Physics

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X-Ray Mammography

1. When a molybdenum (Mo) target is used, why would the Rhodium (Rh) filter be selected instead of a Molybdenum (Mo) filter to image thicker and/or denser breasts?
   (a) The K-shell binding energy of Rh is higher than that of Mo.
   (b) Rh produces less Bremsstrahlung radiation than Mo.
   (c) Rh produces characteristic X-rays with energies that are useful for clinical imaging, whereas Mo does not.
   (d) Rh allows the transmission of more low energy X-rays.

2. What is the primary advantage of digital breast tomosynthesis (DBT) compared to 2D mammography?
   (a) Improved in-plane spatial resolution.
   (b) Reduced patient dose.
   (c) Magnification of suspicious breast lesions.
   (d) Reduced anatomical noise.

3. What are typical technique factors for a 2D contact mammogram of an average-sized breast (6 cm compressed breast thickness, 15% glandularity)?
   (a) 28 kV, 100 mAs, grid, 0.3 mm focal spot.
   (b) 28 kV, 100 mAs, no grid, 0.1 mm focal spot.
   (c) 55 kV, 50 mAs, no grid, 0.3 mm focal spot.
   (d) 55 kV, 50 mAs, grid, 0.1 mm focal spot.

4. What are typical technique factors for a magnification mammogram of an average-sized breast (6 cm compressed breast thickness, 15% glandularity)?
   (a) 28 kV, 100 mAs, grid, 0.3 mm focal spot.
   (b) 28 kV, 100 mAs, no grid, 0.1 mm focal spot.
   (c) 55 kV, 50 mAs, no grid, 0.3 mm focal spot.
   (d) 55 kV, 50 mAs, grid, 0.1 mm focal spot.

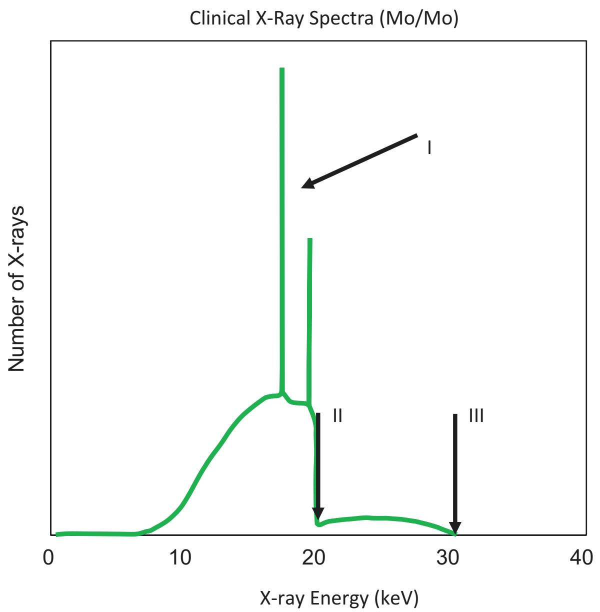
5. What is the primary reason for using lower X-ray tube voltages (kV) in mammography compared with other X-ray imaging modalities?
   (a) Reduced dose to the breast.
   (b) Reduced focal spot blur.
   (c) Improved subject contrast.
   (d) Improved spatial resolution.

6. What is the primary mechanism of interaction between X-ray photons and breast tissue during a mammography exam?
   (a) Rayleigh scattering.
   (b) Photoelectric absorption.
   (c) Compton scattering.
   (d) Pair production.

7. What is the advantage of breast compression?
   (a) Reduced scatter.
   (b) Reduced geometric blurring.
   (c) Longer exposure times are permitted.
   (d) a and b.

8. Spatial resolution is improved in mammography by all of the following, except?
   (a) Smaller focal spot size.
   (b) Reduced X-ray tube voltage (kV).
   (c) Breast compression.
   (d) Reduced detector element size.

9. Match the labeled features of the clinical X-ray spectrum with the parameter that influences its position on the spectrum.

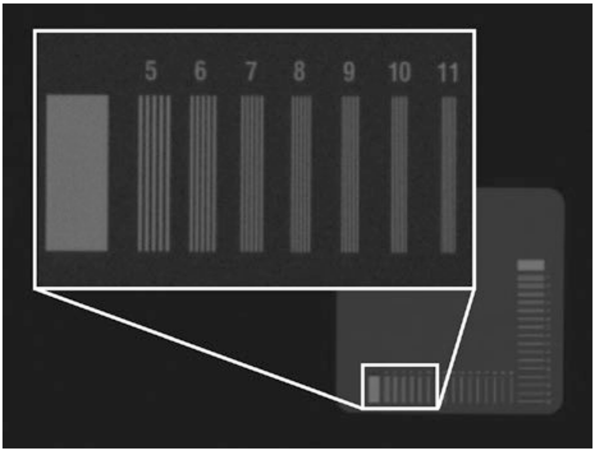


   (a) X-ray tube voltage (kV).
   (b) K-edge energy of the selected filter.
   (c) Target material.

10. Why is the chest wall aligned with the cathode side of the X-ray tube, while the nipple is aligned with the anode side of the X-ray tube?
   (a) To improve subject contrast.
   (b) To improve spatial resolution.
   (c) To achieve a more uniform exposure at the image receptor.
   (d) To increase the field of view.

11. The ACR mammography phantoms include all of the following features, except?
    (a) Fibers.
    (b) Specks.
    (c) Masses.
    (d) Line pairs.

