Physics and Instrumentation
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QUESTIONS

1. A patient scheduled to undergo chemotherapy for breast carcinoma is referred for baseline equilibrium radionuclide angiography (ERNA) for assessment of left ventricular (LV) function to monitor for cardiotoxicity. Which of the following statements is true?
   A. ERNA utilizes technetium-99m sestamibi to tag red blood cells (RBCs).
   B. Hydralazine, prazosin, heparin, and digoxin improve RBC labeling.
   C. Heart/lung ratio can be calculated with this technique.
   D. When calculating left ventricular ejection fraction (LVEF), background activity is added.

2. Which of the following statements regarding first-pass radionuclide angiography (FPRNA) is true?
   A. FPRNA can detect and quantify left-to-right cardiac shunts.
   B. Technetium-99m diethylamine triamine pentaacetic acid (DTPA) can be used for FPRNA.
   C. FPRNA can evaluate right and LV systolic function.
   D. Optimal results are achieved in the upright, straight anterior view.
   E. All of the choices
3. Approximately what fraction of 140 keV gamma rays (technetium-99m) pass through a typical low-energy high-resolution (LEHR) parallel-hole collimator?
   A. 1 in 10 (10%)
   B. 1 in 100 (1%)
   C. 1 in 1,000 (0.1%)
   D. 1 in 10,000 (0.01%)

4. If a gamma camera with parallel-hole collimator is moved farther away from the patient, how are resolution and sensitivity affected?
   A. Resolution worsens, and sensitivity remains approximately constant.
   B. Sensitivity worsens, and resolution remains approximately constant.
   C. Both resolution and sensitivity worsen.
   D. Both resolution and sensitivity remain approximately constant.

5. For thallium-201 imaging, the photons detected in the 70-keV window are produced by which mechanism?
   A. Bremsstrahlung
   B. Gamma-ray emission
   C. Internal conversion
   D. X-ray emission

6. In a planar gated blood pool study, 121,344 net counts are measured in the left ventricle at end diastole, and 53,311 net counts are measured at end systole. What is the LVEF? (Assume that background count subtraction has already been performed.)
   A. 22%
   B. 44%
   C. 56%
   D. 78%
7. Which of the following methods of attenuation correction (AC) is not acceptable for nuclear cardiology?
   A. Transmission source AC
   B. Calculated AC from external boundaries
   C. Computed tomography (CT)-based AC
   D. None of the choices (i.e., all are acceptable)

8. The frequency of energy peaking for a gamma camera should be performed:
   A. Daily.
   B. Weekly.
   C. Only after camera service.
   D. Monthly.

9. The technetium-99m photopeak on a gamma scintillation camera is progressively increasing. The most likely cause for this photopeak shift is:
   A. High-energy collimator.
   B. Energy window set at wrong peak.
   C. High-voltage supply to the photo multiplier tube (PMT).
   D. Software issue.

10. To check if all the PMTs are working properly on a gamma camera, which of the following tests should be performed?
   A. Center of rotation
   B. Linearity
   C. Flood field uniformity
   D. Resolution

11. The interaction of a technetium-99m gamma photon with the scintillation camera is primarily by:
   A. Compton effect.
   B. Photoelectric effect.
   C. Pair production.
   D. Scatter effect.
12. In order for the technetium-99m peak to be acquired within a 20% window, the window setting should be:
   A. 112 to 168 keV.
   B. 126 to 154 keV.
   C. 0 to 140 keV.
   D. 112 to 140 keV.

13. The best method to check for patient motion on a cardiac single photon emission computed tomography (SPECT) study is to:
   A. Use a ramp filter during reconstruction.
   B. Review the long- and short-axis images.
   C. Check projection images in a cine format.
   D. Ask the technologist if the patient moved.

