Diagnostic Radiology Residents Physics Curriculum
AAPM Subcommittee of the Medical Physics Education of Physicians Committee
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Authors: (see complete list in Appendix A)

History and comments: (see complete details in Appendix B)

Preface

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 depth and order of presentation is left to the institution. The weighting of the subject material is a relative indicator of the importance of each area of study. It does not reflect the ABR weighting of topics on the physics certification examination for radiologists. The subject material described in this curriculum should be taught in a clinically relevant manner.

Basic Science	**Weighting**
1. Structure of the Atom	2
2. Electromagnetic (EM) Radiation	2
3. Particulate Radiation	1
4. Interaction of Radiation with Matter	4
5. Radiation Units	2
6. X-ray Production	5
7. Basic Imaging Science and Technology	6
8. Radiation Biology	8
9. Radiation Protection	9
Imaging Modalities	
10. X-ray Projection Imaging Concepts and Detectors	6
11. General Radiography	6
12. Mammography	3
13. Fluoroscopy	3
14. CT	8
15. Ultrasound	9
16. Magnetic Resonance	12
17. Nuclear Medicine	14
Total	**100**

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Basic Science

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. Fission
        - 1.3.6. Fusion
        - 1.3.7. Nuclear Instability - Overview
            - 1.3.7.1. Beta (negative electron) Decay
            - 1.3.7.2. Positron (positive electron) Decay
            - 1.3.7.3. Electron Capture
            - 1.3.7.4. Isomeric Transition
        - 1.3.8. Classification of Nuclides
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
3. **Particulate Radiation**
    - 3.1. Light Particles
    - 3.2. Heavy-Charged Particles
    - 3.3. Uncharged Particles
4. **Interaction of Radiation with Matter**
    - 4.1. Charged Particle Interactions
        - 4.1.1. Ionization/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. Neutron Interactions

- 4.3. Photon Interactions
  - 4.3.1. Coherent Scattering
  - 4.3.2. Compton Scattering
  - 4.3.3. The Photoelectric Effect
  - 4.3.4. Pair Production
  - 4.3.5. Interactions in Tissues
  - 4.3.6. Contrast Media
- 4.4. Photon Attenuation
  - 4.4.1. Linear Attenuation Coefficient
  - 4.4.2. Mass Attenuation Coefficient
  - 4.4.3. Attenuation Equation
  - 4.4.4. Poly-energetic X-Ray Beams
  - 4.4.5. Half -value Layer (HVL)
    - 4.4.5.1. Effective Energy
    - 4.4.5.2. Beam Hardening
    - 4.4.5.3. Geometry
  - 4.4.6. Mass Energy Absorption Coefficient

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
- 5.3. KERMA
- 5.4. Absorbed Dose
  - 5.4.1. Gray
  - 5.4.2. Rad
- 5.5. Imparted Energy
- 5.6. Equivalent Dose
  - 5.6.1. Radiation Weighting Factors
  - 5.6.2. Sievert
  - 5.6.3. rem
- 5.7. Effective Dose
  - 5.7.1. Tissue Weighting Factors
  - 5.7.2. Sievert
  - 5.7.3. rem
  - 5.7.4. Importance in Radiation Protection

6. **X-ray Production**
- 6.1. Properties of X Rays
  - 6.1.1. Bremsstrahlung
    - 6.1.1.1. Importance in Imaging
    - 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
6.1.2.2. Influence of Target Material
6.1.2.3. 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. Biasing
6.2.1.4. Filament and Tube Current
6.2.1.5. Focal Spot Blooming
6.2.1.6. Space Charge
6.2.2. Anode
6.2.2.1. Composition
6.2.2.2. Configuration
6.2.2.3. High-Speed Rotating Anode
6.2.2.4. Line-Focus Principle
6.2.2.5. Focal Spot
6.2.2.6. Heel Effect
6.2.2.7. Off-Focus Radiation
6.2.2.8. Overheating
6.2.3. Application-Specific Tubes
6.2.3.1. Mammography
6.2.3.2. Straton

6.3. Generators
6.3.1. Single-Phase
6.3.2. Three-Phase
6.3.3. High-Frequency
6.3.4. Technique Factors
6.3.4.1. kVp
6.3.4.2. mA
6.3.4.3. Time
6.3.4.4. Automatic Exposure Control (AEC)
6.3.4.5. 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/X-Ray Alignment
6.4.3.3. Effect on Image Quality
6.4.3.4. Importance to Safety
6.4.4. Geometry

6.4.4.1. Source-to-Image Receptor Distance (SID)
6.4.4.2. Magnification

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. Variance
      7.1.6. Confidence Intervals
      7.1.7. Propagation of Error
      7.1.8. Statistical Process Control
   7.2. Image Properties
      7.2.1. Image Representations
         7.2.1.1. Spatial
         7.2.1.2. Frequency
         7.2.1.3. Temporal
         7.2.1.4. Fourier and Other Transforms
      7.2.2. Contrast Degradation Processes
      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 Noise Ratio (CNR), Signal to Noise Ratio (SNR), Detective Quantum Efficiency (DQE), Quantum Detection Efficiency (QDE)
      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. Generic 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. Collimation
         7.3.2.2. Value of Interest