12. Which characteristic of system performance is being evaluated in the image below?

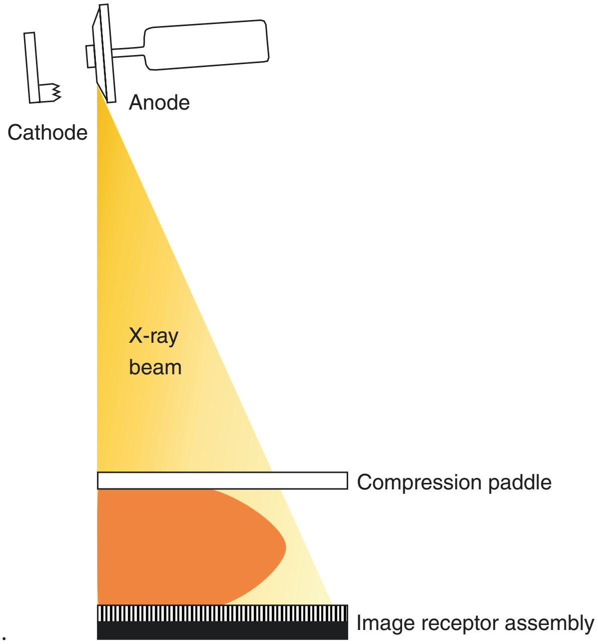


    (a) Contrast resolution.
    (b) Spatial resolution.
    (c) Noise texture.
    (d) Contrast-to-noise ratio.

13. The visibility of a 3 cm low-contrast breast lesion may be improved by which of the following?
    (a) Increasing mAs.
    (b) Reducing kV.
    (c) Reducing detector element size.
    (d) a and b.

14. What is the SI unit of average glandular dose (AGD)?
    (a) Sievert.
    (b) Gray.
    (c) Coulomb per kilogram.
    (d) Roentgen.

15. Why is a “half-field” geometry employed in mammography, as shown in the figure below?

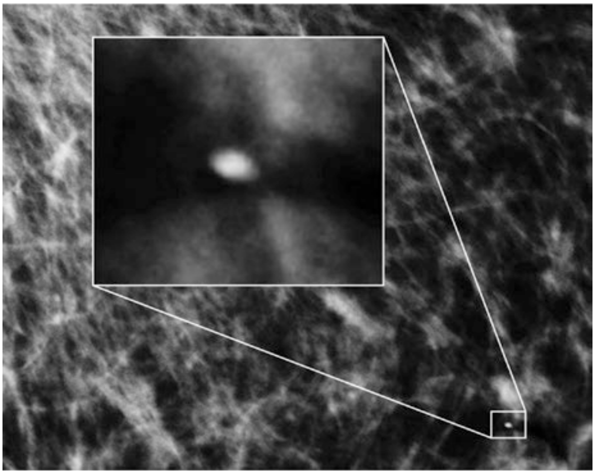


(a) To avoid exposure of the patient’s torso.
(b) To increase X-ray field coverage at the chest wall.
(c) To improve contrast resolution.
(d) a and b.

16. Why does the Mammography Quality Standards Act (MQSA) require a minimum half-value layer (HVL) of clinical X-ray spectra?
(a) To reduce patient dose.
(b) To improve contrast.
(c) To reduce scatter.
(d) a and b.

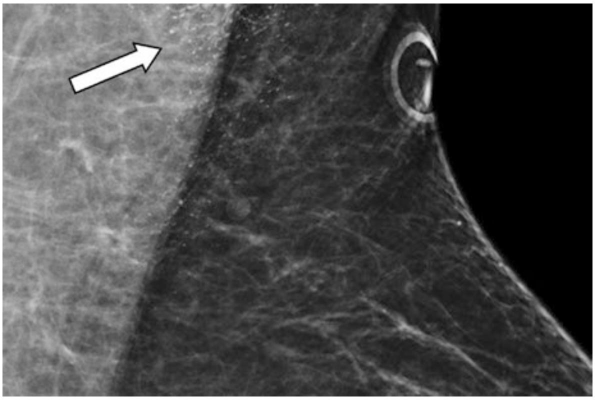
17. What must be done if the average glandular dose (AGD) to a patient exceeds 3 mGy per view?
(a) Stop clinical use of the mammography system.
(b) Correct the issue within 30 days.
(c) No action necessary.
(d) a and b.

18. Identify the artifact in the image below.



(a) Grid lines.
(b) Motion.
(c) Ghosting.
(d) Antiperspirant.

19. Identify the artifact in the image below.



(a) Grid lines.
(b) Motion.
(c) Ghosting.
(d) Antiperspirant.

Breast Ultrasound

20. In B-mode ultrasound imaging, image brightness corresponds to which of the following?
    (a) Linear attenuation coefficient of tissues.
    (b) Electron density of tissues.
    (c) Detected ultrasound wave amplitude.
    (d) Detected ultrasound wave frequency.

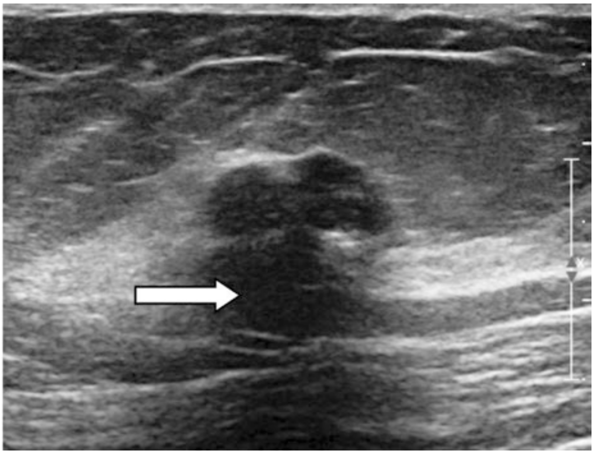
21. What is the most likely ultrasound frequency emitted by a transducer used for breast imaging?
    (a) 1 MHz.
    (b) 3 MHz.
    (c) 6 MHz.
    (d) 12 MHz.

