

Diagnostic Radiology Residents Physics Curriculum
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Preface

The purpose of this curriculum is to outline the breadth and depth of scientific knowledge underlying the practice of Diagnostic Radiology that will aid a practicing radiologist in understanding the strengths and limitations of the tools in his/her practice. This curriculum describes the core physics knowledge related to medical imaging that a radiologist should know when graduating from an accredited radiology residency program. The subject material described in this curriculum should be taught in a clinically relevant manner; the depth and order of presentation is left to the institution.

Although this curriculum was not developed specifically to prepare residents for the American Board of Radiology (ABR) examination, it is understood that this is one of the aims of this curriculum. The ABR Exam of the Future (EOF) will affect radiology residents who enter residency programs in 2010 or later, with the first core exam to be given in 2013. The ABR certification in Diagnostic Radiology is to be divided into two examinations, the first covering basic/intermediate knowledge of all diagnostic radiology and a second certifying exam covering the practice of diagnostic radiology. The first exam will be broken into three primary categories: 1) Fundamental Radiologic Concepts, 2) Imaging Methods and 3) Organ Systems. This curriculum is designed to address the Fundamental Radiologic Concepts and Imaging Methods categories directly. The last category on Organ Systems is not addressed directly within the curriculum; however the educator needs to continuously associate the concepts within the Modules to different organ systems to assure that the clinical applications are evident.

This curriculum contains 17 Modules covering imaging physics. The first 9 Modules cover basic radiation physics and biology and the remaining Modules utilize this base information to examine clinical applications of physics to each modality. Each Module presents its content in three sections: (1) Learning Objectives; (2) Concise Syllabus; and (3) Detailed Syllabus.

The first section of each Module presents the learning objectives for the Module. These learning objectives are organized into three subsections: (1) Fundamental Knowledge relating to Module concepts; (2) specific Clinical Applications of this knowledge; and (3), topics to permit demonstration of Problem Solving, based on the previous sections. The Clinical Applications and Problem Solving subsections contain concepts that a resident should be able to understand and answer following completion of each Module.

The second area within each Module presents Concise Syllabi that delineates the concepts the Module is addressing. These Concise Syllabi may be used as an outline for a course in imaging physics. Not all areas of each concise syllabus module need be taught with the same emphasis or weight, so long as the student can demonstrate an understanding of the educational objectives and solve clinically-relevant problems. The Concise Syllabus should be considered a base or minimal curriculum to present the Educational Objectives

The last area within each Module is a Detailed Syllabus that expands upon the Concise Syllabus and provides a more thorough coverage of each subject. The Detailed Syllabus is presented as a guide to the instructor providing specific topic details that may be needed to cover a subject more thoroughly.

Module 1: Structure of the Atom

After completing this module, the resident should be able to apply the “Fundamental Knowledge” and “Clinical Applications” learned from the module to example tasks, such as those found in “Clinical Problem-Solving.”

Fundamental Knowledge:

1. Describe the components of the atom.
2. Explain the energy levels, binding energy and electron transitions in an atom.
3. For the nucleus of an atom, describe its properties, how these properties determine its energy characteristics and how changes within the nucleus define its radioactive nature.
4. For an atom, describe how its electron structure and associated energy levels define its chemical and radiation-associated properties.
5. Explain how different transformation (“decay”) processes within the nucleus of an atom determine the type of radiation produced and the classification of the nuclide.

Clinical Application:

None

Clinical Problem-Solving:

None

Concise Syllabus:

Same as detailed curriculum

Detailed Curriculum:

1. Structure of the Atom
 - 1.1. Composition
 - 1.1.1. Electrons
 - 1.1.2. Nucleus
 - 1.2. Electronic Structure
 - 1.2.1. Electron Orbits
 - 1.2.2. Orbital Nomenclature
 - 1.2.3. Binding Energy
 - 1.2.4. Electron Transitions
 - 1.2.5. Characteristic Radiation
 - 1.2.6. Auger Electrons
 - 1.3. Nuclear Structure
 - 1.3.1. Composition
 - 1.3.2. Nuclear Force
 - 1.3.3. Mass Defect
 - 1.3.4. Binding Energy
 - 1.3.5. Nuclear Instability—Overview

Module 2: Electromagnetic (EM) Radiation

After completing this module, the resident should be able to apply the “Fundamental Knowledge” and “Clinical Applications” learned from the module to example tasks, such as those found in “Clinical Problem-Solving.”

Fundamental Knowledge:

1. Describe the wave and particle characteristics of electromagnetic (EM) radiation.
2. Within the EM radiation spectrum, identify the properties associated with energy and the ability to cause ionization.

Clinical Application:

1. Explain how the relative absorption of electromagnetic radiation in the body varies across the electromagnetic energy spectrum.

Clinical Problem-Solving:

None

Concise Syllabus:

Same as detailed curriculum

Detailed Curriculum:

2. Electromagnetic (EM) Radiation
 - 2.1. Wave–Particle Duality
 - 2.1.1. Wave Characteristics
 - 2.1.2. Particle Characteristics
 - 2.2. Electromagnetic Spectrum
 - 2.2.1. Ionizing
 - 2.2.2. Non-Ionizing

Module 3: Particulate Radiation

After completing this module, the resident should be able to apply the “Fundamental Knowledge” and “Clinical Applications” learned from the module to example tasks, such as those found in “Clinical Problem-Solving.”

Fundamental Knowledge:

1. Identify the different categories and properties of particulate radiation.

Clinical Application:

None

Clinical Problem-Solving:

None

Concise Syllabus:

Same as detailed curriculum

Detailed Curriculum:

3. Particulate Radiation
 - 3.1. Light Particles
 - 3.2. Heavy Charged Particles
 - 3.3. Uncharged Particles
 - 3.3.1. Neutrons
 - 3.3.2. Neutrinos

Module 4: Interactions of Ionizing Radiation with Matter

After completing this module, the resident should be able to apply the “Fundamental Knowledge” and “Clinical Applications” learned from the module to example tasks, such as those found in “Clinical Problem-Solving.”

Fundamental Knowledge:

1. Describe how charged particles interact with matter and the resulting effects these interactions can have on the material.
2. Describe the processes by which x-ray and γ -ray photons interact with individual atoms in a material and the characteristics that determine which processes are likely to occur.
3. Identify how photons are attenuated (i.e., absorbed and scattered) within a material and the terms used to characterize the attenuation.

Clinical Application:

1. Identify which photon interactions are dominant for each of the following imaging modalities: mammography, projection radiography, fluoroscopy, CT, and nuclear medicine imaging procedures.
2. Understand how image quality and patient dose are affected by these interactions.
3. What are the appropriate x-ray beam energies to be used when iodine and barium contrast agents are used?
4. How does the type of photon interaction change with increasing energy, and what is the associated clinical significance?

Clinical Problem-Solving:

1. Select an appropriate thyroid imaging agent based on its particulate emissions for pediatric imaging and for adult imaging. Would these agents use the same isotopes or different isotopes? How does dose differ between these imaging isotopes?
2. What is the purpose of adding Cu filters in vascular imaging?
3. What makes a contrast agent radiolucent instead of radio-opaque?

Concise Syllabus:

Same as detailed curriculum

Detailed Curriculum:

4. Interactions of Ionizing Radiation with Matter
 - 4.1. Charged-Particle Interactions
 - 4.1.1. Ionization and Excitation
 - 4.1.2. Bremsstrahlung
 - 4.1.3. Secondary Ionization
 - 4.1.3.1. Specific Ionization
 - 4.1.3.2. Linear Energy Transfer (LET)
 - 4.1.4. Positron Annihilation
 - 4.2. Photon Interactions
 - 4.2.1. Coherent Scattering
 - 4.2.2. Compton Scattering
 - 4.2.3. Photoelectric Effect
 - 4.2.4. Interactions in Tissues
 - 4.2.5. Contrast Media

4.3. Photon Attenuation

4.3.1. Linear Attenuation Coefficient

4.3.2. Attenuation Equation

4.3.3. Mono-Energetic and Poly-Energetic X-Ray Beams

4.3.4. Half-Value Layer (HVL)

4.3.4.1. Effective Energy

4.3.4.2. Beam Hardening

Module 5: Radiation Units

After completing this module, the resident should be able to apply the “Fundamental Knowledge” and “Clinical Applications” learned from the module to example tasks, such as those found in “Clinical Problem-Solving.”

Fundamental Knowledge:

1. Recognize that there are 2 different systems for units of measurement (i.e. SI and Classical) used to describe physical quantities.
2. Describe the SI and Classical units for measuring the ionization resulting from radiation interactions in air (e.g., exposure-related quantities).
3. Describe the concepts of dose-related quantities and their SI and Classical units.

Clinical Application:

1. Discuss the appropriate use or applicability of radiation quantities in the health care applications of imaging, therapy, and safety.

Clinical Problem-Solving:

1. Explain radiation exposure and dose quantities in lay language to a patient.

Concise Syllabus:

Same as detailed curriculum

Detailed Curriculum:

5. Radiation Units
 - 5.1. System of Units
 - 5.1.1. SI
 - 5.1.2. Classical
 - 5.2. Exposure
 - 5.2.1. Coulomb/kilogram
 - 5.2.2. roentgen (R)
 - 5.3. KERMA
 - 5.3.1. gray (Gy)
 - 5.3.2. rad
 - 5.4. Absorbed Dose
 - 5.4.1. gray (Gy)
 - 5.4.2. rad
 - 5.5. Equivalent Dose
 - 5.5.1. Radiation Weighting Factors
 - 5.5.2. sievert (Sv)
 - 5.5.3. rem
 - 5.6. Effective Dose
 - 5.6.1. Tissue Weighting Factors
 - 5.6.2. sievert (Sv)
 - 5.6.3. rem
 - 5.6.4. Reference Levels
 - 5.6.5. Importance in Radiation Protection
 - 5.7. Peak Skin Dose

Module 6: X-Ray Production

After completing this module, the resident should be able to apply the “Fundamental Knowledge” and “Clinical Applications” learned from the module to example tasks, such as those found in “Clinical Problem-Solving.”

Fundamental Knowledge:

1. Describe the two mechanisms by which energetic electrons produce x rays and the energy distribution for each mechanism of x-ray production.
2. Describe the function of the cathode and anode of an x-ray tube and how variations in their design influence x-ray production.
3. Describe how the controls of an x-ray system affect the technique factors used in diagnostic imaging.
4. Define the attributes of an x-ray beam including the function of filtration, spectrum of energies produced, and beam restriction.
5. Describe the heel effect and how it can be used to improve clinical radiographs.

Clinical Application:

1. Demonstrate how the x-ray tube design, target material, beam filtration, and focal spot size are optimized for a specific imaging task (e.g., mammography, interventional imaging, CT)

Clinical Problem-Solving:

1. Analyze how changes in the x-ray system components change the image quality and dose for different procedures

Concise Syllabus:

6. X-Ray Production
 - 6.1. Properties of the X-Ray Spectrum
 - 6.1.1. Bremsstrahlung
 - 6.1.2. Characteristic Radiation
 - 6.2. X-Ray Tube
 - 6.2.1. Cathode
 - 6.2.2. Anode
 - 6.2.3. Application-Specific Tubes
 - 6.3. High Frequency Generators
 - 6.3.1. Technique Factors
 - 6.4. X-Ray Beam Modifiers
 - 6.4.1. Beam Filtration
 - 6.4.2. Collimators

Detailed Curriculum:

6. X-Ray Production
 - 6.1. Properties of X Rays
 - 6.1.1. Bremsstrahlung
 - 6.1.1.1. Importance in Imaging and Dose
 - 6.1.1.2. Influence of Electron Energy
 - 6.1.1.3. Influence of Target Material
 - 6.1.1.4. Influence of Filtration
 - 6.1.2. Characteristic Radiation
 - 6.1.2.1. Importance in Imaging and Dose

- 6.1.2.2. Influence of Electron Energy
- 6.1.2.3. Influence of Target Material
- 6.1.2.4. Influence of Filtration
- 6.2. X-Ray Tube
 - 6.2.1. Cathode
 - 6.2.1.1. Filament
 - 6.2.1.2. Focusing Cup
 - 6.2.1.3. Filament Current and Tube Current
 - 6.2.2. Anode
 - 6.2.2.1. Composition
 - 6.2.2.2. Configurations (e.g., Angulation, Stationary vs. Rotating)
 - 6.2.2.3. Line-Focus Principle
 - 6.2.2.4. Focal Spot
 - 6.2.2.5. Heel Effect
 - 6.2.2.6. Off-Focus Radiation
 - 6.2.2.7. Tube Heating and Cooling
 - 6.2.3. Application-Specific Tubes
 - 6.2.3.1. Mammography
 - 6.2.3.2. CT
 - 6.2.3.3. Interventional
 - 6.2.3.4. Dental
- 6.3. High-Frequency Generators
 - 6.3.1. Technique Factors
 - 6.3.1.1. kVp
 - 6.3.1.2. mA
 - 6.3.1.3. Time
 - 6.3.1.4. Automatic Exposure Control (AEC)
 - 6.3.1.5. Technique Charts
- 6.4. X-Ray Beam
 - 6.4.1. Beam Filtration
 - 6.4.1.1. Inherent
 - 6.4.1.2. Added (Al, Cu, Mo, Rh, other)
 - 6.4.1.3. Minimum HVL
 - 6.4.1.4. Shaped Filters
 - 6.4.2. Spectrum
 - 6.4.3. Collimators
 - 6.4.3.1. Field Size Limitation
 - 6.4.3.2. Light Field and X-Ray Field Alignment
 - 6.4.3.3. Effect on Image Quality

Module 7: Basic Imaging Science and Technology

After completing this module, the resident should be able to apply the “Fundamental Knowledge” and “Clinical Applications” learned from the module to example tasks, such as those found in “Clinical Problem-Solving.”

Fundamental Knowledge:

1. Define the methods used to describe the uncertainty in a measurement and how to use data to propagate these uncertainties through a calculation.
2. Describe the different methods for representing image data, and identify the attributes used to assess the quality of the data acquired or an imaging system.
3. Describe the different processes used to convert the acquired raw data into a final image used for interpretation.
4. Review the methods and technology used to display image data accurately and consistently.
5. Associate the characteristics of the human visual system with the task of viewing image data and the metrics used to assess an observer’s response to the data.
6. Describe the purpose of IHE, DICOM and HL7.