7.3.3. Grayscale Processing
7.3.3.1. Window/Level
7.3.3.2. Characteristic Curves
7.3.3.3. Look-Up Tables
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 (CAD) 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, etc.)
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 Adjustments
7.4.3.3. Adaptation/Masking
7.4.3.4. Ambient Lighting/ 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. Astigmatism
7.5.1.4. 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)
7.6.2.1. PACS
7.6.2.2. Radiology Information System (RIS), Hospital Information System (HIS)
7.6.2.3. Electronic Medical Record (EMR)
7.6.2.4. Health Level 7 (HL7)
7.6.2.5. DICOM
7.6.3. Networks
7.6.3.1. Hardware
7.6.3.2. Bandwidth
7.6.3.3. Communication Protocols
7.6.4. Film Digitizers
7.6.5. Storage
7.6.5.1. Hardware
7.6.5.2. Storage Requirements
7.6.5.3. Disaster Recovery
7.6.6. DICOM
7.6.6.1. Modality Worklist
7.6.6.2. Image and Non-Image Objects
7.6.6.3. Components and Terminology
7.6.6.4. DICOM Conformance
7.6.7. Data Compression
7.6.7.1. Clinical Impact
7.6.7.2. Lossy
7.6.7.3. Lossless
7.6.7.4. Image/Video Formats
7.6.8. Security and Privacy
7.6.8.1. Encryption
7.6.8.2. Firewalls
7.6.8.3. Biometrics
7.6.8.4. Health Insurance Portability and Accountability Act (HIPAA)

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
- 8.5. Deterministic (Non-Stochastic) Effects
  - 8.5.1. Radiation Syndromes
    - 8.5.1.1. Hematopoetic
    - 8.5.1.2. Gastrointestinal
    - 8.5.1.3. Cerebrovascular
    - 8.5.1.4. Sequence of Events
    - 8.5.1.5. LD 50/60
    - 8.5.1.6. 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
    - 8.6.1.1. Atomic Bomb Survivors
    - 8.6.1.2. Ankylosing Spondylitis
    - 8.6.1.3. Epilation for Tinea Capita
    - 8.6.1.4. Thorotrast
    - 8.6.1.5. TB Sanitoria
    - 8.6.1.6. Postpartum Mastitis
    - 8.6.1.7. Uranium Miners
    - 8.6.1.8. Marshall Island Residents
    - 8.6.1.9. Radium Dial Painters
    - 8.6.1.10. Early Radiologists
  - 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 Phase II)
8.7.3.2. International Council on Radiation Protection (ICRP)
8.7.3.3. National Council on Radiation Protection (NCRP) (i.e, Report 116)
8.7.3.4. United Nations Scientific Committee on the Effects of Atomic Radiation Reports (UNSCEAR)
8.7.4. Perception of Risk
8.8. Dose Response Models
8.8.1. Linear, No-Threshold (LNT)
8.8.2. Linear-Quadratic
8.8.3. Hormesis

9. **Radiation Protection**
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) (Pipe Scale)
9.2.4. Fallout
9.3. Medical Sources – Occupational and Patient Doses
9.3.1. Projection Radiography
9.3.2. Fluoroscopy
9.3.3. Interventional/Angiography
9.3.4. CT
9.3.5. Sealed Source Radioactive Material
9.3.6. Unsealed Radioactive Material
9.3.7. Therapeutic External Radiation
9.3.8. Non-Ionizing
9.4. Persons at Risk

- 9.4.1. Occupational
- 9.4.2. Non-Occupational Staff
- 9.4.3. Members of the Public
- 9.4.4. Fetus
- 9.4.5. Patient
  - 9.4.5.1. Adult
  - 9.4.5.2. Child
  - 9.4.5.3. Pregnancy known
  - 9.4.5.4. Pregnancy status unknown

9.5. Dose limits
- 9.5.1. Occupational Dose Limits
  - 9.5.1.1. Effective Dose Equivalent
  - 9.5.1.2. Specific Organ
  - 9.5.1.3. Pregnant Workers
- 9.5.2. Members of the Public
  - 9.5.2.1. General
  - 9.5.2.2. Caregivers
  - 9.5.2.3. Limit to Minors

9.6. Radiation Detectors
- 9.6.1. Personnel Dosimeters
  - 9.6.1.1. Whole Body
  - 9.6.1.2. Extremity
  - 9.6.1.3. Emergency/Self-Reading
  - 9.6.1.4. Dosimeter Placement
  - 9.6.1.5. Common Problems
- 9.6.2. Area Monitors
  - 9.6.2.1. Ion Chambers
  - 9.6.2.2. Geiger-Mueller (GM)
  - 9.6.2.3. Scintillators
  - 9.6.2.4. Thermoluminescent Dosimeters (TLDs)
  - 9.6.2.5. Film

9.7. Principles of Radiation Protection
- 9.7.1. Time
- 9.7.2. Distance
- 9.7.3. Shielding
  - 9.7.3.1. Facility
  - 9.7.3.2. Workers
  - 9.7.3.3. Caregivers
  - 9.7.3.4. Patients
  - 9.7.3.5. Members of the Public
  - 9.7.3.6. Types of Materials
- 9.7.4. Contamination Control
- 9.7.5. As Low As Reasonably Achievable (ALARA)
- 9.7.6. Procedure Appropriateness

9.8. Factors Affecting Patient Dose
- 9.8.1. Radiography

9.8.1.1. Technique (e.g., kVp, mA [mAs])
9.8.1.2. Source-to-Detector Distance
9.8.1.3. Beam Filtration and Grid
9.8.1.4. Field Size
9.8.1.5. Receptor Speed

9.8.2. Fluoroscopy/Interventional Radiology
9.8.2.1. Technique
9.8.2.2. Acquisition Mode
9.8.2.3. Exposure Time
9.8.2.4. Last-Image Hold
9.8.2.5. Pulsed Exposure
9.8.2.6. Magnification
9.8.2.7. Collimation
9.8.2.8. Tube-to-Patient Distance
9.8.2.9. Operator Training

