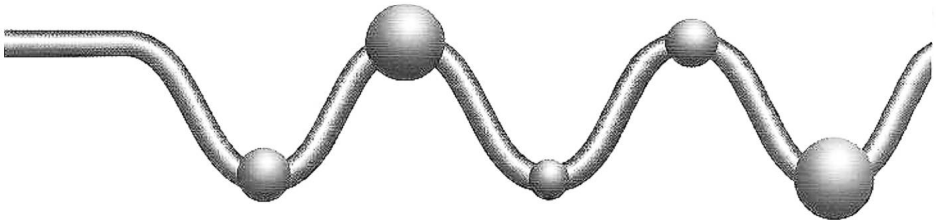
CHAPTER EIGHT



Collimators and Grids

A. Collimators

1. The ***major functions of collimators*** are to:

   e Prevent the irradiation of unnecessary parts of a patient's anatomy

   • Restrict x-rays so that they image only areas of clinical interest

   ® Reduce scatter radiation b}^ using a smaller field of view (FoV)

   © Improve image contrast by means of scatter reduction

2. **Types *of collimation devices*** include the following:

   © ***Fixed aperture,*** which have rectangular holes cut into metal diaphragms. These devices have been used in mammography units and linear tomography units.

   © ***Cones,*** which are cylinders attached to the x-ray tube to provide spacers. These devices have been used on dental units.

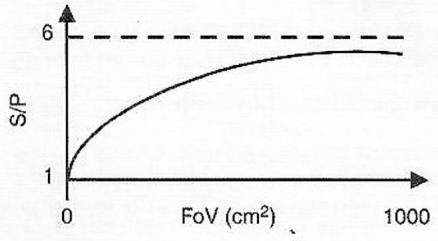
   © ***Variable aperture,*** which have two sets of orthogonal lead blades that can be adjusted to provide variable-size rectangular FoVs. These devices are the most common units used on most x-ray tubes.

   © ***Iris,*** which is a series of leaded blades that provide a circular FoV.

3. The number of scattered x-rays compared with unattenuated primary x-rays that pass through a patient's anatomy is called the ***scatter-to-primary (S/P) ratio.***

   • S/P increases exponentially with a patient's thickness.

   © S/P increases rath larger FoVs but levels out at about 1000 cm^2



   © S/P increases with higher kVp because there is a larger percentage of Compton scatter interactions than photoelectric interactions.

   © S/P increases with greater added filtration because there is a larger percentage of Compton scatter interactions than photoelectric interactions.

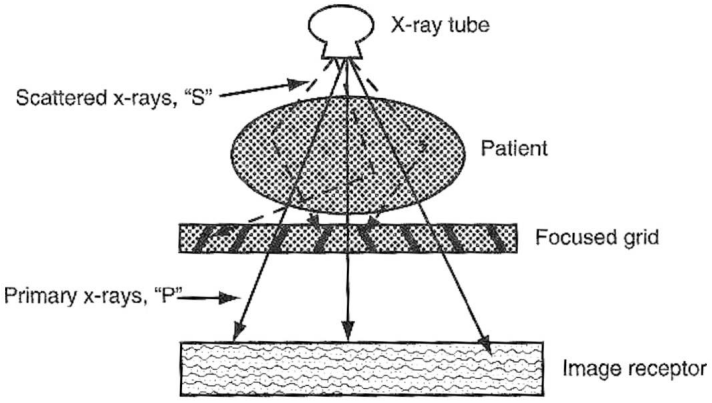
4. A ***positive beam limitation (PBL) device*** is an automatic collimator that senses the size of the cassette and collimates the x-ray FoV to match the cassette.



5. Federal regulations require the light and x-ray field to be congruent to within ***±2%*** of the source-to-image receptor distance (SID) in any one orthogonal direction.
6. For ***positive beam limitation*** (PBL) systems, the errors in x-ray/light alignment must be less than 3% of SID in any one orthogonal direction, and the sum of errors in two orthogonal directions (without regard to positive or negative error) must be less than 4% of SID.
7. X-ray/light alignment is checked by placing pennies on the four sides of the light FoV and then taking a radiograph of the pennies to see the edges of the x-ray FoV. The distance between the edge of the pennies and the dark area on the film where the x-rays struck is measured on both sides and in two orthogonal directions. The errors on the left and right sides are added together as positive values. The summed error is divided by the SID and multiplied by 100%. The requirement is that this value be less than 2%.

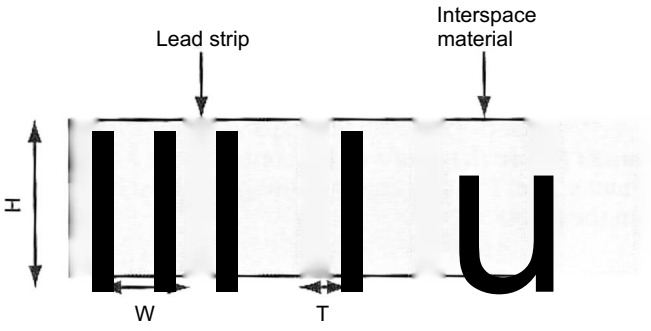
B. Grids

1. The ***major points regarding grids*** are the following:
   - Grids remove x-rays that are scattered in the patient's body.
   - Scattered x-rays degrade the image contrast.
   - e Grids tend to improve the image contrast by removing the scattered x-rays. (This reduces the S/P ratio.)
   - Unfortunately, by removing the scattered x-rays, grids results in fewer x-rays reaching the image receptor. Thus, the radiation dose to the patient must be increased to maintain the same image density for film-screen systems or the same relative noise (signal-to-noise ratio [SNR]) for digital systems.

