Mammography - Chapter 8

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a copy of this lecture may be found at:
http://courses.washington.edu/radxphys/PhysicsCourse.html
1. Introduction

- Mammography is a radiographic modality used for detecting breast pathology and cancer.
- Approximately 1 in 8 women will develop breast cancer over a lifetime in USA.
- Breast cancer accounts for 32% of cancer incidence and 18% of cancer deaths in women in the United States.
1. Introduction

- Breast cancer screening programs depend on x-ray mammography because it is a low-cost, low-radiation-dose procedure that has the sensitivity for early detection and improved treatment.

- Recognition of breast cancer depends on:
  - the detection of masses, particularly with irregular or “spiculated” (Strands of tissue radiating out from an ill-defined mass, producing a stellate appearance) margins
  - clusters of microcalcifications (specks of calcium hydroxyapatite)
  - architectural distortions of breast structures
1. Introduction

- Mass with spiculated margins
- Clustered heterogeneous microcalcifications
- Architectural distortion

1. Introduction

- Screening Mammography – Identify Cancer
  - the AMA, ACS and ACR recommends a baseline mammogram by age 40, biannual examinations between ages 40 and 50, and yearly examinations after age 50
  - NCI recommends women in their 40s, 50s and older should be screened every one to two years with mammography
  - require craniocaudal (CC) and mediolateral oblique (MLO) views of each breast
1. Introduction

- Diagnostic Mammography – Evaluate Abnormalities
  - may require additional views, magnification views, spot compression views, stereotactic biopsy or other studies using other modalities

[Image of mammogram]

c.f. Radiographics 19 (2): 280
1. Mammography Imaging Modalities

- Ultrasound Breast Imaging
  - used for differentiating cysts (typically benign) from solid masses (often cancerous), which have similar appearances on the mammogram
  - provides biopsy needle guidance for extracting breast tissue specimens

- MRI
  - has wonderful tissue contrast sensitivity
  - useful for evaluating silicone implants
  - accurately assess the stage of breast cancer involvement
1. Modern Mammography

- Breast is composed of fatty tissue, glandular tissue and a 50/50 combination of both.
- Normal and cancerous tissues in the breast have small x-ray attenuation differences between them.
- Need x-ray equipment specifically designed to optimize breast cancer detection.

1. Modern Mammography

- Detection of minute calcifications important
  - High correlation of calcification patterns with disease

- Best differential between the tissues is obtained at low x-ray energies

- Mammography equipment
  - Low contrast sensitivity
  - High resolution
  - Low dose

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1. Modern Mammography

- Dedicated Mammography Equipment
- Specialized X-ray Tubes
- Breast Compression Devices
- Optimized Screen/Film detector systems

1. X-Ray Tube Design

- Cathode and Filament Circuit
  - dual filaments in a focusing cup
    - 0.3 mm (contact) and 0.1 mm (magnification) focal spot sizes
  - small focal spot
    - minimizes geometric blurring
    - maintains spatial resolution

- low operating voltage below 35-40 kVp
- Typical tube currents are
  - 100 mA (+/- 25 mA) for large (0.3 mm) focal spot
  - 25 mA (+/- 10 mA) for small focal spot
1. X-Ray Tube Design

- **Anode**
  - rotating anode design
  - Molybdenum (Mo), and dual track molybdenum/rhodium (Mo/Rh) targets are used
  - Characteristic x-ray production is the major reason for choosing molybdenum and rhodium
    - For molybdenum, characteristic radiation occurs at 17.5 and 19.6 keV
    - For rhodium, 20.2 and 22.7 keV
1. X-Ray Tube Design

- Anode
  - Targets used in combination with specific tube filters to achieve optimal energy spectra
  - A source to image distance (SID) of 65 cm typically used
  - The tube is tilted by about 25 degrees to minimize the effective focal spot size
1. X-Ray Tube Design

- Heel effect - lower x-ray intensity on the anode side of the field (attenuation through the target)
- Thus cathode-anode axis is placed from the chest wall (greater penetration of x-rays) to the nipple in breast imaging
- A more uniform exposure is achieved
- This orientation also minimizes equipment bulk near the patient’s head for easy positioning

