer and genetic damage, examples of deterministic effects are skin burns, hair loss, tissue damage and organ dysfunction.
9. The overall objective in medical X-ray imaging is to minimise the probability of stochastic risks and to prevent the occurrence of deterministic effects.

10. The International Commission on Radiological Protection (ICRP) developed three guiding principles of radiation protection and they are the principles of justification, optimisation and dose limitation.
11. The ICRP principle of optimisation means that operators should use doses that are “as low as reasonably achievable” (ALARA) without compromising image quality. This philosophy is intended to protect the patient from unnecessary radiation.
12. Low kV techniques deliver less dose to the patient, while high kV techniques deliver more dose in the tissues of the patient.
13. Collimation restricts the beam size to the anatomy of interest, and smaller beam size results in a decrease in dose since the surface integral exposure (total dose) is directly proportional to the size of the irradiated area.
14. Short source-to-image receptor distance (SID) increases the dose to the patient because the photon concentration per unit area increases.
15. Increasing the detector sensitivity increases the dose to the patient.
16. Decreasing the image noise by a factor of 2 requires that the dose be increased by 2.
17. The spatial resolution of a digital image can be improved by a factor of 2, however, the dose would have to be increased by a factor of 8.
18. The noise level in an image greatly affects its low-contrast resolution.
19. In CR imaging, it is recommended that lower kV should be used since the K-edge of the typical phosphor of a CR imaging plate such as BaFBr/I (barium fluorobromide/iodide) is 37 keV.
20. In CR and Flat-Panel Digital Radiography (FPDR), the kV does not affect the image contrast since image post-processing techniques such as windowing can alter image density, brightness and contrast.

12.4.2 Multiple Choice

1. Which of the following refers to an increase in exposure over time when using digital systems with manual tube settings?
 - (a) Optimisation
 - (b) Exposure creep or dose creep
 - (c) Exposure latitude
 - (d) Technologist error
2. The response of the digital detector to radiation exposure demonstrates:
 - (a) A narrow exposure latitude
 - (b) Exposure creep
 - (c) Exposure indicator
 - (d) A wide exposure latitude
3. Human responses to radiation that do not have a threshold dose and are considered late effects:
 - (a) Occur within weeks or months
 - (b) Require a dose exceeding 10 Gy

- (c) Are called deterministic effects
 - (d) Are called stochastic effects
4. Human responses to radiation that have a threshold dose are considered early effects:
- (a) Occur several years after the exposure
 - (b) Occur with a very small dose close to 0
 - (c) Are called deterministic effects
 - (d) Are called stochastic effects
5. Examples of late effects of radiation exposure are:
- (a) Skin burns
 - (b) Cancer and genetic effects
 - (c) Hair loss
 - (d) Tissue damage
6. Examples of early effects of radiation exposure are:
- (a) Skin burns, hair loss
 - (b) Cancer and genetic effects
 - (c) Tissue damage and organ dysfunction
 - (d) a and c are correct
7. Which of the following ICRP radiation protection principles require that there must be a positive net benefit associated with every exposure to the patient?
- (a) Justification
 - (b) Optimisation
 - (c) Dose limitation
 - (d) ALARA
8. Which of the following ICRP radiation protection principles require that all exposures be kept as low as reasonably achievable without compromising image quality?
- (a) Justification
 - (b) Optimisation
 - (c) Dose limitation
 - (d) b and c are correct
9. The goal of the optimisation principle established by the ICRP is:
- (a) Minimise stochastic effects
 - (b) Prevent deterministic effects
 - (c) Lowering the dose to patients
 - (d) a and b are correct

10. The clinical practice of the optimisation principle established by the ICRP requires that the:
- (1) Lowest dose possible is used for the examination
 - (2) Lowest dose must not compromise the image quality
 - (3) Technologist is responsible for optimisation
 - (4) ALARA be applied to protect the patient and users
- (a) (1) only
 - (b) (1) and (2)
 - (c) (1), (2) and (3)
 - (d) (1), (2), (3) and (4)
11. Which of the following image quality parameters describe the sharpness of the digital image?
- (a) Contrast resolution
 - (b) Detective Quantum Efficiency (DQE)
 - (c) Spatial resolution
 - (d) Noise
12. The mathematical relationship between dose and mAs is as follows:
- (a) Dose is directly proportional to the mAs
 - (b) Dose is inversely proportional to the mAs
 - (c) Dose is directly proportional to the mAs
 - (d) Dose is proportional to the square of the mAs
13. The mathematical relationship between dose and kV is as follows:
- (a) Dose is directly proportional to the square of the kV change
 - (b) Dose is inversely proportional to the kV
 - (c) Dose is directly proportional to the kV
 - (d) Dose is proportional to the square root of the kV
14. The relationship between collimation of the X-ray beam size and the surface integral exposure (SIE) (total radiation to the exposed area) is as follows:
- (a) The SIE is inversely proportional to the size of the irradiated area
 - (b) The SIE is directly proportional to the size of the irradiated area
 - (c) The SIE is directly proportional to the square root of the size of the irradiated area
 - (d) The SIE is equal to the irradiated area + the size of detector used
15. A short source-to-image receptor distance (SID) increases the surface exposure to the patient because:
- (a) The concentration of photons per unit area decreases
 - (b) The number of photons at the detector is directly proportional to SID
 - (c) The surface exposure is directly proportional to the SID
 - (d) The concentration of photons per unit area increases