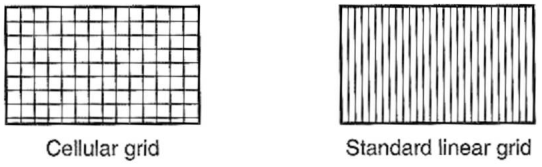


2. Grids consist of a sheet of thin lead strips spaced apart by some other material.
   - ***Interspace material*** is usually aluminum: however, carbon fiber is used on some grids because it attenuates less than aluminum and results in a smaller dose of radiation to the patient.
   - © The ratio of the height, H, to the width between lead strips, W, is known as the grid ratio, r.
   - « Grid ratios range from 6:1 up to 17:1.
   - Higher grid ratios remove more scattered x-rays, but they are sensitive to positioning errors.





3. r = H/W.
4. The number of lead strips per cm, N. equals 1/(W + T). As N increases, the grid lines become less noticeable in the image (for grids that do not move).
5. Grids can be classified in several different ways:
   - ***Focused grids***—-lead strips point to the x-ray tube focal spot.
   - ® ***Parallel grids***—lead strips are parallel.
   - ***Crossed grids***—two sets of grids with grid lines perpendicular to each are sandwiched together. Their grid ratio is the sum of the grid ratios of the two grids: r = ri + r_2.
   - ***Cellular grids*** —instead of lead strips, grids are composed of little rectangular cells. (See the comparison drawing from the top view.) Cellular grids have been used in mammography units.



6. Grids are also classified by their motion:
   - ***Bucky grids***—moving grids. Bucky grids do not show grid lines on the image because of the motion during exposure. However, these grids need slightly more radiation and longer exposure times to allow motion to blur grid lines.
   - ***Stationary (or non-Bucky) grids***—grids that do not move. Generally, stationary grids are used (1) for chest x-rays, because short exposure times are used that do not allow enough time for motion, and (2) for some portable x-ray cassettes.
7. ***Bucky factor*** (patient's dose with grid/patient's dose without grid) = radiation transmitted through patient and incident upon the grid versus the portion of this radiation that passes through the grid to the image receptor. As the Bucky factor increases, the patient's radiation dose increases.
8. ***Selectivity (1)***—ratio of the primary radiation transmitted through the grid divided by the scattered radiation transmitted through the grid.

   $S = T_P/T_s$

   • As the selectivity increases, more scattered x-rays are removed by the grid and the image contrast improves.
9. If Co is the contrast of ^n image with no scattered x-rays included, the contrast with scattered x-rays included (C') depends on the amount of scattered x-rays, defined by the scatter-to-primary x-ray ratio (S/P).

   C'= CQ/[1 + (S/P)]

   - As the amount of scattered x-rays increases (because of higher kVp or larger FoV collimation or thicker body anatomy), the S/P ratio increases and the inherent image contrast decreases.



- A grid removes some of the scattered x-rays from the image as a result of its selectivity. Primary x-rays pass preferentially through the grid, whereas a significant portion of the scattered x-rays are attenuated.

  $C'' = C_O/[1+(S/P)(1/X)]$

- ***Contrast improvement factor* (K)—**ratio of the contrast with a grid divided by the contrast without a grid. The grid improves image contrast by removing scattered x-rays from the image.

  K = C7C'

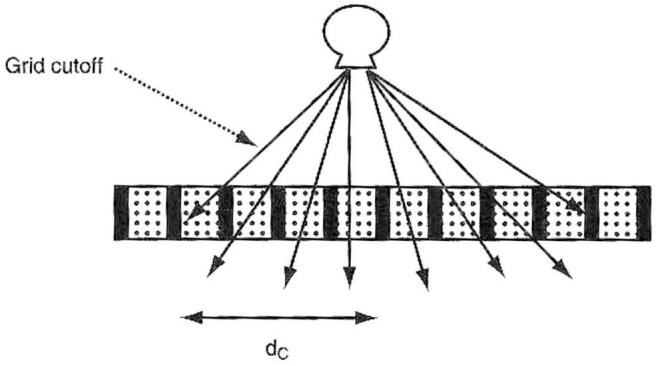
- In general, as the grid ratio (r) increases, the selectivity (X) increases, the Bucky factor increases, the patient's radiation dose increases, the image contrast improves (K), and fewer scattered x-rays are used in the resultant image.

10. ***Grid cutoff***—at a distance from the center of the grid, the grid design attenuates both scatter and primary x-rays from passing through it. Beyond this distance, film density (or digital value) is greatly diminished. For example, with parallel grids, there is a cutoff distance (d_c) from the center of the image receptor.

$d_c = [SID/r]$

e where SID = distance from focal spot (source) to image receptor and r = grid ratio.

® Parallel grids are designed to be operated with an x-ray source far from the grid (e.g., infinitely far away from the grid) so that incident x-rays are nearly parallel, like the lead strips in the grid.



11. ***Reasons for cutoff with focused grids*** are the following:

- Grid placed "upside down"—center dark and rest of image light
- Distance decentering—density gradually decreases on both sides of center of image

© Lateral decentering—image uniformly decreased in density or more radiation dose required to get equivalent density.

- Combined lateral and distance decentering—dark on one side and light on other side of center of image

12. Moving grids (Bucky grids) require a larger dose to the patient and greater exposure time than stationary grids.

13. Recommendations:

a Use r = 8:1 with less than 90 kVp or small anatomic thickness, or both

***** Use r = 12:1 with greater than 90 kVp or large anatomic thickness, or both

14. ***Focal distance*** is the distance at which the focused grid is intended to be used. It is the optimal distance from the focal spot of the x-ray tube to the grid surface. There is usually a range of distances in wliich cutoff is minimal.