14. In a cardiac SPECT study, the acquired planar projections are first reconstructed into which body plane?
   A. Transaxial
   B. Long axis
   C. Coronal
   D. Planar

15. In a multigated acquisition (MUGA) study, the cardiac cycle is divided in 20 equal time frames and the patient heart rate is 60 beats per minute. Average time per frame is:
   A. 5 seconds.
   B. 50 seconds.
   C. 0.05 seconds.
   D. 0.5 seconds.
16. Dual-head camera detectors are mounted next to each other in a 90-degree orientation to the gantry for a cardiac study; this is primarily done because:
   A. The resolution is improved.
   B. The time is reduced in half compared to full 180-degree rotation.
   C. Scatter is reduced.
   D. The resolution is increased.

17. The amount of energy deposited by the radiation per unit length in an absorber is known as:
   A. Specific ionization.
   B. Linear transfer energy (LET).
   C. Range of radiation.
   D. Exposure.

18. Attenuation artifacts are prevalent in SPECT imaging modalities. Which of the following statements is true?
   A. Anterior wall attenuation is present in males more than females.
   B. Specificity of diagnosing right coronary artery (RCA) disease is compromised in male patients.
   C. Gated SPECT images are of little help in ruling out attenuation artifacts.
   D. Attenuation artifacts affect the sensitivity of SPECT imaging but not specificity.

19. Using AC and resolution compensation has been recently introduced in SPECT imaging. This newer technology:
   A. Reduces the sensitivity of SPECT to detect coronary artery disease (CAD).
   B. Improves the sensitivity of SPECT to detect multivessel CAD.
   C. Improves the number of false-negative SPECT studies.
   D. Reduces the number of false-positive SPECT studies.
20. When comparing pharmacologic SPECT versus pharmacologic positron emission tomography (PET), all the following statements are true except:
   A. PET has a higher spatial resolution.
   B. PET perfusion tracers have a shorter half-life.
   C. Quantification of absolute myocardial blood flow is more feasible with PET.
   D. PET agents are readily and widely available.

21. What percentage of 140-keV gamma rays (technetium-99m) is attenuated by 10 cm of water (attenuation coefficient of water at 140 keV = 0.15 cm⁻¹)?
   A. 22%
   B. 44%
   C. 56%
   D. 78%

22. In the above situation (technetium-99m in water), the interaction of gamma rays with the medium is dominated by which process?
   A. Photoelectric absorption
   B. Compton scattering
   C. Rayleigh scattering
   D. Pair production
1. **ANSWER: C.** Technetium-99m is used to radiolabel the patient’s RBCs. There are three methods for radiolabeling: *in vivo*, *in vitro*, and *in vivitro*. For *in vivo* labeling, the patient receives intravenous stannous pyrophosphate 15 minutes prior to injection of 15 to 30 millicuries of technetium-99m pertechnetate. This method is the fastest and least expensive but has the lowest labeling efficiency of the RBCs and has a high background due to non-specific labeling of circulating proteins. For the *in vitro* method, 10 to 15 mL of the patient’s blood is drawn and the stannous pyrophosphate and technetium-99m are added outside the body. Once labeling has been completed, the RBCs are reinjected into the patient. A commercial kit called Ultratag is available. This technique results in the highest labeling efficiency and lowest background activity but is more expensive and time-consuming. The third method involves intravenous injection of the stannous pyrophosphate prior to removal of 10 to 15 mL of the patient’s RBCs that are then mixed with the technetium-99 pertechnetate.

There are many frequently used medications (hydralazine, prazosin, heparin, and digoxin) that inhibit binding of the technetium-99 pertechnetate to the hemoglobin molecule inside the RBCs. Poor binding is easily detected by finding free technetium-99m pertechnetate in the mucosa of the stomach and in the thyroid gland.

LVEF is calculated by measuring LV counts at end systole and end diastole and correcting for background activity due to overlying radioactivity and background scatter adjacent to the lateral or inferoapical walls of the ventricle. Failure to correct for background activity results in a lower ejection fraction measurement.

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\text{LVEF} = \text{Background corrected end diastolic counts} - \text{Background corrected end systolic counts} / \text{Background corrected end diastolic counts}.
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Heart/lung ratio can be calculated by this technique. This ratio measures how well the ventricles compensate by comparing the counts in the heart and lung. Pooling of blood in the lungs has been reported to be present in heart failure.