Clinical Application:

1. Calculate the statistical significance of a measurement or a combination of measurements.
2. Determine how changes in each image processing procedure impact the final image produced. Evaluate how these changes affect the image of different objects or body parts and their associated views.
3. You have been asked to design a new radiology reading room. What are the important aspects in this design?
4. Illustrate how the properties of the imaging system can be used to select the best system for a specific task.
5. Give examples of what is required to optimize a display system and its associated environment in viewing images for different applications.
6. Trace the information associated with a patient exam through the HIS and RIS to the PACS.

Clinical Problem-Solving:

1. A series of portable chest x-ray images show blurring in the lung parenchyma. Explain possible causes for this occurrence.
2. Calculate the statistical significance of a measurement or a combination of measurements to determine if the data can be used for a particular purpose, e.g., quantifying radioactivity with a dose calibration instrument.
3. Choose the appropriate image processing to be used for a specific exam.
4. Use an observer performance result to determine whether there is a difference in a procedure or study compared to the standard procedure or study.

Concise Syllabus:

7. Basic Imaging Science and Technology
 - 7.1. Basic Statistics
 - 7.2. Image Properties
 - 7.3. Image Representations
 - 7.3.1. Contrast
 - 7.3.2. Spatial Resolution
 - 7.3.3. Noise
 - 7.3.4. Temporal Resolution

- 7.3.5. Sampling and Quantization
- 7.4. Image Processing
 - 7.4.1. Pre-Processing
 - 7.4.2. Segmentation
 - 7.4.3. Grayscale Processing
 - 7.4.4. Frequency Processing
 - 7.4.5. Reconstruction
 - 7.4.6. Three-Dimensional Representations
 - 7.4.7. Image Fusion/Registration
 - 7.4.8. Computer-Aided Detection (CAD) and Diagnosis
- 7.5. Display Characteristics and Viewing Conditions
- 7.6. Perception
- 7.7. Informatics

Detailed Curriculum:

- 7. Basic Imaging Science and Technology
 - 7.1. Basic Statistics
 - 7.1.1. Systematic and Random Error
 - 7.1.2. Precision and Accuracy
 - 7.1.3. Statistical Distributions
 - 7.1.4. Mean, Median and Mode
 - 7.1.5. Standard Deviation and Variance
 - 7.1.6. Confidence Intervals
 - 7.1.7. Propagation of Error
 - 7.2. Image Properties
 - 7.2.1. Image Representations
 - 7.2.1.1. Spatial Domain
 - 7.2.1.2. Frequency Domain
 - 7.2.1.3. Temporal Domain
 - 7.2.1.4. Fourier Transform between Domains
 - 7.2.2. Contrast
 - 7.2.3. Spatial Resolution
 - 7.2.3.1. Point Spread Function (PSF)
 - 7.2.3.2. Line Spread Function (LSF)
 - 7.2.3.3. Full-Width-at-Half-Maximum (FWHM)
 - 7.2.3.4. Modulation Transfer Function (MTF)
 - 7.2.4. Noise
 - 7.2.4.1. Quantum Mottle
 - 7.2.4.2. Electronic
 - 7.2.4.3. Structured
 - 7.2.4.4. Other Sources of Noise
 - 7.2.5. Dynamic Range
 - 7.2.6. Contrast-to-Noise Ratio (CNR), Signal-to-Noise Ratio (SNR), Detection Efficiency (e.g., DQE)
 - 7.2.7. Temporal Resolution
 - 7.2.8. Sampling and Quantization
 - 7.2.8.1. Analog-to-Digital Conversion (ADC) and Digital-to- Analog Conversion (DAC)
 - 7.2.8.2. Aliasing

- 7.2.8.3. Nyquist Limit
- 7.2.8.4. Bit Depth
- 7.3. Image Processing
 - 7.3.1. Pre-Processing
 - 7.3.1.1. Non-Uniformity Correction
 - 7.3.1.2. Defect Corrections
 - 7.3.2. Segmentation
 - 7.3.2.1. Region of Interest (Field of View)
 - 7.3.2.2. Value of Interest
 - 7.3.2.3. Anatomical
 - 7.3.3. Grayscale Processing
 - 7.3.3.1. Window and Level
 - 7.3.3.2. Characteristic Curves
 - 7.3.3.3. Look-Up Table (LUT)
 - 7.3.4. Frequency Processing
 - 7.3.4.1. Edge Enhancement
 - 7.3.4.2. Noise Reduction
 - 7.3.4.3. Equalization
 - 7.3.5. Reconstruction
 - 7.3.5.1. Simple Back-Projection
 - 7.3.5.2. Filtered Back-Projection
 - 7.3.5.3. Iterative Reconstruction Methods
 - 7.3.5.4. Sinogram
 - 7.3.6. Three-Dimensional
 - 7.3.6.1. Multi-Planar Reconstruction
 - 7.3.6.2. Maximum-Intensity Projection
 - 7.3.6.3. Volume Rendering/Surface Shading
 - 7.3.6.4. Quantitative Assessments
 - 7.3.7. Image Fusion/Registration
 - 7.3.8. Computer-Aided Detection and Diagnosis
- 7.4. Display
 - 7.4.1. Display Technologies
 - 7.4.1.1. Hard-Copy Printers
 - 7.4.1.2. Film
 - 7.4.1.3. Cathode Ray Tube (CRT)
 - 7.4.1.4. Liquid Crystal Display (LCD)
 - 7.4.1.5. Other Displays (e.g., Plasma, Projection)
 - 7.4.2. Display Settings
 - 7.4.2.1. Film Quality Control
 - 7.4.2.2. Luminance
 - 7.4.2.3. Matrix Size
 - 7.4.2.4. Grayscale Display Function Calibration
 - 7.4.2.5. Display Quality Control
 - 7.4.3. Viewing Conditions
 - 7.4.3.1. Viewing Distance, Image and Pixel Size
 - 7.4.3.2. Workstation Ergonomics
 - 7.4.3.3. Adaptation and Masking
 - 7.4.3.4. Ambient Lighting and Illuminance
- 7.5. Perception

- 7.5.1. Human Vision
 - 7.5.1.1. Visual Acuity
 - 7.5.1.2. Contrast Sensitivity
 - 7.5.1.3. Conspicuity
- 7.5.2. Metrics of Observer Performance
 - 7.5.2.1. Predictive Values
 - 7.5.2.2. Sensitivity, Specificity and Accuracy
 - 7.5.2.3. Contrast-Detail
 - 7.5.2.4. Receiver Operating Characteristic (ROC) Curve
- 7.5.3. Perceptual Influence of Technology (e.g., CAD)
- 7.6. Informatics
 - 7.6.1. Basic Computer Terminology
 - 7.6.2. Integrating Healthcare Enterprise (IHE)
 - 7.6.3. PACS
 - 7.6.4. Radiology Information System (RIS), Hospital Information System (HIS)
 - 7.6.5. Electronic Medical Record (EMR)
 - 7.6.6. Health Level 7 (HL7)
 - 7.6.7. Networks
 - 7.6.7.1. Hardware
 - 7.6.7.2. Bandwidth
 - 7.6.7.3. Communication Protocols
 - 7.6.8. Film Digitizers
 - 7.6.9. Storage
 - 7.6.9.1. Hardware
 - 7.6.9.2. Storage Requirements
 - 7.6.9.3. Disaster Recovery
 - 7.6.10. DICOM
 - 7.6.10.1. Modality Worklist
 - 7.6.10.2. Image and Non-Image Objects
 - 7.6.10.3. Components and Terminology
 - 7.6.10.4. DICOM Conformance
 - 7.6.11. Data Compression
 - 7.6.11.1. Clinical Impact
 - 7.6.11.2. Lossy
 - 7.6.11.3. Lossless
 - 7.6.11.4. Image and Video Formats
 - 7.6.12. Security and Privacy
 - 7.6.12.1. Encryption
 - 7.6.12.2. Firewalls

Module 8: Biological Effects of Ionizing Radiation

After completing this module, the resident should be able to apply the “Fundamental Knowledge” and “Clinical Applications” learned from the module to example tasks, such as those found in “Clinical Problem-Solving.”.

Fundamental Knowledge:

1. Describe the cell cycle, and discuss the radiosensitivity of each phase.
2. Discuss the probability of cell survival for low-LET radiations.
3. Compare the radiosensitivities of different organs in the body.
4. Explain the effects of massive whole body irradiation and how it is managed.
5. Understand the threshold for deterministic effects, including cutaneous radiation injury, cataracts and sterility.
6. Explain the risk of carcinogenesis due to radiation.
7. Understand the latencies for different cancers.
8. Explain the effects of common drugs on radiation sensitivity.
9. Describe the effect of radiation on mutagenesis and teratogenesis.
10. List the most probable *in utero* radiation effects at different stages of gestation.
11. Define the principles of how radiation deposits energy that can cause biological effects.
12. Explain the difference between direct and indirect effects, how radiation affects DNA and how radiation damage can be repaired.
13. Recognize the risk vs. benefit in radiation uses, and recognize the information sources that can be used to assist in assessing these risks.
14. Describe the different dose response models for radiation effects.

Clinical Application:

1. Understand the risks to patients from high-dose fluoroscopy regarding deterministic effects, such as cutaneous radiation injury and cataractogenesis, and the importance of applying radiation protection principles in clinical protocols to avoid damage.
2. Understand the risks to the female breast, especially in girls, from repeated imaging for scoliosis, from mobile chest radiography and CT scans; and the importance of applying radiation protection principles in clinical protocols to minimize future harm.
3. Explain radiation risks to pregnant technologists assisting in fluoroscopic procedures.
4. Explain radiation risks to pregnant nurses who are incidentally exposed in mobile radiography (“portables”).
5. Understand the best use of gonad shielding and breast shields.

Clinical Problem-Solving:

1. Plan an interventional procedure to minimize the risk of deterministic effects.
2. Select the most appropriate radiological exam for a pregnant patient.
3. Determine the risk vs. benefit for a new procedure shown at a conference.

Concise Syllabus:

- 8.1. Principles of Radiation Biology
- 8.2. Molecular Effects of Radiation
- 8.3. Cellular Effects of Radiation
 - 8.3.1. Law of Bergonié and Tribondeau
 - 8.3.2. Radiosensitivities of Different Cell Types
 - 8.3.3. Radiosensitivities of Phases of the Cell Cycle
 - 8.3.4. Cell Damage
 - 8.3.5. Cell Survival Curves

- 8.3.6. Repair
- 8.4. System Effects of Radiation
- 8.5. Deterministic (Non-Stochastic) Effects
 - 8.5.1. Radiation Syndromes
 - 8.5.2. Erythema
 - 8.5.3. Epilation
 - 8.5.4. Cataracts
 - 8.5.5. Sterility
- 8.6. Probabilistic (Stochastic) Radiation Effects
 - 8.6.1. Radiation Epidemiology: Case Studies
 - 8.6.2. Carcinogenesis
 - 8.6.3. Mutagenesis
 - 8.6.4. Teratogenesis
- 8.7. Radiation Risk
- 8.8. Dose-Response Models

Detailed Syllabus:

- 8. Radiation Biology
 - 8.1. Principles
 - 8.1.1. Linear Energy Transfer
 - 8.1.2. Relative Biological Effectiveness
 - 8.1.3. Weighting Factors
 - 8.2. Molecular Effects of Radiation
 - 8.2.1. Direct Effects
 - 8.2.2. Indirect Effects
 - 8.2.3. Effects of Radiation on DNA
 - 8.3. Cellular Effects of Radiation
 - 8.3.1. Law of Bergonié and Tribondeau
 - 8.3.2. Radiosensitivity of Different Cell Types
 - 8.3.3. Cell Cycle Radiosensitivity
 - 8.3.4. Cell Damage
 - 8.3.4.1. Division Delay
 - 8.3.4.2. Mitotic Death
 - 8.3.4.3. Apoptosis
 - 8.3.5. Cell Survival Curves
 - 8.3.6. Repair
 - 8.4. System Effects of Radiation
 - 8.4.1. Tissues
 - 8.4.2. Organs
 - 8.4.3. Whole Body
 - 8.4.4. Population
 - 8.4.5. Common Drugs
 - 8.5. Deterministic (Non-Stochastic) Effects
 - 8.5.1. Radiation Syndromes
 - 8.5.1.1. Prodromal
 - 8.5.1.2. Hematopoietic
 - 8.5.1.3. Gastrointestinal
 - 8.5.1.4. Cerebrovascular and CNS
 - 8.5.1.5. Sequence of Events

- 8.5.1.6. LD_{50/60}
- 8.5.1.7. Monitoring and Treatment
- 8.5.2. Other Effects
 - 8.5.2.1. Erythema
 - 8.5.2.2. Epilation
 - 8.5.2.3. Cataracts
 - 8.5.2.4. Sterility
- 8.6. Probabilistic (Stochastic) Radiation Effects
 - 8.6.1. Radiation Epidemiology–Case Studies
 - 8.6.2. Carcinogenesis
 - 8.6.2.1. Radiation-Induced Cancers
 - 8.6.2.1.1. Leukemia
 - 8.6.2.1.2. Solid Tumors
 - 8.6.2.2. Spontaneous Rate
 - 8.6.2.3. Latency
 - 8.6.3. Mutagenesis
 - 8.6.3.1. Baseline Mutation Rate
 - 8.6.3.2. Doubling Dose
 - 8.6.4. Teratogenesis
 - 8.6.4.1. Developmental Effects
 - 8.6.4.2. Childhood Leukemia
 - 8.6.4.3. Gestational Sensitivity
- 8.7. Radiation Risk
 - 8.7.1. Risk-Benefit in Radiology
 - 8.7.2. Risk Models
 - 8.7.2.1. Relative
 - 8.7.2.2. Absolute
 - 8.7.3. Information Sources
 - 8.7.3.1. Biological Effects of Ionizing Radiation Reports (e.g., BEIR VII)
 - 8.7.3.2. International Council on Radiation Protection (ICRP)
 - 8.7.3.3. National Council on Radiation Protection (e.g., NCRP 116)
 - 8.7.3.4. United Nations Scientific Committee on the Effects of Atomic Radiation Reports (UNSCEAR)
 - 8.7.4. Perception of Risk
 - 8.7.4.1. Compare radiation risk with smoking, drinking, driving etc.
- 8.8. Dose-Response Models
 - 8.8.1. Linear, No-Threshold (LNT)
 - 8.8.2. Linear-Quadratic
 - 8.8.3. Radiation Hormesis

Module 9: Radiation Protection and Associated Regulations

After completing this module, the resident should be able to apply the “Fundamental Knowledge” and “Clinical Applications” learned from the module to example tasks, such as those found in “Clinical Problem-Solving.”