15. **Air *gap techniques*** can be used instead of a grid to reduce the number of scattered x-rays in the image. These techniques require an air gap between the patient's exit surface and the image receptor at least equal to the patient's thickness. Long SIDs are used to reduce geometric magnification of anatomy. Air gaps are more effective at lower kVp values.

C. Questions

8=1. The most commonly used type of x-ray beam collimation in diagnostic radiology is._____

(a) Fixed aperture (b) Cones (c) Variable aperture
(d) Intensity-modulated radiation therapy (IMRT) (e) Wedges

8=2. The most commonly used type of x-ray beam collimation in dental units is _____.

(a) Fixed aperture (b) Cones (c) Variable aperture
(d) IMRT (e) Wedges

8-3. Mammography units use either or collimation devices._____

(a) Fixed aperture (b) Cone (c) Variable aperture
(d) IMRT (e) Wedge

8-4. Collimation beyond the edges of the cassette results in all of the following *except* _____.

(a) Increased number of scattered x-rays (b) Degraded resolution
(c) Degraded contrast (d) Greater biologic risk to the patient
(e) Higher radiation dose per gram of tissue

8-5. The automatic collimation system that tracks the cassette size and SED is called the,,_____

(a)AEC (b)ABC (c)PBL (d) SSD (e)AoP

8-6. Regulations require the x-ray field and light alignment to be within ±_____% of the SID in both orthogonal directions.

(a) 0.5 (b)1.0 (c)2.0 (d) 3.0 (e) 4.0

8-7. For standard radiographic and fluoroscopic x-ray tubes, the collimator blades are composed of. _____

(a) Plastic (b) Aluminum (c) Copper (d) Lead (e) Uranium

8-8. The amount of scattered radiation increases with FoV and gradually levels out at about an FoV of cm x cm. _____

(a) 10,10 (b) 15,15 (c) 20, 20 (d) 25,25 (e) 30, 30

8-9. The scatter-to-primary (S/P) ratio is influenced by all of the following, *except* _____.

(a) kVp (b) Focal spot size (c) FoV (d) Patient's thickness
(e) X-ray filtration

8-10. The S/P ratio for thick anatomy can be as large as, _____

(a) 0.5:1 (b)l:l (c)2:l (d) 5:1 (e) 10:1

8=11. The ideal source-to-image receptor distance (SID) for a parallel grid is. _____

(a) 100 cm (b) 40 inches (c) 72 inches (d) 180 cm (e) Infinity

8=12. Grid cutoff becomes more likely with. _____

(a) High line frequencjr (b) Low lead content (c) Low selectivity
(d) High grid ratios (e) Low Bucky factors



8-13. Use of grids results in _____ radiation dose to the patient and _____ image contrast.

(a) Increased, improved (b) Decreased, improved (c) Increased, degraded (d) Decreased, degraded (e) The same, degraded

8-14. As grid selectivity increases, the Bucky factor and scattered x-ray transmission. _____

(a) Increases, increases (b) Increases, decreases (c) Decreases, increases (d) Decreases, decreases (e) Stays the same, decreases

8-15. In comparison with a stationary grid, a moving (Bucky) grid requires _____.

(a) Higher kVp (b) More radiation dose to the patient
(c) Shorter exposure times (d) Longer SID (e) Smaller FoV

8-16. The S/P ratio increases with. _____

(a) Larger FoV (b) Higher kVp (c) Thicker patient anatomy
(d) Denser body tissue (e) All of the above

8-17. A grid problem that results in higher density on one side of the center of the image than the other side is due to. _____

(a) Upside-down grid (b) Distance decentering (c) Lateral decentering
(d) Distance and lateral decentering

8-18. A grid problem that results in the center of the image being dark and all other portions of the image being clear is due to. _____

(a) Upside-down grid (b) Distance decentering (c) Lateral decentering
(d) Distance and lateral decentering (e) Tilted grid

8-19. A grid problem that results in a uniform reduction in the density everywhere in the image is due to. _____

(a) Upside-down grid (b) Distance decentering (c) Lateral decentering
(d) Distance and lateral decentering (e) Tilted grid

8-20. A grid problem that results in the density gradually decreasing from the center of the image toward both edges is due to. _____

(a) Upside-down grid (b) Distance decentering (c) Lateral decentering
(d) Distance and lateral decentering (e) Tilted grid

8-21. Another way to reduce the number of scattered x-rays that reach the image receptor without the use of grids is to use. _____

(a) Heavy filtration (h) Small focal spot sizes (c) Longer SIDs
(d) Air gaps (e) Wedge filters

8-22. Grids can result in a contrast improvement factor of about. _____

(a) 0.5-1.0 (b) 1.0-2.0 (c) 2.0-3.0 (d) 4.0-6.0 (e) >10.0

8-23. The Bucky factor is the. _____

(a) Contrast with a grid divided by contrast without a grid
(b) Dose with a moving grid divided by dose with a stationary grid
(c) Dose with a grid divided by dose without a grid
(d) Density with a grid divided by density without a grid
(e) kVp used with a grid divided by kVp used without a grid

8-24. For a parallel grid with a 10:1 ratio used at an SID of 100 cm, the grid cutoff occurs with cassette sizes greater than__ cm.

(a) 10 (b)20 (c) 30 (d) 40 (e) 50

8-25. If two grids with a ratio of 6:1 are mounted as crossed grids, the effective grid ratio is._____

(a) 1:1 (b) 6:1 (c) 8.5:1 (d) 12:1 (e) 36:1



8-26. Stationary grids are usually employed for radiographic images of the. _____

(a) Breast (b) Extremities (c) Chest (d) Skull (e) Abdomen

8-27. When higher kVp values are used in radiographs, typically grids with _____ are employed.