1. Tube Port, Tube Filtration & Beam Quality

- Monoenergetic x-rays of 15 to 25 keV are best choice, but not available

- Polychromatic spectra compromises:
  - High-energy x-rays in the bremsstrahlung spectrum diminish subject contrast
  - Low-energy x-rays in the bremsstrahlung spectrum have inadequate penetration and contribute to patient dose without providing a useful image

- Molybdenum (Mo) and Rhodium (Rh) are used for mammography targets and produce characteristic x-ray peaks at 17.5 and 19.6 keV (Mo) and 20.2 and 22.7 keV (Rh)
1. Tube Port, Tube Filtration & Beam Quality

- 1-mm thick Beryllium used as the tube port
  - Beryllium provides both low attenuation and good structural integrity

- Added tube filters of the same element as the target reduce the low- and high-energy x-rays in the x-ray spectrum and allow transmission of characteristic x-ray energies

- Common target/filters in mammography include
  - Mo/Mo
  - Rh/Rh
  - Mo/Rh
1. Tube Port, Tube Filtration & Beam Quality

- A Mo target with Rh filter are common for imaging thicker and denser breasts

- This combination produces slightly higher effective energy than Mo/Mo

- Provides 20 and 23 keV leading to increased penetration of thick and/or dense breasts
- Ro target with Rh filter provides the highest effective energy beam
  - 2 to 3 keV higher
  - useful for the thickest and densest breasts

- Tungsten (W) targets with Mo and Rh filters not usually used but sometimes are available with the mammography unit

Raphex 2000 Diagnostic Question

- **D25.** Which of the following is *not* a modern mammography target/filter combination for screen-film?
  - A. Mo/Mo
  - B. Mo/Rh
  - C. Rh/Rh
  - D. W/Al
  - E. W/Rh
The K-characteristic x-rays of molybdenum target tubes comprise a significant portion of the total x-ray flux. These x-rays have energies predominantly between _________ keV and _________ keV

- A. 10, 12
- B. 15, 16
- C. 17, 20
- D. 24, 26
- E. 59, 69
The filtration in mammography units primarily transmits the characteristic x-rays. The very low-energy bremsstrahlung x-rays are filtered because they contribute to ____________, and the higher energy bremsstrahlung x-rays are filtered because they contribute to ______________.

- A. tube heating, off-focus radiation
- B. heel effect, focal spot blooming
- C. radiation dose, loss of contrast
- D. grid cut-off, septal penetration
- E. coherent scatter, K-edge photons
2. The low voltage used in screen/film mammography reduces:

- (A) Subject contrast
- (B) Dose
- (C) Microcalcification visibility
- (D) Scatter
- (E) Film processing time
1. Half Value Layer (HVL)

- The HVL ranges from 0.3 to 0.45 mm Al in mammography
  - depends on kVp, compression paddle thickness, added tube filtration, target material and age of tube
  - In general, HVL increases with higher kVp and higher atomic number targets and filters

- Breast dosimetry relies on accurate HVL measurement
- The approximate HVL in breast tissue is ~ 1 to 2 cm (strongly dependent on tissue composition: glandular, adipose and fibrous).
  - Thus a 4cm breast will attenuate \(1 - 1/2^4 \approx 0.93\), or 93% of the incident primary radiation
    - [reduction in beam intensity or fraction transmitted is \(1/2^n\) and attenuation is \((1-1/2^n)\)]
1. Collimation

- Fixed-size metal apertures or variable field size shutters collimate the x-ray beam
- The field size matches the film cassette sizes
  - 18 x 24 cm or 24 x 30 cm
- Collimator light and mirror assembly define the x-ray field
  - X-ray field – light field congruence must be within 2% of SID for any edge
  - The useful x-ray field must extend to the chest wall edge without field cutoff
1. X-Ray Generator

- A dedicated mammography x-ray generator is similar to a standard x-ray generator in design and function. Differences exist in:
  - Generator power rating is 3 kW
  - The voltage supplied to the x-ray tube (22-40 kVp),
  - Automatic Exposure Control (AEC) circuitry different

- High-frequency generators are the standard for mammography
1. Automatic Exposure Control (AEC)

- The AEC, also called a phototimer, uses a radiation sensor (or sensors), an amplifier, a voltage comparator, to control the exposure.
- AEC detector is located *underneath* the cassette in mammography unlike conventional radiography.

