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. Hematopoetic
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
  9.12.5. Reportable Events
9.13. Estimating Patient, Pediatric and Fetal Dose (Procedure-Specific Doses)
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)
  9.10.5. U.S. Department of Transportation
    9.10.5.1. U.S. Department of Labor (OSHA)

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
  9.12.1. 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
  9.14.1. Incidents
    9.14.1.3. Transportation 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 system 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.
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 principal 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
15.1. Controls ("Knobology")
15.2. Image Data Acquisition
15.3. Image Processing and Display
15.4. Topics of Clinical Applications in Ultrasound Imaging
15.4.1. Ultrasound Contrast Agents
15.4.2. Compound Imaging
15.4.3. Harmonic Imaging
15.4.4. 3D Imaging
15.4.5. Time-Dependent (4D) Imaging
15.5. Doppler Ultrasound Measurements and Flow Imaging
15.6. Artifacts
15.7. 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


16.14.4. 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 Residence 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 (B₀)
   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 B₀
   16.1.5.1. Equilibrium Magnetization (M₀)
   16.1.5.2. Longitudinal Magnetization (M₀)
   16.1.5.3. Transverse Magnetization (Mₓᵧ)
   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 (B₁)
   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. T2 (Transverse) Relaxation
     16.3.2.1. Intrinsic Spin-Spin Interactions
     16.3.2.2. Transverse Magnetization Decay
     16.3.2.3. Typical Tissue T2 Values
   16.3.3. T2* Relaxation
     16.3.3.1. Dependence on Field Inhomogeneity
     16.3.3.2. Susceptibility-Induced Dephasing (e.g., Tissue-Air Interfaces)
   16.3.4. T1 (Longitudinal) Relaxation
     16.3.4.1. Spin-Lattice Interactions
     16.3.4.2. Longitudinal Recovery
     16.3.4.3. Typical Tissue T1 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 (T1, Proton Density, T2-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 (T2*/T1, T2*, and T1–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 (B₀) 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. B₀ Inhomogeneity Compensation
    16.5.3.2. Passive and Active Shim Types
    16.5.3.3. Overview of Shim Geometry
  16.5.4. RF Transmitter (B₁) 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)
  16.12.10. 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
16.13.9. “MR Safe” and “MR Compatible” Equipment and Devices
   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. $^{99}$Mo – $^{99m}$Tc
17.2.3.2. Other (e.g., $^{82}$Sr – $^{82}$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
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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.