16. The relationship between detector sensitivity (relative detector speed) and dose is as follows:
- (a) Dose is α to the detector sensitivity
 - (b) Dose is $1/\alpha$ to the detector sensitivity
 - (c) Dose is not related to detector speed
 - (d) Dose is proportional to the area of the size of the detector surface
17. Reducing the quantum noise in a digital image by a factor of 2 requires that the dose be increased by a factor of:
- (a) 2
 - (b) 8
 - (c) 4
 - (d) 3
18. Improving the spatial resolution in a digital image (influenced by pixel size) by a factor of 2 requires that the dose be increased by a factor of:
- (a) 2
 - (b) 8
 - (c) 4
 - (d) 3
19. Which of the following image quality parameters is greatly affected by the noise level in an image?
- (a) Low-contrast resolution
 - (b) Spatial resolution
 - (c) Detective Quantum Efficiency
 - (d) Image detail
20. Which of the following is a valid and simple method of subjectively assessing image quality in a dose-image quality optimisation study?
- (a) Visual Grading Analysis (VGA)
 - (b) The Modulation Transfer Function (MTF)
 - (c) Receiver Operating Characteristics (ROC)
 - (d) Detective Quantum Efficiency (DQE)

12.4.3 Short Answers

1. Identify two categories of biological effects of radiation exposure
2. Medical imaging involves purposeful exposures and therefore every effort is made to minimise the probability of stochastic effects and prevent deterministic effects from occurring. Identify and describe the International Commission on Radiological Protection (ICRP) framework for achieving this goal.
3. List the technical factors affecting the dose to the patient in digital radiography and describe briefly the major factors under the direct control of the technologist.

4. Describe briefly the influence of kV, mAs, collimation, SID and detector sensitivity on dose.
 5. Explain briefly the influence of dose on image quality characteristics such as noise, spatial resolution and contrast resolution.
 6. Why should lower kV be used in Computed Radiography (CR) imaging and does lower kV improve the image contrast in digital imaging?
 7. What is the major difference between objective physical methods and observer performance methods for assessing image quality?
 8. Explain briefly the six minimum requirements of any optimisation research in digital radiography.
-

12.5 Answers to Challenge Questions

12.5.1 True/False

1. T
2. T
3. T
4. T
5. T
6. F
7. F
8. T
9. T
10. T
11. T
12. F
13. T
14. T
15. F
16. F
17. T
18. T
19. T
20. T

12.5.2 Multiple Choice

1. b
2. d
3. d
4. c
5. b
6. d

7. a
8. b
9. d
10. d
11. c
12. c
13. a
14. b
15. d
16. b
17. c
18. b
19. a
20. a

12.5.3 Short Answers

1. Radiation bioeffects fall into two categories, namely, stochastic effects and deterministic effects. Stochastic effects are effects for which the probability of occurrence depends on the amount of dose received by an individual. The probability increases as the dose increases and for which there is no threshold dose. Any dose, no matter how small, has the potential to cause harm. Examples of stochastic effects include cancer, leukaemia and genetic effects. Stochastic effects are also referred to as late effects since if any harm occurs, it generally shows up years after the exposure. These effects are considered a risk from exposure to the low levels of radiation used in medical imaging, including CT examinations.

Deterministic effects on the other hand are effects for which the severity (rather than the probability) of the effect increases with increasing dose and for which there is a threshold dose. Examples of deterministic effects include skin burns, hair loss, tissue damage and organ dysfunction. Since these effects involve high exposures and occur minutes, hours and days after the exposure, they are also referred to as early effects. Furthermore, these effects are unlikely to occur from exposures in medical imaging examinations.

2. Medical imaging ensures that X-ray procedures adhere to the framework of the ICRP in order to minimise the probability stochastic effects and prevent deterministic effects. This framework is based on ICRP's radiation protection principles. These principles include justification, optimisation and dose limitation. For individuals who are exposed to radiation during their imaging examination, the principles of justification and optimisation apply. While justification refers to the fact that every exposure a patient receives must have a positive net benefit associated with it, optimisation is intended to ensure that all exposures be kept as low as reasonably achievable (ALARA) without compromising the diagnostic quality of the examination. Dose limits have been established by the ICRP and are intended for those who are occupationally exposed and excludes medical expo-

sure. For example, the annual dose limit for radiation workers is 20 mSv (not greater than 20 mSv/year averaged over 5 years).