1. Automatic Exposure Control (AEC)

- If the transmission of photons is insufficient to trigger the comparator switch after and extended exposure time, a \textit{backup} timer terminates the exposure.

  - For a retake, the operator must select a higher kVp for greater beam penetrability and shorter exposure time.
1. Technique Chart

- Technique charts are useful guides to determine the appropriate kVp for specific imaging tasks, based on breast thickness and breast composition
  - posted near the console

- Proper kVp is essential for a reasonable exposure time, defined as a range from approx. 0.5 to 2.0 seconds, to achieve an optical density of 1.5 to 2.0
Section 1 - Take Home Points

- Breast Cancer – masses, microcalcifications and architectural distortions in breast
- Low energies used to optimize contrast (photoelectric effect)
- Specialized equipment needed
  - Improve contrast and resolution, decrease dose
- kVp range 22-40 kVp
- Molybdenum and Rhodium targets used in mammography
  - Characteristic radiation for Mo at 17.5 and 19.6 keV
  - For rhodium, 20.2 and 22.7 keV
- Heel effect due to attenuation in target
  - Chest wall on cathode side and nipple on anode side to get uniform exposure

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Section 1 - Take Home Points

- Common target/filters in mammography include
  - Mo/Mo (thin breasts), Rh/Rh (thickest, dense breasts), Mo/Rh (thicker, denser breasts)
  - Tungsten target available on some units but not used
- Generator similar to conventional radiography except for
  - lower power rating, different AEC circuitry, low kVp used
- 18 x 24 and 24 x 30 cm cassettes used
- AEC detector is located *underneath* the cassette in mammography unlike conventional radiography
2. Compression

- **Breast compression is necessary**
  - it reduces overlapping anatomy and decreases tissue thickness of the breast
  - less scatter, more contrast, less geometric blurring of the anatomic structures, less motion and lower radiation dose to the tissues

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2. Compression

- Compression is achieved with a low attenuating lexan paddle attached to a compression device
- 10 to 20 newtons (22 to 44 pounds) of force is typically used
- A flat, 90° paddle (not curved) provides a uniform density image
- Parallel to the breast support table
- Spot compression uses small paddles
- Principal drawback of compression is patient discomfort

2. Scatter Radiation

- Scatter radiation degrades subject contrast.
- The amount of scatter increases with breast thickness and breast area, and is relatively constant with kVp (25-35 kVp).
- Without scatter rejection, only 50 to 70% of the inherent subject contrast will be detected.

2. The Antiscatter Grid

- Grids are used to reject scatter
- The grid is placed between the breast and the image receptor
- *Linear grids with a grid ratio of 4:1 to 5:1 are typical.* Cellular grids used by some manufacturers
- Higher grid ratios provide greater x-ray scatter removal but also a greater dose penalty
- Aluminum and carbon fiber are typical interspace materials
  - Carbon fiber is preferred because aluminum would attenuate too many of the low-energy x-rays used in mammography

2. Anti-Scatter Grids

- Grid frequencies (lead strip densities) range from 30 to 50 lines/cm for moving grids and up to 80 lines/cm for stationary grids.

- The Bucky factor is the ratio of exposure with the grid compared to the exposure without the grid for the same film optical density.
  - *For mammo, Bucky factor is about 2 to 3*, so breast dose is doubled or tripled, but image contrast improves by 40%.
2. Air Gaps

- The use of an air gap between the patient and the screen-film detector reduces the amount of detected scatter.
- Grids not used in magnification, air gap used.
- Reduction of the breast dose is offset by the shorter focal spot to skin distance.