22. Ultrasound waves are strongly reflected at tissue boundaries with large differences in what?
    (a) Ultrasound attenuation.
    (b) Acoustic impedance.
    (c) Atomic number.
    (d) Electron density.

23. Identify the artifact in the image below.

    (a) Mirror image.
    (b) Acoustic shadowing.
    (c) Acoustic enhancement.
    (d) Reverberation.

24. Identify the artifact in the image below.



(a) Mirror image.
(b) Acoustic shadowing.
(c) Acoustic enhancement.
(d) Reverberation.

MRI

25. Which of the following statements is true?
(a) 1 Tesla = 1000 Gauss.
(b) Higher magnetic field strength increases polarization, which contributes to better image quality.
(c) Exams performed at higher magnetic field strengths have lower SAR.
(d) 1H always precesses at the same Larmor frequency.

26. Which of the following statements is false?
(a) Spin and precession are the same.
(b) Larmor frequency increases with larger B0.
(c) Larmor frequency increases with higher gyromagnetic ratio.
(d) Higher Larmor frequencies produce stronger signals.

27. A device labeled as “MRI Conditional” means:
(a) The device should never be used in a low-field MRI environment.
(b) The device is considered to be safe in a ≤1.5 T MRI environment.
(c) The device is safe in all types of MRI environment.
(d) Specific conditions must be met to ensure the safe use of the device.

28. What is a potential adverse health effect related to the MRI scanner?
    (a) Temporary or permanent hearing loss.
    (b) Production of small pockets of gas in body fluids.
    (c) Radiation-induced erythema.
    (d) Cancer.

29. When a spin-echo sequence is used for acquisition, what are the relative TE and TR values for proton-density weighting?
    (a) Short TE and long TR.
    (b) Short TE and intermediate TR.
    (c) Intermediate TE and intermediate TR.
    (d) Intermediate TE and long TR.

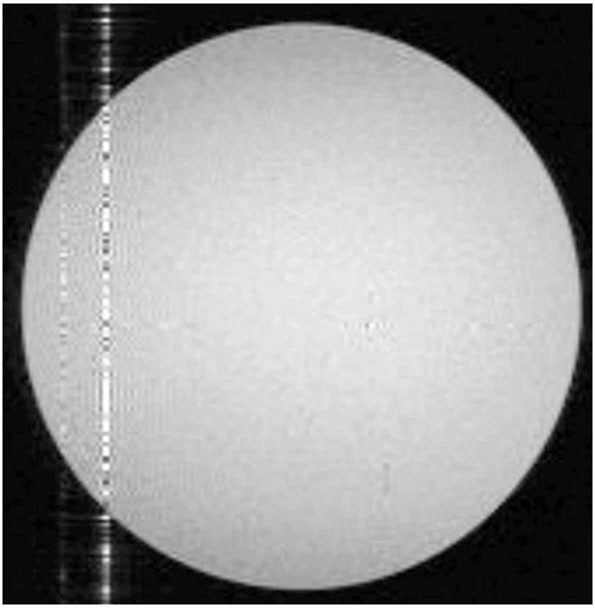
30. Which statement is false for multi-echo spin-echo imaging?
    (a) Multi-echo imaging can decrease scan times by 2x or more.
    (b) Turbo spin echo is excellent for fast T2-weighted imaging.
    (c) Short TRs are important for T2-weighted imaging because they eliminate T1-contrast.
    (d) Spin echo EPI is routine for diffusion-weighted imaging.

31. What is echo time (TE)?
    (a) The time between the middle of the first RF pulse and the peak of the spin echo.
    (b) The time between the end of the first RF pulse and the peak of the spin echo.
    (c) The time between successive pulse sequences.
    (d) Duration of first RF pulse.

32. How many RF pulses are required per TR in spin-echo imaging?
    (a) One.
    (b) Two.
    (c) Three.
    (d) Zero.

33. How many RF pulses are required per TR in gradient echo imaging?
    (a) One.
    (b) Two.
    (c) Three.
    (d) Zero.

34. The following image contains a “zipper” artifact. What is the main cause of the zipper artifact?



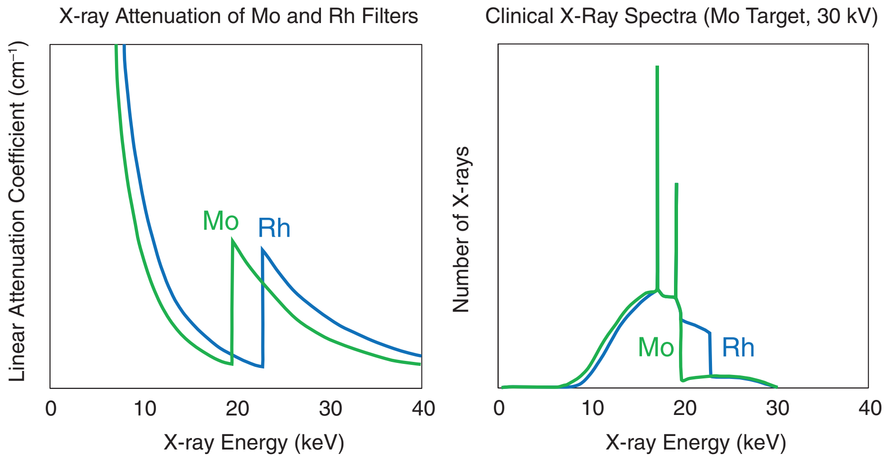
(a) Patient motion.
(b) Susceptibility.
(c) Radiofrequency interference.
(d) Low spatial resolution.