3. Major technical factors affecting the dose in digital radiography and in film-screen radiography include: the type of X-ray generator, filtration, collimation, automatic exposure control systems, X-ray beam alignment, the source-to-detector distance (SID), patient thickness, scattered radiation grid characteristics (grid ratio, selectivity and grid frequency), gonad shielding, sensitivity of the detector, exposure technique factors (kV and mAs) and the repeat rate. Furthermore, the major factors under the direct control of the technologist during the examination are the exposure technique factors, the AEC system, collimation, Source-to-Skin Distance (SSD), grid selection, detector sensitivity, gonad shielding and repeat rate.
4. The influence of kV, mAs, collimation, SID and detector sensitivity on dose are as follows:
 - *kV*: $Dose \propto [kV_{new}/kV_{old}]^2$
 - Low kV exposure techniques result in more dose to the patient since the photons do not have enough energy to penetrate the thickness of the patient. High kV techniques result in less dose to the patient since the photons have enough energy to penetrate the patient.
 - *mAs*: $Dose \propto mAs$
 - Doubling the mAs will double the dose
 - *Collimation*
 - Collimation of the X-ray beam to the anatomy of interest decreases the dose to the patient since the surface integral exposure (total radiation) is directly proportional to the size of the irradiated area.
 - *Source-to-Image Receptor Distance (SID)*
 - Decreasing the SID and hence the source to skin (SSD) will increase the divergence of the beam increases, and this offset has an impact on the concentration of photons on the surface of the patient. A short SID increases the photon concentration per unit area thus increasing the surface exposure to the patient.
 - *Detector Sensitivity*
 - Detector sensitivity refers to the relative speed of the detector. The dose is inversely proportional to the detector sensitivity. As the sensitivity increases, the dose to the patient decreases.
5. In digital radiography, the general influence of dose on noise, spatial resolution and contrast resolution are as follows:
 - Dose is inversely proportional to the noise². If the noise is reduced by a factor of 2, then the dose increases by a factor of 4.
 - The spatial resolution of a digital image is related to the size of the pixels. Smaller pixels mean a sharper image. The dose is inversely proportional to the pixel size³. Improving the spatial resolution by a factor of 2 requires that the dose by increases by a factor of 8.
 - Image noise level greatly influences low-contrast resolution. Increased noise means poor low-contrast resolution.

6. Lower kV techniques should be used in CR imaging since the K-edge of the typical phosphor of a CR imaging plate such as BaFBr/I (barium fluorobromide/iodide) is 37 keV (compared to the K-edge of 50 keV for the phosphor Gd_2O_2S typically used in film-screen radiography). Furthermore, kV does not affect image contrast in digital radiography because the digital processing operation of windowing is used to post-process images by changing the brightness and contrast of the displayed image.
7. Two measurement procedures to assess image quality are objective physical measures and observer performance methods. While the former examines the performance of the digital imaging system, the latter uses human observers to evaluate the quality of images produced by various techniques. Objective physical measures include the modulation transfer function (MTF), the signal-to-noise ratio (SNR), the Wiener spectrum (also known as the noise power spectrum) and the Detective Quantum Efficiency (DQE).

Observer performance methods are designed to examine visualisation of anatomical structures (a function of technologists) and lesion detection (a function of radiologists). While lesion detection makes use of the receiver operating characteristics (ROC) analysis, identifying and visualisation of anatomical structures make use visual grading analysis (VGA). ROC and its variants are based on the scientific method and considered the gold standard for image quality assessment. The VGA approaches are well established, valid and simple method of subjectively assessing image quality based on the visibility and reproduction of anatomical structures. A fundamental problem with VGA is that bias may be introduced due to the subjective evaluation of the visualisation of anatomical structures. To address this problem, the European Guidelines on Quality Criteria for Diagnostic Radiographic Images provide definitions for four terms that are used to explain the meaning of the degree of visibility. These terms include visualisation, reproduction, visually sharp reproductions and important image details.

8. Any optimisation research in medical imaging should consider several essential principles before conducting such research. Essentially, the researcher must ensure that the doses to patients are “safe” and that the image quality required should be based on the diagnostic task at hand. Subsequently, images are obtained at various levels of dose ranging from high to low and image quality must not be compromised at low doses. Once images are obtained, the next step involves the use of reliable and valid methodologies for the dosimetry, image acquisition and evaluation of image quality should be used. Human observers should be used for the assessment of image quality, keeping in mind the nature of the detection task (lesion detection or visualisation of anatomical structures). The following considerations should be useful in meeting these requirements:
 - (a) The imaging system used must be calibrated to ensure consistent and reliable performance. Since a number of exposures and images will be obtained during the research, it is important that the machine provides reproducibility of exposures.
 - (b) The dosimeters used to capture dose levels are calibrated using reliable methodology.