(a) Lower lead content (b) Higher line frequency (c) Longer SID range (d) Higher grid ratio (e) Copper covers

8-28. For fluoroscopy of newborn infants, grids with the following ratio are employed:_____

(a) 2:1 (b) 5:1 (c)8:1 (d) 12:1 (e) No grids are used

8-29. For routine mammography imaging, grids with the following ratio are employed:_____

(a) 2:1 (b) 5:1 (c) 8:1 (d) 12:1 (e) No grids are used

8-30. To reduce the patient's radiation dose, grids can be modified by using for_____ the interspace material.

(a) Air (b) Aluminum (c) Carbon fiber (d) Copper (e) Paper

D. Answers

8-1. Answer = (c). Collimators with adjustable knobs to limit the x-ray field in the longitudinal and transverse directions are called variable aperture collimators. Some mammography units use metal plates with rectangular holes cut into the plates called fixed apertures. Dental x-ray units use a cone to space the x-ray tube away from the skin to reduce the radiation dose to the patient. IMRT refers to ***intensity-modulated radiation therapy,*** in which special multileaf collimators are used for radiation therapy. Wedges are leaded plastic plates that can be inserted to modulate the intensity of the x-rays at the edges of the body or near the lungs, where there is little attenuation of the x-rays.

8-2. Answer = (b). See explanation provide in Answer 8-1.

8-3. Answer = (a) for older units or (c) for newer units. See explanation provided in Answer 8-1.

8-4. Answer = (b). Collimation beyond the edge of the cassette results in radiation exposure of tissue that is not imaged. This increases the biologic risk of radiation exposure. Large FoVs result in an increase in scattered radiation. The excess scattered radiation decreases image contrast and increases the radiation dose a little. High contrast, spatial resolution is not affected by an increase in scattered radiation.

8-5. Answer = (c). AEC is automatic exposure control, or phototiming. ABC refers to automatic brightness control, which is the system that adjusts the kVp and mA to maintain the fluoroscopic television display brightness. SSD is source-to-skin distance. AoP refers to automatic optimization of parameters, which employs the automatic selection of kVp, mA, filter, and exposure duration in mammography. PBL is positive beam limitation, which is the automatic collimator adjustment system.

8-6. Answer = (c). See notes about regulatory requirements for collimator and light alignment accuracy (point 5 in section A).

8-7. Answer = (d). Aluminum fixed apertures are sometimes used in mammography. Uranium collimator blades are often used in radiation therapy accelerators. Plastic and copper are not used for collimator blades.

8-8. Answer = (e). The number of scattered x-rays increases with FoV up to a size of about 30 cm x 30 cm = 900 cm^2.



8-9. Answer = (b). Focal spot size affects image blur and thus spatial resolution. Higher kVp and added filters increase the average energy of the x-rays; higher energies mean more Compton scatter interactions. Thicker body anatomy results in fewer primary x-rays and more scatter interactions in the body. Large FoV, as stated, increases the number of scattered x-rays.

8-10. Answer = (d). Only very thin body parts, such as hands and feet, have a low S/P ratio of 1:1 or less. Abdomen radiographs of large adults can have a S/P ratio of 4:1 or more.

8-11. Answer = (e). Parallel grids require parallel incident x-rays to avoid cutoff. Large SIDs best produce parallel x-ray beams.

8-12. Answer = (d). High line frequencies result in the grid lines being less visible on stationary[7] grids. Lead content affects the ability of x-rays to penetrate through the grid lead strips; high lead content is needed for high-kVp x-rays. Low selectivity and low Buck}[7] factors mean low grid ratios. Selectivity is related to contrast improvement because it removes scattered x-rays. Bucky factor is the increase in radiation dose to the patient that results from using a grid.

8-13. Answer = (a). Grids remove scattered x-rays; to maintain density (or SNR for digital image receptors), more x-ray photons must be used to replace the scattered x-rays eliminated by the grid. Because many scattered photons are removed and not absorbed by the image receptor, there is less degradation of contrast due to the scattered x-rays.

8-14. Answer = (b). Increased selectivity results from higher grid ratios. High selectivity removes a considerable number of scattered x-rays, so that fewer x-rays are transmitted to the image receptor; thus, radiation must be increased to darken the image, which results in a larger radiation dose to the patient. The positive aspect is that the contrast in the image improves.

8-15. Answer = (b). Moving versus stationary grids are not influenced by kVp, SID, or FoV. However, because moving lead grid strips cover the entire image receptor instead of one fixed area, as do stationary grids, more radiation is required for moving grids. This increased radiation is usually produced by increasing the exposure time.

8-16. Answer = (e). All the listed factors increase the S/P ratio.

8-17. Answer = (d). See Grids section for grid problems.

8-18. Answer = (a). See Grids section for grid problems.

8-19. Answer = (c). See Grids section for grid problems.

8-20. Answer = (b). See Grids section for grid problems.

8-21. Answer = (d). Longer SIDs and smaller focal spots have no effect on the number of scattered x-rays. More filtration increases the energy of the x-rays, which results in more scattered x-rays, not less. Wedge filters are use in cardiac and angiographic rooms to block excess transmission at the edge of the body and in the lungs. An air gap allows the scattered x-rays to miss the image receptor.

8-22. Answer = (d). The contrast improvement depends on both the number of scattered x-rays (S/P) in the beam and the grid ratio. For thick anatomy, scattered x-rays severely degrade image contrast. A high-ratio grid can remove a significant number of the scattered x-rays and thus improve contrast over that seen without the grid.

8-23. Answer =(c). Self-explanatory.

8-24. Answer = (b). Size = (2 x d_c) = (2 x SID)/r = (2 x 100)/10 = 20 cm.

8-25. Answer = (d). For crossed grids, add the grid ratios; 6 + 6 = an effective ratio of 12.