35. What is true about parallel imaging?
(a) The is no SNR penalty in parallel imaging.
(b) Parallel imaging can be used with single-channel coils.
(c) Typical acceleration factors in parallel imaging are 20 to 30.
(d) Parallel imaging can improve either spatial- or temporal resolution without increasing scan time.

Answers

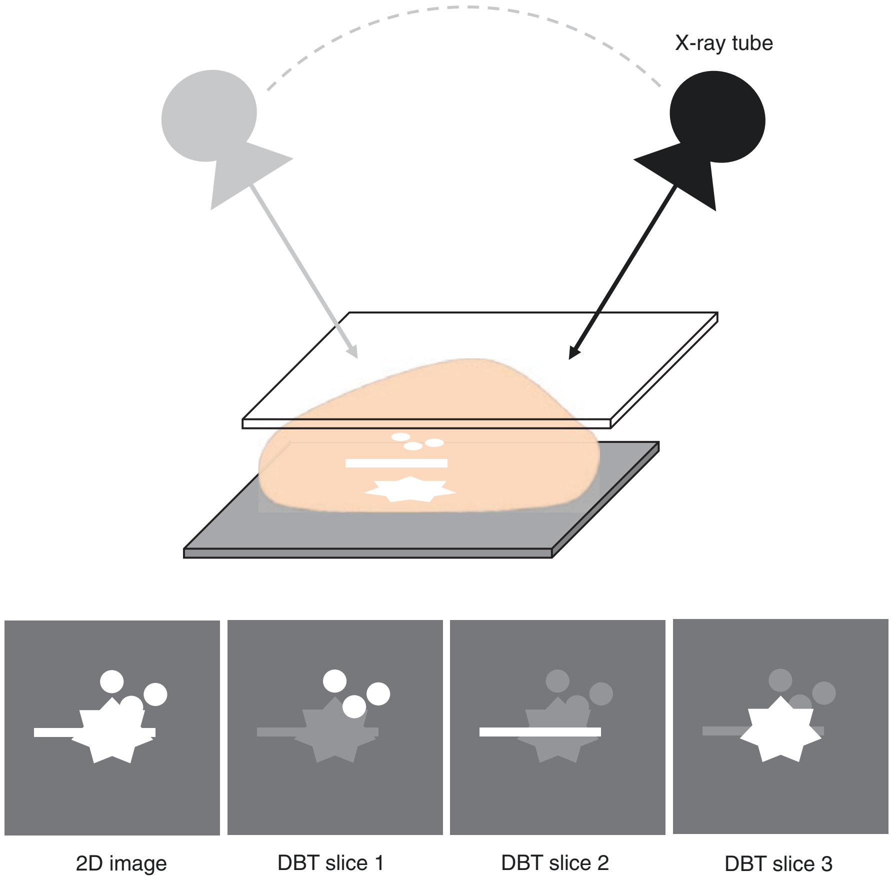
1. a. The K-shell binding energy of Rh is higher than that of Mo.

   The k-shell binding energy of Mo is approximately 20 keV, while the k-shell biding energy of Rh is approximately 23 keV. The higher k-shell binding energy, and thus higher photoelectric absorption k-edge, of Rh permits higher-energy X-rays to penetrate the Rh filter and produces a "harder," more penetrating X-ray beam of a higher effective energy. This more penetrating X-ray beam reduces patient dose and keeps exposure times reasonably low when imaging thicker and/or denser breasts using automatic exposure control (AEC). Patient dose is reduced because the "harder" Rh-filtered beam results in a greater proportion of X-ray photons passing through the breast to reach the detector than a "softer" Mo-filtered beam (i.e., lower dose to achieve similar image noise) [1].



2. d. Reduced anatomical noise.

   DBT involves acquiring multiple low-dose projection X-rays of the breast at various angles, then reconstructing axial slices of the breast from the acquired projection data. Each axial slice focuses on a thin (approximately 1 mm) layer of breast tissue while blurring out the under- and overlying anatomy that may otherwise obscure the structures within a given slice. This reduction in anatomical noise improves image contrast and the sensitivity of DBT. In-plane spatial resolution in DBT is often poorer than in conventional 2D mammography because signals from adjacent detector elements are binned together to improve the signal-to-noise ratio of the low-dose projection images. The radiation dose is approximately equal for DBT and conventional 2D breast exams and DBT is performed in contact mode, like 2D imaging, so there is no change in the magnification factor.

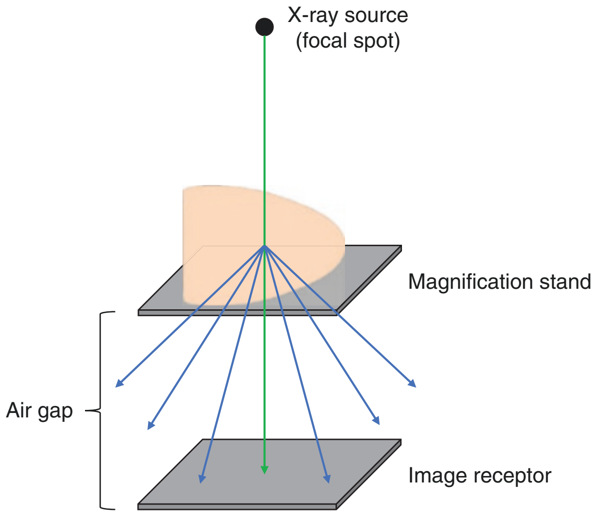


3. a. 28 kV, 100 mAs, grid, 0.3 mm focal spot.