9.8.3. Computed Tomography (CT)
9.8.3.1. Beam Width and Pitch
9.8.3.2. Variable mA
9.8.3.3. Scan Length
9.8.3.4. Number of Passes
9.8.3.5. Technique Selection
9.8.3.6. Pediatric Patients

9.8.4. Mammography
9.8.4.1. Exposure Limits (e.g., mandatory accreditation standards)
9.8.4.2. Techniques
9.8.4.3. Compression
9.8.4.4. Screening Exams
9.8.4.5. Diagnostic Examinations including Magnification

9.8.5. Nuclear Medicine
9.8.5.1. Source Control (e.g., patient location)
9.8.5.2. Administered Pharmaceutical, Isotope and Activity
9.8.5.3. Contamination Control
9.8.5.4. Patient Flow

9.9. Advisory Bodies
9.9.1. Radiation-Related
9.9.1.1. International Commission on Radiological Protection
9.9.1.2. National Council on Radiation Protection and Measurements
9.9.1.3. Conference of Radiation Control Program Directors
9.9.1.4. International Atomic Energy Agency

9.9.2. Accreditation Organizations (X-Ray and Nuclear Medicine)
9.9.2.1. Joint Commission on Accreditation of Healthcare Organizations
9.9.2.2. American College of Radiology
9.9.2.3. InterSocietal Accreditation Commission

9.9.3. Other
9.9.3.1. National Academy of Sciences

9.9.3.2. Institute of Medicine
9.9.3.3. International ElectroTechnical Commission
9.9.3.4. Joint Commission on Accreditation of Healthcare Organizations

9.10. Regulatory Agencies
9.10.1. U.S. Nuclear Regulatory Commission/Agreement States
9.10.1.1. 10 CFR Parts 19, 20, 30, 32, 35, 110
9.10.1.2. Guidance Documents (e.g., NUREG 1556, Vols. 9 & 11)
9.10.1.3. Regulatory Guides
9.10.2. States – for Machine-Producing Sources (e.g., Suggested State Regulations)
9.10.3. U.S. Food and Drug Administration
9.10.3.1. Center for Devices and Radiological Health
9.10.3.2. Center for Drug Evaluation and Research
9.10.4. U.S. Office of Human Research Protections
9.10.5. U.S. Department of Transportation
9.10.6. U.S. Department of Labor (OSHA)

9.11. Radiation Safety in Nuclear Medicine
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. Procedures
9.11.5.1. Diagnostic (e.g., 10 CFR 35.200 or equivalent Agreement State)
9.11.5.2. Therapeutic (e.g., 10 CFR 35.300 or equivalent Agreement State)
9.11.6. Special Considerations
9.11.6.1. Pregnant Patients
9.11.6.2. Breast-Feeding Patients
9.11.6.3. Caregivers
9.11.6.4. Patient Release

9.12. Estimating Patient and Fetal Dose (Procedure-Specific Doses)
9.12.1. Radiography
9.12.2. Mammography
9.12.3. Fluoroscopy
9.12.4. Computed Tomography (CT)
9.12.5. Nuclear Medicine

9.13. Shielding
9.13.1. Design Philosophy
9.13.2. Primary
9.13.3. Secondary
9.13.4. Leakage
9.13.5. Controlled/Uncontrolled areas
9.13.6. Definitions
9.13.6.1. Use Factor

9.13.6.2. Occupancy
9.13.6.3. Workload
9.13.7. Examples of Shielding Design
9.13.7.1. Diagnostic
9.13.7.2. PET
9.13.7.3. Hot Lab/Nuclear Medicine
9.14. Radiological Emergencies
9.14.1. Incidents
9.14.1.1. Nuclear Power
9.14.1.2. Military Equipment
9.14.1.3. Transportation Accidents
9.14.1.4. Research Lab / Radiopharmacy Accidents
9.14.2. Purposeful Exposures
9.14.2.1. Nuclear Detonation
9.14.2.2. Radiological Dispersion Device (RDD)
9.14.2.3. Environmental Contamination
9.14.3. Treatment of Radiological Casualties
9.14.3.1. Notification/Patient Arrival
9.14.3.2. Triage/Evaluation/Initial Treatment
9.14.3.3. Exposure/External 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

Imaging Modalities

10. **X-ray Projection Imaging Concepts and Detectors**
10.1.1. Radiography Concepts
10.1.2. Geometry
10.1.2.1. Source-to-Image Receptor Distance/Source-to-Object Distance (SID/SOD)
10.1.2.2. Magnification
10.1.2.3. Inverse Square Law
10.1.3. Radiographic Contrast
10.1.3.1. Subject
10.1.3.2. Object
10.1.3.3. Detector
10.1.4. Scatter and Scatter Reduction
10.1.4.1. Scatter-to-Primary Ration
10.1.4.2. Scatter Fraction
10.1.4.3. Collimation
10.1.4.4. Anti-Scatter Grids
10.1.4.5. Air Gap
10.1.5. Artifacts and Image Degradation
10.1.5.1. Geometrical Distortion
10.1.5.2. Focal Spot Blur/Penumbra
10.1.5.3. Grid Artifacts/Cutoff