The assessment of left ventricle and right ventricle (RV) using ERNA is a class I indication in the ACC/AHA Radionuclide Guidelines. The majority of other indications fall in the class II and III categories.

**REFERENCE:**


2. **ANSWER: E.** In addition to measuring LV and RV function, FPRNA can also detect and quantify atrial and ventricular shunts. DTPA, cleared by the kidneys, and technetium-99m sulfur colloid, cleared by the liver, give accurate results. technetium-99m sestamibi and tetrofosmin used to assess myocardial perfusion at rest or peak stress can be given as a bolus for FPRNA when concentrated in a sufficiently small volume, ideally 0.5 to 1 mL. FPRNA can be performed when doing an ERNA study by the *in vivo* method but not when labeling is performed by *in vitro* or *in vivitro*.
methods due to the large volume administered. For timing purposes and quality of image (count density), large veins close to the heart are required for the rapid bolus of DTPA. The straight upright anterior view has the advantage of stabilizing the patient’s chest against the detector and positioning the patient so that the right and left ventricles will be in the field of view. FPRNA allows for RV function assessment. A shallow right anterior oblique (RAO) view is recommended to enhance right atrial–RV separation.

**REFERENCE:**

3. **ANSWER: D.** A typical LEHR collimator has a sensitivity of around 200 cpm/μCi for technetium-99m, which equals (3.3 cps)/(3.7 x 10^4 Bq) = 0.9 x 10^-4 cps/Bq. Considering that the crystal efficiency is about 90% and that the 140-keV emission efficiency of technetium-99m is 89%, the collimator efficiency is 1.1 x 10^-4, or about 1 in 10,000.

4. **ANSWER: A.** Collimator blur increases with distance, and thus resolution worsens. The number of counts passing through the collimator does not change appreciably as distance increases.

5. **ANSWER: D.** Thallium-201 decays by electron capture to mercury-201. The mercury-201 is in an excited state and releases x-rays with energies near 70 keV.

6. **ANSWER: C.** The difference between the net counts (121,344 − 53,311 = 68,033) indicates the activity ejected by the left ventricle. The ejection fraction is (68,033/121,344) = 56%.

7. **ANSWER: B.** Transmission and CT-based AC use a radioactive source or CT to create density or attenuation maps that are applied to the emission activity from the heart during reconstruction. Calculated AC does not directly measure the attenuation but calculates it based on assumptions of uniform attenuation and has been used successfully for brain SPECT or PET since the attenuation coefficient is approximately constant over the entire slice. However, for cardiac imaging, there is large variance in attenuation coefficient (lungs vs. other tissues such as diaphragm and breast), and calculated methods are not reliable.

8. **ANSWER: A.** The gamma camera should be checked each day before use to ensure that the energy window has not drifted and the energy spectrum is of the appropriate shape. The energy spectrum of a radionuclide source is acquired, and the photopeak is checked (either automatically or visually) to confirm that it is centered in the energy window.
9. **Answer:** C. The PMT consists of a photocathode that is light sensitive and a series of metallic plates (dynodes). A high voltage is applied to the plates and when a light photon strikes the crystal, the photoelectron is absorbed by the photocathode and is multiplied by each dynode and a pulse is generated, which is proportional to the amount of energy of the isotope interacting with the crystal. The voltage to these plates has to be very stable, and a slight variation will greatly affect the pulse generated.

**REFERENCES:**

10. **Answer:** C. A uniform source of radioactive source (flood sheet) is placed on the camera detector to check if all the PMTs are operational. If a PMT tube is malfunctioning, then a blank spot is observed on the flood scan. The large white area in the lower right corner shows the abnormality (Fig. 1.1). The rest of the detector is uniform.

