Preparing for Medical Physics Components of the ABR Qualifying (Core) Exam
ABR Physics Study Guide

The ABR Qualifying (Core) Exam for radiologists contains material on medical physics. This content is based on medical physics that is used in practice by working radiologists. Thus, the best preparation for the exam is to learn to use medical physics in your routine practice. If you do that well, you should have no problems with medical physics on the Qualifying (Core) Exam. It is the position of the ABR and all professional radiological organizations that an understanding of this material is crucial to the safe and effective practice of radiology.

We recognize, however, that candidates would like additional guidance to assist them with preparation for the exam. While it is impossible to provide the details on the content that many candidates would desire, this document explains how the material is structured and how candidates should prepare for the exam during their years of residency.

General Content

The purpose of examining the candidate about fundamentals is to determine that the candidate has knowledge of:

- Basic concepts of x-ray production and x-ray interactions
- Basic physics concepts, quality assurance, and common artifacts (for all modalities)
- Image quality
- Informatics, image display, reading room monitors
- Radiation dose metrics and units
- Regulatory, accreditation, and advisory agencies
- Radiation, ultrasound, and MRI safety
- Radiation biology

Category-based Questions

On average, the distribution of questions by imaging modality on the exam is as shown in Figure 1. Please note that this is a general guide and there may be variation from exam to exam.

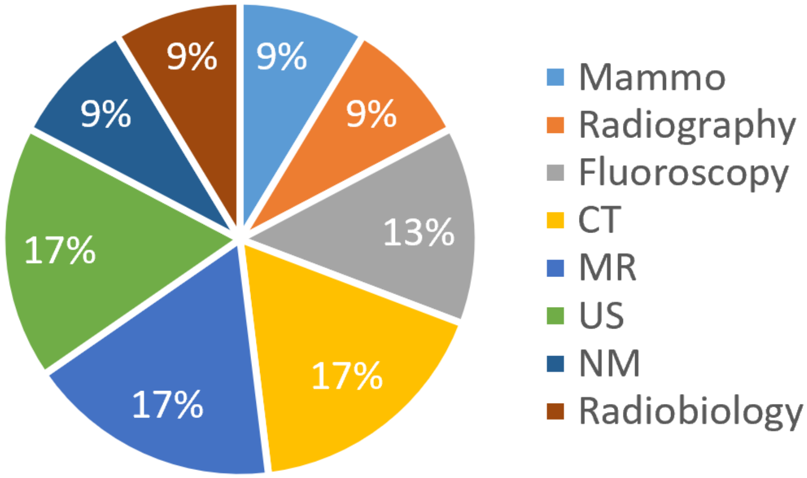

Figure 1: The approximate distribution of medical physics questions by imaging modality.

These modality-based questions are divided into three main categories:

- Application of medical physics in the effective use of the modality
- Safety related to the imaging modality
- Understanding the causes and methods to reduce artifacts associated with a particular modality

These questions are distributed approximately as shown in Figure 2.

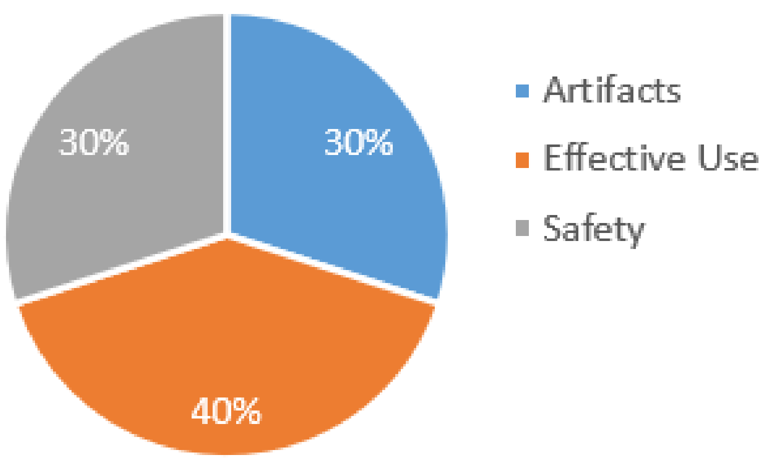

Figure 2: Distribution of the modality-based question categories

Application of Medical Physics to the Effective Use of the Modality

Each imaging modality has certain characteristics that the radiologist must understand to create effective protocols, help technologists adjust imaging technique, and compensate for the size of a patient (e.g., pediatric or obese patients). For example, increasing the amount of a PET radiopharmaceutical to a patient does not necessarily improve image quality but often degrades the image. The questions of this type focus on how the physics characteristics of the modality relate to provide optimal images.