   Low X-ray tube voltages (kV) are used in mammography to maximize subject contrast between adipose-, glandular-, and cancerous breast tissues. For an average-sized breast, 28 kV and 100 mAs are typical technique factors. The grid is always utilized in 2D contact mammography to reduce the proportion of scattered radiation reaching the image receptor. The 0.3 mm focal spot size is used in contact mammography to provide excellent spatial resolution while permitting reasonably low exposure times (approximately 1 s).

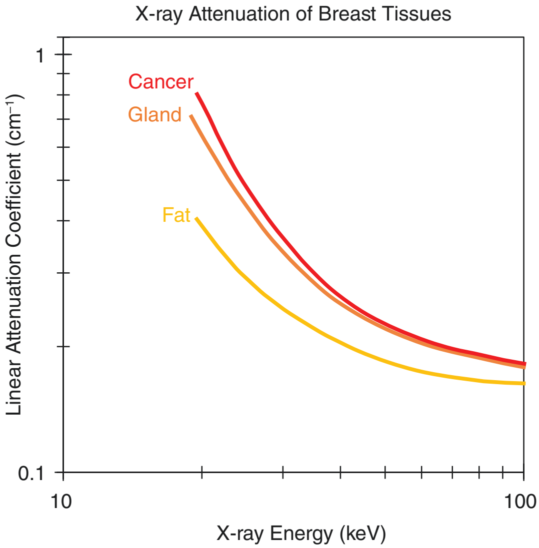
4. b. 28 kV, 100 mAs, no grid, 0.1 mm focal spot.

   For an average-sized breast, 28 kV and 100 mAs are typical technique factors. In magnification mammography, the breast is positioned closer to the X-ray source (focal spot) while the source-to-image distance (SID) remains constant. This geometry creates an "air gap" between the breast and the image receptor and allows space for scattered radiation travelling at oblique trajectories to miss the image receptor. The grid is removed in magnification mammography because scatter reduction is achieved via the air gap technique and use of the grid would needlessly increase radiation dose to the breast. The 0.1 mm focal spot size is utilized in magnification mammography to counteract the increased geometric blurring that is introduced as the geometric magnification factor increases. The magnification factor of a projection X-ray image is equal to the source-to-image distance (SID) divided by source-to-object distance (SOD): magnification factor = SID/SOD. Since a smaller SOD is used in magnification mammography, selection of a smaller focal spot offsets the resulting increased geometric blurring to maintain excellent spatial resolution.



5. c. Improved subject contrast.

   The kV determines the maximum energy of the polyenergetic X-ray spectrum. At lower X-ray energies, there is a greater disparity between the linear attenuation coefficients of fat, glandular tissue, and cancerous tissue, and thus improved subject contrast. Imaging at low kV is especially critical in mammography because the linear attenuation coefficients of these tissues are quite similar and difficult to distinguish at higher kV.



6. b. Photoelectric absorption.

   Within the X-ray energy range utilized in diagnostic radiology, X-ray photons interact with matter via Rayleigh scattering, photoelectric absorption, and Compton scattering. Rayleigh scattering is only likely to occur at very low photon energies and accounts for less than approximately 10% of all X-ray interactions with tissue in mammography (and an even smaller percentage for other, higher-energy imaging modalities). A rule of thumb is that photoelectric absorption is the dominant interaction mechanism of X-rays in soft tissue below 25 keV, and Compton scattering is the dominant interaction mechanism of X-rays in soft tissue above 25 keV. For a typical mammography exam performed at 28 kV, the average energy of the polyenergetic X-ray spectrum is approximately 14 keV. Thus, the dominant mechanism of interaction between X-rays and breast tissue will be photoelectric absorption.

7. d. a and b.

   There are many advantages to breast compression including reduced scatter production and reduced geometric blurring. Less scattered radiation is produced in thinner body parts, and geometric blurring is reduced as breast tissue is moved closer to the image receptor (increased SOD). Other advantages include reduced motion blurring due to immobilization of the breast, reduced patient dose, reduced anatomical noise, and reduced exposure times.

8. b. Reduced X-ray tube voltage (kV).

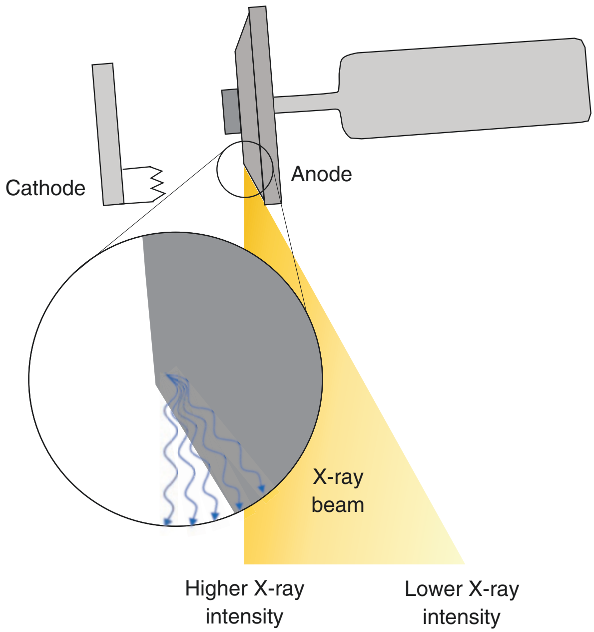
   Spatial resolution is not significantly impacted by technique factors such as the kV and mAs. Smaller focal spot sizes reduce geometric blurring and improve spatial resolution. Breast compression improves spatial resolution by reducing both motion blurring (immobilization) and geometric blurring (reduced magnification factor: SID/SOD). Smaller detector element size allows smaller objects to be visualized.