Appendix

Review Examination

This review examination is based on questions of the multiple-choice format, a format that is similar to the certification examinations set by the American Registry of Radiologic Technologists (ARRT) and the Canadian Association of Medical Radiation Technologists (CAMRT). Additionally, the examination is based on the following topics:

- Film-Screen Radiography
- Digital Image Processing
- Computed Radiography
- Flat-Panel Digital Radiography
- The Standardised Exposure Indicator
- Picture Archiving and Communication Systems (PACS)
- Quality Assurance and Quality Control

1. In Film-Screen Radiography (FSR) what visual cue on the image is used to indicate that the correct technical exposure factors have been used for the examination?
 - A. The anatomy of interest
 - B. The optical density
 - C. The amount of transmitted light from the film view box
 - D. The visualisation of the correct right or left marker
2. The response of the film to radiation exposure (film contrast) can best be described by the:
 - A. Film characteristic curve
 - B. Contrast response
 - C. Optical density
 - D. Linear radiation response graph

3. The film response to radiation results in a graph show the film optical density plotted as a function of the log of the radiation exposure. Which portion of the graph indicates the useful density range or the correct exposure (acceptable image)?
 - A. The shoulder region
 - B. The toe region
 - C. The slope
 - D. A and B are correct

4. The mathematical relationship between film speed (sensitivity of the film to radiation) and radiation exposure (E)
 - A. Speed in directional proportional to E
 - B. Speed in inversely proportional to E
 - C. Speed = exposure
 - D. Speed = exposure + thickness of the cassette

5. A narrow film exposure latitude means that:
 - A. The kV used for the body part must be correct
 - B. The mA must be accurate for the anatomy under study
 - C. The exposure time in seconds must not exceed 0.5
 - D. The correct exposure technique factors (kV, mAs) must be very precise for the examination

6. Low mAs techniques used in FSR will produce images with:
 - A. Improved spatial resolution
 - B. Improved image contrast
 - C. Less noise
 - D. More noise

7. Low kV techniques used in FSR will produce images with
 - A. Improved image contrast
 - B. Decreased image contrast
 - C. Less noise
 - D. Higher degree of film blackening

8. Which of the following are limitations of FSR that have been overcome by digital radiography?
 - A. Film cannot discriminate tissue contrast differences of less than 10%
 - B. The optical range and contrast for film are fixed and limited
 - C. As an archive medium, film is usually stored in envelopes and housed in a large storage room
 - D. All are correct

9. Which of the following digital radiography detectors is based on the principle of photostimulable luminescence?
 - A. Computed Radiography (CR)
 - B. Indirect Flat-Panel Digital Radiography (FPDR)
 - C. Direct FPDR
 - D. Charge Coupled Device (CCD)

10. The digital radiography detector based on the use of amorphous selenium to create the image is:
 - A. CR
 - B. Indirect FPDR
 - C. Direct FPDR
 - D. CCD

11. The digital radiography detector that uses caesium iodide phosphor to create an image is
 - A. CR
 - B. Indirect FPDR
 - C. Direct FPDR
 - D. CCD

12. Which category of digital image processing operations can perform contrast enhancement, edge enhancement, spatial and frequency filtering, image combining and noise reduction?
 - A. Image enhancement
 - B. Image restoration
 - C. Image analysis
 - D. Image synthesis

13. Which category of digital image processing operations is meant to reduce the size of the image in order to decrease transmission time and reduce storage space?
 - A. Image compression
 - B. Image enhancement
 - C. Image analysis
 - D. Image synthesis

14. A two-dimensional array of numbers arranged in columns (M) and rows (N) is referred to as:
 - A. The spatial resolution of a digital image
 - B. The matrix of a digital image
 - C. The contrast resolution of a digital image
 - D. Picture elements called pixels

-
15. Which of the following can be used to calculate the pixel size (PS) of a digital image given the field-of-view (FOV) and the matrix size (MS)?
- A. $PS = MS + FOV$
 - B. $FOV \times MS$
 - C. MS/FOV
 - D. FOV/MS
16. The spatial resolution of a digital image is influenced by the:
- A. Size of the pixel
 - B. Focal spot size
 - C. Bit depth
 - D. Size of the phosphor particles on the detector
17. In a digital image with a bit depth of 10, the number of shades of grey a pixel can assume is:
- A. 10
 - B. 512
 - C. 1024
 - D. 256
18. The density resolution of a digital image depends on the:
- A. Pixel size
 - B. Bit depth
 - C. Detective Quantum Efficiency (DQE)
 - D. mAs
19. When digitising an image, the process whereby the brightness levels obtained from sampling are assigned an integer (zero, a negative or a positive number) called a grey level is referred to as:
- A. Scanning
 - B. Quantisation
 - C. Analog-to-digital conversion
 - D. Sampling
20. In digital image processing, greyscale processing such as windowing is a:
- A. Point processing operation
 - B. Local processing operation
 - C. Global processing operation
 - D. Fourier Transform operation
21. The use of a high-pass filter in digital image processing will:
- A. Improve the sharpness of the original image
 - B. Smooth the original image
 - C. Burr the original image
 - D. Change the contrast of the original image