Questions in the “Effective Use” section are designed to determine if the candidate understands how the fundamental physics principles affect the everyday practice of radiology. Emphasis is on principles rather than the memorization of facts that are not directly relevant or that could be easily looked up online. For example, there would be no questions about the relationship $c = \lambda \cdot \nu$ as it applies to electromagnetic radiation since there is no practical application in radiology. However, that same relationship, as it applies to ultrasound, is of interest since it affects resolution and penetration of the ultrasound beam.

EXAMPLE of Effective Use of the Modality Items

1. In a fast-spin-echo (FSE) pulse sequence (TR = 4000 ms, TE = 100 ms, ETL = 12, field of view [FOV] = 30 cm, 256x256), which of the following modifications would reduce imaging time? (*Answer is highlighted yellow.*)

A. Reduce TE to 50 ms
B. Reduce FOV to 25 cm
C. Reduce ETL to 10
D. Reduce TR to 3000 ms

2. What CT acquisition factor will provide the greatest patient radiation dose reduction? (*Answer is highlighted yellow.*)

A. Change helical pitch from 1.2 to 0.9
B. Reduce kV from 120 to 80
C. Reduce mA from 400 to 200
D. Increase rotation speed from 0.5 sec/rot to 0.3 sec/rot

Safety as It Relates to Specific Modalities and Categories

While there is a general quality and safety category on the Qualifying (Core) Exam, there are also safety questions as they relate specifically to medical physics in each category and modality. These questions may involve tissue effects possibly encountered when using ionizing radiation, specific concerns about appropriate thermal index (TI) or mechanical index (MI) in ultrasound, and keeping patients and staff safe in an MRI environment. These safety questions are tied specifically to the modality used. Additional safety questions may be asked regarding radiologist personal safety, such as annual exposure limits for radiation workers, or regarding radiation safety personal protective equipment (PPE).

1. Patient burns in MRI are usually associated with which of the following? (*Answer is highlighted yellow.*)

A. Long TR pulse sequences
B. Loops in EKG leads
C. Patient touching wall of scanner
D. Patients weighing less than 20 kg

2. What is the minimum radiation dose threshold that typically results in epilation? (*Answer is highlighted yellow.*)

A. 1 Gy
B. 3 Gy
C. 10 Gy
D. 15 Gy

Artifacts

All modalities produce imaging artifacts. Radiologists need to be able to recognize these artifacts, separate them from normal/abnormal pathology, and recommend to technologists how to modify the imaging procedure to minimize them. The artifact-related questions may ask the candidate to identify the artifact, to distinguish the artifact from normal or abnormal findings on the image, or to recommend strategies to reduce or eliminate the artifact.

1. What is the cause of the ultrasound artifact shown by the arrow? (*Answer is highlighted yellow.*)

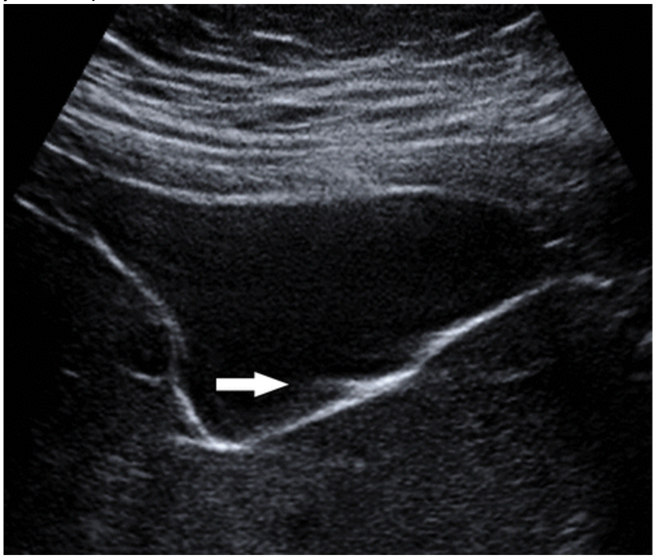

Image taken from Baad M. et al. RadioGraphics 2017 37(5):1408-23 (https://doi.org/10.1148/rg.2017160175)