9. I-c; II-b; III-a.

   When electrons strike the target material in an X-ray tube, both characteristic X-rays and Bremsstrahlung X-rays are produced. Characteristic X-rays (I) have discrete energies which are "characteristic" of the target material in which they are produced, whereas Bremsstrahlung interactions produce a broad spectrum of X-ray energies with a shape that depends on the selected kV and mAs. The selected kV determines the maximum energy of Bremsstrahlung X-rays that can be produced in the X-ray tube (III). The k-edge of the selected filter material determines the maximum energy of X-rays that are most likely to be transmitted through the filter (II).

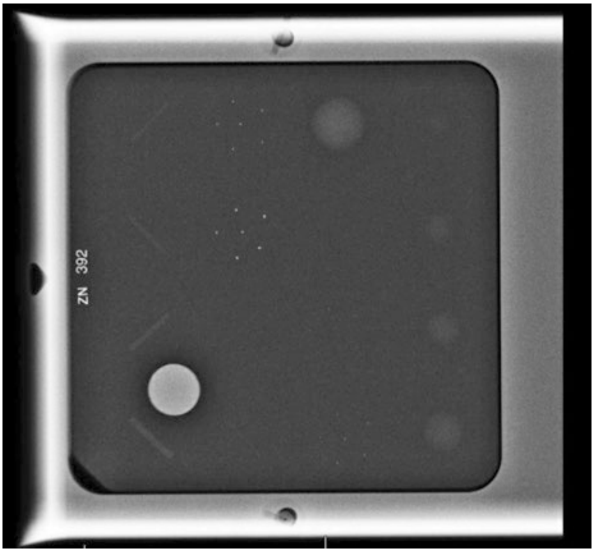
10. c. To achieve a more uniform exposure at the image receptor.

    The heel effect describes a loss of X-ray intensity on the anode side of the X-ray field. The X-ray intensity is reduced on the anode side due to the increased path-length and self-attenuation of X-rays within the angled anode. The thickest part of the breast (chest wall) is positioned at the more-intense side of the X-ray field and the thinnest part of the breast (nipple) is positioned at the less-intense side of the X-ray field to achieve a relatively uniform exposure of the image receptor.



11. d. Line pairs.

The ACR mammography phantoms contain simulated fibers, specks, and masses of various sizes. There are three ACR-approved accreditation phantoms: the mini Digital Stereotactic Phantom, small ACR Mammography Phantom (pictured below), and large ACR Digital Mammography Phantom. Technologists and medical physicists acquire images of an ACR phantom and document the number of fibers, specks, and masses that can be visualized. The ACR phantoms may also be used by medical physicists to determine the average glandular dose, signal-to-noise ratio, contrast-to-noise ratio, and geometric accuracy.



12. b. Spatial resolution.

High-contrast line pair phantoms are used to evaluate limiting system spatial resolution. Excellent spatial resolution is required in mammography so that microcalcifications as small as 100 μm may be visualized.

13. d. a and b.

Improving the contrast-to-noise ratio (CNR) of a large, low-contrast lesion will improve its radiographic visibility. Increasing the mAs reduces image noise (quantum mottle), while reducing the kV improves subject contrast. Therefore, both options A and B improve the CNR. Reduced detector element size improves spatial resolution but will not significantly impact the visibility of large, low-contrast lesions.

14. b. Gray.

The gray (Gy) is equal to 1 joule per kilogram (J/kg) and is the SI unit of absorbed dose. The sievert (Sv) is also equal to 1 J/kg, but it is reserved for the equivalent dose and effective dose (as well as older quantities that these quantities have since replaced). In other words, the Sv is used to distinguish instances where weighting factors have been applied to the absorbed dose to provide additional information about the associated risk of biological damage. The SI unit of exposure is the coulomb per kilogram (C/kg), whereas the conventional unit of exposure is the Roentgen (R).

15. d. a and b.

    In mammography, the X-ray field is bisected so that central axis of the X-ray beam is perpendicular to the image receptor and aligned with the chest wall edge, as shown in the figure above. This “half-field” geometry is unique to mammography and is utilized to avoid unnecessary exposure of the patient’s torso and increase X-ray field coverage of the chest wall.

16. a. To reduce patient dose.

    The HVL is the thickness of material required to reduce the X-ray beam intensity to half of its initial value. High energy, more penetrating X-ray beams have higher HVLs. A minimum HVL ensures adequate removal of the low energy components of the clinical X-ray spectrum, i.e., adequate “beam hardening.” It is desirable to remove the low energy components of the X-ray spectrum because they contribute to patient dose but are unlikely to reach the image receptor and contribute to image formation.

17. c. No action necessary.

    The AGD limit of 3 mGy per view only applies to the ACR mammography phantom. If a medical physicist determines that the AGD to the ACR phantom exceeds 3 mGy per view, then the system cannot be used clinically until the issue is corrected. However, the AGD to patients may exceed 3 mGy per view and still be considered acceptable, particularly for large, dense breasts.

18. b. Motion.

    Because the focal spot sizes used in mammography are very small, low X-ray tube currents (mA) and relatively long exposure times (approximately 1 s) are required to avoid overheating of the target material. Breast compression immobilizes the breast and significantly reduces motion artifacts; however, motion blur is fairly common because of the relatively long exposure times in mammography.