Fundamental Knowledge:

1. Identify the sources of background radiation, and describe the magnitude of each source.
2. State the radiation limits to the public and radiation workers (Maximum Permissible Dose Equivalent limits).
3. Understand the differences among advisory bodies, accrediting organizations and regulatory organizations for radioactive materials and radiation-generating equipment, and recognize their respective roles.
4. Define the principles of time, distance and shielding in radiation protection.
5. Define ALARA and its application in radiation protection.
6. Identify the methods used to monitor occupational exposure.
7. Discuss appropriate equipment used to monitor radiation areas or areas of possible exposure or contamination.
8. Describe the fundamental methods used to determine patient and fetal doses.
9. Explain the basic principles for designing radiation shielding.
10. List the steps in managing radiological emergencies.

Clinical Application:

1. Understand the safety considerations for patients and staff, including pregnant staff, in mobile radiography (“portables”).
2. Use your knowledge of radiation effects in planning for and reacting to an emergency that includes the exposure of personnel to radiation.
3. Discuss the contributions of medical sources to the collective effective dose.
4. Define the responsibilities and qualifications of an authorized user (all categories) and the radiation safety officer.
5. Describe the training and experience requirements for using sealed and unsealed sources of radioactive material.
6. Describe the use of personnel radiation protection equipment.
7. Describe the appropriate equipment for wipe tests and contamination surveys.
8. Provide information to the public concerning radon.
9. Provide clinical examples that demonstrate ALARA principles.
10. Discriminate between workers in an area who are occupationally exposed and those who are treated as members of the general public.

Clinical Problem-Solving:

1. Discuss the factors that determine dose to a pregnant person seated next to a patient injected with a radionuclide for a diagnostic or therapeutic procedure.
2. Describe the steps used in applying appropriateness criteria.
3. Describe what must be done before administering a radioactive material in a patient.
4. Describe what is required to have a person listed on a facility’s Nuclear Materials license as an Authorized User.

Concise Syllabus:

9. Radiation Protection and Associated Regulations

- 9.1. Background Radiation
- 9.2. Non-Medical Sources
- 9.3. Medical Sources
 - 9.3.1. JCAHO Sentinel Event
- 9.4. Persons at Risk
- 9.5. Dose Limits
- 9.6. Personnel Dosimetry
- 9.7. Radiation Detectors
- 9.8. Principles of Radiation Protection
 - 9.8.1. Time
 - 9.8.2. Distance
 - 9.8.3. Shielding
 - 9.8.4. Contamination Control
 - 9.8.5. As Low As Reasonably Achievable (ALARA)
 - 9.8.6. Culture of Safety
- 9.9. Factors Affecting Patient Dose
 - 9.9.1. Radiography
 - 9.9.2. Fluoroscopy and Interventional Radiology
 - 9.9.3. Computed Tomography (CT)
 - 9.9.4. Mammography
 - 9.9.5. Nuclear Medicine
- 9.10. Advisory Bodies
- 9.11. Regulatory Agencies
- 9.12. Radiation Safety in the Use of Radioactive Materials
 - 9.12.1. Surveys
 - 9.12.2. Ordering, Receiving, and Unpacking Radioactive Materials
 - 9.12.3. Contamination Control
 - 9.12.4. Radioactive Waste Management
 - 9.12.5. Reportable Events
- 9.13. Estimating Patient, Pediatric and Fetal Dose (Procedure-Specific Doses)
- 9.14. Shielding
- 9.15. Radiological Emergencies

Detailed Curriculum:

- 9. Radiation Protection and Associated Regulations
 - 9.1. Background Radiation
 - 9.1.1. Cosmic
 - 9.1.2. Terrestrial
 - 9.1.3. Internal
 - 9.1.4. Radon
 - 9.2. Non-Medical Sources
 - 9.2.1. Nuclear Power Emissions
 - 9.2.2. Tobacco
 - 9.2.3. Technologically-Enhanced Naturally-Occurring Radioactive Material (TENORM)
 - 9.2.4. Fallout
 - 9.3. Medical Sources: Occupational and Patient Doses
 - 9.3.1. Projection Radiography
 - 9.3.2. Mammography
 - 9.3.3. Fluoroscopy

- 9.3.4. Interventional Radiology and Diagnostic Angiography
- 9.3.5. CT
- 9.3.6. Sealed Source Radioactive Material
- 9.3.7. Unsealed Radioactive Material
- 9.3.8. Therapeutic External Radiation
- 9.3.9. Non-Ionizing
- 9.4. Factors Affecting Patient Dose
 - 9.4.1. Radiography
 - 9.4.2. Fluoroscopy and Interventional Radiology
 - 9.4.3. Computed Tomography (CT)
 - 9.4.4. Mammography
 - 9.4.5. Nuclear Medicine
 - 9.4.6. Regulatory Dose Limits and “Trigger” Levels
 - 9.4.6.1. Institutional
 - 9.4.6.2. Local
 - 9.4.6.3. State
 - 9.4.6.4. Federal
 - 9.4.7. JCAHO Reviewable and Non-Reviewable Events
 - 9.4.7.1. Person or Agency to Receive Report
- 9.5. Persons at Risk
 - 9.5.1. Occupational
 - 9.5.2. Non-Occupational Staff
 - 9.5.3. Members of the Public
 - 9.5.4. Fetus
 - 9.5.5. Patient
 - 9.5.5.1. Adult
 - 9.5.5.2. Child
 - 9.5.5.3. Pregnancy Identified
 - 9.5.5.4. Pregnancy Status Unknown
- 9.6. Dose limits
 - 9.6.1. Occupational Dose Limits
 - 9.6.1.1. Effective Dose
 - 9.6.1.2. Specific Organ
 - 9.6.1.3. Pregnant Workers
 - 9.6.2. Members of the Public
 - 9.6.2.1. General
 - 9.6.2.2. Caregivers
 - 9.6.2.3. Limit to Minors
- 9.7. Radiation Detectors
 - 9.7.1. Personnel Dosimeters
 - 9.7.1.1. Film
 - 9.7.1.2. Thermoluminescent Dosimeters (TLDs)
 - 9.7.1.3. Optically-Stimulated Luminescent (OSL) Dosimeters
 - 9.7.1.4. Electronic Personnel Dosimeters
 - 9.7.1.5. Applications: Appropriate Use and Wearing
 - 9.7.1.6. Limitations and Challenges in Use
 - 9.7.2. Area Monitors
 - 9.7.2.1. Dosimeters
 - 9.7.2.2. Ion Chambers

- 9.7.2.3. Geiger-Mueller (GM)
 - 9.7.2.4. Scintillators
- 9.8. Principles of Radiation Protection
 - 9.8.1. Time
 - 9.8.2. Distance
 - 9.8.3. Shielding
 - 9.8.3.1. Facility
 - 9.8.3.2. Workers
 - 9.8.3.3. Caregivers
 - 9.8.3.4. Patients
 - 9.8.3.5. Members of the Public
 - 9.8.3.6. Appropriate Materials
 - 9.8.4. Contamination Control
 - 9.8.5. As Low As Reasonably Achievable (ALARA)
 - 9.8.5.1. Culture of Safety
 - 9.8.5.2. "Open Door" Policy
 - 9.8.6. Procedure Appropriateness
- 9.9. Advisory Bodies
 - 9.9.1.1. International Commission on Radiological Protection (ICRP)
 - 9.9.1.2. National Council on Radiation Protection and Measurements (NCRP)
 - 9.9.1.3. Conference of Radiation Control Program Directors (CRCPD)
 - 9.9.1.4. International Atomic Energy Agency (IAEA)
 - 9.9.1.5. Joint Commission on Accreditation of Healthcare Organizations (JC)
 - 9.9.1.6. American College of Radiology (ACR)
 - 9.9.1.7. National Electrical Manufacturers Association (NEMA) (Medical Imaging and Technology Alliance or MITA)
- 9.10. Regulatory Agencies
 - 9.10.1. U.S. Nuclear Regulatory Commission and Agreement States
 - 9.10.1.1. 10 CFR Parts 19, 20, 30, 32, 35, 110
 - 9.10.1.2. Guidance Documents (NUREG 1556, Vols. 9 & 11)
 - 9.10.1.3. Regulatory Guides
 - 9.10.2. States: for Machine-Produced Sources
 - 9.10.2.1. Suggested State Regulations
 - 9.10.3. U.S. Food and Drug Administration
 - 9.10.3.1. Center for Devices and Radiological Health (CDRH)
 - 9.10.3.2. Center for Drug Evaluation and Research (CDER)
 - 9.10.4. U.S. Office of Human Research Protections
 - 9.10.5. U.S. Department of Transportation
 - 9.10.5.1. U.S. Department of Labor (OSHA)
 - 9.10.6. International ElectroTechnical Commission (IEC)
- 9.11. Radiation Safety with Radioactive Materials
 - 9.11.1. Surveys
 - 9.11.1.1. Area
 - 9.11.1.2. Wipe Test
 - 9.11.1.3. Spills
 - 9.11.2. Ordering, Receiving, and Unpacking Radioactive Materials
 - 9.11.3. Contamination Control

- 9.11.4. Radioactive Waste Management
- 9.11.5. Qualifications for Using Radioactive Materials
 - 9.11.5.1. Diagnostic (10 CFR 35.200 and 35.100, or Equivalent Agreement State Regulations)
 - 9.11.5.2. Therapeutic (10 CFR 35.300 and 35.1000, or Equivalent Agreement State Regulations)
- 9.11.6. Medical Events
 - 9.11.6.1. Reportable
 - 9.11.6.2. Non-reportable
 - 9.11.6.3. Person or Agency to Receive Report
- 9.11.7. Special Considerations
 - 9.11.7.1. Pregnant Patients
 - 9.11.7.2. Breast-Feeding Patients
 - 9.11.7.3. Caregivers
 - 9.11.7.4. Patient Release
- 9.12. Estimating Effective Fetal Dose (Procedure-Specific Doses)
 - 9.12.1. Radiography
 - 9.12.2. Mammography
 - 9.12.3. Fluoroscopy
 - 9.12.4. Computed Tomography (CT)
 - 9.12.5. Nuclear Medicine
- 9.13. Shielding
 - 9.13.1. Design Philosophy
 - 9.13.1.1. Occupancy
 - 9.13.1.2. Workload
 - 9.13.2. Controlled vs. Uncontrolled Areas
 - 9.13.3. Examples of Shielding Design
 - 9.13.3.1. Diagnostic X-Ray Room
 - 9.13.3.2. PET Facility
 - 9.13.3.3. Hot Lab and Nuclear Medicine Facility
- 9.14. Radiological Emergencies
 - 9.14.1. Incidents
 - 9.14.1.1. Nuclear Power
 - 9.14.1.2. Military Equipment
 - 9.14.1.3. Transportation Accidents
 - 9.14.1.4. Research Lab and Radiopharmacy Accidents
 - 9.14.2. Purposeful Exposures
 - 9.14.2.1. Nuclear Detonation
 - 9.14.2.2. Radiological Dispersion Device (RDD)
 - 9.14.2.3. Environmental Contamination
 - 9.14.2.4. Radiological Exposure Device (RED)
 - 9.14.3. Treatment of Radiological Casualties
 - 9.14.3.1. Notification and Patient Arrival
 - 9.14.3.2. Triage: Evaluation, Dispensation and Initial Treatment
 - 9.14.3.3. External Exposure and Internal Contamination
 - 9.14.3.4. Radiological Assessment
 - 9.14.3.5. Medical Management
 - 9.14.3.6. Oak Ridge Radiation Emergency Assistance Center

Module 10: X-Ray Projection Imaging Concepts and Detectors

After completing this module, the resident should be able to apply the “Fundamental Knowledge” and “Clinical Applications” learned from the module to example tasks, such as those found in “Clinical Problem-Solving.”

Fundamental Knowledge:

1. Describe the fundamental characteristics of all projection imaging systems that determine the capabilities and limitations in producing an x-ray image.
2. Review the detector types used to acquire an x-ray imaging. Describe how radiation is detected by each detector type and the different attributes of each detector for recording information.

Clinical Application:

7. Demonstrate how variations in each of the fundamental characteristics of a projection imaging system affect the detected information in producing an image.
8. Give examples of how each detector type performs in imaging a specific body part or view, and describe how the attributes of each detector type influence the resulting image.

Clinical Problem-Solving:

1. What is the difference in exposure class between CR and DR systems? How does this difference affect patient dose?
2. Describe some of the common artifacts seen in a portable chest x-ray image, and explain how these can be minimized.
3. Describe how distance to the patient and detector affect patient dose.
4. Describe how the transition from film to a digital detector systems\ eliminates some artifacts and creates the possibility of others.
5. What are the properties of a detector system that determines its suitability for pediatric procedures?