A. Ring down
B. Reverberation
C. Mirror image
D. Side lobe

2. In the CT image of the head, what is the most likely cause of the "streak" artifact (arrow)? (*Answer is highlighted yellow.*)

A. Partial volume effect
B. Wrong reconstruction filter
C. Low tube current (mA) selection
D. Partial data loss

Summary

The medical physics content on the Qualifying (Core) Exam is intended to reflect the medical physics that is commonly encountered by radiologists in image interpretation, executing procedures, and consulting with colleagues, staff, and patients. It addresses basic material only to the extent that fundamental knowledge is necessary to practice effectively.

Study Guide

The ABR Physics Study Guide aims to give the diagnostic radiology resident an idea of the underlying physics topics and principles that a radiologist should know when graduating from an accredited radiology residency program.

The guide is not a comprehensive list of all topics possible under the realm of medical imaging physics but some core topics to give the resident guidance for preparation for the ABR Qualifying (Core) Exam. For further guidance, the resident can refer to the AAPM curriculum designed for the radiology residents. The AAPM curriculum also contains additional test questions which a resident may find helpful.

1. **Basic Science**
    a. Structure of the atom
        i. Nuclear structure & interactions
        ii. Electron cloud structure & interactions
    b. Electromagnetic radiation
        i. Properties and origins of photons
        ii. Electromagnetic spectrum used in imaging
    c. Particle radiation
2. **Interactions of ionizing radiation with matter**
    a. Charged particle interactions
        i. Ionization
        ii. Excitation
        iii. Bremsstrahlung
        iv. Positron annihilation
    b. Photon interactions
        i. Coherent scattering
        ii. Photoelectric effect
        iii. Compton effect
    c. Photon attenuation
        i. Linear & Mass attenuation
        ii. Half-value layer (HVL) and Beam Hardening
    d. Methods of interaction

        i. Exposure
        ii. Kinetic energy released in matter (KERMA)
        iii. Absorbed Dose
        iv. Equivalent Dose
        v. Effective Dose

3. **X-ray Production**
    a. X-ray tube cathode and anode
        i. Filament and focusing cup
        ii. Anode angle and Line focus principle
        iii. Anode heel effect
    b. Electron interactions with the anode
        i. Probability of interactions
        ii. Contributions to the x-ray beam spectrum
    c. X-ray beam characteristics
        i. Quality
        ii. Quantity
    d. Technique factors and their effect on image quality (kV, mA, exposure time, focal spot size)
    e. X-ray beam filtration
    f. Beam collimation
4. **Image Quality Metrics**
    a. Generation of image contrast
    b. Factors that affect visibility of contrast (low-contrast resolution)
        i. Image Noise (quantum and electronic)
        ii. Signal-to-noise ratio and Contrast-to-noise ratio
        iii. Scatter
        iv. Contrast agents
    c. Spatial resolution and sources of blur
    d. Temporal resolution
5. **Image Processing, Informatics & Display**
    a. Signal sampling
        i. Nyquist limit
        ii. Aliasing
    b. Image matrix
    c. Pixel size and bit depth
    d. Image processing
        i. Reconstruction methods
        ii. Smoothing
        iii. Edge enhancement
        iv. Window and level adjustments
    e. DICOM
    f. PACS
    g. Image compression (lossy, lossless)

h. Computer-aided detection (CAD)
i. Basic concepts of artificial intelligence (i.e., machine learning and deep learning)
j. Display monitor characteristics
k. Optimal image viewing conditions