19. d. Antiperspirant.

    Antiperspirants often contain highly attenuating additives such as aluminum. Antiperspirant artifacts are commonly seen in the axilla. The artifactual hyperdensities have a distinct appearance but may be mistaken for pathology or obscure actual pathology in the axilla. Cleaning the skin of antiperspirant residue will remediate the artifact.

20. c. Detected ultrasound wave amplitude.

    Ultrasound transducers transmit and receive ultrasound waves by converting electrical energy into mechanical (sound) energy and vice versa. Ultrasound waves are produced and transmitted into the patient by vibrating piezoelectric transducer elements. The ultrasound waves are ultimately reflected, refracted, scattered, and/or absorbed within the patient. In B-mode ultrasound imaging, the measured amplitudes of reflected and scattered sound waves that are received by the transducer are converted into brightness levels (grayscale) in the ultrasound image.

21. d. 12 MHz.

    Clinical ultrasound transducers are typically operated between 1 and 20 MHz. Transducer frequency is inversely proportional to the maximum depth of penetration of the ultrasound wave, and transducer frequency is generally selected to match the depth of the body part being imaged. The spatial pulse length is inversely proportional to transducer frequency, thus axial spatial resolution improves with increasing transducer frequency. For breast imaging, 12 MHz transducers generally provide adequate depth of penetration and relatively high axial spatial resolution.

22. b. Acoustic impedance.

    Acoustic impedance (Z) is the product of physical density (ρ) of a material and its speed of sound (c): $Z = \rho * c$. Most of the ultrasound energy is transmitted through a tissue boundary when the acoustic impedances of the tissues are similar, whereas most of the ultrasound energy is reflected at a tissue boundary when there is a large mismatch in acoustic impedance. The large difference in acoustic impedance at air-soft tissue and soft tissue-bone interfaces explains why it is impractical to acquire ultrasound images beyond these interfaces. Ultrasound gel displaces air and is formulated to have an acoustic impedance similar to that of soft tissue, allowing the ultrasound beam to be transmitted into the patient to produce useful ultrasound images.

23. c. Acoustic enhancement.

    Acoustic enhancement describes an increased echo intensity that occurs distal to structures of low acoustic attenuation. Acoustic enhancement can aid in the characterization of breast lesions, for example by distinguishing fluid-filled lesions from solid masses.

24. b. Acoustic shadowing.

    Acoustic shadowing describes a decreased echo intensity that occurs distal to structures of high acoustic attenuation. Like acoustic enhancement, acoustic shadowing can aid in the characterization of breast lesions, for example by distinguishing calcified objects from fluids and air.

25. b. Higher magnetic field strength increases polarization, which contributes to better image quality.

$$1\ \text{Tesla} = 10{,}000\ \text{Gauss}$$

Certain atomic nuclei, such as the hydrogen nucleus, ^{1}H, possess a property known as "spin," and the spinning nucleus induces a magnetic field which behaves like a bar magnet. Application of a strong, external magnetic field (B_0) aligns the nucleus either in parallel or antiparallel with the B_0 field. As the strength of the B_0 field increases, a larger proportion of protons will align in parallel with the B_0 field. This increases the magnitude of the net magnetization vector and the measurable MR signal, thus the image signal-to-noise ratio.

Although a bar magnet would orientate completely parallel or antiparallel to the B_0 field, the nucleus has an angular momentum due to its rotation, so it will rotate, or precess, around the B_0 axis. The frequency of precession around the field direction is the Larmor frequency (ω), described by the Larmor equation:

$$\omega = \gamma B_0$$

where γ is the gyromagnetic ratio and the fixed constant for a specific nucleus. For example, the gyromagnetic ratio of the hydrogen nucleus is approximately 42.58 MHz/T. Thus, the precession frequency increases with a larger B_0 field for a given nucleus.

26. a. Spin and precession are the same.

Protons intrinsically have spin and precession in the presence of a B_0 field. The proton spins about its axis and precesses around the B_0 field. The spinning and precessing proton are analogous to a spinning top, which spins about its axis and also precesses around the earth's gravitation field.

27. d. Specific conditions must be met to ensure the safe use of the device [2].

- MR Safe: Items pose no known hazards in all MR environments and are indicated by a green and white icon.
- MR Conditional: Items do not pose any known hazards in a specific MR environment with specific conditions of use. The icon consists of "MR" inside of a yellow triangle.
- MR Unsafe: Items such as any magnetic item are unsafe in all MR environments. Unsafe icon features an "MR" inside of a red circle with a bar through it.

28. a. Temporary or permanent hearing loss.

    High-intensity noise produced by MRI scanners can reach peak sound pressure levels of 125.7–130.7 dB and have an average equivalent intensity of 100 to 115 dB. The intensity of noise produced by MRI scanners generally has a positive correlation with the magnetic field strength (i.e., 3 T scanners are louder than 1.5 T scanners) and is caused by motion of the gradient coils as they are rapidly switched on and off. Exposure to such high-intensity noise could result in noise-induced hearing loss if someone were to be imaged frequently or was imaged without proper ear protection [3, 4].

29. a. Short TE and long TR.

    Image contrast for spin echo (S_{SE}) is proportional to the following signal equation:

    $$S_{SE} \propto \rho\left(1 - e^{-TR/T_1}\right)e^{-TE/T_2},$$

    where ρ is the spin density, TR is repetition time, and TE is echo time. When a long TR is used, e^{-TR/T_1} becomes close to 0, resulting in no T_1-contrast. When a short TE is used, e^{-TE/T_2} becomes close to 1, resulting in no T_2-contrast.