Concise Syllabus:

10. X-Ray Projection Imaging Concepts and Detectors
 - 10.1. Radiography Concepts
 - 10.1.1. Geometry
 - 10.1.2. Radiographic Contrast
 - 10.1.3. Scatter and Scatter Reduction
 - 10.1.4. Artifacts and Image Degradation
 - 10.2. Radiographic Detectors
 - 10.2.1. Intensifying Screen and Film
 - 10.2.2. Computed Radiography (CR)
 - 10.2.3. Direct Digital Radiography (DR)
 - 10.2.4. Indirect Digital Radiography (DR)

Detailed Curriculum:

10. X-Ray Projection Imaging Concepts and Detectors
 - 10.2.1. Radiography Concepts
 - 10.2.2. Geometry
 - 10.2.2.1. Source-to-Image Receptor Distance (SID), Source-to-Object Distance (SOD) and Object-to-Image Receptor Distance (OID)
 - 10.2.2.2. Magnification
 - 10.2.2.3. Inverse-Square Law

- 10.2.3. Radiographic Contrast
 - 10.2.3.1. Subject
 - 10.2.3.2. Object
 - 10.2.3.3. Detector
- 10.2.4. Scatter and Scatter Reduction
 - 10.2.4.1. Scatter-to-Primary Ratio
 - 10.2.4.2. Scatter Fraction
 - 10.2.4.3. Collimation
 - 10.2.4.4. Anti-Scatter Grids
 - 10.2.4.5. Air Gap
- 10.2.5. Artifacts and Image Degradation
 - 10.2.5.1. Geometrical Distortion
 - 10.2.5.2. Focal Spot: Blur and Penumbra
 - 10.2.5.3. Grid: Artifacts and Cutoff
 - 10.2.5.4. Motion
 - 10.2.5.5. Superposition
- 10.3. Radiographic Detectors
 - 10.3.1. Intensifying Screen and Film
 - 10.3.1.1. Phosphors
 - 10.3.1.2. Film
 - 10.3.1.3. Screen/Film Systems
 - 10.3.1.4. Latent Image Formation
 - 10.3.1.5. Chemical Processing
 - 10.3.1.6. Characteristic Curve
 - 10.3.1.7. Spatial and Contrast Resolution
 - 10.3.1.8. Artifacts
 - 10.3.2. Computed Radiography (CR)
 - 10.3.2.1. Storage Phosphors
 - 10.3.2.2. Latent Image Formation
 - 10.3.2.3. Image Digitization
 - 10.3.2.4. Pre-Processing (e.g., Gain and Bad-Pixel Correction)
 - 10.3.2.5. Imaging Characteristics
 - 10.3.2.6. Artifacts
 - 10.3.3. Direct Digital Radiography (DR)
 - 10.3.3.1. Semiconductor and Thin-Film Transistor
 - 10.3.3.2. Image Formation and Readout
 - 10.3.3.3. Pre-Processing (e.g., Gain and Bad-Pixel Correction)
 - 10.3.3.4. Imaging Characteristics
 - 10.3.3.5. Artifacts
 - 10.3.4. Indirect Digital Radiography (DR)
 - 10.3.4.1. Phosphor, Photodiodes and Thin-Film Transistor
 - 10.3.4.2. Image Formation and Readout
 - 10.3.4.3. Pre-Processing (e.g., Gain and Bad-Pixel Correction)
 - 10.3.4.4. Imaging Characteristics
 - 10.3.4.5. Artifacts

Module 11: General Radiography

After completing this module, the resident should be able to apply the “Fundamental Knowledge” and “Clinical Applications” learned from the module to example tasks, such as those found in “Clinical Problem-Solving.”

Fundamental Knowledge:

1. Describe the components of a radiographic imaging system.
2. List and describe the factors affecting radiographic image quality.
3. Explain how the geometric features of a general radiographic system affect the resulting image.
4. Describe the different types of acquisition systems used in general radiography.
5. Distinguish among the basic imaging requirements for specific body part or views acquired in general radiography.
6. Define entrance skin exposure and how it relates to patient dose.

Clinical Application:

1. Give examples of appropriate technique factors used in common radiographic procedures.
2. Differentiate among the imaging acquisition parameters used in various clinical applications.
3. Why is image quality frequently compromised in mobile radiography?

Clinical Problem-Solving:

1. Specify the geometric requirements for image acquisition that affect image quality.
2. List the system components that affect patient radiation dose, and describe how to reduce patient dose.
3. Analyze the radiation dose from a medical procedure, and communicate the benefits and risks to the referring physician.
4. Which factors determine the appropriate grid to use for different radiographic exams?

Concise Syllabus:

11. General Radiography
 - 11.1. X-Ray System Components
 - 11.2. Geometrical Requirements
 - 11.3. Acquisition System Types
 - 11.3.1. Screen/Film
 - 11.3.2. Digital
 - 11.3.3. Dual-Energy
 - 11.3.4. Linear Tomography
 - 11.3.5. Tomosynthesis
 - 11.4. Image Characteristics
 - 11.5. Application Requirements
 - 11.5.1. Chest
 - 11.5.2. Abdomen
 - 11.5.3. Spine
 - 11.5.4. Extremities
 - 11.5.5. Pediatrics and Neonatal
 - 11.5.6. Portable/Mobile
 - 11.6. Dosimetry
 - 11.6.1. Entrance Skin Exposure
 - 11.6.2. Effective Dose

- 11.6.3. Doses for Different Procedures
- 11.6.4. Factors Affecting Patient Dose
- 11.7. Quality Control (QC) Tests and Frequencies

Detailed Curriculum:

- 11. General Radiography
 - 11.1. System Components
 - 11.1.1. Tube
 - 11.1.2. Filtration
 - 11.1.3. Collimation
 - 11.1.4. Automatic Exposure Control (AEC)
 - 11.1.5. Grid and Bucky Factor
 - 11.1.6. Compensation Filters
 - 11.2. Geometrical Requirements
 - 11.2.1. Focal Spot Size
 - 11.2.2. Collimation
 - 11.2.3. Heel Effect
 - 11.3. Acquisition Systems
 - 11.3.1. Screen/Film
 - 11.3.2. Digital
 - 11.3.3. Dual-Energy
 - 11.3.4. Linear Tomography
 - 11.3.5. Tomosynthesis
 - 11.4. Image Characteristics
 - 11.4.1. Spatial Resolution
 - 11.4.2. Contrast Sensitivity
 - 11.4.3. Noise
 - 11.4.4. Temporal Resolution
 - 11.4.5. Artifacts
 - 11.4.6. Body-Part and View-Specific Image Processing
 - 11.4.7. Computer-Aided Detection (CAD)
 - 11.5. Application Requirements
 - 11.5.1. Chest
 - 11.5.2. Abdomen
 - 11.5.3. Spine
 - 11.5.4. Extremities
 - 11.5.5. Pediatrics and Neonatal
 - 11.5.6. Portable/Mobile
 - 11.6. Dosimetry
 - 11.6.1. Entrance Skin Exposure
 - 11.6.2. Effective Dose
 - 11.6.3. Appropriate Organ Doses
 - 11.6.4. Doses for Different Procedures
 - 11.6.5. Technique Optimization
 - 11.7. Factors Affecting Patient Dose
 - 11.7.1. Technique (e.g., kVp, mA, time)
 - 11.7.2. Imaging Geometry
 - 11.7.3. Beam Filtration and Grid
 - 11.7.4. Field Size

- 11.7.5. Exposure Class
- 11.8. Technical Assessment and Equipment Purchase Recommendations
- 11.9. Quality Control (QC) Tests and Frequencies
- 11.10. Guidelines
 - 11.10.1. Reference Levels

Module 12: Mammography

After completing this module, the resident should be able to apply the “Fundamental Knowledge” and “Clinical Applications” learned from the module to example tasks, such as those found in “Clinical Problem-Solving.”

Fundamental Knowledge:

1. Describe unique features of mammography tubes and how they affect the x-ray spectrum produced.
2. Describe automatic exposure control (AEC) performance. Explain compression benefits.
3. Review magnification techniques.
4. Describe the characteristics of the different detectors used in mammography, e.g. screen-film and full-field digital mammography systems.
5. Discuss breast radiation dosimetry.
6. Discuss MQSA (Mammography Quality Standards Act) and its effect on mammography image quality and dose.

Clinical Application:

1. Describe appropriate uses of the different targets and filters available in mammography systems.
2. Explain when magnification is indicated.
3. Associate image quality changes with radiation dose changes.
4. What are the MQSA training and CME requirements for radiologists, technologists and physicists?
5. What are the QA requirements of MQSA for digital mammography?

Clinical Problem-Solving:

1. Identify factors influencing image contrast and detail as they relate to the visualization of lesions in mammography.
2. Discuss possible image artifacts in mammography and corrective methods that could be used to reduce them.

Concise Syllabus:

- 12.1. Clinical Importance
- 12.2. Mammography Equipment
 - 12.2.1. Dedicated X-Ray Tube
 - 12.2.2. Focal Spot
 - 12.2.3. Target-Filter Combinations
 - 12.2.4. X-Ray Spectra
 - 12.2.5. Low Peak Kilovoltage (kVp)
 - 12.2.6. Half-Value Layer (HVL)
 - 12.2.7. Breast Compression Paddle
 - 12.2.8. Collimation
 - 12.2.9. Grids
 - 12.2.10. Automatic Exposure Control
- 12.3. Geometry
 - 12.3.1. Source-to-Image Receptor Distance (SID)
 - 12.3.2. Source-to-Object Distance (SOD)
 - 12.3.3. Object-to Image Receptor Distance (OID)
 - 12.3.4. Heel Effect
 - 12.3.5. Magnification

- 12.3.6. Advantages of Magnification
- 12.4. Acquisition Systems
 - 12.4.1. Screen/Film
 - 12.4.2. Full-Field Digital Mammography
 - 12.4.3. Stereotactic Biopsy Systems
- 12.5. Artifacts
- 12.6. Radiation Dose
 - 12.6.1. Entrance Skin Exposure
 - 12.6.2. Average Glandular Dose
 - 12.6.3. Dose Limits
 - 12.6.4. Factors Affecting Radiation Dose
 - 12.6.5. Radiation Risk vs. Benefits of Screening
- 12.7. Viewing Images
 - 12.7.1. Dedicated Viewboxes and Displays
 - 12.7.2. Lighting Requirements: Luminance and Illuminance
 - 12.7.3. Dedicated PACS
- 12.8. Quality Control
 - 12.8.1. Mammography Quality Standards Act (MQSA)
 - 12.8.2. Radiologist, Physicist, Technologist Requirements
 - 12.8.3. American College of Radiology (ACR) Accreditation

Detailed Curriculum:

- 12. Mammography
 - 12.1. Clinical Importance
 - 12.1.1. Benefits and Risks
 - 12.1.2. Purpose of Screening Mammography
 - 12.1.3. Diagnosis and Detection Requirements
 - 12.1.4. Attenuation Characteristics of Breast Tissue and Lesions
 - 12.2. Spectrum Requirements
 - 12.2.1. Anode Material
 - 12.2.2. kVp
 - 12.2.3. Filtration
 - 12.2.4. HVL
 - 12.3. Geometrical Requirements
 - 12.3.1. Source-to-Image Receptor Distance (SID), Source-to-Object Distance (SOD), and Object-to-Image Receptor Distance (OID)
 - 12.3.2. Focal Spot Size
 - 12.3.3. Collimation
 - 12.3.4. Beam Central Axis
 - 12.3.5. Chest-Wall Coverage
 - 12.3.6. Heel Effect
 - 12.3.7. Grid vs. Air Gap
 - 12.3.8. Magnification
 - 12.4. Acquisition Systems
 - 12.4.1. Screen/Film
 - 12.4.2. Full-Field Digital Mammography
 - 12.4.3. Stereotactic Biopsy Systems
 - 12.4.4. Tomosynthesis
 - 12.5. Compression

- 12.6. Dose
 - 12.6.1. Entrance Skin Exposure
 - 12.6.2. Average Glandular Dose
 - 12.6.3. AEC
 - 12.6.4. Technique Optimization
- 12.7. Factors Affecting Patient Dose
 - 12.7.1. Breast Composition
 - 12.7.2. Breast Thickness and Compression
 - 12.7.3. Dose Limits
 - 12.7.4. Techniques
 - 12.7.5. Screening Exams
 - 12.7.6. Diagnostic Examinations, Including Magnification
- 12.8. Digital Image Processing
 - 12.8.1. Skin Equalization
 - 12.8.2. Advanced Proprietary Processing
 - 12.8.3. Computer-Aided Detection (CAD)
- 12.9. Artifacts
 - 12.9.1. Film and Processing
 - 12.9.2. Digital
- 12.10. MQSA Regulations
 - 12.10.1. Responsibilities of Physician, Technologist and Physicist
 - 12.10.2. Dose Limits
 - 12.10.3. Image Quality and Accreditation Phantom
 - 12.10.4. QC Tests and Frequencies
- 12.11. American College of Radiology (ACR) Accreditation
- 12.12. Technical Assessment and Equipment Purchase Recommendations

Module 13: Fluoroscopy and Interventional Imaging

After completing this module, the resident should be able to apply the “Fundamental Knowledge” and “Clinical Applications” learned from the module to example tasks, such as those found in “Clinical Problem-Solving.”

Fundamental Knowledge:

1. Describe and identify the basic components of a fluoroscopic system.
2. Explain how the geometric features of a fluoroscopic system contribute to the resulting image.
3. Explain the features and functions of image intensifier (II) systems used for fluoroscopy.
4. Explain the features and functions of flat panel detector systems used for fluoroscopy.
5. Describe the different operating modes used in fluoroscopy imaging.
6. Identify the components that determine image quality in a fluoroscopy system and the causes of image degradation.
7. Discuss basic image processing methods used in fluoroscopy and describe how they are used clinically.
8. Review the various application requirements for fluoroscopy and interventional radiology systems.
9. Name the factors that affect patient dose during a fluoroscopic or interventional procedure.
10. Describe concepts of exposure and how patient radiation dose is estimated in fluoroscopy and interventional procedures.
11. Describe the artifacts that can occur with image intensified and flat-panel fluoroscopy systems.

Clinical Application:

4. Differentiate among the various image acquisition parameters used in specific clinical applications of fluoroscopy and interventional radiology.
5. Describe where the operator should stand to minimize personnel dose when performing an interventional fluoroscopy procedure with the C-arm positioned horizontally?
6. Discuss radiation safety considerations and methods to modify a procedure to minimize the dose for operators of short stature.
7. Describe the geometric and clinical equipment settings which can be implemented to minimize patient peak skin dose in fluoroscopy and interventional radiology.