22. The most frequently used (and least complicated) image processing operation used by technologists working in digital radiography is:
 - A. Edge enhancement
 - B. Windowing
 - C. Image smoothing
 - D. Image restoration

23. In Computed Radiography (CR), the purpose of pre-processing is also referred to as acquisition processing is:
 - A. Spatial frequency enhancement
 - B. Contrast rescaling
 - C. Edge enhancement
 - D. Exposure Field Recognition, sometimes referred to as Exposure Data Recognition (EDR)

24. In CR imaging, when the imaging plate (IP) is exposed to radiation:
 - A. Electrons return to their original level (valence band)
 - B. Electrons are raised to a higher energy level (conduction band) and remain trapped in so-called “F-centers”
 - C. The IP phosphor is ionised and the ejected electrons are used to create the CR digital image
 - D. All trapped electrons return to their valence band

25. In CR imaging, what happens to the IP when it is being scanned in the IP reader?
 - A. Electrons of the conduction band (higher energy level) are returned to a lower energy level (valence band), and in the process emit light.
 - B. Electrons from the valence band are raised to a higher energy level (conduction band)
 - C. Light emitted from the IP is sent directly to the analog-to-digital converter (ADC)
 - D. Electrons still trapped in the conduction band (the higher energy state) are returned to their valence band (the lower energy state) so that the IP can be used again.

26. When the CR IP is being scanned in the IP reader by a laser beam, the phenomenon of light emission is referred to as:
 - A. Photostimulable luminescence
 - B. Photoemission
 - C. X-ray photostimulable phosphorescence
 - D. Fluorescence

27. The purpose of erasure of the IP in the Image Reader is to:
 - A. Ensure that all trapped electrons return to their normal state, and that the IP can be reused for another exposure
 - B. Remove any residual dirt particles on the IP.

- C. Ensure that the technologist does not have to clean the IP for the next exposure.
 - D. Remove any dust particles trapped on the IP
28. In CR, which signal has to be digitised and contains patient information to create the image?
- A. The laser beam signal
 - B. The light emitted from the IP as it is scanned by the laser beam
 - C. The signal from the photomultiplier tube
 - D. The output from the analog-to-digital converter (ADC)
29. The most significant difference between CR imaging and Film Screen Radiography (FSR) is:
- A. the wide exposure latitude of CR.
 - B. the mAs is always higher in CR.
 - C. the kV is always higher in CR.
 - D. both mAs and kV are always higher in CR
30. In CR, the image presented to the observer always appears to be acceptable regardless of the magnitude of the exposure (low or high) used. This feature of the CR system is basically performed by which of the following?
- A. The Look Up Table (LUT) which converts the raw image data (scanned histogram) to match the stored histogram that is the acceptable “film look-alike” (good image).
 - B. The laser beam that scans the IP when it is placed in the Image Reader.
 - C. The analog-to-digital converter (ADC) which produces digital data.
 - D. The photomultiplier tube (PMT) that receives all the light from the light guide.
31. The Exposure Indicator (EI) in digital radiography provides a numerical value printed on the image indicating that:
- A. The system is in perfect working condition
 - B. The radiologist has established the value to be used for any examination
 - C. The correct exposure factors (dose to the detector) have been used for the examination
 - D. The dose to the patient
32. The exposure indicator in digital radiography is derived from which of the following:
- A. The quantity of exposure (radiation) falling on the patient
 - B. The quantity of exposure falling on the digital detector
 - C. The exposure factors (mAs and kV) set by the technologist
 - D. The type of examination being done
33. The term “exposure creep” in CR refers to the routine use of:
- A. Optimum exposure factors required for the examination
 - B. Higher than required exposure factors required for the examination

- C. Lower that required exposure factors for the examination
 - D. Lower EI numbers recommended by the manufacturer
34. Which of the following organisations championed the development of the standardised EI?
- A. The International Electrotechnical Commission (IEC)
 - B. The American Association of Physicists in Medicine (AAPM)
 - C. The American Society of Radiologic Technologists (ASRT)
 - D. The European Federation of Organizations for Medical Physics (EFOMP)
35. The Detective Quantum Efficiency (DQE) of a digital detector refers to:
- A. A measure of the fidelity with which a resultant digital image represents the transmitted X-ray exposure pattern.
 - B. How efficiently a system converts the X-ray input signal into a useful output image.
 - C. A measure of the noise (electronic and quantum) added.
 - D. All are correct.
36. Which is true for the DQE for a digital radiography detector?
- A. The higher the DQE, the higher the radiation exposure needed to achieve a set amount of image noise.
 - B. The higher the DQE, the lower the radiation exposure needed to achieve a set amount of image noise.
37. What is the main source of noise in a CR image?
- A. The number of X-ray photons on the surface of the imaging plate (IP)
 - B. The number of light photons collected in the IP reader
 - C. The number of electrons in the imaging phosphor before the IP is exposed to radiation
 - D. The number of X-ray photons at the entrance surface of the patient
38. Which of the following objective descriptors of CR image quality is a ratio of the signal-to-noise ratio (SNR) out of the CR IP to the SNR incident on the CR IP?
- A. Spatial resolution
 - B. Density resolution
 - C. Electronic noise
 - D. DQE
39. The appearance of different types of Moiré patterns on a digital radiography image is a result of:
- A. Scattered radiation falling on the detector
 - B. Exposure through the back of the cassette
 - C. Improper scattered radiation grid usage
 - D. Double exposure