6. Radiation Biology

a. Molecular and cellular effects of radiation
    i. Direct vs. Indirect Effects
    ii. Cell type and cell cycle radiosensitivity
    iii. Cell damage, survival, repair, and death (apoptosis)
b. Tissue reactions (Deterministic) effects
    i. Skin
    ii. Eye lens
    iii. Gonads
c. Stochastic effects
    i. Epidemiological Studies
    ii. Radiation induced cancer
d. Teratogenesis
    i. Developmental effects
    ii. Childhood Leukemia
    iii. In-utero Sensitivity
e. Acute Radiation Syndromes
    i. Hematopoietic
    ii. Gastrointestinal
    iii. Neurovascular
    iv. LD50/60
f. Radiation risk and dose response models
    i. Benefit vs. Risk in Radiology (BIER VII)
    ii. Relative and Absolute Risk
    iii. Dose-Response Models

7. Radiation Protection

a. Sources of radiation to the U.S. population
    i. Natural
    ii. Medical
b. Patient and fetal doses from imaging procedures
c. Monitoring and management of patient and fetal dose
    i. Diagnostic Reference Levels (DRL)
    ii. Joint Commission Sentinel Events
    iii. Nuclear Regulatory Commission (NRC) Medical Event
    iv. Patient Dose Tracking
d. Occupational and public dose regulatory dose limits
    i. Effective dose and organ dose
    ii. Declared pregnant workers
    iii. Members of the public

        iv. Personnel dosimeters
    e. Radiation protection principles and methods
        i. Time, distance, shielding
        ii. As Low as Reasonably Achievable (ALARA)
    f. Regulatory, accreditation, and advisory agencies

8. **General Radiography**
    a. X-ray tube, filtration, and collimation
    b. Scatter reduction and grids
        i. Grid ratio
        ii. Bucky factor
    c. Radiographic detector systems (CR, DR, etc.)
        i. Basic design and operation
        ii. Sensitivity and spatial resolution
    d. System geometry and magnification
    e. Applications, acquisition modes, and protocols
        i. Typical technique factors for common examinations
        ii. Pediatric, adult, and bariatric patients
        iii. Automatic exposure control operation
        iv. Mobile/portable examinations
        v. Exposure index
        vi. Deviation index
    f. Patient radiation dose
        i. Factors that affect entrance skin air KERMA and absorbed dose
        ii. Average effective dose for common exams
    g. Image quality and factors that affect
        i. Subject contrast
        ii. Low contrast visibility
        iii. Geometric blur
        iv. Detector blur
        v. Motion blur
    h. Common artifacts and artifact mitigation

9. **Mammography**
    a. X-ray tube targets and filtration materials
    b. Tube alignment and collimation
    c. Breast compression
    d. Scatter reduction and grids
    e. Mammography detectors (CR and DR)
        i. Basic design and operation
        ii. Sensitivity and spatial resolution
        iii. Automatic exposure control
    f. Contact vs magnification mammography
    g. Digital breast tomosynthesis
        i. Sweep angle and acquisition time

    ii. Number of acquisitions and image reconstruction
    iii. In plane and z-axis spatial resolution
    iv. Synthetic 2D images
h. Stereotactic breast biopsy systems
    i. System configuration
    ii. Principles of lesion localization
i. Dose
    i. Typical values for the standard breast (average glandular and effective dose)
    ii. MQSA requirements for 2D and 3D mammography
j. Common 2D and 3D artifacts and artifact mitigation
k. Quality assurance and quality control
    i. MQSA standards
    ii. Accreditation requirements
    iii. Common quality control testing requirements
    iv. Radiologist workstation display and viewing requirements

10. Fluoroscopy and Interventional Imaging

a. X-ray tube and filtration
b. Collimation and grids
c. Automatic exposure rate control system
d. Fluoroscopic detectors
    i. Image Intensifier and Flat panel
    ii. Field of View (FOV), Binning and Electronic Magnification
e. System geometry and geometric magnification
    i. Geometric Magnification
    ii. System Configurations (c-arm, under table tube, over table tube, etc.)
f. Image quality and factors that affect
    i. Low-Contrast Resolution
    ii. Spatial Resolution
    iii. Temporal Resolution
g. Operating modes
    i. Continuous Fluoroscopy
    ii. High-Dose Rate Fluoroscopy
    iii. Variable Frame-Rate Pulsed Fluoroscopy
    iv. Digital Spot
    v. Cine/Fluorography
    vi. Digital Subtraction Angiography (DSA)
    vii. Cone-beam CT Imaging (3D Rotational Angiography)
h. Applications
    i. Conventional Fluoroscopy
    ii. Interventional Fluoroscopy
    iii. Pediatric
i. Protocol optimization