8-26. Answer = (c). To stop respiratory motion of the lungs, very short exposure times (of the order of 5-10 msec) are required. Moving grids not only cannot start but also completely blur the grid lines in this short x-ray exposure time. Hence, chest x-rays use stationary grids.



8-27. Answer = (d). For higher energy x-rays, either greater lead content or high grid ratios are used to prevent penetration through the lead strips of the grid.

8-28. Answer = (e). Because newborn babies are small, very few scattered x-rays are produced. Hence, no grid is necessary.

8-29. Answer = (b). Because of the low kVp and the thin anatomy of the compressed breast, there is onty a moderate amount of scattered x-radiation. Hence, low-ratio grids are adequate to maintain acceptable image contrast.

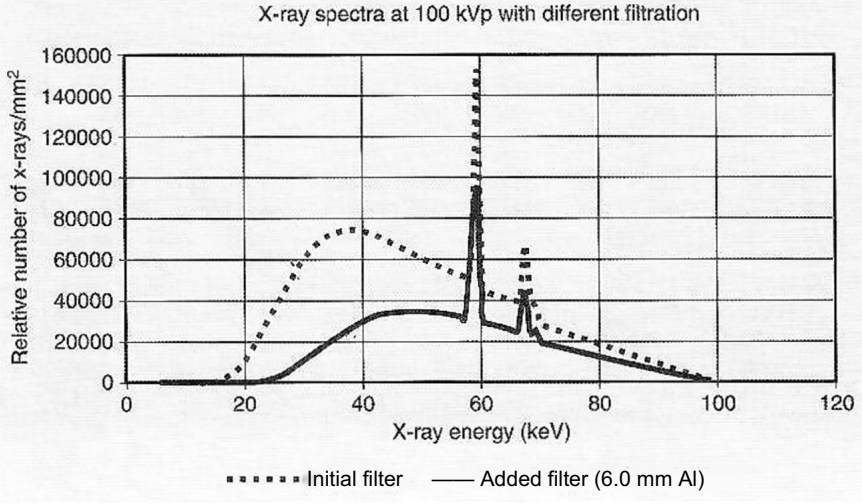
8-30. Answer = (c). Air cannot be used because there is nothing to support physically the structure of the lead grid strips. Metals with a high atomic number attenuate too many of the primary x-rays. Paper and wood were used for interspace materials on some older grids; however, the paper and wood absorbed humidity from the air over time and became nonuniform. Hence, a material with low atomic number that is solid and nonhygroscopic, such as carbon fiber, is ideal.

CHAPTER SEVEN

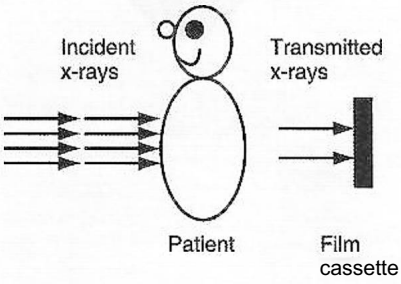
X-ray Filters

A. Basic Concepts

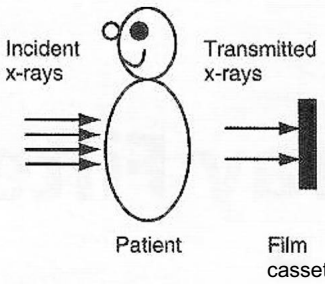
1. X-ray beam filters include any materials in the path of the x-rays (generated inside the x-ray tube) that must pass through the glass tube, housing, and collimator.
2. There are two basic tj^pes of filters:
   - ® ***Inherent filters*** are materials that cannot be removed from the x-ray beam. These inherent filters include the glass wall of the x-ray tube, the oil inside the x-ray tube housing, and the mirror in the collimator. Typically, inherent filters have the equivalence of 0.5 to 1.5 mm of aluminum.
   - ® ***Added filters*** are materials that can be removed from the x-ray beam. Added filters are usually metals such as aluminum or copper in radiographic and fluoroscopic x-ray tubes or molybdenum or rhodium in mammography tubes. In radiographic x-ray tubes, the added filters are typically[7] 0.0 to 3.0 mm of aluminum. In cardiac and angiography x-ray tubes, the added filtration is more; these x-ray tubes can have up to 0.9 mm of copper filtration.
3. Filters affect both the ***quantity*** and ***quality*** of the x-ray beam.
   - ***$ Quantity*** is the energy in the x-ray beam (number of x-rays and energies), and it is usually expressed as the measured exposure in mR or coulombs/kg.
   - • ***Quality*** is the penetration of the x-ray beam, and it is expressed by its half-value layer (HVL) in millimeters of aluminum.
4. The basic purpose of filters is to remove preferentially more of the low-energy x-rays than the high-energy x-rays (which reduces the patient's radiation dose). See the accompanying graph.



5. The remaining x-rays are more penetrating, and the radiation dose to the patient is reduced because fewer incident x-rays are required to get the necessary radiation to the image receptor.



Lower filtration x-rays are less penetrating and more incident x-rays are required to have adequate x-rays at film cassette



High filtration x-rays are more penetrating. A smaller number of incident x-rays can be used to get the same number of x-rays onto the film cassette.

6. The effects of added filtration on the x-ray beam are the following:

♦ There are fewer x-rays in the x-ray beam because the filter absorbs or scatters x-rays, or both.

e More low-energy than high-energy x-rays are removed.

• Thus, the average energy of all the remaining x-rays is increased.

$ The maximum energy is always controlled by and numerically equal to the kVp.

Emax = h V p

• Average x-ray energy = E_{avcr} =1/3 to 1/2 E_{max}.

@ The average x-ray energy is higher after more filtration.