Clinical Problem-Solving:

5. Identify the technique factors and appropriate system features to use to optimize image quality while minimizing patient dose in fluoroscopy and interventional radiology.
6. Describe the geometric factors that affect operator dose during an interventional fluoroscopy procedure.
7. What steps can be taken to minimize the dose to the fetus of a pregnant patient who needs a fluoroscopic or interventional procedure?

Concise Syllabus:

13. Fluoroscopy and Interventional Imaging
 - 13.1. System Components
 - 13.2. Geometry
 - 13.3. Detector Systems
 - 13.3.1. Image Intensifiers
 - 13.3.2. Flat-Panel Detectors
 - 13.4. Real-time Imaging Characteristics
 - 13.4.1. Continuous Fluoroscopy

- 13.4.2. High-Dose Rate Fluoroscopy
- 13.4.3. Variable Frame-Rate Pulsed Fluoroscopy
- 13.4.4. Spot Images and Fluorography (Serial Imaging)
- 13.5. Image Quality
 - 13.5.1. Temporal Resolution
 - 13.5.2. Noise
 - 13.5.3. Contrast: kVp and Scatter
 - 13.5.4. Field of View (FOV), Magnification and Resolution
- 13.6. Image Processing
 - 13.6.1. DSA
 - 13.6.2. Last-Image Hold
 - 13.6.3. Frame Averaging
- 13.7. Applications
- 13.8. Dose and Dosimetry
- 13.9. Technique Optimization and Factors Affecting Patient Dose

Detailed Curriculum:

13. Fluoroscopy and Interventional Imaging

- 13.1. System Components
 - 13.1.1. Tube
 - 13.1.2. Filtration
 - 13.1.3. Collimation
 - 13.1.4. Grids
 - 13.1.5. Automatic Brightness Control (ABC)
 - 13.1.6. Automatic Brightness Stabilization (ABS)
 - 13.1.7. Compensation Filters
- 13.2. Geometry
 - 13.2.1. Source-to-Image Receptor Distance (SID), Source-to-Object Distance (SOD) and Object-to-Image Receptor Distance (OID)
 - 13.2.2. Focal Spot Size
 - 13.2.3. Magnification
 - 13.2.4. Under-Table vs. Over-Table X-Ray Tube
 - 13.2.5. C-Arms
- 13.3. Image Intensifier (II) Acquisition Systems
 - 13.3.1. II Structure
 - 13.3.2. Minification Gain
 - 13.3.3. Brightness Gain
 - 13.3.4. Field of View (FOV), Magnification and Resolution
 - 13.3.5. Camera and Video System
 - 13.3.6. Image Distortions
 - 13.3.6.1. Lag
 - 13.3.6.2. Veiling Glare
 - 13.3.6.3. Vignetting
 - 13.3.6.4. Pincushion, Barreling, "S"-distortion
- 13.4. Flat-Panel Acquisition Systems
 - 13.4.1. Detectors
 - 13.4.2. Magnification
 - 13.4.3. Binning
 - 13.4.4. Comparison to II

- 13.4.5. Image Distortions
 - 13.4.5.1. Correlated Noise
 - 13.4.5.2. Lag
 - 13.4.5.3. Ghosting
- 13.5. Real-time Imaging
 - 13.5.1. Continuous Fluoroscopy
 - 13.5.2. High-Dose Rate Fluoroscopy
 - 13.5.3. Variable Frame-Rate Pulsed Fluoroscopy
 - 13.5.4. Spot Images
 - 13.5.5. Operation Mode Variations
 - 13.5.5.1. Effective mA
 - 13.5.5.2. Variable Beam Filtration
 - 13.5.5.3. Software Processing
- 13.6. Image Quality
 - 13.6.1. Low-Contrast Sensitivity
 - 13.6.2. High-Contrast (Spatial) Resolution
 - 13.6.3. Temporal Resolution
 - 13.6.4. Noise
- 13.7. Image Processing
 - 13.7.1. Frame Averaging
 - 13.7.2. Temporal Recursive Filtering
 - 13.7.3. Last-Image Hold and Last-Series Hold
 - 13.7.4. Edge Enhancement and Smoothing
 - 13.7.5. Digital Subtraction Angiography (DSA)
 - 13.7.6. Road Mapping
- 13.8. Applications
 - 13.8.1. Conventional Fluoroscopy (e.g., GI, GU)
 - 13.8.2. Contrast Imaging (e.g., Iodine, Barium)
 - 13.8.3. Cinefluorography
 - 13.8.4. Interventional
 - 13.8.5. DSA
 - 13.8.6. Bi-Plane
 - 13.8.7. Cardiac
 - 13.8.8. Pediatric
 - 13.8.9. Bolus Chasing
 - 13.8.10. Cone-Beam CT Imaging
- 13.9. Dose and Dosimetry
 - 13.9.1. Federal and State Regulations
 - 13.9.1.1. Dose Rate Limits
 - 13.9.1.2. Audible Alarms
 - 13.9.1.3. Recording of “Beam-On” Time
 - 13.9.1.4. Minimum Source-to-Patient Distance
 - 13.9.1.5. Sentinel Event
 - 13.9.2. Dose-Area-Product (DAP) and KERMA-Area-Product (KAP) Meters
 - 13.9.3. Entrance Skin Exposure
 - 13.9.4. Peak Skin Dose
 - 13.9.5. Cumulative Dose
 - 13.9.6. Patient Dose for Various Acquisition Modes
 - 13.9.7. Operator and Staff Dose

13.9.8. Shielding and Protection Considerations

- 13.10. Technique Optimization and Factors Affecting Patient Dose
 - 13.10.1.1. Technique
 - 13.10.1.2. Filters
 - 13.10.1.3. Acquisition Mode
 - 13.10.1.4. Exposure Time
 - 13.10.1.5. Last-Image Hold
 - 13.10.1.6. Pulsed Exposure
 - 13.10.1.7. Magnification
 - 13.10.1.8. Collimation
 - 13.10.1.9. Geometry
 - 13.10.1.10. Operator Training

Module 14: CT

After completing this module, the resident should be able to apply the “Fundamental Knowledge” and “Clinical Applications” learned from the module to example tasks, such as those found in “Clinical Problem-Solving.”

Fundamental Knowledge:

1. Identify the major components of a CT system.
2. Describe the differences between conventional and helical scanning.
3. Explain the equipment differences between single-slice and multi-slice helical scanning.
4. Explain the difference between reconstructing and reformatting an image.
5. Explain how dose modulation affects patient dose.
6. List the image acquisition parameters, and explain how each affects the CT image quality.
7. Define the Hounsfield unit, and describe how a CT image is formed.
8. Compare image characteristics of CT to other modalities such as digital radiography.
9. Describe the concepts of CT Dose Index (CTDI), Dose-Length Product (DLP), Effective Dose and Organ Dose.
10. Understand how the reconstruction kernel (i.e., software filter) selected affects image quality.
11. Describe common artifacts and their causes.
12. Describe the relationship between contrast resolution and radiation dose and the effect of imaging parameters on both.
13. Explain over-beaming and over-ranging and how each affects patient dose.
14. Identify the sources of CT image artifacts, and describe how those artifacts may be eliminated or reduced.

Clinical Application:

1. List typical CT numbers for tissues such as air, water, fat, blood, brain, and bone.
2. Explain why pre-set window width and levels are selected for viewing images.
3. Describe the modes of CT operation and their clinical applications.
4. Identify several clinical applications where multi-slice helical scanning is employed.
5. Differentiate among the different rendering techniques used in 3D imaging.
6. Discuss the radiation exposure to patients and personnel during CT fluoroscopy.

Clinical Problem-Solving:

1. Specify the image acquisition parameters that affect patient radiation dose, and describe how dose can be minimized.
2. Review the considerations necessary when a CT scan needs to be performed on a pregnant patient.
3. Discuss the use of breast shields and lead shielding in CT.
4. Discuss appropriate protocols for pediatric CT.

Concise Syllabus:

14. CT
 - 14.1. System Components
 - 14.2. System Geometry
 - 14.3. Parameters for Image Acquisition
 - 14.3.1. kVp
 - 14.3.2. mA
 - 14.3.3. Rotation Time

- 14.3.4. Table Speed
- 14.3.5. Pitch
- 14.3.6. Rotational Data Acquisition
- 14.3.7. Image Slice Thickness vs. Beam Width
- 14.4. Image Formation
 - 14.4.1. Linear Attenuation Coefficient
 - 14.4.2. Hounsfield Unit Definition
 - 14.4.3. Filtered Back-Projection
 - 14.4.4. Helical Reconstruction
- 14.5. Modes of Operation
- 14.6. Image Contrast, Detail and Noise
- 14.7. Artifacts
- 14.8. Image Processing and Display
- 14.9. Clinical Application and Protocols
- 14.10. Dose and Dosimetry
- 14.11. Technique Optimization and Factors Affecting Patient Dose

Detailed Curriculum:

- 14. Computed Tomography (CT)
 - 14.1. System Components
 - 14.1.1. System Geometry
 - 14.1.2. Tube (Fixed and Flying Focal Spot)
 - 14.1.3. Beam Shaping (Bow-Tie) Filters
 - 14.1.4. Beam Filtration
 - 14.1.5. Collimation
 - 14.1.6. Data Acquisition System
 - 14.1.7. Detector Types and Arrays
 - 14.2. System Types
 - 14.2.1. Third Generation
 - 14.2.2. Electron-Beam
 - 14.2.3. Dual Source
 - 14.2.4. Cone-Beam
 - 14.3. Image Acquisition Parameters
 - 14.3.1. kVp
 - 14.3.2. mAs and Effective mAs
 - 14.3.3. Rotation Time
 - 14.3.4. Pitch (Collimator)
 - 14.3.5. Slice Thickness and Sensitivity Profile
 - 14.3.6. Detector Binning
 - 14.4. Image Formation
 - 14.4.1. Back-Projection
 - 14.4.2. Filtered Projection
 - 14.4.3. Reconstruction Filters
 - 14.4.4. Helical Reconstruction
 - 14.4.5. Cone-Beam Reconstruction
 - 14.4.6. Linear Attenuation Coefficient
 - 14.4.7. Hounsfield Unit Definition
 - 14.4.8. Typical CT Numbers (Hounsfield Units)
 - 14.5. Modes of Operation

- 14.5.1. Axial and Helical Modes
- 14.5.2. Fixed mA
- 14.5.3. Automatic mA
- 14.5.4. Dose-Reduction Techniques
- 14.5.5. CT Fluoroscopy
- 14.5.6. Localizer Image (Scout)
- 14.5.7. Contrast CT
- 14.5.8. Temporal CT and Perfusion
- 14.5.9. Dual-Energy
- 14.5.10. CT Angiography
- 14.6. Image Characteristics and Artifacts
 - 14.6.1. Spatial and Contrast Resolution
 - 14.6.2. Relationships between Acquisition Parameters and SNR
 - 14.6.3. Beam-Hardening
 - 14.6.4. Motion
 - 14.6.5. Partial-Volume
 - 14.6.6. Incomplete Projections
 - 14.6.7. Photon Starvation
 - 14.6.8. Streak Artifacts
 - 14.6.9. Ring Artifacts
 - 14.6.10. Cone-Beam Artifacts
- 14.7. Image Processing and Display
 - 14.7.1. Pre-Set and Variable Display Modes
 - 14.7.2. Multi-Planar Reconstruction (MPR)
 - 14.7.3. Maximum Intensity Projection (MIP)
 - 14.7.4. Volume and Surface Rendering
 - 14.7.5. Perfusion
- 14.8. Clinical Application and Protocols
 - 14.8.1. Head
 - 14.8.2. Spine
 - 14.8.3. Thoracic
 - 14.8.4. Angiography
 - 14.8.5. Cardiac
 - 14.8.6. Abdomen
 - 14.8.7. Virtual Colonoscopy
 - 14.8.8. CT Fluoroscopy
 - 14.8.9. Whole-Body
 - 14.8.10. Pediatric
 - 14.8.11. Cone-Beam Angiography
- 14.9. Dose and Dosimetry
 - 14.9.1. Dose Profile
 - 14.9.2. CT Dose Index and CTDIvol
 - 14.9.3. Multiple Scan Average Dose (MSAD)
 - 14.9.4. Dose-Length Product (DLP)
 - 14.9.5. Organ Dose and Effective Dose
 - 14.9.6. Adult and Pediatric Technique Optimization
- 14.10. Factors Affecting Patient Dose
 - 14.10.1. Beam Width and Pitch

- 14.10.2. kVp, mA and Time
- 14.10.3. Patient Size
- 14.10.4. Slice Increment
- 14.10.5. Scan Length
- 14.10.6. Number of Phases (e.g., Pre- and Post-Contrast)
- 14.10.7. Technique Selection
- 14.10.8. Dose Modulation
- 14.10.9. Dual Source
- 14.10.10. Patient Shielding
- 14.11. Technical Assessment and Equipment Purchase Recommendations

Module 15: Ultrasound

After completing this module, participants should be able to apply the “Fundamental Knowledge” and “Clinical Applications” learned from the module to example tasks, such as those found in “Clinical Problem-Solving.”

Fundamental Knowledge:

1. Identify common terms of sound wave propagation and ultrasound interactions with matter.
2. Describe the basic design of ultrasound transducers, and explain the principles of beam formation.
3. Describe the different types of array transducers.
4. Describe the principle of real-time pulse-echo imaging.
5. Understand the definitions of axial, lateral and elevational resolution. Describe the factors affecting spatial and temporal resolution, including multiple focal zones.
6. Identify common artifacts seen in ultrasound.
7. Describe the Doppler principle and its applications in various Doppler imaging modes. Explain aliasing and other Doppler-related artifacts.
8. Understand the principles of advanced ultrasound technologies, such as harmonic imaging, extended field of view, compound imaging, 3D/4D ultrasound and ultrasound contrast agents.
9. Delineate the mechanisms for producing ultrasound bioeffects and describe the significance of the parameters MI and TI.