    i. Acquisition Parameters (e.g., kV, Pulse Rate)
    ii. Patient Positioning/Geometry
    iii. Acquisition mode
    iv. Dose saving options (last image hold, beam-on time etc.)
j. Artifacts and artifact mitigation
    i. Image Intensifier (II) (e.g., Pincushion etc.)
    ii. Flat Panel (e.g., Dead Pixels etc.)
k. Patient dose, dose metrics and dose tracking
    i. Dose Rate Limits
    ii. Audible Alarms
    iii. Minimum Source-to-Patient Distance
    iv. Interventional Reference Point
    v. Dose Metrics (peak skin dose, air KERMA, DAP etc.)
    vi. Sentinel Event
    vii. Personnel Protection (time, distance, shielding, optimization)

11. Computed Tomography

a. X-ray tube, beam filtration, and bow-tie filters
b. System geometries and operating modes
    i. Gantry/Beam Geometry
    ii. Localizer Radiograph, axial, helical etc.
    iii. Cardiac/Respiratory Gated
    iv. CT Fluoroscopy
    v. Dual Source and Dual Energy
c. Acquisition parameters
    i. Tube Voltage (kV) and Automatic kV Selection
    ii. Tube Current-Time Product (mAs) and Effective mAs
    iii. Automatic Tube Current Modulation
    iv. Organ Dose Modulation
    v. Pitch
    vi. Detector Configuration, Beam Width
    vii. Scan Field of View
d. Image formation and reconstruction
    i. Sinogram
    ii. Reconstruction Methods (FBP, Iterative and AI)
    iii. Reconstruction Filters/Convolution Kernels
    iv. CT Number/Hounsfield Unit
    v. Reconstruction Thickness (slice) and Interval
    vi. Reconstruction Field of View
e. Image quality and Artifacts
    i. Spatial, Contrast, and Temporal Resolution
    ii. Common Artifacts and Mitigation
f. Adult, Pediatric, and Bariatric Protocol Applications and Optimization
    i. Single vs. Multi-Phase Exams

ii. Perfusion CT
iii. Pediatric CT
iv. Cardiac CT
v. CT Angiography
vi. Dual Energy CT

g. Patient dose metrics and typical values
    i. Computed Tomography Dose Indices (CTDIvol, etc.)
    ii. Dose-Length Product (DLP)
    iii. Organ and Effective Dose
    iv. Size-Specific Dose Estimate (SSDE)

12. Ultrasound

a. Properties of ultrasound waves
b. Beam formation and characteristics
    i. Near and Far Fields
    ii. Side and Grating Lobes
    iii. Linear and Sector Scanning
    iv. Transmit and Receive Focusing
    v. Beam Steering and Shaping
c. Interactions of sound waves with tissue
    i. Acoustic Impedance
    ii. Density, Speed, and Compressibility
    iii. Reflection, Refraction, and Transmission
    iv. Scattering, Absorption, and Attenuation
d. Transducer components and Arrays
    i. Backing material, piezoelectric, matching layer, acoustic lens
    ii. Types of transducer arrays (Linear, Curvilinear etc.)
e. Pulse-echo imaging principles
    i. Pulse-Repetition Period, Frequency, and Duty Cycle
    ii. Field of View and Maximum Depth
    iii. Frame Rate
    iv. Time Gain compensation
    v. Power, gain and dynamic range
f. Display modes (A-mode, B-mode etc.)
g. Doppler imaging principles
    i. Flow Dynamics (e.g., Laminar etc.)
    ii. Continuous Wave, Pulsed
    iii. Power, Spectral, Color Doppler
h. Special imaging techniques
    i. Harmonic Imaging
    ii. Compound Imaging
    iii. Contrast-enhanced
    iv. Elastography
i. Image quality and common artifacts

    i. Spatial Resolution: Axial, Lateral, Elevational
    ii. Temporal Resolution
    iii. Image Contrast, Noise, CNR
    iv. Transducer artifacts (e.g., Grating Lobes, etc.)
    v. Propagation artifacts (e.g., Shadowing, Ring Down, etc.)
    vi. Doppler artifacts (e.g., Twinkle, Flash, Flow Ambiguity, etc.)
- j. Safety and typical limiting values
    - i. Heating and Thermal Indices (TI)
    - ii. Cavitation and Mechanical Index (MI)
    - iii. Acoustic Power
    - iv. Pregnant Patient and Pediatric Protocols