10.1.5.4. Motion
10.1.5.5. Superimposition

10.2. Radiographic Detectors
10.2.1. Screen/Film
10.2.1.1. Phosphors
10.2.1.2. Film
10.2.1.3. Screen/Film Systems
10.2.1.4. Latent Image Formation
10.2.1.5. Chemical Processing
10.2.1.6. Characteristic Curve
10.2.1.7. Spatial and Contrast Resolution
10.2.1.8. Artifacts
10.2.2. Computed Radiography (CR)
10.2.2.1. Storage Phosphors
10.2.2.2. Latent Image Formation
10.2.2.3. Image Digitization
10.2.2.4. Pre-Processing (e.g., gain and bad-pixel correction)
10.2.2.5. Imaging Characteristics
10.2.2.6. Artifacts
10.2.3. Direct Digital Radiography (DR)
10.2.3.1. Semiconductor and Thin-Film Transistor
10.2.3.2. Image Formation and Readout
10.2.3.3. Pre-processing (e.g., gain and bad-pixel correction)
10.2.3.4. Imaging Characteristics
10.2.3.5. Artifacts
10.2.4. Indirect DR
10.2.4.1. Phosphor, Photo Diodes and Thin Film Transistor
10.2.4.2. Image Formation and Readout
10.2.4.3. Preprocessing (e.g., gain and bad-pixel correction)
10.2.4.4. Imaging Characteristics
10.2.4.5. Artifacts

11. **General Radiography**
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11.1.1. Tube
11.1.2. Filtration
11.1.3. Collimation
11.1.4. Automatic Exposure Control (AEC)
11.1.5. Grids and Bucky Factors
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 and Contrast Resolution
11.4.2. Body-Part and View-Specific Processing
11.4.3. CAD/Diagnosis
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11.5.1. Chest
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11.5.4. Extremities
11.5.5. Bone Densitometry (DEXA)
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11.5.7. Portable
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12.1. Clinical Importance
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12.1.2. Diagnosis and Detection Requirements
12.1.3. 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. Focal Spot Size
12.3.2. Collimation
12.3.3. Beam Central Axis
12.3.4. Chest-Wall Coverage
12.3.5. Heel Effect
12.3.6. Grid
12.3.7. Magnification
12.4. Acquisition Systems
12.4.1. Screen/Film
12.4.2. Full-Field Digital Mammography
12.4.3. Stereotactic Biopsy Systems
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12.6. Magnification Mode
    12.6.1. Use
    12.6.2. Small Focal Spot
    12.6.3. Air Gap
12.7. Dose
    12.7.1. Average Glandular Dose
    12.7.2. Dosimetry
    12.7.3. AEC
    12.7.4. Technique Optimization
12.8. Digital Image Processing
    12.8.1. Skin Equalization
    12.8.2. Advanced Proprietary Processing
    12.8.3. CAD/Diagnosis
12.9. MQSA Regulations
    12.9.1. Responsibilities of Physician, Technologist and Physicist
    12.9.2. Dose
    12.9.3. Image Quality/Accreditation Phantom
    12.9.4. QC Tests and Frequencies
12.10. American College of Radiology (ACR) Accreditation
12.11. Technical Assessment and Equipment Purchase Recommendations

13. **Fluoroscopy/Interventional**
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 (semi-transparent)
13.2. Geometry
    13.2.1. Focal Spot Size
    13.2.2. Magnification
    13.2.3. Under-Table vs. Over-Table X-Ray Tube
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
13.4. Flat-panel Acquisition Systems
    13.4.1. Detectors
    13.4.2. Magnification
    13.4.3. Binning
    13.4.4. Comparison to II
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 Film (digital and film)
13.5.5. Effective mA as a Function of Mode
13.5.6. Variable Beam Filtration as a Function of Mode
13.5.7. Software Processing as a Function of Mode
13.6. Image Degradations
13.6.1. Lag
13.6.2. Contrast Ratio and Veiling Glare
13.6.3. Distortion
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13.7.1. Frame Averaging
13.7.2. Temporal Recursive Filtering
13.7.3. Last Image Hold
13.7.4. Edge Enhancement/Smoothing
13.7.5. Digital Subtraction Angiography (DSA)
13.7.6. Road Mapping
13.8. Application Requirements
13.8.1. Contrast Imaging (e.g., Iodine, barium)
13.8.2. Cine
13.8.3. C-Arms
13.9. Clinical Applications
13.9.1. Conventional Fluoroscopy (e.g., GI, GU)
13.9.2. Interventional
13.9.3. DSA
13.9.4. Bi-Plane
13.9.5. Cardiac
13.9.6. Pediatric
13.10. Dose and Dosimetry
13.10.1. FDA and State (where applicable) Dose Rate Limits
13.10.2. Dose-Area-Product (DAP) Meters
13.10.3. Entrance Skin Exposure
13.10.4. Patient Dose for Various Acquisition Modes
13.10.5. Patient Size
13.10.6. Operator and Staff Dose
13.10.7. Operator, Staff and Caregiver Shielding and Protection Considerations
13.10.8. Technique Optimization
13.11. Image Quality
13.11.1. Low-Contrast Resolution
13.11.2. High-Contrast Resolution
13.11.3. Temporal Resolution
13.12. Regulations
13.12.1. Five-Minute Timer
13.12.2. Minimum Source to Patient Distance
13.12.3. Sentinel Event