![FIGURE 1.1](image_url)

**REFERENCES:**

11. **Answer:** B. In photoelectric absorption, the gamma ray transfers all its energy to an orbital electron of the absorbing material and a photoelectron is released. Compton scatter occurs when the gamma photon transfers only part of its energy to an orbital electron. The scattered photon travels in a different direction and may further interact in the material.
REFERENCES:


12. **ANSWER: B.** Technetium-99m has a mean photopeak energy of 140 keV. In order to set a 20% window centered on the photopeak, the window width is 140 x 0.2 = 28. This gives a range of 14 keV on either side of 140 keV, thus the energy window limits are 126 to 154 keV.

REFERENCE:


13. **ANSWER: C.** A ramp filter is routinely used during reconstruction by filtered backprojection and does not give any information on motion. Motion during acquisition may give the following artifacts: misalignment of the apex, matching 180-degree areas of decreased intensity in the anterior and inferior walls, hotspots in the septum or lateral wall, and “blobs” or a ring of activity in the anterior wall or an apical nipple. However, seeing such artifacts on the long- and short-axis images does not confirm that there was motion. Review of the raw projection images in a cine format allows visual detection of vertical or up-and-down motion. This can be corrected using motion correction or, if it is excessive, reacquiring the study. Horizontal or side-to-side motion is difficult to detect and cannot be corrected. Rapid or deep breathing may also cause motion like artifacts. Acquisition with a dual-head camera will sometimes give the appearance of motion as the images from each head are displayed in a continuous loop. The last acquisition from one head is displayed next to the first acquisition from the other head. Spatially these images are adjacent, but temporally one is at the end and the other at the beginning of acquisition. If the patient moved gradually, such motion may not be detected on individual projections but is seen in the transition from one head to the other. Such motion should not be motion corrected.

The technologist should be questioned, but this in itself is not sufficient as he or she may not have been observing the patient throughout the study.

REFERENCE:


14. **ANSWER: A.** Thirty-two to sixty-four planar projections are acquired 180 degrees around the patient perpendicular to the long axis of the body, and the initial reconstruction is into the transaxial plane. From these transaxial images, the long axis of the heart is defined, and subsequently the conventional vertical and horizontal long-axis and the short-axis images are reconstructed for analysis.

REFERENCE:

15. **ANSWER: C.**

60 s/(heart rate × the numbers of frames)

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\frac{60}{(60 \times 20)} = 0.05
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**REFERENCE:**


16. **ANSWER: B.** In a cardiac SPECT study, typically 64 projections are obtained over 180 degrees at 3-degree increments, and each projection usually takes about 20 seconds. A total of approximately 21 minutes will be required. However, if two detectors at 90-degree orientation are used, the time to acquire the 64 projection will be half (11 minutes).

**REFERENCE:**


17. **ANSWER: B.** LET is the amount of energy deposited per unit length of the absorber, and units are expressed as keV/μm. Electromagnetic and beta particles have low LET, since they lose little energy per interaction. Alpha particles are heavy particles and lose energy very rapidly and have high LET.

**REFERENCE:**


18. **ANSWER: B.** Inferior wall attenuation is often present in male patients (diaphragmatic attenuation), and anterior attenuation is often seen in female patients (breast attenuation). These artifacts often affect the specificity of diagnosing CAD by introducing false-positive tests. Normal systolic thickening on gated SPECT in a fixed defect on both rest and stress images represents an attenuation artifact rather than a myocardial scar, which is associated with reduced systolic thickening.

**REFERENCES:**


20. **ANSWER: D.** PET agents used currently for perfusion (rubidium-82 and 13N-ammonia) have limited availability.

21. **ANSWER: D.** The fraction of nonattenuated gamma rays is given by $e^{-\mu x} = 0.22$, where $\mu$ is the attenuation coefficient and $x$ is the length. The percent attenuated is $(1 - 0.22) \times 100\% = 78\%$.

22. **ANSWER: B.** Compton scattering dominates. Photoelectric absorption is approximately proportional to $Z^3/E^3$ and is negligible at 140 keV for a low-$Z$ material like water. Rayleigh scattering is not significant at photon energies used in nuclear medicine. Pair production requires photon energies of at least 1.02 MeV ($= 2 \times 511$ keV).