• The minimum x-ray energy is higher because the lowest energy x-rays, which are not very penetrating, have been eliminated. The longest wavelength (lowest energy) is now slightly shorter.

© The remaining x-rays are more penetrating and have a longer HVL.

> Because x-rays are removed by the filters, fewer x-rays remain, which may necessitate the usage of more mAs.

• Because of the aforementioned loss of x-rays and more mAs, the exposure time required for clinical images may increase, resulting in more motion blur.

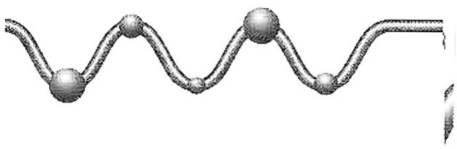
© More mAs means more x-ray tube heating effects. The reduced number of x-rays and greater mAs needed to produce images with filtration reduce tube life.

7. The effects of added filtration on the patient and radiographic image are the following:

e Added filtration reduces the patient's radiation dose by 30% to 60% because the remaining x-rays are more penetrating and fewer incident x-rays can be used.

© Added filtration causes a decrease in subject contrast by removing the lower energy x-rays, which interact primarily by means of the photoelectric effect.

© The higher energy x-rays that remain after filtration interact mostly by means of Compton scatter, and the scattered x-rays degrade subject contrast.



- Image quality is degraded because of the aforementioned effects.
- The absorption efficiency of the image receptor decreases because of the greater penetration of the high-energy photons.

8. The HVL increases with added filtration of the x-ray beam. It is usually measured in the thickness of aluminum required to reduce the radiation exposure to exactly 50%. The HVL of diagnostic x-rays is usually 2.5 to 8.0 mm of aluminum.

- Measured HVL is greater with increasing kVp.
- Measured HVL is greater with more x-ray tube filtration material.
- Measured HVL is ***not*** the same value as the actual amount of material in the x-ray beam.
- The measurement conditions for HVL require a narrowly collimated x-ray beam, placement of the detector far from the aluminum sheets used to measure the HVL to eliminate inclusion of scattered photons, pure aluminum sheets, and a radiation detector that has a relatively uniform response to different x-ray energies.

9. Federal requirements for filtration can be specified in two different ways: the minimum measured HVL allowed or the minimum amount of material allowed in the x-ray beam.

10. The purpose of these limits is to ensure adequate filtration in the x-ray beam to remove the lowest energy x-rays, which contribute significantly to the patient's radiation dose. These lowest energy x-rays do not have adequate energy to penetrate through the patient to reach the image receptor.

11. Federal requirements for HVL limits are the following:

- Mammography:

  HVL > (kVp/100) + 0.03 in mm Al eq

  HVL < (kVp/100) + C in mm Al eq

  where C - 0.12 for Mo/Mo, 0.19 Mo/Rh, and 0.21 for Rh/Rh.
- Diagnostic above 71 kVp:

  HVL > (2.2)(kVp/100) + 0.56 in mm Al eq

12. Federal requirements for the minimum amount of material to be placed in the path of an x-ray beam:

- Below 30 kVp: total filtration > 0.3 mm Al eq
- Between 30 and 50 kVp: total filtration > 0.5 mm AI eq

® Between 50 and 70 kVp: total filtration >1.5 mm Al eq

- Above 70 kVp: total filtration >2.5 nun Al eq

13« For tissue, the HVL for mammography x-ray beams is about 1 cm of compressed tissue. For diagnostic x-ray beams, the HVL in tissue depends on the kVp used for the examination; however, the HVL is typically between 3.0 and 5.0 cm of tissue. Therefore, a 24-cm-thick patient is about 6 HVL, and only 1% to 5% of the incident x-rays actually pass through the patient.

14. ***Summary:*** Too little filtration results in a high radiation dose to the patient because of inclusion of many low-energy x-rays that cannot penetrate through the patient. Too much'filtration results in degraded image quality because high-energy x-rays produce less subject contrast and more Compton-scattered x-rays.



B. Questions

7-1. The quantity of an x-ray beam is usually measured in units of. _____

(a) Number of photons (b) Coul/kg of air (c) keV
(d) mm Al eq (e) dB

7-2. Added filtration to an x-ray beam the quantity of the x-rays.

(a) Does not change (b) Increases (c) Decreases
(d) Cannot be determined

7-3. The quality of an x-ray beam is usually measured in units of. _____

(a) Number of photons (b) Coul/kg of air (c) keV
(d) mm Al eq (e) dB

7-4. The quality of an x-ray beam increases with an increase in. _____

(a) kVp only (b) kVp and mA only (c) kVp, mA, and time
(d) kVp and filtration (e) kVp, filtration, and ripple

7-5. The quantity of an x-ray beam increases with an increase in. _____

(a) kVp only (b) kVp and mA only (c) kVp, mA. and time
(d) kVp and filtration (e) kVp, filtration, and ripple

7-6. Good geometry for HVL measurements requires all of the following, *except* _____.

(a) Narrow x-ray beam (b) Detector close to aluminum sheets
(c) Air gap (d) Small detector size
(e) Detector with uniform energy response

7-7. If 6% of the incident x-rays pass through a portion of the patient's anatomy that is 20 cm thick, the HVL of that tissue is about. (Neglect beam hardening.)

(a) 2 cm (b) 3 cm (c) 4 cm (d) 5 cm (e) 6 cm

7-8. The typical value of HVL for an 80-kVp x-ray beam is about mm_____ Al eq.

(a) 20 pm (b) 0.4 mm (c) 0.35 cm (d) 0.07 m (e) 0.05 inch

7-9. The typical HVL in lead of a normally filtered 100-kVp x-ray beam is about ____mm.