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2. Magnification

- Advantages
  - Magnification of 1.5x to 2.0x is used
  - Increased effective resolution of the image receptor by the magnification factor
  - Small focal spot size used
  - Reduction of scatter

![Image of magnification diagram]

2. Magnification

- Disadvantages
  - Geometric blurring caused by the finite focal spot size (more on cathode side)
  - High breast dose (in general similar to contact mammography)
  - Long exposure times (small focal spot, low mA)
    - patient motion and blur

2. MTF in magnification mammography


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7. In mammography, a fiber interspaced grid is preferred over aluminum because it:

(A) Reduces the dose
(B) Improves resolution
(C) Removes more scatter
(D) Reduces image mottle
(E) Improves contrast
Raphex 2001 Diagnostic Question

- **D19.** Ideally, the AEC (phototimer) sensor in mammography should be placed:
  - A. As close to the chest wall as possible.
  - B. Under the densest portion of the breast.
  - C. Under the least dense portion of the breast.
  - D. Under the most anterior portion of the breast.
  - E. In the center of the breast.
Raphex 2002 Diagnostic Question

- D28. Which grid would be the best choice for use as a stationary grid in mammography?
  - A. 44 lines/cm, 5:1 ratio
  - B. 44 lines/cm, 12:1 ratio
  - C. 80 lines/cm, 5:1 ratio
  - D. 80 lines/cm, 12:1 ratio
  - E. Any of the above, as long as they are made of carbon fiber
Raphex 2002 Diagnostic Question

D29. Which of the following is not true? Vigorous compression in mammography reduces:

- A. Patient dose.
- B. Scatter.
- C. Motion unsharpness.
- D. Subject contrast.
14. Magnification radiography using current imaging equipment:

- (A) Reduces the entrance skin exposure
- (B) Improves the definition of fine detail
- (C) Requires large focal spots larger than 0.3 mm
- (D) Reduces film density
- (E) Requires moving the film further from the tube
2. Screen/Film Cassettes

- Cassettes have a single phosphor screen and single emulsion film

- Mammography screen-film speeds (sensitivity):
  - regular (100 or par speed) (12-15 mR required)
  - medium (150 – 190 speed)

- For comparison, a conventional “100-speed” screen film cassette requires about 2 mR
Limiting spatial resolution is about 15-20 lp/mm (0.025 - 0.030 mm object size)

2. Film Processing

- Film processing is a critical step in the mammographic imaging chain
- Consistency in film speed, contrast, optical density levels are readily achieved by following the manufacturer’s recommendations
2. Film Sensitometry

- A film processor quality control program is required by Mammography Quality Standards Act of 1992 (MQSA) regulations, and daily sensitometric strips prior to the first clinical images must verify acceptable performance.

- Film sensitometry confirms proper film contrast, speed and base + fog values of mammographic film.
  - Typical fog values are 0.17 – 0.2 OD, Dmax = 3.8 – 4.0 OD and the target film OD ranges from 1.2 – 1.8.
2. Film Sensitometry


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2. Extended Cycle Processing

- Extended cycle processing (or push processing) increases the speed of some single emulsion mammography films by extending the developer immersion time by a factor of two (usually from ~ 20 to ~ 40 seconds)
- The rationale is to completely develop all latent image centers, which does not occur with standard processing
- Up to 35% to 40% decrease in required x-ray exposure is obtained compared to standard processing for same OD
- On conventional 90 second processor, the processing time is extended to 180 seconds
2. Extended Cycle Processing

2. Film Viewing Conditions

- Optimal film viewing conditions are important in detecting subtle lesions.
- Mammography films are exposed to high optical densities to achieve high contrast, view boxes providing a high luminance are necessary.
- The luminance of a mammography viewbox should be at least 3000 cd/m².
- In comparison, a typical viewbox in diagnostic radiology is about 1500 cd/m².
2. Film Viewing Conditions

- Film masking is essential for blocking clear portions of the film and the viewbox.

- The ambient light intensity in a mammography reading room should be low to eliminate reflections from the film.

- A high intensity bright light to penetrate high optical density regions of the film, such as skin line and the nipple area.