13.13. Technical Assessment and Equipment Purchase Recommendations
13.14. QC Tests and Frequencies
13.15. Guidelines

14. **Computed Tomography (CT)**
    14.1. System Components
        14.1.1. System Geometry
        14.1.2. Tube
        14.1.3. Bow-Tie Filters
        14.1.4. Added 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/effective mAs
        14.3.3. Pitch (Collimator)
        14.3.4. Slice Thickness and Sensitivity Profile
        14.3.5. Detector Binning
    14.4. Image formation
        14.4.1. Filtered Projection
        14.4.2. Back-Projection
        14.4.3. Convolution Algorithms (Filters)
        14.4.4. Helical Reconstruction
        14.4.5. Linear Attenuation Coefficient
        14.4.6. Hounsfield Unit Definition
        14.4.7. Typical CT Numbers
    14.5. Modes of operation
        14.5.1. Axial and Helical Modes
        14.5.2. Fixed and Variable mA
        14.5.3. CT Fluoroscopy
        14.5.4. Localizer Image (Scout)
        14.5.5. Contrast CT
        14.5.6. Temporal CT / Perfusion
        14.5.7. Dual-Energy
        14.5.8. CT Angiography
    14.6. Image Characteristics and Artifacts
        14.6.1. Spatial and Contrast Resolution
        14.6.2. SNR vs. Acquisition Parameters
        14.6.3. Beam Hardening
        14.6.4. Motion
        14.6.5. Partial Volume

14.6.6. Incomplete Projection
14.6.7. Photon Starvation
14.6.8. Streak Artifacts
14.6.9. Ring Artifacts
14.7. Image Processing and Display
14.7.1. Pre-Set Tissue Windows
14.7.2. Multi-Planar Reconstruction (MPR)
14.7.3. Maximum Intensity Projection (MIP)
14.7.4. Volume and Surface Rendering
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
14.9. Dose and Dosimetry
14.9.1. CT Dose Index (CTDI, etc.)
14.9.2. Multiple Scan Average Dose (MSAD)
14.9.3. Dose Length Product (DLP)
14.9.4. Dose Profile
14.9.5. Effective Dose
14.9.6. Phantom Measurement Methods
14.9.7. Dose for Different Application Protocols
14.9.8. Technique Optimization
14.10. Technical Assessment and Equipment Purchase Recommendations
14.11. QC Tests and Frequencies
14.12. Guidelines

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15.1. Sound Wave Propagation
15.1.1. Definition of Sound and Ultrasound
15.1.2. Longitudinal Waves
15.1.3. Transverse Waves
15.2. Sound Wave Properties
15.2.1. Wavelength, Frequency, Period and Velocity
15.2.2. Density and Pressure Changes in Materials
15.2.3. Particle Motion and Particle Velocity
15.2.4. Compressibility and Bulk Modulus
15.2.5. Dependence of Sound Speed on Medium and Properties
15.3. Power and Intensity
15.3.1. Decibel Scale
15.3.2. Relationship between Intensity and Pressure

15.4. Interactions of Ultrasound with Matter
- 15.4.1. Acoustic Impedance
  - 15.4.1.1. Relationship to Density, Speed and Compressibility
  - 15.4.1.2. Impedance in Tissues
- 15.4.2. Attenuation
  - 15.4.2.1. Causes and Relationship to Sound Properties
  - 15.4.2.2. Attenuation Coefficient
  - 15.4.2.3. 0.5 dB/cm/MHz for Soft Tissue
- 15.4.3. Reflection
  - 15.4.3.1. Role of Impedance
  - 15.4.3.2. Normal and Oblique Incidence
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  - 15.4.3.4. Diffuse Reflection
  - 15.4.3.5. Reflection Coefficient
- 15.4.4. Transmission
- 15.4.5. Refraction - Snell's Law
- 15.4.6. Scattering
  - 15.4.6.1. Hyperechoic and Hypoechoic Regions
  - 15.4.6.2. Relationship to Frequency and Scatterer Size
  - 15.4.6.3. Rayleigh Scattering

15.5. Transducer Components
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  - 15.5.1.1. Composition
  - 15.5.1.2. Piezoelectric Reception and Transmission
  - 15.5.1.3. Physical and Electrical Properties
  - 15.5.1.4. Resonance Frequency and Crystal Thickness
- 15.5.2. Transducer Construction
  - 15.5.2.1. Electronics
  - 15.5.2.2. Matching Layers
  - 15.5.2.3. Capacitive Micromachined Ultrasonic Transducers (C-MUT) Transducers

15.6. Transducer Arrays
- 15.6.1. Linear and Curvilinear Arrays
- 15.6.2. Phased Arrays
- 15.6.3. Annular Arrays
- 15.6.4. 1.5D and 2D Arrays

15.7. Beam properties
- 15.7.1. The Near Field
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- 15.7.3. Focused Transducers
- 15.7.4. Side and Grating Lobes

15.8. Transducer Array Beam Formation and Focusing
- 15.8.1. Linear and Sector Scanning
- 15.8.2. Transmit Focusing
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- 15.8.4. Beam Steering

15.8.5. Beam Shaping
15.9. Resolution
15.9.1. Axial
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15.10.3. Field of View/Maximum Depth
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15.11. Image Data Acquisition
15.11.1. Signal Acquisition
15.11.2. Pre-amplification and Analog to Digital Conversion
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15.11.4. Logarithmic Compression
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15.11.6. Rejection
15.11.7. Processed Signal
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15.12.1. Display Modes
15.12.1.1. A-Mode
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15.12.2. Scan Converter
15.12.3. Image Frame Rate Dependencies
15.12.3.1. Depth Setting
15.12.3.2. Transmit Focal Zones
15.12.3.3. Sector Size and Line Density
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15.12.4.1. Preprocessing and Post-processing
15.12.4.2. Speckle and Speckle Reduction
15.12.4.3. Read Zoom and Write Zoom
15.12.5. Distance, Area and Volume Measurements
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15.14.1. Nonlinear Propagation and Origin of Harmonics
15.14.2. Formation of Harmonics in Ultrasound
15.14.3. Features of Harmonic Imaging
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15.14.4. Discrimination of Fundamental and Harmonic Frequencies