(a) 0.02 (b)0.10 (c) 0.25 (d) 0.5 (e) 1.0

7-10. A 0.5-mm leaded radiation protection apron transmits about of the_____ incident x-rays.

(a) 25% (b) 10% (c)5% (d) 1% (e)O.25%

7-11. X-ray beams with low HVL values generally result in radiation dose to the patient and image subject contrast.

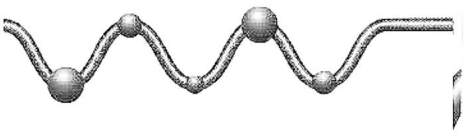
(a) Increased, increased (b) Increased, decreased (c) Decreased, increased
(d) Decreased, decreased (e) Decreased, no change in

7-12. Increased x-ray beam HVLs generally result in_____quantity and .quality.___

(a) Increased, increased (b) Increased, decreased (c) Decreased, increased
(d) Decreased, decreased (e) Decreased, no change in

7-13. Regulatory agencies specify that the filtration of an x-ray beam used clinically at 71 kVp must have a measured HVL of at least mm of aluminum equivalent.

(a) 1.0 (b)1.5 (c)2.1 (d)2.7 (e) 3.3



7-14. The reason for the regulatory limits on minimum measured HVL is to _____.

(a) Decrease motion blur (b) Reduce patient's radiation dose
(c) Decrease focal spot size (d) Improve subject contrast
(e) Reduce anode heating

7-15. Detrimental effects of added x-ray beam filtration include all of the following, *except.*_____

(a) Increased image unsharpness (b) Reduction of contrast
(c) Reduction of x-ray tube life (d) More scattered photons
(e) Latent image fading

7-16. For mammography with a molybdenum anode and filter, regulations require the measured HVL at 27 kVp to be at least nun of aluminum equivalent.

(a) 0.10 (b)0.30 (c)0.50 (d) 1.0 (e) 1.5

7-17. Mammography regulations specify lower measured HVL values for the x-ray beam for all of the following reasons, *except.* _____

(a) Lower kVp values are used (b) Anatomic thickness is less
(c) Subject contrast is needed (d) Breast radiation dose sensitivity is low
(e) Motion blur concerns exist

7-18. K-edge filters refer to. _____

(a) Greater and discontinuous attenuation at K-shell binding energy of the filter
(b) Characteristic x-rays of the anode
(c) Potassium-based x-ray filters
(d) Artifacts at the edge of the collimator
(e) Different copper alloys

7-19. Added filters degrade image contrast because. _____

(a) Characteristic x-rays are emitted from the filter
(b) Average x-ray energies into the Compton region are higher
(c) Average x-ray energies are lower into photoelectric region
(d) Filters make grids ineffective
(e) Filters reduce image receptor efficiency

7-20. The shortest wavelength x-rays are affected primarily by the. _____

(a) Filtration (b) Ripple (c) kVp (d) mA (e) Focal spot size

7-21. The longest wavelength x-rays (emerging from the x-ray tube and collimator) are affected primarily by the. _____

(a) Filtration (b) Ripple (c) kVp (d) mA (e) Focal spot size

7-22. The average energy of an x-ray spectrum is-affected by all of the following, *except.*_____

(a) Filtration (b) Ripple (c) kVp (d) mA (e) Anode material

7-23. Lower energy x-rays are preferentially absorbed in metallic filters because _____ occurs more often at low energies.

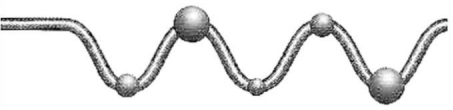
(a) Coherent scatter (b) Photoelectric effect (c) Compton scatter
(d) Pair production (e) Inverse square effect

7-24. The following materials have all been used as filtration in diagnostic x-ray beams, *except.*_____

(a) Aluminum (b) Copper (c) Molybdenum (d) Rhodium (e) Lead

7-25. The average energy of a 100-kVp beam is about keV._____

(a) 10 (b)25 (c)40 (d) 69.5 (e) 77.7



C. Answers

7-1. Answer = (b). Quantity is measured by the effect of the x-rays on air in terms of exposure in units of either milliroentgens (mR) or coulombs per kg of air. Quantity increases with: higher kVp, more mAs, or less filtration.

7-2, Answer = (c). The filters preferentially remove the low-energy x-rays, leaving the higher energy x-rays. The average energy increases: however, the total number of x-rays is smaller because a significant number of low-energy x-rays are removed by the filter.

7-3. Answer = (d). The quality is the measure of the penetration of the x-ray beam. It is usually given as the HVL of the beam in mm of aluminum. As the penetration increases, more mm of aluminum are required to reduce the x-rays to 50% of the unattenuated value.

7-4. Answer = (d). Increasing the kVp results in an increase in both the maximum x-ray energy (which is equal numerically to the kVp) and the average x-ray energy. Greater filtration removes the lower energy x-rays so that the remaining x-rays have a higher average energy. The product of mA and tune is the mAs, which increases only the number of x-rays; the distribution of x-ray energies is unchanged. Greater ripple in the x-ray tube voltage results in the x-rays having a lower average energy.

7-5. Answer = (c). The quantity is related to the total number of x-rays. mAs increases the number of x-rays without changing their energy distribution. Greater kVp increases both the number of x-rays and their average/maximum energy. More filtration results in fewer x-rays with a higher average energy and with greater penetration. More ripple produces fewer x-rays with a lower average energy.

7-6. Answer = (b). Measurement of HVL requires that any scatter resulting from interactions in the aluminum sheets be excluded from detection by the dosimeter. This requires an air gap and a small detector to allow the scatter to miss the detector. A narrow x-ray beam minimizes the amount of scatter. A uniform energy response allows the detector to measure all energies equally well.