- Magnifying glass should be available to view fine detail such as microcalcifications.
2. Radiation Dosimetry

- Risk of carcinogenesis from the radiation dose to the breast is of concern thus monitoring of dose is important and is required yearly by MQSA (Mammography Quality Standards Act of 1992)

- Indices used in Mammography
  - Entrance Skin Exposure (ESE)
    - the free-in-air ionization chamber measurement of the entrance skin exposure of the breast
    - typical ESE values for a 4.5 cm breast are 500 to 1000 mR
  - Half Value Layer (HVL)
    - Typical HVL from 0.3 to 0.4 mm Al for 25 – 30 kVp
2. Radiation Dosimetry

- Glandular tissue is sensitive to cancer induction by radiation

- Average Glandular Dose
  - Dependent on the composition of breast, breast thickness, HVL and kVp of beam
  - The Roentgen to Rad conversion factor, $D_gN$ is used to convert the measured ESE to glandular dose
    - $D_g = D_gN \times X_{ESE}$
2. Radiation Dosimetry

- Factors affecting breast dose
  - Higher kVp increases beam penetrability (lower ESE and lower average glandular dose), but decreases inherent subject contrast
  - ↑kVp and ↓mAs will result in low dose because of greater penetrability (use higher kVp)

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2. Radiation Dosimetry

- Factors affecting breast dose
  - Increased breast thickness requires increased dose
  - Vigorous compression lowers breast dose by reducing thickness

[Graph showing average glandular dose vs. breast thickness for different kVp settings]

2. Radiation Dosimetry

- Variables impacting breast dose
  - Rh/Rh combination will result in lowest average dose, followed by Mo/Rh and Mo/Mo (use Rh for thicker, denser breasts)
  - Screen/film speed and film processing conditions (use faster screen film or digital detectors)
  - Higher OD target on film will ↑ dose
  - Use of a grid will ↑ dose

- Tissue composition of the breast
  - Glandular tissue will have higher breast dose due to increased attenuation and a greater mass of tissue at risk
2. Radiation Dosimetry

- The MQSA limits the average glandular breast dose to 3 mGy or 300 mrad per film for a compressed breast thickness of 4.2 cm and a breast composition of 50% glandular and 50% adipose tissue (using the MQSA approved mammography phantom).

- If the average glandular dose for this phantom exceeds 3 mGy, mammography cannot be performed.

- The average glandular dose for this phantom is typically 1.5 to 2.2 mGy per view or 3 to 4.4 mGy for two views for a film optical density of 1.5 to 2.0.
Risks and Benefits

- Based on AGD of 3 mGy, the increased breast cancer risk from radiation is 6 per million examined women.
- This is equivalent to dying in an accident when traveling 5000 miles by airplane or 450 miles by car.
- Screening in 1 million women is expected to identify 3000 cases of breast cancer.
- The breast cancer mortality rate is about 50%.
- Screening would reduce the mortality rate by about 40%.
- That would potentially mean 600 lives being saved due to screening.
- The benefits of getting a mammogram far outweigh the risks associated with the radiation due to the mammogram.


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Section 2. Take Home Points

✓ Breast compression is necessary
  ➢ reduces overlapping anatomy, decreases tissue thickness of the breast, less scatter, more contrast, less motion and lower radiation dose to the tissues

✓ Scatter reduced by grids
  ➢ 5:1 grid ratio
  ➢ Bucky factor of 2 to 3

✓ Magnification of 1.5 to 2 times in mammography
  ➢ Increased resolution, decreased scatter, increased dose, long exposure times, motion, increase in geometric blur with increased magnification
Section 2. Take Home Points

- Single-screen and single emulsion film used
  - 15-20 lp/mm resolution
- Film processing is very important
- A film processor quality control program is required by Mammography Quality Standards Act of 1992 (MQSA) regulations
- The luminance of a mammography viewbox should be at least 3000 cd/m²
- Glandular tissue is sensitive to cancer induction by radiation
Section 2. Take Home Points

- Average glandular breast dose limited to 3 mGy or 300 mrad per film for a compressed breast thickness of 4.2 cm, 50/50 glandular/adipose breast composition
  - Increasing kVp reduces dose
  - Increased breast size increases dose
  - Vigorous compression lowers breast dose by reducing thickness

- Risk of mammogram induced breast cancer is far less than the risk of developing breast cancer
3. Quality Assurance & Quality Control

- Regulations mandated by the MQSA of 1992 specify the operational and technical requirements necessary to perform mammography in the USA.