15.14.5. Narrow-Band Harmonic Imaging
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15.15.2.1. Rotating Single-Element Transducers
15.15.2.2. Phased Array Transducers
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15.16.1. Image Reconstruction
15.16.2. Transducer Registration Methods
15.16.2.1. Free-Form Motion with External Localizers
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15.17.5. Comet Tail
15.17.6. Side and Grating Lobes
15.17.7. Multipath Reflection and Mirror Image
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15.18.2.1. Reflector Velocity Dependence
15.18.2.2. Doppler Angle Dependence
15.18.3. Spectral Analysis
15.18.4. Continuous Wave (CW) Doppler
15.18.5. Pulsed Doppler
15.18.5.1. Pulse Transmission and Range Gating
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15.18.6. Duplex Scanning
15.18.7. Color Flow Imaging
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15.22. Safety and Bioeffects
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15.22.1.1. Heating
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15.22.1.3. Direct Mechanical
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15.22.2.4. Operation Mode
15.22.3. Intensity Measures of Pulsed Ultrasound
15.22.3.1. Spatial Average/Temporal Average Intensity [I(SATA)]
15.22.3.2. Spatial Peak /Temporal Average Intensity [I(SPTA)]
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15.22.4. Real-time Acoustical Output Labeling
15.22.4.1. Thermal Index (TI)
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16. **Magnetic Resonance**
16.1. Magnetism and Magnetic Fields
16.1.1. Magnetic Susceptibility
16.1.2. Type of Magnetic Materials
16.1.3. Magnetic Fields (B)
16.1.3.1. Units for B
16.1.3.2. Magnetic Dipole
16.1.3.3. Magnetic Moment
16.1.3.4. Nuclear Magnetism (protons and biologically relevant nuclei)
16.1.4. Magnetic Moment Interaction with an External Field (B_0)
16.1.4.1. Alignment (low-energy/high-energy states)
16.1.4.2. Precession
16.1.4.3. Larmor Equation
16.1.5. Net Magnetization Due to B_0
16.1.5.1. Longitudinal Magnetization (M_z)
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16.1.5.3. Proton Density (Spin-Density)
16.1.5.4. Field Strength Dependence
16.2. Nuclear Magnetic Resonance and Excitation
16.2.1. Radiofrequency (RF) field (B_1)
16.2.2. Flip Angle RF Pulse
16.2.3. Free-Induction Decay (FID)
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16.3. Spin Density
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16.4.3. Typical Tissue T_2 Values
16.5. T_2* Relaxation
16.5.1. Dependence on Field Inhomogeneity
16.5.2. Susceptibility-Induced Dephasing (e.g., tissue-air interfaces)
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16.6.1. Spin-Lattice Interactions
16.6.2. Longitudinal Recovery
16.6.3. Typical Tissue T_1 values
16.6.4. Field-Strength Dependence

16.7. Contrast Mechanisms (Pulse Sequences)
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16.7.1.1. Pulse Sequence Basics (Timing Diagrams)
16.7.1.2. Echo Time (TE)
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16.7.1.4. SE Signal Intensity Dependence on TE and TR
16.7.1.5. SE Contrast (T_1, Proton density, T_2-weighted)
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16.7.3. Gradient Echo Pulse Sequence
16.7.3.1. Basic Advantages/Disadvantages Compared to SE Sequence
16.7.3.2. Gradient-Echo Signal-Intensity and Effect of Flip Angle
16.7.3.3. RF-Pulse Spoiling
16.7.3.4. Gradient Echo Contrast (T_2*/T_1, T_2*, and T_1 – weighting)

16.8. MR instrumentation
16.8.1. Static Magnetic Field (B_0) Systems
16.8.2. Gradient Field Subsystem
16.8.2.1. Gradient Coil Geometry (x,y and z)
16.8.2.2. Gradient Strength (mT/m)
16.8.2.3. Eddy Currents and Effects on Gradient Performance
16.8.2.4. Compensation for Effects of Eddy Currents
16.8.2.5. Slew-Rate Specification (mT/m/s)
16.8.3. Shim Coils
16.8.3.1. Inhomogeneity Compensation
16.8.3.2. Passive and Active
16.8.3.3. Geometry
16.8.4. RF Transmitter (B_1) Subsystem
16.8.4.1. RF-Pulse Bandwidth
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16.8.5. RF Receiver Subsystem
16.8.5.1. Digital Sampling of Received Signals
16.8.5.2. Receive Bandwidth
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16.8.6. RF Coils
16.8.6.1. Transmit-and-Receive Coils
16.8.6.2. Volume vs. Surface Coils
16.8.6.3. Receive-Only Coils
16.8.6.4. Quadrature vs. Linear Coils
16.8.6.5. Birdcage Coils
16.8.6.6. Phased-Array Coils