40. Figure 1 below shows the Flat-Panel Digital Radiography (FPDR) detector. Which of the following components is responsible for the digitisation of the output signal from the active matrix detector?

- A. Data electronics
- B. Analog-to-digital converter (ADC)
- C. Internal memory
- D. Control electronics

Fig. 1

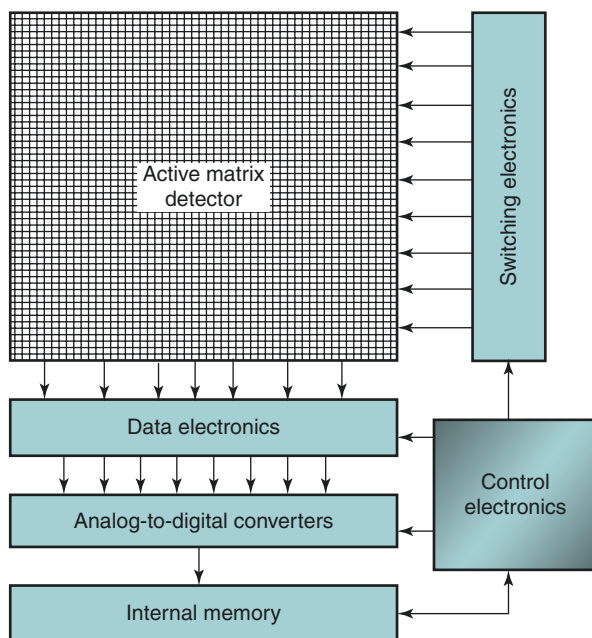
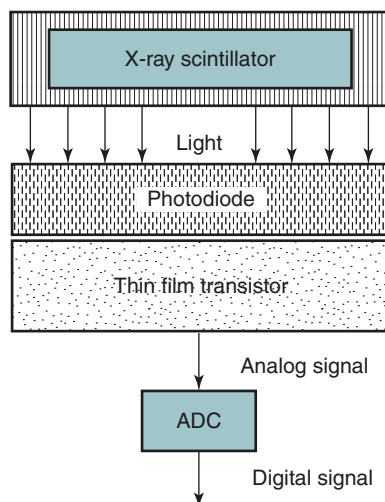
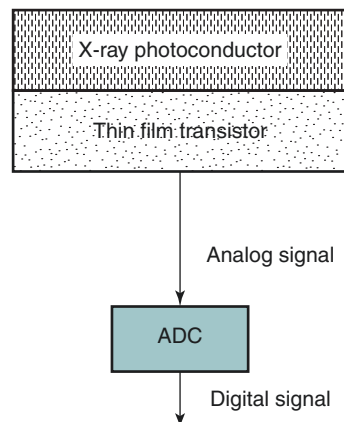


Fig. 2



41. Figure 2 above shows an illustration of the indirect FPDR detector consisting of a structured (needle-like fashion) X-ray scintillator (as opposed to a turbid arrangement). The purpose of the structured phosphor arrangement is to:
- A. Degrade the image contrast because light is scattered in the phosphor.
 - B. Improve the spatial resolution since the lateral spread of light is reduced.
 - C. Increase the dose to the patient thus resulting in a better image.
 - D. Improve the DQE.
42. Figure 2 above shows an illustration of the indirect FPDR detector. The purpose of the thin film transistor (TFT) is to:
- A. Capture the X-rays from the patient.
 - B. Convert X-rays to electrical signal.
 - C. Store electrical charge produced in the photodiode.
 - D. Act as a switch when reading the information on each pixel of the detector.
43. In Fig. 2 above, the photodiode is:
- A. amorphous-silicon (a-Si)
 - B. a-Selenium (a-Se)
 - C. Caesium Iodide (CsI)
 - D. Gadolinium (Gd₂)
44. In Fig. 2 above, a typical scintillator is:
- A. Zinc Cadmium Sulfide
 - B. Calcium Tungstate
 - C. Caesium Iodide (CsI)
 - D. All are correct
45. In Fig. 3 below, the X-ray photoconductor is:
- A. amorphous-silicon (a-Si)
 - B. a-Selenium (a-Se)
 - C. Caesium Iodide (CsI)
 - D. Gadolinium (Gd₂)