7-7. Answer = (d). The first HVL reduces the intensity to 50%. The second HVL reduces the beam to 25%. The third HVL reduces the intensity to 12.5%. The fourth HVL reduces the beam to 6.25%. If four HVLs have a thickness of 20 cm, one HVL would be about 5 cm in thickness.

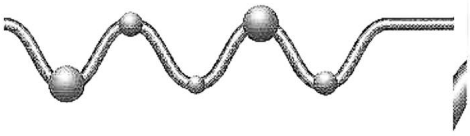
7-8. Answer = (c). At 80 kVp with routine filtration, the HVL is typically 2.4 to 4.5 mm of aluminum equivalent. Test questions can use different set of units; 3.5 mm of aluminum is equal to 0.35 cm of aluminum.

7-9. Answer = (b). A normally filtered 100-kVp beam has an HVL of 0.10 mm of lead, and a highly filtered beam (such as leakage radiation) has an HVL of about 0.24 mm of lead.

7-10. Answer = (c). If the normally filtered 100-kVp x-ray beam has an HVL of 0.10 mm of lead and a standard protective apron has 0.50 mm of lead, the protective apron has about five HVLs. A five-HVL thickness reduces the intensity to 3%. The measured value in published literature is about 4% to 6%.

7-11. Answer = (a). Low HVLs mean that the x-ray beam is lightly filtered. The average x-ray energy is low. Hence, the lower energy x-rays do not penetrate well and radiation doses are high. Low-energy x-rays have more photoelectric effect interactions in matter, which improve image contrast.

7-12. Answer = (c). If the increased HVL is due to more filtration of the x-rays, the number of x-rays decreases because of removal of low-energy x-rays, and the penetration of the remaining x-rays is greater. However, if the increased HVL is due to higher kVp. both the number of x-rays and the penetration are increased. Thus, the answer for higher kVp would be (a).



7-13. Answer = (c). Using the equation provided, specified HVL = 2.2(71/100) + 0.56 = 1.54 + 0.56 = 2.10 mm aluminum equivalent.

7-14. Answer = (b). The use of added filtration to increase the HVL requires longer exposure times because the number of x-rays is reduced, so there is more motion blur. The filters will not change the size of a given focal spot, but larger focal spot sizes may need to be selected when significant filtration is used. The extra filtration results in higher average energy x-rays, which reduces contrast. Because the added filters remove some of the x-rays and longer exposure times are required, the anode heating increases.

7-15. Answer = (e). Added filtration requires longer x-ray exposures and thus more motion blur (unsharpness). The higher energy x-rays produce more scatter (more Compton interactions) and reduced image contrast (less photoelectric interactions). Because of longer x-ray exposures and increased anode heating, the tube life is decreased. Latent image fading occurs when film-screen cassettes are processed much later than the x-ray exposure.

7-16. Answer = (b). For mammography with a molybdenum anode, the equation for minimum HVL is (kVp/100) + 0.03 = (27/100) + 0.03 = 0.30 mm Al eq.

7-17. Answer = (d). Lower kVp values are used in mammography to enhance subject contrast. This results in lower HVLs. Fortunately, the thickness of the compressed breast is only a few centimeters; otherwise, the radiation doses would be very high because of the lack of penetration. Minimum HVLs are specified so that the radiation dose does not become excessive; this is important because the breast tissue is sensitive to cancer risk as a result of the radiation. More filtration (to obtain higher HVLs) could result in longer exposure time and more motion blur.

7-18. Answer = (a). When the energy of the incident x-rays is less than the K-shell binding energy of the attenuation material, the photoelectric interaction can occur only with the L-shell, M-shell, and so on. At energies just above the K-shell binding energy, the interactions include the K-shell electrons, and the attenuation coefficient increases discontinuously at this point.

7-19. Answer = (b). Filters do not affect grid efficiency much. The higher energy x-rays do slightly decrease image receptor efficiency, but this has little effect on the image contrast. There are also some characteristic x-rays from the filters, but the air gap results in little effect on image contrast. The higher average x-ray energy from added filtration results in a greater portion of Compton interactions, which in turn reduces the contrast.

7-20. Answer = (c). The shortest wavelength x-rays are the highest energy x-rays. These x-rays are directly related to the kVp used. The mA affects the total number of x-rays produced; it does not affect the energy. Focal spot size affects spatial resolution, anode heating, and maximum mA that can be used.

7-21. Answer = (a). The longest wavelength x-rays are the lowest energy x-rays. The x-ray beam filtration removes many of the lower energy x-rays; thus, it controls the minimum x-ray energy emerging from the collimator.

7-22. Answer = (d). kVp controls the maximum and average energy. The filters eliminate the lowest energy x-rays so that the remaining x-rays have a higher average energy. Higher ripple in the kVp waveform reduces the average x-ray energy. The anode material determines the energy of the characteristic x-ray produced. The mA controls only the total number of x-rays, not the x-ray energy.

7-23. Answer = (b). Coherent scatter.interactions affect only a small percentage of all x-ray interactions. Compton scatter interactions occur at higher x-ray energies, and pair production requires greater than 1.02 MeV. Inverse square effect is related to distance and not x-ray energy.



7-24. Answer = (e). Lead is too attenuating for most x-ray beam filtration. It is used primarily as a radiation shielding material. Be aware that special plastics with some lead content are used as "shaped filters" for scoliosis, orthopedic leg, and cardiac studies.

7=25. Answer = (c). The average energy is about 0.33 to 0.50 of the kVp; hence, the average energy for 100-kVp x-rays would be about 33 to 50 keV. For most x-ray beams, the average energy is closer to 0.5 times the kVp than to 0.33 times the kVp. The best answer in this range is 40 keV