Clinical Application:

1. Describe the relationship between ultrasound image formation and the resulting images.
2. Describe how scanner settings affect the clinical image and how to adjust the scan parameters to optimize image quality for different clinical applications.
3. Describe appropriate indications when advanced ultrasound technologies, such as harmonic imaging, extended field of view, compound imaging, 3D and 4D ultrasound, and ultrasound contrast agents, should be used in clinical imaging.
4. Discuss the accuracies of distance measurements with respect to scanning orientation.

Clinical Problem-Solving:

1. Explain how to improve image quality during ultrasound imaging.
2. Explain the causes of ultrasound imaging artifacts and Doppler aliasing. Discuss how to reduce such artifacts, and explain how to use imaging effects and artifacts for diagnosis.
3. Describe the ultrasound parameters related to ultrasound bioeffects and safety.
4. Discuss risks versus benefits of using ultrasound in various clinical areas, especially in obstetrics.

Concise Syllabus:

15. Ultrasound
 - 15.1. Basic Physics of Ultrasound
 - 15.2. Transducer Fundamentals
 - 15.3. Beam-Forming
 - 15.4. Image Resolution Measures
 - 15.4.1. Axial
 - 15.4.2. Longitudinal
 - 15.4.3. Elevational/Azimuthal
 - 15.5. Ultrasound Imaging Machines for Pulse-Echo Imaging

- 15.5.1. Controls (“Knobology”)
- 15.5.2. Image Data Acquisition
- 15.5.3. Image Processing and Display
- 15.6. Topics of Clinical Applications in Ultrasound Imaging
 - 15.6.1. Ultrasound Contrast Agents
 - 15.6.2. Compound Imaging
 - 15.6.3. Harmonic Imaging
 - 15.6.4. 3D Imaging
 - 15.6.5. Time-Dependent (4D) Imaging
- 15.7. Doppler Ultrasound Measurements and Flow Imaging
- 15.8. Artifacts
- 15.9. Safety and Bioeffects

Detailed Curriculum:

- 15. Ultrasound
 - 15.9. Sound Wave Propagation
 - 15.9.1. Definition of Sound and Ultrasound
 - 15.9.2. Properties of Longitudinal as compared to Transverse Waves
 - 15.10. Sound Wave Properties
 - 15.10.1. Wavelength, Frequency, Period, Speed and Velocity
 - 15.10.2. Density and Pressure Changes in Materials
 - 15.10.3. Particle Motion and Particle Velocity
 - 15.10.4. Compressibility and Elasticity
 - 15.10.5. Dependence of Sound Speed on Medium and Properties
 - 15.11. Power and Intensity
 - 15.11.1. Decibel Scale
 - 15.11.2. Relationship between Intensity and Pressure
 - 15.12. Interactions of Ultrasound Waves with Matter
 - 15.12.1. Acoustic Impedance
 - 15.12.1.1. Relationship to Density, Speed and Compressibility
 - 15.12.1.2. Impedance Changes at Tissue Interfaces
 - 15.12.2. Attenuation and Absorption
 - 15.12.2.1. Causes and Relationship to Sound Properties
 - 15.12.2.2. Attenuation as compared to absorption Coefficients
 - 15.12.2.3. Typical Attenuation in the Body
 - 15.12.3. Reflection, Refraction and Transmission
 - 15.12.3.1. Role of Impedance
 - 15.12.3.2. Reflection Coefficient
 - 15.12.3.3. Normal and Oblique Incidence
 - 15.12.3.4. Specular and Diffuse Reflection
 - 15.12.3.5. Transmission
 - 15.12.3.6. Refraction and Snell’s Law
 - 15.12.4. Scattering
 - 15.12.4.1. Hyperechoic and Hypoechoic Regions
 - 15.12.4.2. Relationship to Frequency and Scatterer Size
 - 15.12.4.3. Rayleigh Scattering
 - 15.12.4.4. Constructive and Destructive Interference
 - 15.12.4.5. Speckle

- 15.13. Transducer Components
 - 15.13.1. Piezoelectric Materials
 - 15.13.2. Capacitive Micro-Machined Ultrasonic Transducers (C-MUT)
 - 15.13.3. Transducer Construction
 - 15.13.3.1. Electronics
 - 15.13.3.2. Matching Layers
 - 15.13.3.3. Backing Block
- 15.14. Transducer Arrays
 - 15.14.1. Linear and Curvilinear Arrays
 - 15.14.2. Phased Arrays
 - 15.14.3. Annular Arrays
 - 15.14.4. 1.5D and 2D Arrays
- 15.15. Special Purpose Transducer Assemblies
 - 15.15.1. Intra-Cavitary Transducers
 - 15.15.2. IVUS Transducers
- 15.16. Beam properties
 - 15.16.1. The Near Field
 - 15.16.2. The Far Field
 - 15.16.3. Focused Transducers
 - 15.16.4. Side and Grating Lobes
- 15.17. Transducer Array Beam Formation and Focusing
 - 15.17.1. Linear and Sector Scanning
 - 15.17.2. Transmit Focusing
 - 15.17.3. Receive Focusing
 - 15.17.4. Beam Steering
 - 15.17.5. Beam Shaping
- 15.18. Resolution
 - 15.18.1. Axial
 - 15.18.2. Lateral
 - 15.18.3. Elevational (Slice Thickness)
 - 15.18.4. Temporal
 - 15.18.5. Image Contrast
- 15.19. Pulse-Echo Imaging
 - 15.19.1. Method
 - 15.19.2. Timing
 - 15.19.2.1. Pulse-Repetition Frequency
 - 15.19.2.2. Pulse-Repetition Period
 - 15.19.3. Field of View and Maximum Depth
 - 15.19.4. Frame Rate
- 15.20. Image Data Acquisition
 - 15.20.1. Signal Acquisition
 - 15.20.2. Pre-amplification and Analog to Digital Conversion
 - 15.20.3. Time-Gain (or Depth-Gain) Compensation
 - 15.20.4. Logarithmic Compression
 - 15.20.5. Demodulation and Envelope Detection
 - 15.20.6. Rejection
 - 15.20.7. Processed Signal
- 15.21. Image Processing and Display

- 15.21.1. Display Modes
 - 15.21.1.1. A-Mode
 - 15.21.1.2. B-Mode
 - 15.21.1.3. M-Mode
- 15.21.2. Image Frame-Rate Dependencies
 - 15.21.2.1. Depth Setting
 - 15.21.2.2. Transmit Focal Zones
 - 15.21.2.3. Sector Size and Line Density
- 15.21.3. Image Display
 - 15.21.3.1. Pre-Processing and Post-Processing
 - 15.21.3.2. Noise and Speckle Reduction
 - 15.21.3.3. Read Zoom and Write Zoom
- 15.21.4. Distance, Area and Volume Measurements
- 15.22. Ultrasound Contrast Agents
- 15.23. Elastography
- 15.24. Compound Imaging
- 15.25. Harmonic Imaging
 - 15.25.1. Nonlinear Propagation and Origin of Harmonics
 - 15.25.2. Formation of Harmonics in Ultrasound
 - 15.25.3. Advantages and Disadvantages
 - 15.25.4. Narrow-Band Harmonic Imaging
 - 15.25.5. Pulse-Inversion Harmonic Imaging
 - 15.25.6.
- 15.26. Three-Dimensional (3D) Imaging
 - 15.26.1. Image Reconstruction and Registration
- 15.27. Time-Dependent Imaging (4D)
- 15.28. Doppler Ultrasound
 - 15.28.1. Doppler Theory
 - 15.28.2. Spectral Analysis
 - 15.28.3. Continuous Wave (CW) Doppler
 - 15.28.4. Pulsed Doppler
 - 15.28.4.1. Pulse Transmission and Range Gating
 - 15.28.4.2. Aliasing
 - 15.28.5. Duplex Scanning
 - 15.28.6. Color Flow Imaging
 - 15.28.7. Power Doppler
- 15.29. Artifacts
 - 15.29.1. Refraction
 - 15.29.2. Shadowing and Enhancement
 - 15.29.3. Reverberation
 - 15.29.4. Speed Displacement
 - 15.29.5. Comet Tail
 - 15.29.6. Side and Grating Lobes
 - 15.29.7. Multipath Reflection and Mirror Image
 - 15.29.8. Range Ambiguity
 - 15.29.9. Mirror Artifact
 - 15.29.10. Doppler and Color Flow Aliasing
 - 15.29.11. Flow Ambiguity
- 15.30. Safety and Bioeffects

- 15.30.1. Mechanisms for Producing Bioeffects
 - 15.30.1.1. Heating
 - 15.30.1.2. Cavitation
 - 15.30.1.3. Direct Mechanical
- 15.30.2. Acoustic Power
 - 15.30.2.1. Variation with Focus and Output Setting
 - 15.30.2.2. Pulse Repetition Frequency
 - 15.30.2.3. Transducer Frequency
 - 15.30.2.4. Operation Mode
- 15.30.3. Intensity Measures of Ultrasound Energy Deposition
 - 15.30.3.1. Spatial Average/Temporal Average Intensity [I(SATA)]
 - 15.30.3.2. Spatial Peak /Temporal Average Intensity [I(SPTA)]
 - 15.30.3.3. Spatial Peak/Pulse Average Intensity [I(SPPA)]
 - 15.30.3.4. Spatial Peak/Temporal Peak Intensity [I(SPTP)]
- 15.30.4. Real-Time Acoustical Output Labeling
 - 15.30.4.1. Thermal Indices (TI and TIx)
 - 15.30.4.2. Mechanical Index (MI)
- 15.30.5. Pregnant Patient and Pediatric Protocols
 - 15.30.5.1. Acceptable TIB and TIC limits
 - 15.30.5.2. Current Clinical Statements on Ultrasound Safety
- 15.31. Phantoms and Tests for Ultrasound Quality Control and Quality Assurance

Module 16: MRI

After completing this module, the resident should be able to apply the “Fundamental Knowledge” and “Clinical Applications” learned from the module to example tasks, such as those found in “Clinical Problem-Solving.”

Fundamental Knowledge:

1. Describe the properties of magnetism and how materials react to and interact with magnetic fields.
2. Describe how the magnetic resonance signal is created.
3. Describe magnet designs and typical magnetic field strengths employed for clinical imaging.
4. Define the physical properties of a material that determine the MR signal.
5. Compare the basic pulse sequences used to produce contrast between tissues in MRI.
6. List the components of an MR system and how they are used.
7. Describe how spatial localization is achieved in MRI.
8. Review the principles of k -space generation and describe how to “fill k -space” to optimize signal strength (signal-to-noise ratio) or acquisition time.
9. Describe how T1, T2, proton density and T2* contrast can be achieved in MRI.
10. Explain how secondary tissue properties like diffusion, perfusion and flow can be distinguished in MRI.
11. Distinguish between phase contrast, 2D and 3D time of flight MRA.
12. Review the important concepts of functional MRI.
13. Review the important concepts of MR spectroscopy.
14. Describe the types of contrast agents used in MR and how they affect the signal relative to the pulse sequence used.
15. Describe the concept of partial saturation and how it affects the signal acquired.
16. Recognize how MRI acquisition techniques can be made to provide unique physiologic and anatomic information or decrease the image acquisition time.
17. Identify the source and appearance of MRI artifacts.
18. Review the safety and bioeffects of concern in MR systems.
19. Summarize the issues related to planning the installation of an MR system and the concerns for ancillary equipment and persons in the areas around an MR site.

Clinical Application:

1. Determine how the magnetic properties of a material affect the overall signal obtained in an MR image.
2. Identify the most appropriate pulse sequences for a specific diagnostic task.
3. Describe contrast-induced nephropathy and methods to reduce risk of such an outcome.
4. Describe the risks and benefits when MR imaging is used on a pregnant patient.
5. Discuss clinical situations in which MRI should be requested over alternative diagnostic procedures.
6. Discuss clinical situations in which MRI procedures are contra-indicated.

Clinical Problem-Solving:

1. Estimate how the installation of different hardware (e.g., different field strength system) might change the acquisition parameters and image quality in MRI.
2. Analyze how a change in the acquisition parameters affects the resulting MR image.
3. Determine the source of an artifact, and describe a change or changes to the acquisition parameters to reduce the appearance of the artifact.

4. Describe common clinical artifacts and methods for reducing or eliminating these artifacts in an MRI scan, including: motion, chemical shift, gradient non-linearity, aliasing, Gibbs ringing, radiofrequency interference, susceptibility and local B_0 field non-uniformities.