13. Magnetic Resonance Imaging

- a. MRI Instrumentation
    - i. Static magnetic field (B_0-field), i.e., Fringe field
    - ii. Coils (Gradient field subsystems, Shim coils, and RF coils)
    - iii. Transmit/receive systems
- b. Fundamentals of magnetism
    - i. Magnetic fields
    - ii. Susceptibility
    - iii. Magnetic moments and net magnetization
    - iv. Magnetic resonance (Larmor equation)
- c. Signal generation and encoding
    - i. Radiofrequency field (RF) excitation
    - ii. Tissue relaxation
    - iii. Signal localization (imaging gradient interactions)
- d. Pulse sequences and contrast mechanisms
    - i. Tissue characteristics (i.e., T1, T2, proton density)
    - ii. Pulse sequence parameters and timing diagrams
    - iii. Spin-Echo pulse sequences (basic, fast)
    - iv. Gradient-Echo pulse sequences
    - v. Echo-planar imaging (EPI) and functional MRI (fMRI)
        1. Diffusion and Diffusion tensor imaging (DTI)
        2. Blood oxygenation level dependent (BOLD)
        3. Perfusion
    - vi. Signal suppression
        1. Inversion recovery
        2. Spatial
        3. Spectral (or chemical)
        4. Magnetization transfer
        5. Dixon method
        6. Gradient moment nulling (GMN)
    - vii. MR angiography (MRA) & cardiac
    - viii. MR spectroscopy (MRS)

ix. Susceptibility weighted imaging (SWI)
x. Breast MRI

e. Image reconstruction
    i. k-space filling techniques
    ii. Parallel imaging
f. Image quality characteristics and factors that affect SNR and spatial resolution
g. Common Artifacts and artifact mitigation
h. MRI Safety and biological effects (see Non-interpretative skills study guide)

14. Nuclear Medicine

a. Fundamentals of Nuclear Medicine
    i. Counting statistics
    ii. Nuclear transformation, radioactivity, and equilibrium
    iii. Radioisotope production (reactors, cyclotrons, and generators)
    iv. Instrumentation (well counter, dose calibrator, survey meters, thyroid probe)
b. Radiopharmaceuticals and their administration
    i. Tracer concept
    ii. Uptake, distribution, & clearance
    iii. Specific activity
    iv. Quality assurance and control procedures
c. Occupational and patient safety, quality management, and regulatory issues
    i. External exposure and internal dosimetry
    ii. Pregnancy, Fetal dose, and Breastfeeding patients
d. Nuclear medicine imaging
    i. Scintillation and solid-state camera design and operation
        1. Photomultiplier tube (PMT) and Anger logic
        2. Collimator types and characteristics
        3. Quality control
    ii. Planar imaging properties and techniques
    iii. SPECT imaging properties and techniques
    iv. Nuclear medicine therapy
        1. Radiopharmaceutical usage and regulatory considerations
        2. Written directive, patient safety, and release considerations
e. PET imaging
    i. Positron Annihilation
    ii. Scintillation and solid-state detector material
    iii. Positron emission scanner design and operation
    iv. Imaging properties and techniques
    v. Quality control
f. Use of CT in hybrid PET and SPECT imaging
    i. Attenuation correction
    ii. Radiation dose tradeoff
g. Reconstruction

        i. Filtered back projection (FBP)
        ii. Iterative reconstruction (i.e., MLEM & OSEM)
        iii. Quantitative imaging
        iv. Standardized uptake value (SUV)
h. Image quality characteristics
    i. SNR
    ii. Spatial resolution
    iii. Sensitivity and count rate
    iv. Image noise
i. Common Artifacts and artifact mitigation
j. Radioisotope Safety Content (See RISC study guide)