- For a facility to perform mammography legally under MQSA, it must be certified and accredited (ACR or some states).
3. Quality Assurance & Quality Control

- The accreditation body verifies that the mammography facility meets standards set forth by the MQSA such as initial qualifications, continuing experience, education of physicians, technologists and physicists, equipment quality control etc.

- Certification is the approval of a facility by the U.S. FDA to provide mammography services, and is granted when accreditation is achieved.
3. Radiologist Responsibilities

- Responsibilities include
  - Ensuring that technologists are appropriately trained in mammography and perform required quality assurance measurements
  - Providing feedback to the technologists regarding aspects of clinical performance and QC issues
3. Radiologist Responsibilities

- Responsibilities include
  - Having a qualified medical physicist perform the necessary tests and administer the QC program
  - Ultimate responsibility for mammography quality assurance rests with the radiologist in charge of the mammography practice
  - The medical physicist and technologist are responsible for the QC tests
3. Mammography phantom

- Is a test object that simulates the radiographic characteristics of compressed breast tissues, and contains components that model breast disease and cancer in the phantom image.

- It is intended to mimic the attenuation characteristics of a “standard breast” of 4.2-cm compressed breast thickness of 50% adipose and 50% glandular tissue composition.
3. Mammography phantom

- 6 nylon fibers, 5 simulated calcification groups, 5 low contrast disks that simulate masses

- To pass the MQSA quality standards, at least 4 fibers, 3 calcification groups and 3 masses must be clearly visible (with no obvious artifacts) at an average glandular dose of less than 3 mGy
<table>
<thead>
<tr>
<th>Test and Frequency</th>
<th>Requirements for Acceptable Operation</th>
<th>Documentation Guidance</th>
<th>Timing of Corrective Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processor base fog density —daily</td>
<td>$\leq +0.03$ OD of established operating level</td>
<td>QC records and charts for last 12 months; QC films for 30 days</td>
<td>Before any further clinical films are processed</td>
</tr>
<tr>
<td>Processor mid-density (MD) value —daily</td>
<td>Within $\pm 0.15$ OD of established operating level for MD</td>
<td>QC records and charts for last 12 months; QC films for 30 days</td>
<td>Before any further clinical films are processed</td>
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<tr>
<td>Processor density difference (DD) value —daily</td>
<td>Within $\pm 0.15$ OD of established operating level for DD</td>
<td>QC records and charts for last 12 months; QC films for 30 days</td>
<td>Before any further clinical films are processed</td>
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<tbody>
<tr>
<td>Phantom image center OD and reproducibility—weekly</td>
<td>Established operating level OD $\geq 1.20$ within $\pm 0.20$ OD of established operating level at typical clinical setting</td>
<td>QC records and charts for last 12 months; phantom images for the last 12 weeks</td>
<td>Before any further exams are performed using the x-ray unit</td>
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<tr>
<td>Phantom density difference background and test object</td>
<td>Within $\pm 0.05$ OD of established operating level</td>
<td></td>
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<tr>
<td>Phantom scoring—weekly</td>
<td>Minimum score of four fibers, three speck groups, three masses</td>
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<tbody>
<tr>
<td>Fixer retention in film—quarterly</td>
<td>Residual fixer no greater than 5 μg/cm²</td>
<td>QC records since the last inspection or the past three tests</td>
<td>Within 30 days of the date of the test</td>
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<tr>
<td>Repeat analysis—quarterly</td>
<td>Operating level for repeat rate &lt;2% change (up or down) from previous rate</td>
<td>QC records since last inspection or the past three tests; fog QC films from the previous three tests</td>
<td>Before any further clinical films are processed</td>
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<tr>
<td>Darkroom fog—semiannually</td>
<td>OD difference ≤0.05</td>
<td>QC records since last inspection or the past three tests</td>
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</thead>
<tbody>
<tr>
<td>Screen-film (S-F) contact—semiannually</td>
<td>All mammography cassettes tested with a 40-mesh copper screen, with no obvious artifacts</td>
<td>QC records since last inspection or the past three tests; S-F contact QC films from the previous three tests</td>
<td>Before any further examinations are performed using the cassettes</td>
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<tr>
<td>Compression device—semiannually</td>
<td>Compression force ≥11 newtons (25 pounds)</td>
<td>QC records since the last inspection or the past three tests</td>
<td>Before examinations are performed using the compression device</td>
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<table>
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<tr>
<th>Test</th>
<th>Regulatory Action Levels</th>
<th>Required Documentation</th>
<th>Timing of Corrective Action</th>
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</thead>
<tbody>
<tr>
<td>AEC</td>
<td>OD exceeds the mean by more than 0.30 (over 2–6 cm range) or the phantom image density</td>
<td>The two most recent survey reports</td>
<td>Before any further examinations are performed using the x-ray machine</td>
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<td></td>
<td>at the center is less than 1.20</td>
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<tr>
<td>kVp</td>
<td>Exceeds 5% of indicated or selected kVp; C.O.V. exceeds 0.02</td>
<td></td>
<td>Within 30 days of the date of the test</td>
</tr>
<tr>
<td>Focal spot</td>
<td>See Table 8.1</td>
<td></td>
<td></td>
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<tr>
<td>HVL</td>
<td>See Tables 8.2 and 8.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air kerma (exposure) and AEC</td>
<td>Reproducibility C.O.V. exceeds 0.05</td>
<td></td>
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<tr>
<td>Dose</td>
<td>Exceeds 3.0 mGy (0.3 rad) per exposure</td>
<td></td>
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<tr>
<td>X-ray field/light field/compression device alignment</td>
<td>Exceeds 2% SID at chest wall Paddle visible on image O.D. variation exceeds 0.30 from the maximum to the minimum</td>
<td></td>
<td>Within 30 days of the date of the test</td>
</tr>
<tr>
<td>Screen speed uniformity</td>
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<tr>
<td>System artifacts</td>
<td>Determined by physicist</td>
<td></td>
<td></td>
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<tr>
<td>Radiation output</td>
<td>Less than 4.5 mGy/sec (513 mR/sec)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automatic decompression control</td>
<td>Failure of override or manual release</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Any applicable annual new modality tests</td>
<td>To be determined</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