Concise Syllabus:

16. MRI

- 16.11. Fundamental Magnetic Properties and Physics
- 16.12. Basic Magnetic Resonance Imaging
 - 16.12.1. RF Pulses for Echo Formations
 - 16.12.2. Gradient Coils and Timing for Image Formation
 - 16.12.3. 2D Image Formation by Fourier Transform from Spin Echoes
 - 16.12.4. Basic Spin-Echo Pulse Sequence
 - 16.12.5. Basic Inversion-Recovery Sequence
 - 16.12.6. Basic Gradient-Echo Sequences
 - 16.12.7. Fast (Turbo) Spin-Echo Sequences
 - 16.12.8. Echo-Planar Imaging Sequences
 - 16.12.9. Tradeoffs among Spatial Resolution, SNR and Acquisition Time
- 16.13. MRI Contrast Mechanisms and Contrast Agents
 - 16.13.1. Spin Density
 - 16.13.2. T1 Weighting
 - 16.13.3. T2 Weighting
 - 16.13.4. T2* Weighting
 - 16.13.5. Effects of Exogenous Contrast Agents
- 16.14. MRI Instrumentation
 - 16.14.1. Static Magnetic Field (B_0) System
 - 16.14.2. Gradient Field Subsystem
 - 16.14.3. Shim Coils
 - 16.14.4. RF Transmitter (B_1) Subsystem
 - 16.14.5. RF Receiver Subsystem
 - 16.14.6. RF Coils
- 16.15. Additional Acquisition Techniques
 - 16.15.1. Flow Compensation
 - 16.15.2. Selective Tissue Suppression
 - 16.15.3. Angiography
 - 16.15.4. Diffusion and Perfusion Imaging
 - 16.15.5. Magnetization Transfer Contrast
- 16.16. Artifacts
- 16.17. Safety and Bioeffects

Detailed Curriculum:

16. Magnetic Resonance Imaging

- 16.1. Magnetism and Magnetic Fields
 - 16.1.1. Magnetic Susceptibility
 - 16.1.2. Types of Magnetic Materials (e.g., Diamagnetic, Paramagnetic, Super-Paramagnetic and Ferromagnetic)
 - 16.1.3. Magnetic Fields (B)
 - 16.1.3.1. Units for Magnetic Field Strength
 - 16.1.3.2. Magnetic Dipole
 - 16.1.3.3. Magnetic Moment

- 16.1.3.4. Nuclear Magnetism (Protons and Biologically-Relevant Nuclei)
- 16.1.4. Magnetic Moment Interaction with an External Field (B_0)
 - 16.1.4.1. Alignment (Low-Energy and High-Energy States)
 - 16.1.4.2. Precession
 - 16.1.4.3. Larmor Equation and Frequency
 - 16.1.4.4. Rotating versus Laboratory Frames of Reference
- 16.1.5. Net Magnetization Due to B_0
 - 16.1.5.1. Equilibrium Magnetization (M_0)
 - 16.1.5.2. Longitudinal Magnetization (M_z)
 - 16.1.5.3. Transverse Magnetization (M_{xy})
 - 16.1.5.4. Proton Density (Spin-Density)
 - 16.1.5.5. Field Strength Dependence
- 16.2. Nuclear Magnetic Resonance and Excitation
 - 16.2.1. Radiofrequency (RF) field (B_1)
 - 16.2.2. Flip Angle
 - 16.2.3. Free-Induction Decay (FID)
 - 16.2.4. 90° and 180° RF Pulses
- 16.3. Magnetic Resonance Signal Properties
 - 16.3.1. Spin Density (Proton-Oriented)
 - 16.3.2. T_2 (Transverse) Relaxation
 - 16.3.2.1. Intrinsic Spin-Spin Interactions
 - 16.3.2.2. Transverse Magnetization Decay
 - 16.3.2.3. Typical Tissue T_2 Values
 - 16.3.3. T_2^* Relaxation
 - 16.3.3.1. Dependence on Field Inhomogeneity
 - 16.3.3.2. Susceptibility-Induced Dephasing (e.g., Tissue-Air Interfaces)
 - 16.3.4. T_1 (Longitudinal) Relaxation
 - 16.3.4.1. Spin-Lattice Interactions
 - 16.3.4.2. Longitudinal Recovery
 - 16.3.4.3. Typical Tissue T_1 values
 - 16.3.4.4. Field-Strength Dependence
- 16.4. Pulse Sequences and Contrast Mechanisms
 - 16.4.1. Spin-Echo (SE) Pulse Sequence
 - 16.4.1.1. Pulse Sequence Basics (Timing Diagrams)
 - 16.4.1.2. Echo Time (TE)
 - 16.4.1.3. Repetition Time (TR)
 - 16.4.1.4. SE Signal Intensity Dependence on TE and TR
 - 16.4.1.5. SE Contrast (T_1 , Proton Density, T_2 -Weighted)
 - 16.4.2. Inversion-Recovery Spin-Echo Pulse Sequence
 - 16.4.2.1. Inversion Time (TI)
 - 16.4.2.2. Short (Inversion) Time Inversion-Recovery (STIR)
 - 16.4.2.3. Fluid-Attenuated Inversion-Recovery (FLAIR)
 - 16.4.3. Gradient-Echo Pulse Sequence
 - 16.4.3.1. Advantages and Disadvantages, Compared to SE Sequence
 - 16.4.3.2. Gradient-Echo Signal-Intensity and Effect of Flip Angle
 - 16.4.3.3. Cumulative Phase Correction by Crusher Gradient and RF-Pulse Spoiling
 - 16.4.3.4. Gradient Echo Contrast (T_2^*/T_1 , T_2^* , and T_1 -Weighting)
 - 16.4.4. Echo-Planar (EPI)
 - 16.4.4.1. Single-Shot Method

- 16.4.4.2. Multi-Shot Method
- 16.4.4.3. T2* Contrast
- 16.4.5. Fast or Turbo Spin-Echo
 - 16.4.5.1. Echo Train Length
 - 16.4.5.2. Echo Spacing
 - 16.4.5.3. Effective TE
 - 16.4.5.4. Contrast (T2 and T1 Weighting)
 - 16.4.5.5. Introduction to Phase Reordering
- 16.4.6. Specifications of Pulse Sequences
 - 16.4.6.1. Acquisition Time Calculations
 - 16.4.6.2. Multi-Slice Acquisition
 - 16.4.6.3. 2D and 3D Acquisitions
 - 16.4.6.4. Timing Diagrams
 - 16.4.6.5. Flow Compensation Methods
- 16.5. MR Instrumentation
 - 16.5.1. Static Magnetic Field (B_0) Systems
 - 16.5.1.1. Types of Magnets
 - 16.5.1.2. Fringe Field
 - 16.5.1.3. Main Magnetic Field Shielding (Fringe Field Reduction)
 - 16.5.2. Gradient Field Subsystem
 - 16.5.2.1. Gradient Coil Geometry (X, Y and Z)
 - 16.5.2.2. Gradient Strength (mT/m)
 - 16.5.2.3. Slew-Rate: Specification (mT/m/s), Eddy Currents and Effects on Gradient Performance
 - 16.5.2.4. Compensation for Effects of Eddy Currents
 - 16.5.3. Shim Coils
 - 16.5.3.1. B_0 Inhomogeneity Compensation
 - 16.5.3.2. Passive and Active Shim Types
 - 16.5.3.3. Overview of Shim Geometry
 - 16.5.4. RF Transmitter (B_1) Subsystem
 - 16.5.4.1. RF-Pulse Bandwidth
 - 16.5.4.2. Control of Flip Angle
 - 16.5.5. RF Receiver Subsystem
 - 16.5.5.1. Receiver Gain Controls
 - 16.5.5.2. Digital Sampling of Received Signals
 - 16.5.5.2.1. Analog-to-Digital Converter (ADC) Sampling
 - 16.5.5.2.2. Other Data Acquisition Elements
 - 16.5.5.3. Receive Bandwidth and Filters
 - 16.5.5.4. Parallel (and Phased-Array) Receive Channels
 - 16.5.6. RF Coils
 - 16.5.6.1. Transmit-and-Receive Coils
 - 16.5.6.2. Volume vs. Surface Coils
 - 16.5.6.3. Receive-Only Coils
 - 16.5.6.4. Quadrature vs. Linear Coils
 - 16.5.6.5. Birdcage Coils
 - 16.5.6.6. Phased-Array Coils
 - 16.5.6.7. Parallel Imaging (e.g., SENSE) Coils
- 16.6. Spatial Localization
 - 16.6.1. Slice-Selection

- 16.6.2. Phase-Encoding
- 16.6.3. Frequency-Encoding
- 16.7. Two-Dimensional Fourier Transform (2DFT) Image Reconstruction
 - 16.7.1. k -Space Description
 - 16.7.2. Methods of “Filling k -Space”
 - 16.7.2.1. Rectangular
 - 16.7.2.2. Spiral
 - 16.7.2.3. Radial
 - 16.7.2.4. Fractional
 - 16.7.2.5. EPI Phase Reordering
- 16.8. Image Characteristics
 - 16.8.1. Factors Affecting Spatial Resolution
 - 16.8.1.1. Field-of-View (FOV)
 - 16.8.1.2. Sampling Bandwidth
 - 16.8.1.3. Slice Thickness
 - 16.8.1.4. Image Matrix Dimensions
 - 16.8.2. Factors Affecting Signal-to-Noise Ratio (SNR)
 - 16.8.2.1. Voxel Size
 - 16.8.2.2. Signal Averages
 - 16.8.2.3. Receiver (Sampling) Bandwidth
 - 16.8.2.4. Magnetic Field Strength
 - 16.8.2.5. Slice “Cross-Talk”
 - 16.8.2.6. Reconstruction Algorithms
 - 16.8.2.7. RF Coil Quality Factor (Q)
 - 16.8.2.8. Pulse Sequence Specific Effects
 - 16.8.2.9. Surface Coil B_1 Homogeneity Corrections
 - 16.8.2.10. Parallel Imaging Acceleration Factors
 - 16.8.2.11. Saturation and Flow
 - 16.8.3. Tradeoffs among Spatial Resolution, SNR, and Acquisition Time
 - 16.8.4. Factors Affecting Image Contrast
 - 16.8.4.1. Proton Density, T1, T2
 - 16.8.4.2. Susceptibility
 - 16.8.4.3. Appearance of Blood and Blood Products
- 16.9. Contrast Agents
 - 16.9.1. Paramagnetic
 - 16.9.2. Other Susceptibility Agents
 - 16.9.3. Contrast Nephropathy
- 16.10. Saturation Methods and Effects
 - 16.10.1. Spatial
 - 16.10.2. Chemical (e.g., Fat, Silicone)
- 16.11. Special Acquisition Techniques
 - 16.11.1. Angiography
 - 16.11.1.1. Effect of Blood Flow on Signal Intensity
 - 16.11.1.2. Time-of-Flight (2D and 3D) Techniques
 - 16.11.1.3. Phase-Contrast Techniques
 - 16.11.1.4. Contrast-Agent Enhanced MRA Techniques
 - 16.11.2. Diffusion, Perfusion and Neuro Imaging
 - 16.11.2.1. Basic Principles
 - 16.11.2.2. Diffusion-Weighted Imaging (DWI) Techniques

- 16.11.2.3. Apparent Diffusion Coefficient (ADC)
- 16.11.2.4. Diffusion-Tensor Imaging (DTI) Techniques
- 16.11.2.5. Neural Tractography Applications
- 16.11.3. Functional MRI (fMRI)
 - 16.11.3.1. Blood Oxygen-Level Dependent (BOLD) Principles
 - 16.11.3.2. Clinical Applications
- 16.11.4. Magnetization Transfer Contrast (MTC)
 - 16.11.4.1. Basic Principles
 - 16.11.4.2. Contrast Mechanisms
 - 16.11.4.3. Clinical Applications
- 16.11.5. Parallel MRI
 - 16.11.5.1. Basic Principles
 - 16.11.5.2. Image-Based Implementation
 - 16.11.5.3. *k*-Space-Based Implementation
- 16.11.6. Proton Spectroscopy
 - 16.11.6.1. Basic Principles
 - 16.11.6.2. Single Voxel Techniques
 - 16.11.6.3. Chemical-Shift Imaging (CSI), 2D and 3D
 - 16.11.6.4. Water Suppression
 - 16.11.6.5. Importance of TE and TR Values
 - 16.11.6.6. Clinical Applications
- 16.12. Artifacts
 - 16.12.1. Metal and Susceptibility Artifacts
 - 16.12.2. Gradient-Field and Static-Field Inhomogeneity Artifacts
 - 16.12.3. Radiofrequency Artifacts
 - 16.12.4. *k*-Space Errors
 - 16.12.5. Motion Artifacts
 - 16.12.6. Chemical Shift Artifacts (Fat/Water)
 - 16.12.7. Gibbs (Ringing, Truncation) Artifacts
 - 16.12.8. Aliasing (Wraparound)
 - 16.12.9. Partial-Volume Artifacts
 - 16.12.10. High Speed Imaging Artifacts (e.g., Echo-Planar Distortion, Ghosting)
 - 16.12.11. Effect of High Field Strength on Artifacts
- 16.13. Safety and Bioeffects
 - 16.13.1. Static Magnetic Field
 - 16.13.1.1. Biological Effects
 - 16.13.1.2. Projectile Hazards
 - 16.13.1.3. Effects on Implanted Devices
 - 16.13.1.4. FDA Limits
 - 16.13.2. RF Field
 - 16.13.2.1. Biological Effects, e.g., Tissue Heating and Other
 - 16.13.2.2. RF Heating of Conductors and Potential Burns
 - 16.13.2.3. Specific Absorption Rate (SAR)
 - 16.13.2.4. High Field Strength System Issues
 - 16.13.2.5. FDA Limits
 - 16.13.3. Gradient Field
 - 16.13.3.1. Biological Effects, Including Peripheral Nerve Stimulation
 - 16.13.3.2. Sound Pressure Level (“Noise”) Issues and Limits
 - 16.13.3.3. FDA Limits

- 16.13.4. Contrast Agent Safety Issues
- 16.13.5. Screening Patients and Healthcare Workers
- 16.13.6. MR Safety Systems and Superconducting Magnet “Quench” Systems
- 16.13.7. Cryogenic Materials
- 16.13.8. Current Risk vs. Benefit Guidance for Pregnant Patients and Staff
- 16.13.9. “MR Safe” and “MR Compatible” Equipment and Devices
- 16.14. Magnet System Siting
 - 16.14.1. Basic Facility Design and Safety Zone Design)
 - 16.14.2. Magnetic Fringe Field and the 0.5 mT (5G) Line
 - 16.14.3. Magnetic Field Shielding
 - 16.14.4. RF Field Shielding
 - 16.14.5. Effects of MRI on Other Equipment and Objects
 - 16.14.6. Effects of Equipment and Objects on MRI
- 16.15. Accreditation, Quality Control (QC) and Quality Improvement
 - 16.15.1. Components of an ACR MRI Accreditation Program
 - 16.15.2. Quality Control Phantoms and Measurements
 - 16.15.3. Quality Improvement Program Considerations

Module 17: Nuclear Medicine

After completing this module, the radiology resident should be able to apply the “Fundamental Knowledge” and “Clinical Applications” learned from the module to example tasks, such as those found in “Clinical Problem-Solving.”

Fundamental Knowledge:

1. Describe the structure of matter, modes of radioactive decay, particle and photon emissions and interactions of radiation with matter.
2. Describe the instrumentation, major components, and principles of operation for instruments commonly used for detecting, measuring, and imaging radioactivity.
3. Describe the instrumentation and software required for image generation and display.
4. Describe instrumentation and software QC tests and test frequencies.
5. Describe the factors that affect image quality.
6. Describe radionuclide production and the principles of radiochemistry.
7. Identify established radiopharmaceuticals, the indications for use and appropriate adult and pediatric dosages.
8. Describe radiopharmaceutical QC tests and test frequencies.
9. Describe the methods of determining organ dose and whole body dose to patients and care givers.
10. Describe probability distributions, nuclear counting statistics and statistics applicable to nuclear imaging.
11. Demonstrate a working knowledge of computational image-processing, quality control of image acquisition and processing.
12. Identify the elements of radiation biology and cell biology applicable to risk and radionuclide uptake and distribution in nuclear medicine.
13. Describe the required radiation protection practices for implementing of laboratory tests, diagnostic imaging procedures and therapeutic applications of radiopharmaceuticals.