Fig. 3

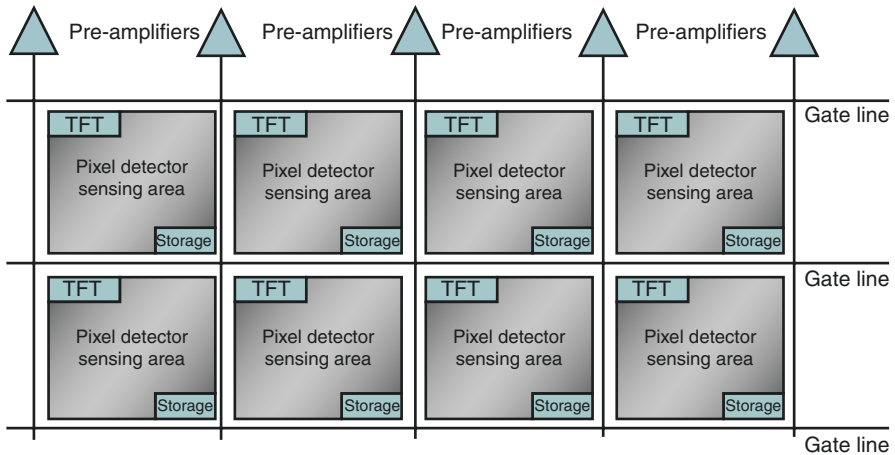


Fig. 4

46. Figure 4 above shows eight pixel-detector sensing areas of the active matrix detector elements of a FPDR detector. The fill factor of each pixel is defined as:

- Area of the pixel minus the sensing area
- Sensing area of the pixel/area of the pixel.
- Sensing area of the pixel
- Ratio of the area of the pixel to the sensing area

47. In Fig. 4 above, a fill factor of 80% means that:

- The detector electronics occupy 20% of the pixel
- The sensing area is 20% of the pixel area
- The sensing area is $80\% \pm 20\%$
- The ratio of the area of the pixel to the sensing area is 20%

48. The purpose of pre-processing in FPDR systems is to:

- Improve raw data image contrast
- Adjust the brightness of the raw data image
- Improve the spatial resolution of the raw data image
- Correct the raw data from artefacts created from bad detector elements

49. In digital radiography imaging, what is meant by the term “flat-fielding”?

- A pre-processing operation intended to correct artefacts that arise from bad detector elements
- A post-processing technique intended to correct artefacts from bad detector elements
- Adjusting the raw data to indicate exactly which pixel contains the data from the patient
- The use of a smoothing digital filter to enhance visualisation of anatomical structures

50. Which of the following measures the ability of the digital detector to transfer its spatial resolution characteristics to the image?
- A. Edge Response Function (EFS)
 - B. Line Spread Function (LSF)
 - C. Modulation Transfer Function (MTF)
 - D. Detective Quantum Efficiency (DQE)
51. In the standardised Exposure Indicator (EI) paradigm, the EI is:
- A. Directly proportional to the detector dose
 - B. Inversely proportional to the detector dose
 - C. Directly proportional to the surface entrance exposure (ESE) to the patient
 - D. Inversely proportional to the ESE
52. Which of the following is the International Electrotechnical Commission (IEC) definition for the “expected value of the exposure index when exposing the x-ray image receptor properly”?
- A. Exposure Indicator (EI)
 - B. Target Exposure Indicator (EI_T)
 - C. Deviation Index (DI)
 - D. Volume of Interest (VOI)
53. The following relationship can be used to calculate the DI in the standardised EI paradigm:
- A. $DI = \log_{10} (EI - EI_T)$
 - B. $DI = \log (EI + EI_T)$
 - C. $DI = EI/EI_T$
 - D. $DI = 10 \log_{10} (EI/EI_T)$
54. A DI value of 0, indicates:
- A. A perfect exposure where $EI = EI_T$
 - B. An overexposure
 - C. An underexposure
 - D. The VOI value is 0
55. Which of the following is a significant responsibility of the users in the standardised EI paradigm?
- A. Establish EI_T values based on exposure technique factors used in their departments for different body parts
 - B. Calibrate the digital detector so that the EI is directly proportional to the dose.
 - C. The image is free of noise
 - D. Specific digital image processing operations
56. What is the meaning of DICOM?
- A. Digital Imaging and Computers in Medicine
 - B. Digital Computers