16.8.6.7. SENSE Coils
16.8.7. Data acquisition
16.8.7.1. Analog-to-Digital Converter (ADC) Sampling
16.8.7.2. Other Data Acquisition Elements
16.9. Image Acquisition
16.9.1. Slice-Selection Gradient (SSG)
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16.10.1. Acquisition Time Calculations
16.10.2. Multi-Slice Acquisition
16.10.3. Timing Diagrams of Common Pulse Sequences
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16.10.3.4. Multi-Planar
16.10.3.5. Fast- or Turbo-Spin-Echo (FSE/TSE)
16.10.3.6. Echo-Planar Imaging (EPI)
16.10.3.7. Volume Imaging (3D)
16.11. Two-dimensional Fourier Transform (2DFT) Image Reconstruction
16.11.1. *k*-Space Description
16.11.2. Methods of "Filling *k*-Space"
16.11.2.1. Rectangular
16.11.2.2. Spiral
16.11.2.3. Radial
16.11.2.4. Fractional (e.g., Propeller, One-Half NEX, etc.)
16.12. Image Characteristics
16.12.1. Factors Affecting Spatial Resolution
16.12.1.1. Field-of-View (FOV)
16.12.1.2. Pixel Size
16.12.1.3. Slice Thickness
16.12.1.4. Image Matrix Size
16.12.2. Factors Affecting Signal-to-Noise Ratio (SNR)
16.12.2.1. Voxel Size
16.12.2.2. Signal Averages
16.12.2.3. Receiver (Sampling) Bandwidth
16.12.2.4. Magnetic Field Strength
16.12.2.5. Slice "Cross-Talk"
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16.12.2.7. RF Coil Quality Factor
16.12.2.8. Pulse Sequence Specific Effects
16.12.3. Tradeoffs among Spatial Resolution, SNR, and Aquisition Time
16.12.4. Factors Affecting Image Contrast
16.12.4.1. Proton Density, T_1, T_2
16.12.4.2. Susceptibility
16.13. Contrast Agents

16.13.1. Paramagnetic
16.13.2. Superparamagnetic
16.13.3. Susceptibility Agents
16.14. Saturation
16.14.1. Spatial
16.14.2. Chemical (e.g., fat, silicone)
16.15. Special Acquisition Techniques
16.15.1. Angiography
16.15.1.1. Effect of Blood Flow on Signal Intensity
16.15.1.2. Time-of-Flight (2D/3D) Techniques
16.15.1.3. Phase-Contrast Techniques
16.15.1.4. Contrast-Agent Enhanced MRA Techniques
16.15.2. Diffusion Imaging
16.15.2.1. Basic Principles
16.15.2.2. Diffusion-Weighted Imaging (DWI) Techniques
16.15.2.3. Apparent Diffusion Coefficient (ADC)
16.15.2.4. Diffusion Tensor Imaging (DTI) Techniques
16.15.3. Functional MRI (fMRI)
16.15.3.1. Blood Oxygen Level Dependent (BOLD) Principles
16.15.3.2. Clinical Applications
16.15.4. Magnetization Transfer Contrast (MTC)
16.15.4.1. Basic Principles
16.15.4.2. Contrast Mechanisms
16.15.4.3. Clinical Applications
16.15.5. Parallel MRI
16.15.5.1. Basic Principles
16.15.5.2. Image-Based Implementation
16.15.5.3. *k*-Space-Based Implementation
16.15.6. Spectroscopy
16.15.6.1. Basic Principles
16.15.6.2. Single Voxel Techniques
16.15.6.3. Chemical-Shift Imaging (CSI), 2D and 3D
16.15.6.4. Water Suppression
16.15.6.5. Importance of TE and TR Values
16.15.6.6. Clinical Applications
16.16. Artifacts
16.16.1. Metal and Susceptibility Artifacts
16.16.2. Gradient Field and Static Field Inhomogeneity Artifacts
16.16.3. Radiofrequency Artifacts
16.16.4. *k*-Space Errors
16.16.5. Motion Artifacts
16.16.6. Chemical Shift Artifacts (Fat/Water)
16.16.7. Gibbs (Ringing, Truncation) Artifacts
16.16.8. Aliasing (Wraparound)
16.16.9. Partial-Volume Artifacts
16.16.10. High Speed Imaging Artifacts (e.g., Echo-Planar Distortion, Ghosting)

16.16.11. Effect of High Field Strength on Artifacts
16.17. Image Processing and Display
16.17.1. Maximum-Intensity Projection (MIP)
16.17.2. Volume-/Surface-Rendering
16.18. Safety and Bioeffects
16.18.1. Static Magnetic Field
16.18.1.1. Biological Effects
16.18.1.2. Projectile Hazards
16.18.1.3. Effects on Implanted Devices
16.18.1.4. FDA Limits
16.18.2. RF Field
16.18.2.1. Biological Effects, Including Tissue Heating
16.18.2.2. RF Heating of Conductors and Potential Burns
16.18.2.3. Specific Absorption Rate (SAR)
16.18.2.4. Problems with High Field Strength Systems
16.18.2.5. FDA Limits
16.18.3. Gradient Field
16.18.3.1. Biological Effects, Including Peripheral Nerve Stimulation
16.18.3.2. Sound Pressure Level ("Noise") Issues and Limits
16.18.3.3. FDA Limits
16.18.4. Contrast Agent Safety Issues
16.18.5. Screening of Patients and Healthcare Workers
16.18.6. MR Safety Systems (including superconducting magnet "quench" systems)
16.18.7. Cryogenic Materials
16.19. Magnet System Siting
16.19.1. Basic Facility Design (including "zone" design)
16.19.2. Magnetic Fringe Field and the 0.5 mT (5G) Line
16.19.3. Magnetic Field Shielding
16.19.4. RF Field Shielding
16.19.5. Effects of MRI on Other Equipment/Objects
16.19.6. Effects of Equipment/Objects on MRI
16.20. Technical Assessment and Equipment Purchase Recommendations
16.21. QC tests and frequencies
16.22. Guidelines