    Please note memorization of this equation is not required material for board preparation.

    In summary, different tissue contrast for spin-echo imaging can be created by selecting a certain combination of TE and TR.

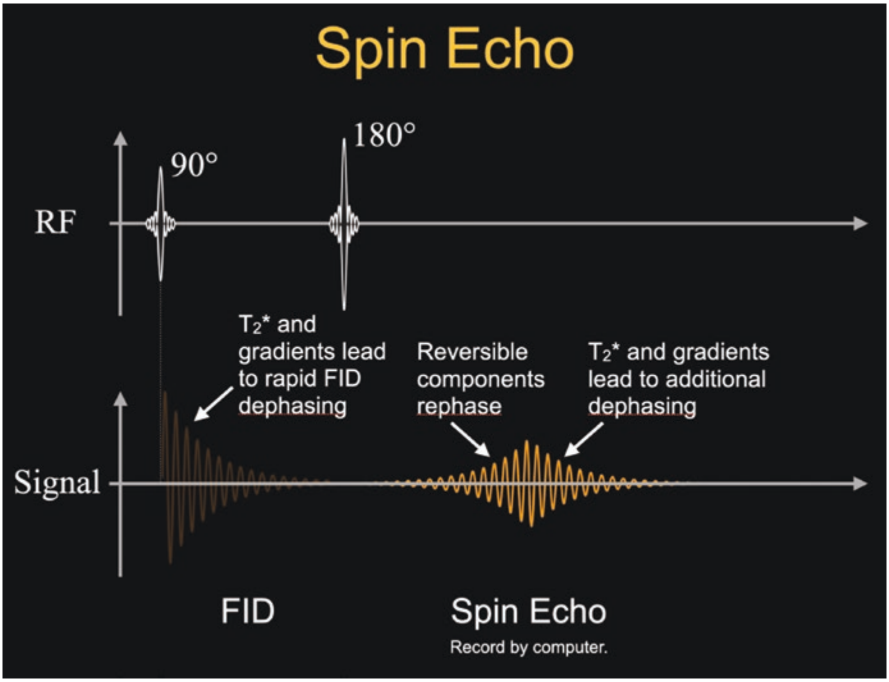
	TE	TR
Spin density	Short	Long
T1-weighted	Short	T1-Short, Short
T2-weighted	T2-Long, Long	Long

30. c. Short TRs are important for T2-weighted imaging because they eliminate T1-contrast.

    Long TRs should be used to eliminate T1-contrast for T2-weighted imaging.

31. a. The time between the middle of the first RF pulse and the peak of the spin echo.

The time between the center of the first RF pulse (usually 90° for spin-echo pulse sequence) and the peak of the spin echo is called the echo time (TE).

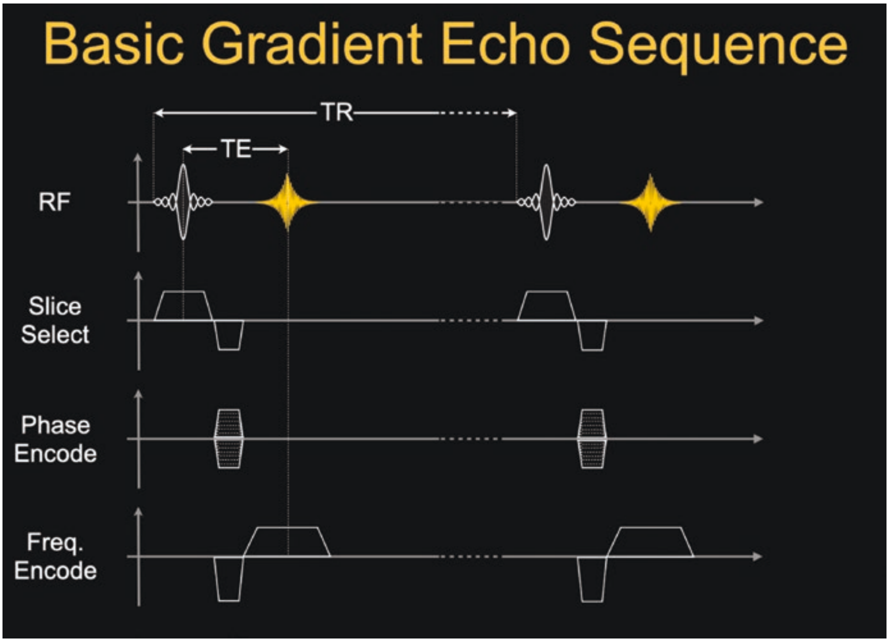


32. b. Two.

A spin echo (SE) is produced by a pair of RF pulses. The first pulse (usually 90°) rotates the net magnetization into the transverse plane. The second RF pulse is the refocusing pulse (usually 180°), which generates the spin echo.

33. a. One.

    A gradient recalled echo (GRE) is produced by a single RF pulse and a gradient polarity reversal.



34. c. Radiofrequency interference.

    Zipper artifacts are caused by radiofrequency (RF) noise contamination that enters the scanner room or from within the room itself. For example, zipper artifacts may occur when the scanner door is left open or if the room's RF shielding is compromised.

35. d. Parallel imaging can improve either spatial- or temporal resolution without increasing scan time.

    Parallel imaging is a widely used technique where the placement of multiple receiver coils is used to allow a reduction in the number of phase-encoding steps during image acquisition. The typical acceleration factors in imaging time are 2–4, which come with SNR penalties [5].

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