- C. Digital Computers in Medicine
 - D. Digital Imaging and Communications in Medicine
57. The communication standard used for moving images in a Picture Archiving and Communication System (PACS) environment is:
- A. DICOM.
 - B. Health Level-7.
 - C. Transmission Control Protocol/Internet Protocol.
 - D. Ethernet.
58. Which of the following represents the first point of entry of images to a PACS?
- A. Interface
 - B. PACS controller
 - C. Imaging modalities
 - D. Hospital information system
59. The transfer and sharing of information among several computers is a function carried out by:
- A. Storage devices.
 - B. Display work stations.
 - C. Servers and routers.
 - D. LANs and WANs.
60. In a PACS environment, a RAID is all of the following, *except*:
- A. Redundant Array of Inexpensive Disks.
 - B. Redundant Array of Independent Disks.
 - C. A system of magnetic or optical disks that can act as a large disk drive.
 - D. An automated library system or “jukebox.”
61. Which type of PACS display workstation must be used for primary diagnosis?
- A. High-resolution workstation
 - B. Medium-resolution workstation
 - C. Desktop workstation
 - D. Hardcopy workstation for image printing
62. Compression of images in a PACS environment is intended to do all of the following, *except*:
- A. Speeds up transmission.
 - B. Reduce storage requirements.
 - C. Can be lossless or lossy.
 - D. Depends on whether a portrait or landscape computer screen is used
63. Which of the following makes use of the HL-7 standard for communication in the enterprise-wide distribution of medical information?
- A. PACS
 - B. Image acquisition from digital radiography modalities

- C. HIS and RIS
 - D. CR systems
64. Integrating the Healthcare Enterprise (IHE) deals with all of the following efforts *except*:
- A. Foster communications between information systems and PACS vendors to integrate the use of standards such as DICOM and HL-7.
 - B. Enhance access to clinical patient information and to facilitate integrity of this information.
 - C. Eliminate data redundancy between information systems and PACS.
 - D. Increase the pace of acquiring equipment in the department.
65. Which of the following organisations regulate PACS as a medical device?
- A. American Association of Physicists in Medicine (AAPM)
 - B. United States Food and Drug Administration (FDA)
 - C. Healthcare Information and Management Systems Society (HIMSS)
 - D. Society of Imaging Informatics in Medicine (SIIM)
66. Which of the following serves to protect information in PACS and places a good deal of importance on the security of electronic data and information?
- A. The Medical Devices Act
 - B. The Health Insurance Portability and Accountability Act (HIPPA)
 - C. PACS vendors
 - D. Freedom of Information Act
67. An archive in a PACS environment that “can be easily migrated, ported to interface with another vendor’s viewing, acquisition, and workflow engine to manage medical images and related information” is referred to as a:
- A. RAID
 - B. Jukebox of Optical Disks
 - C. Random Access Memory
 - D. Vendor Neutral Archive
68. A recent approach that creates a comprehensive program that can combine data from different departments into one system is referred to as:
- A. Enterprise Imaging
 - B. Integrating the Healthcare Enterprise
 - C. Electronic Health Record (EHR)
 - D. All of the above are correct
69. The first major step in a Quality Control (QC) program that is intended to ensure that the equipment meets the specifications set by the manufacturers is:
- A. Acceptance testing
 - B. Routine tests of equipment performance
 - C. Error correction
 - D. Develop a strategy to purchase QC test tools

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70. According to the US Food and Drug Administration (FDA) and The Joint Commission (TJC), who has the primary responsibility for the development, implementation and maintenance of a QA program in radiology?
- A. The hospital physicist
 - B. The radiologist in charge of the radiology facility
 - C. The manager of the radiology department
 - D. The hospital diagnostic services manager
71. Which of the following is used to indicate that the QC results for a particular test has been met?
- A. Tolerance limit
 - B. Routine performance
 - C. Acceptance testing
 - D. Continuous quality improvement
72. The following QC test can be performed to check for non-uniformity by exposing the digital detector to a uniform field of radiation using a long source-to-image detector distance (SD)?
- A. Dark noise test
 - B. Spatial accuracy test
 - C. Erasure thoroughness test
 - D. Flat field test
73. Which of the following QC test for DR can be used to assess the level of noise present in the system (intrinsic noise)?
- A. Spatial accuracy
 - B. Uniformity
 - C. Dark Noise
 - D. Erasure thoroughness
74. It is recommended that the following QC test for DR should be carried out by a qualified medical physicist (QMP):
- A. Erasure thoroughness
 - B. Verification of detector calibrations
 - C. Dark Noise
 - D. Detector uniformity
75. It is recommended that the following QC test for DR should be carried out by a clinical engineer:
- A. Erasure thoroughness
 - B. Verification of detector calibrations
 - C. Verification of monitor display calibrations
 - D. Detector uniformity

Answers to Review Examination

1. B
2. A
3. C
4. B
5. D
6. D
7. A
8. D
9. A
10. C
11. B
12. A
13. A
14. B
15. D
16. A
17. C
18. B
19. B
20. A
21. A
22. B
23. D
24. B
25. A
26. A
27. A
28. B
29. A
30. A
31. C
32. B
33. B
34. A
35. D
36. B
37. A
38. D
39. C
40. B

41. B
42. D
43. A
44. C
45. B
46. B
47. A
48. D
49. A
50. C
51. A
52. B
53. D
54. A
55. A
56. D
57. A
58. C
59. D
60. A
61. A
62. D
63. C
64. D
65. B
66. B
67. D
68. A
69. A
70. B
71. A
72. D
73. C
74. B
75. C