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
17.1.3. Radioactive Equilibrium
17.1.3.1. Transient
17.1.3.2. Secular
17.1.4. Nuclear Fission
17.1.5. Nuclear Fusion
17.2. Radioisotope Production
17.2.1. Accelerator/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. Quality Control
17.2.4. Radiopharmaceuticals
17.2.4.1. Preparation of Radiopharmaceuticals
17.2.4.2. Mechanisms of Localization
17.2.4.3. Uptake and Decay
17.2.4.4. Quality Control
17.3. Radiation Detection Instrumentation
17.3.1. Gas-filled Detectors
17.3.1.1. Mechanisms of Operation
17.3.1.2. Applications and Limitations
17.3.1.3. Survey Meters (e.g., GM Counter, Ionization Chamber)
17.3.1.4. Dose Calibrator
17.3.1.5. Quality Control
17.3.2. Scintillation Detectors
17.3.2.1. Mechanisms of Operation
17.3.2.2. Applications and Limitations
17.3.2.3. Pulse-Height Spectroscopy
17.3.2.4. Thyroid Probe
17.3.2.5. Well Counter
17.3.2.6. Survey Meter
17.3.2.7. Quality Control
17.3.3. Semi-Conductor Detectors
17.3.3.1. Mechanisms of Operation
17.3.3.2. Applications and Limitations
17.3.3.3. Pulse-height Spectroscopy
17.3.4. Thermoluminescent Dosimeters (TLDs)
17.3.4.1. Mechanisms of Operation
17.3.4.2. Applications and Limitations
17.3.5. Optically-Stimulated Luminescent (OSL) Dosimeters

17.3.5.1. Mechanisms of Operation
17.3.5.2. Applications and Limitations

17.4. Scintillation Camera
17.4.1. Clinical Purpose
17.4.2. Camera Design
17.4.2.1. Crystal Parameters
17.4.2.2. Spatial Localization
17.4.2.3. Energy Discrimination
17.4.3. Collimators
17.4.3.1. Parallel Hole
17.4.3.2. Pinhole
17.4.3.3. Sensitivity
17.4.3.4. Resolution
17.4.4. Image Acquisition
17.4.4.1. Static
17.4.4.2. Dynamic
17.4.4.3. Gated
17.4.4.4. List-Mode
17.4.5. Image Processing
17.4.5.1. Subtraction
17.4.5.2. Region of Interest (ROI)
17.4.5.3. Time-Activity Curves
17.4.5.4. Spatial Filtering
17.4.5.5. Temporal Filtering
17.4.6. Measures of Performance
17.4.6.1. Uniformity
17.4.6.2. Spatial Resolution
17.4.6.3. Energy Resolution
17.4.6.4. Spatial Linearity
17.4.6.5. Sensitivity
17.4.6.6. Count-Rate Performance
17.4.6.7. Patient Parameters
17.4.7. Artifacts
17.4.7.1. Damaged or Broken Crystal
17.4.7.2. Non-Uniformity
17.4.7.3. Bad Phototube
17.4.7.4. Improper Energy Peaking
17.4.7.5. Mechanical Separation of Coupling Elements
17.4.7.6. Damaged Collimators
17.4.7.7. Motion
17.4.8. Clinical Examples
17.4.8.1. Thyroid
17.4.8.2. Bone
17.4.8.3. Renal
17.4.8.4. Liver/Spleen
17.4.8.5. Cardiac (Ejection Fraction, Myocardial Perfusion)

17.4.8.6. Ventilation Perfusion (VQ)
17.4.8.7. Multi-Energy Imaging
17.4.8.8. Tumor Imaging
17.4.9. Procedure Types (Alternate to Above)
17.4.9.1. Adult
17.4.9.2. Pediatric
17.4.9.3. Infant
17.4.9.4. Pregnant Patient
17.4.9.5. Breast-Feeding Patient
17.4.10. Technical Assessment and Equipment Purchase Recommendations
17.5. SPECT Imaging
17.5.1. Clinical Purpose
17.5.2. Mechanisms of Operation
17.5.2.1. Single- and Multi-Head Units
17.5.2.2. Rotational Arc
17.5.2.3. Continuous Motion
17.5.2.4. Step-and-Shoot
17.5.2.5. Non-Circular Orbits
17.5.3. Attenuation Correction
17.5.4. Image Reconstruction
17.5.5. Sensitivity and Resolution
17.5.6. Technical Assessment and Equipment Purchase Recommendations
17.5.7. Quality Control
17.5.8. Artifacts
17.5.8.1. Attenuation
17.5.8.2. Center of Rotation
17.5.8.3. Uniformity
17.5.8.4. Stray Magnetic Field Effects
17.5.8.5. Motion
17.5.9. Clinical Examples
17.6. Positron Emission Tomography (PET)
17.6.1. Clinical Purpose
17.6.2. Mechanisms of Operation
17.6.3. Detector
17.6.3.1. Type
17.6.3.2. Configuration
17.6.4. Coincidence Detection
17.6.5. Time-of-Flight
17.6.6. Attenuation Correction
17.6.7. Standardized Uptake Value (SUV)
17.6.8. 2D vs. 3D Operation
17.6.9. Count Rate / Administered Dose Considerations
17.6.10. Image Reconstruction
17.6.11. Sensitivity and Resolution
17.6.12. Technical Assessment and Equipment Purchase Recommendations
17.6.13. Quality Control

17.6.14. Artifacts
17.6.14.1. Attenuation Correction
17.6.14.2. Motion
17.6.15. Clinical Examples
17.7. Combined Modalities
17.7.1. SPECT/CT
17.7.1.1. Mechanisms of Operation
17.7.1.2. Clinical Applications
17.7.1.3. Quality Control
17.7.1.4. Artifacts
17.7.2. PET/CT
17.7.2.1. Mechanisms of Operation
17.7.2.2. Clinical Applications
17.7.2.3. Quality Control
17.7.2.4. Artifacts

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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.