D27. A typical half-value layer (HVL) for a screen-film mammographic unit is:

- A. 0.03 mm Mo
- B. 0.30 mm Mo
- C. 2.5 mm Al
- D. 0.30 mm Al
- E. 0.10 mm Cu
Raphex 2000 Diagnostic Question

D24. The average glandular dose for a 4.2 cm compressed breast is about:

- A. 1.3 mGy (130 mrad)
- B. 1.7 mGy (170 mrad)
- C. 3.0 mGy (300 mad)
- D. 120 mR
- E. 170 mR
21. Breast doses in mammography are most likely to be reduced by increasing the:

- (A) X-ray tube voltage
- (B) X-ray tube current
- (C) Focal spot size
- (D) Grid ratio
- (E) Number of views taken
15. Geometric unsharpness in mammography is:

- (A) Unimportant
- (B) Minimized with a large focal spot
- (C) Reduced by a small SID
- (D) Increased with magnification
- (E) Reduced with a large air gap
16. Optimal viewing of screen/film mammograms require all of the following except:

- (A) A bright viewbox (3000 cd/m²)
- (B) Availability of a hotlight
- (C) Use of a magnifying glass
- (D) Masking around the films
- (E) Overhead lighting (200 lux)
Raphex 2000 Diagnostic Question

D28. Mammograms cannot be processed if the weekly phantom does not pass. A passing score would be:

<table>
<thead>
<tr>
<th></th>
<th>Fibers</th>
<th>Speck</th>
<th>Masses</th>
<th>Disk</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4.0</td>
<td>3.0</td>
<td>3.0</td>
<td>0.40</td>
</tr>
<tr>
<td>B</td>
<td>5.0</td>
<td>2.5</td>
<td>3.0</td>
<td>0.50</td>
</tr>
<tr>
<td>C</td>
<td>3.5</td>
<td>4.0</td>
<td>3.0</td>
<td>0.50</td>
</tr>
<tr>
<td>D</td>
<td>4.0</td>
<td>4.0</td>
<td>2.5</td>
<td>0.50</td>
</tr>
<tr>
<td>E</td>
<td>6.0</td>
<td>5.0</td>
<td>2.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>
D31. In mammography, average glandular tissue dose depends on:

- A. Breast compression.
- B. Breast thickness.
- C. kVp.
- D. mAs.
- E. All of the above.
3. Stereotactic Breast Biopsy


Kalpana M. Kanal, Ph.D., DABR
3. Stereotactic Breast Biopsy

3. Digital Mammography

c.f. www.gehealthcare.com/rad/xr/education/dig_xray_intro.html
3. Full Field Digital Mammography Systems (FFDM)

FDA approved the following FFDM units for use in mammography facilities as indicated by date:

GE Senographe 2100DS Full Field Digital Mammography (FFDM) System on 02/19/04

Hologic/Lorad Selenia Full Field Digital Mammography (FFDM) System on 10/2/02

Lorad Digital Breast Imager Full Field Digital Mammography (FFDM) System on 03/15/02

Fischer Imaging SenoScan Full Field Digital Mammography (FFDM) System on 09/25/01

GE Senographe 2000D Full Field Digital Mammography System on 01/28/00

c.f. www.fda.gov

Kalpana M. Kanal, Ph.D., DABR
The Evolution of Digital Radiography Detectors

**Indirect imaging**

- **Screen-Film System**
  - X-ray energy
  - Scintillator screen
  - Film

- **Computed Radiography**
  - X-ray energy
  - Photo-stimulable storage phosphor imaging plate
  - Imaging plate moved to reader

- **CCD Detector with Scintillator Screen**
  - X-ray energy
  - Scintillator screen
  - CCD Cameras

- **Scintillator (Phosphor or Cesium Iodide) with Photodiode Array**
  - X-ray energy
  - Surface reflector
  - CsI (TI)
  - Focusing Lenses
  - Photodiode array with a-Silicon Thin-Film Transistor (TFT) and storage capacitor

**Direct imaging**

- **Amorphous Selenium DirectRay® Detector**
  - X-ray energy
  - Field electrode
  - Dielectric layer
  - Semiconductor (a-Selenium)
  - Electrode collection array with a-Silicon Thin-Film Transistor (TFT) matrix and storage capacitor

**Signal profile**

- CR
- Fischer
- GE
- Hologic/Lorad


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### Commercially Available Digital Mammography Detectors

The following is a list of full-field-of-view digital mammography detectors commercially available in the U.S.

#### Indirect-conversion detectors
- **GE**
  - Scintillator: CsI(Tl)
  - Pixel size: TFT 100 microns
  - Field of view: 18 x 23 cm

- **Fischer Imaging**
  - Scintillator: CsI(Tl)
  - Pixel size: CCD 24/48 microns
  - Field of view: 22 x 30 cm (scanning)

#### Direct-conversion detectors
- **Hologic/Lorad**
  - Photoconductor: amorphous selenium
  - Pixel size: TFT 70 microns
  - Field of view: 24 x 29 cm

3. GE Senographe DS FFDM system

Can use in association with CAD systems

c.f. private document, GE Medical Systems

Kalpana M. Kanal, Ph.D., DABR
3. Fischer SenoScan FFDM System

Fischer's patented CCD based "Slot Scan" detector

c.f. www.fischerimaging.com
3. Fischer SenoScan FFDM System

Fischer's patented CCD based "Slot Scan" detector

3. Hologic/Lorad Selenia FFDM System

c.f. www.hologic.com

Kalpana M. Kanal, Ph.D., DABR
Advantages and Disadvantages

- **Advantages**
  - Optimize post-processing of images
  - Permit computer-aided detection to improve the detection of lesions
  - Storage of images easier

- **Disadvantages**
  - Image display and system cost
  - Limiting spatial resolution is inferior to film, 10 lp/mm vs. 20 lp/mm
Section 3. Take Home Points

- Quality Assurance important and regulated by MQSA in mammography
  - Radiologist oversees program
  - Physicist and technologist responsibilities
  - Phantom – 4 fibers, 3 masses, 3 specks should be seen
- Stereotactic units used for breast biopsy, use geometry to calculate lesion location
- Digital mammography becoming common
  - GE, Fischer, Lorad/Hologic approved by FDA
  - Indirect and Direct systems used
  - CAD used in association with digital systems
  - Advantages and disadvantages