Clinical Application:

1. Explain and discuss for each organ system the advantages, disadvantages, indications and contraindications for each radiopharmaceutical used in imaging and therapeutic procedures.
2. Discuss the need for and importance of clinical history prior to performing radioisotope imaging and therapeutic procedures.
3. Explain how radioisotope imaging supports staging disease, determining residual or recurrent disease, assessing response to and monitoring of therapy, and providing prognostic information.
4. Explain how each imaging study or each therapeutic procedure can affect patient management.
5. Explain how various disease processes (e.g., malignant, metabolic, infectious, etc.) can be evaluated by each imaging agent.
6. Explain how to determine the radiopharmaceutical activity administered to adults and pediatric patients for various imaging procedures.

Clinical Problem-Solving:

1. Evaluate images for quality and artifacts, and explain the causes of each artifact.
2. Describe the appropriate imaging order for multiple examinations (e.g., X-Ray, US, CT, MRI, and NM) ordered on a patient.
3. Discuss the impact that contrast agents used in non-nuclear imaging procedures have on the nuclear medicine image.

4. Determine the period of time a lactating patient should be instructed to cease breastfeeding following a radioisotope imaging or therapeutic procedure.
5. Evaluate the risk of performing a nuclear imaging procedure on a pregnant patient. Which isotopes cross the placenta and which isotopes do not?
6. Perform organ dose and external dose calculations for two Tc-99m compounds, an intermediate-energy and a high-energy isotope used in routine nuclear medicine imaging and therapy.
7. Analyze the radiation dose from a nuclear medicine procedure and correlate the radiation risks to the potential benefit.
8. Determine when a nuclear medicine procedure should not be performed.

Concise Syllabus:

17. Nuclear Medicine

- 17.1. Radioactivity: Definition, Units, Decay Equation, Half-Life.
- 17.2. Nuclear Transformation
- 17.3. Radioactive Equilibrium
- 17.4. Radioisotope Production
- 17.5. Radionuclide Generators
- 17.6. Radiopharmaceuticals
- 17.7. Radiation Detection Instrumentation
- 17.8. Scintillation Cameras
 - 17.8.1. Camera Design and Characteristics
 - 17.8.2. Collimators
 - 17.8.3. Image Acquisition and Processing
 - 17.8.4. Measures of Performance
 - 17.8.5. Artifacts
- 17.9. Clinical Imaging
 - 17.9.1. Imaging Various Organs
 - 17.9.2. Clinical Considerations: Adult, Pediatric, Pregnancy, Breastfeeding
- 17.10. SPECT Imaging
- 17.11. PET Imaging
- 17.12. Fusion Imaging: PET/CT, SPECT/CT
- 17.13. Nuclear Medicine Therapy
- 17.14. Safety: Patient, Staff, Public
- 17.15. Training and Experience for Authorized Users of Radioactive Materials.
- 17.16. Radiation Doses

Detailed Curriculum:

17. Nuclear Medicine

- 17.1. Radionuclide Decay
 - 17.1.1. Radioactivity
 - 17.1.1.1. Definition
 - 17.1.1.2. Units
 - 17.1.1.3. Decay Constant
 - 17.1.1.4. Decay Equation
 - 17.1.1.5. Half-Life (Physical, Biological and Effective)
 - 17.1.2. Nuclear Transformation

- 17.1.2.1. N/Z Ratio and Nuclear Stability
- 17.1.2.2. Beta (Negative Electron) Decay
- 17.1.2.3. Positron (Positive Electron) Decay
- 17.1.2.4. Electron Capture
- 17.1.2.5. Isomeric Transition
- 17.1.2.6. Alpha Decay
- 17.1.2.7. Internal Conversion
- 17.1.2.8. Nuclear Fission
- 17.1.3. Radioactive Equilibrium
 - 17.1.3.1. Transient
 - 17.1.3.2. Secular
- 17.2. Radioisotope Production
 - 17.2.1. Linear Accelerator and Cyclotron
 - 17.2.2. Reactor
 - 17.2.2.1. Fission Products
 - 17.2.2.2. Neutron-Activation Products
 - 17.2.3. Radionuclide Generators
 - 17.2.3.1. $^{99}\text{Mo} - ^{99\text{m}}\text{Tc}$
 - 17.2.3.2. Other (e.g., $^{82}\text{Sr} - ^{82}\text{Rb}$ PET)
 - 17.2.3.3. Elution and Quality Control
- 17.3. Radiopharmaceuticals
 - 17.3.1. Preparation
 - 17.3.2. Range of Required Activities for Clinical Studies
 - 17.3.3. Localization
 - 17.3.4. Uptake, Distribution and Decay
 - 17.3.5. Quality Assurance and Quality Control Procedures
 - 17.3.6. Internal Organ Dosimetry
 - 17.3.7. Dose Rates from Radioactive Patients
- 17.4. Radiation Detection Instrumentation
 - 17.4.1. Gas-Filled Detectors
 - 17.4.1.1. Mechanisms of Operation
 - 17.4.1.2. Applications and Limitations
 - 17.4.1.3. Survey Meters (e.g., GM Counter, Ionization Chamber)
 - 17.4.1.4. Dose Calibrator
 - 17.4.1.5. Quality Control
 - 17.4.2. Scintillation Detectors
 - 17.4.2.1. Mechanisms of Operation
 - 17.4.2.2. Applications and Limitations
 - 17.4.2.3. Pulse-Height Spectroscopy
 - 17.4.2.4. Thyroid Probe
 - 17.4.2.5. Well Counter
 - 17.4.2.6. Survey Meter
 - 17.4.2.7. Quality Control
 - 17.4.3. Other Types of Detectors
- 17.5. Scintillation Camera
 - 17.5.1. Clinical Purpose
 - 17.5.2. Camera Design
 - 17.5.2.1. Crystal Parameters
 - 17.5.2.2. Spatial Localization

- 17.5.2.3. Energy Discrimination
- 17.5.3. Collimator Characteristics
 - 17.5.3.1. Sensitivity
 - 17.5.3.2. Resolution
 - 17.5.3.3. Energy
- 17.5.4. Collimators
 - 17.5.4.1. Parallel-Hole
 - 17.5.4.2. Pinhole
 - 17.5.4.3. Specialized
- 17.5.5. Image Acquisition
 - 17.5.5.1. Static
 - 17.5.5.2. Dynamic
 - 17.5.5.3. Gated
 - 17.5.5.4. List-Mode
- 17.5.6. Image Processing
 - 17.5.6.1. Subtraction
 - 17.5.6.2. Region of Interest (ROI)
 - 17.5.6.3. Time-Activity Curves
 - 17.5.6.4. Spatial Filtering
 - 17.5.6.5. Temporal Filtering
- 17.5.7. Measures of Performance (Extrinsic and Intrinsic)
 - 17.5.7.1. Uniformity
 - 17.5.7.2. Spatial Resolution
 - 17.5.7.3. Energy Resolution
 - 17.5.7.4. Spatial Linearity
 - 17.5.7.5. Sensitivity
 - 17.5.7.6. Count-Rate Performance
 - 17.5.7.7. Dead-Time
- 17.5.8. Artifacts
 - 17.5.8.1. Damaged or Broken Crystal
 - 17.5.8.2. Non-Uniformity
 - 17.5.8.3. Bad Phototube
 - 17.5.8.4. Improper Energy Peaking
 - 17.5.8.5. Mechanical Separation of Coupling Elements
 - 17.5.8.6. Damaged Collimators
 - 17.5.8.7. Motion
 - 17.5.8.8. Dual Isotope
 - 17.5.8.9. Wrong Collimator Selection
- 17.5.9. Clinical Imaging
 - 17.5.9.1. Thyroid
 - 17.5.9.2. Bone
 - 17.5.9.3. Renal
 - 17.5.9.4. Liver/Spleen
 - 17.5.9.5. Cardiac (Ejection Fraction, Myocardial Perfusion)
 - 17.5.9.6. Ventilation Perfusion (VQ)
 - 17.5.9.7. Multi-Energy Imaging
 - 17.5.9.8. Tumor Imaging
 - 17.5.9.9. PET/CT Imaging
- 17.5.10. Clinical Procedure Considerations

- 17.5.10.1. Adult
- 17.5.10.2. Infant and Pediatric
- 17.5.10.3. Pregnant Patient
- 17.5.10.4. Breast-Feeding Patient
- 17.6. Single Photon Emission Computed Tomography (SPECT)
 - 17.6.1. Clinical Purpose
 - 17.6.2. Mechanisms of Operation
 - 17.6.2.1. Single- and Multi-Head Units
 - 17.6.2.2. Rotational Arc
 - 17.6.2.3. Continuous Motion
 - 17.6.2.4. Step-and-Shoot
 - 17.6.2.5. Non-Circular Orbits
 - 17.6.3. Attenuation Correction
 - 17.6.4. Image Reconstruction
 - 17.6.5. Sensitivity and Resolution
 - 17.6.6. Technical Assessment and Equipment Purchase Recommendations
 - 17.6.7. Quality Assurance and Quality Control
 - 17.6.8. Artifacts
 - 17.6.8.1. Attenuation
 - 17.6.8.2. Center of Rotation
 - 17.6.8.3. Uniformity
 - 17.6.8.4. Stray Magnetic Field Effects
 - 17.6.8.5. Motion
 - 17.6.9. Clinical Examples
- 17.7. Positron Emission Tomography (PET)
 - 17.7.1. Clinical Purpose
 - 17.7.2. Mechanisms of Operation
 - 17.7.3. Detector
 - 17.7.3.1. Type and Materials
 - 17.7.3.2. Configuration
 - 17.7.4. Coincidence Detection
 - 17.7.5. Time-of-Flight
 - 17.7.6. Attenuation Correction
 - 17.7.7. Standardized Uptake Value (SUV)
 - 17.7.8. 2D vs. 3D Operation
 - 17.7.9. Count Rate and Administered Dose Considerations
 - 17.7.10. Image Reconstruction
 - 17.7.11. Sensitivity and Resolution
 - 17.7.12. Technical Assessment and Equipment Purchase Recommendations
 - 17.7.13. Quality Assurance and Quality Control
 - 17.7.14. Artifacts
 - 17.7.14.1. Attenuation Correction
 - 17.7.14.2. Motion
 - 17.7.14.3. Stray Magnetic Fields
 - 17.7.14.4. Module Loss, Block Loss or Miscalibration
 - 17.7.14.5. Coincidence Timing
 - 17.7.15. Clinical Examples
- 17.8. Combined Modalities
 - 17.8.1. SPECT/CT

- 17.8.1.1. Mechanisms of Operation
- 17.8.1.2. Clinical Applications
- 17.8.1.3. Quality Assurance and Quality Control
- 17.8.1.4. Artifacts
- 17.8.2. PET/CT
 - 17.8.2.1. Mechanisms of Operation
 - 17.8.2.2. Clinical Applications
 - 17.8.2.3. Quality Assurance and Quality Control
 - 17.8.2.4. Artifacts
- 17.9. Nuclear Medicine Therapy
 - 17.9.1. Written Directive
 - 17.9.2. Safety Considerations
- 17.10. Factors Affecting Public, Staff and Unintended Patient Dose
 - 17.10.1. Source Control (e.g., Patient Location)
 - 17.10.2. Administered Pharmaceutical, Isotope and Activity
 - 17.10.3. Contamination Control
 - 17.10.4. Patient Flow
- 17.11. Patient Dose
 - 17.11.1. MIRD

Appendix A Committee Members-2009

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Appendix B History and general comments about intent of curriculum

It has been suggested that radiologists embody three principal attributes: clinical acumen, mastery of technology, and dedication to safety and quality [William Hendee, PhD]. A compelling argument exists that mastery of imaging technology is the lynchpin to these attributes, and that one cannot master the technology without learning the principles and applications of the physics underlying the technology.

To ensure that every radiologist has the knowledge necessary to ensure the safe practice of radiology, especially in the daily application of radiation safety measures and in all other facets of patient safety during imaging, a more standardized approach to physics education at the resident level is necessary. The American Association of Physicists in Medicine (AAPM) held a Forum on Physics Education in January 2006 to address the issue. The RSNA sponsored a multi-organizational follow-up meeting in February 2007. The curriculum which follows is the result of that initiative.

This curriculum builds on basic principles of physics in order to facilitate an in depth understanding of all imaging modalities and how they form high quality and clinically significant images. Ultrasound and magnetic resonance imaging have not been shown to date to pose risks to patients, other than the obvious concern for patient safety in MRI caused by either internal or external ferromagnetic objects. However, the situation is different for modalities using ionizing radiation, such as radiography, fluoroscopy, nuclear medicine studies, and computed tomography, particularly the late generation multi-detector row CT machines.

Ionizing radiation has been used for diagnostic imaging purposes in medicine for over a century. The benefits of such imaging exams almost certainly exceed the risks, and have no doubt further improved the lives of our patients. However, the dramatic growth of imaging use over the past few decades has also resulted in a significant increase in the population's cumulative exposure to ionizing radiation. Data extrapolated from the atomic bomb survivors in Japan and the nuclear catastrophe at Chernobyl predict that the incidence of imaging-related cancer in the exposed population may significantly increase in the coming years. This presumption makes it incumbent on radiologists to assume even further responsibility for the appropriate utilization of imaging studies, and then to ensure when imaging is used in a diagnostic setting that image quality is balanced by the concept of ALARA (as low as reasonably achievable) as it pertains to radiation dose.

All stakeholders in diagnostic imaging are encouraged to embrace the principles of imaging physics included in this curriculum, and to employ them in the best interests of patient safety by optimizing imaging to answer the clinical question posed while placing the patient at minimal risk.