Mammography – Technical Aspects

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Reading Assignment

1. Bushberg et al. The Essential Physics of Medical Imaging, Ch. 8
2. Huda. W., Review of Radiologic Physics, 4th edition, Ch.8
3. AAPM/RSNA Physics Tutorial for Residents:

   http://pubs.rsna.org/doi/pdf/10.1148/rg.246045102

Mammograhy

- Most sensitive imaging test available for early breast cancer detection
- Detect early stage disease, improved prognosis

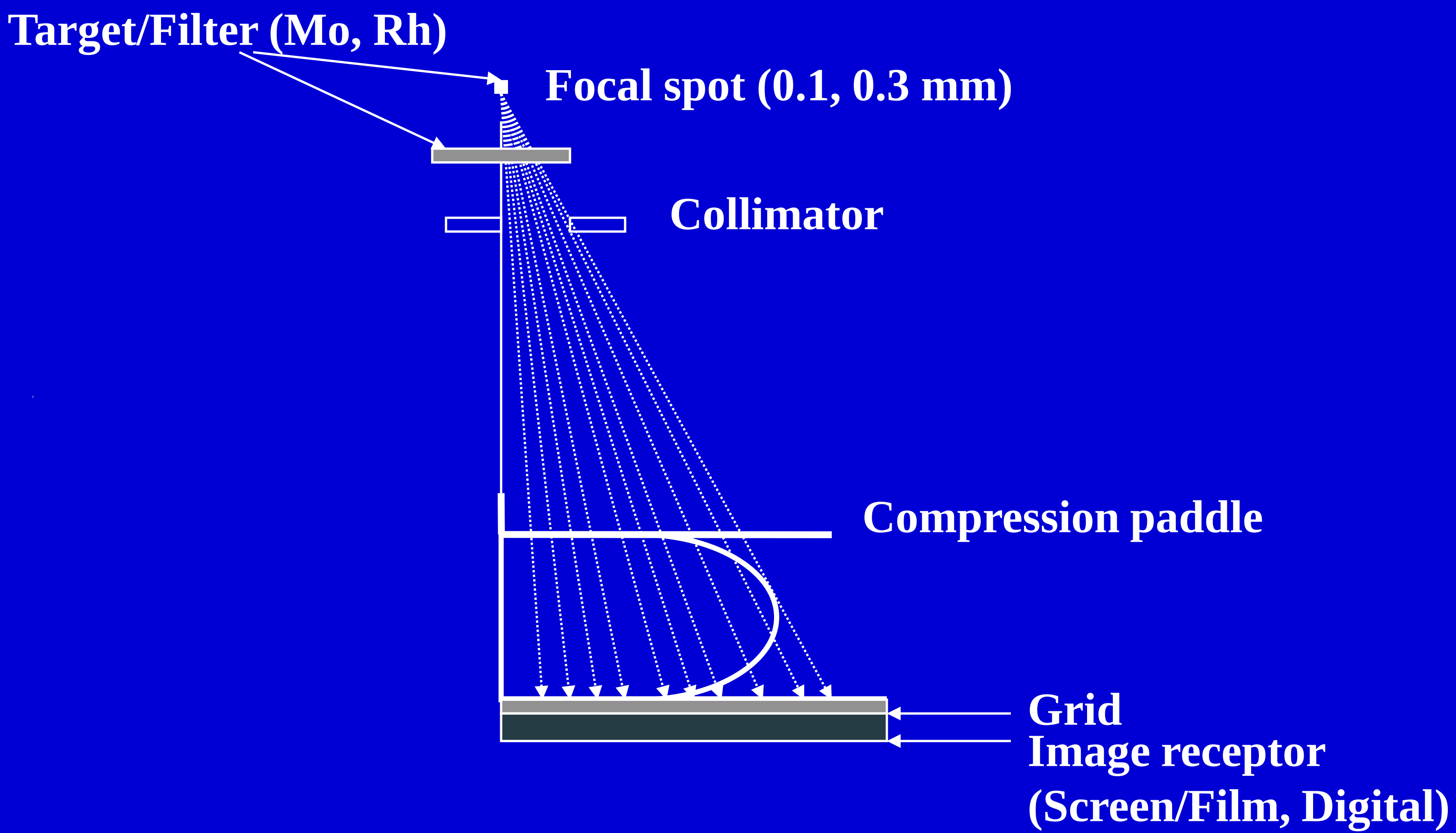
Stage	Survival Rate (%)
1	100
2	93
3	72
4	22

- Only x-ray imaging test used for screening (asymptomatic patient)
- Screening – potential to reduce breast cancer mortality by 25% over the last 20 years
- ~ 15 – 20% cancers missed despite high quality images

Mammograhy

- **Technically difficult radiographic exam**
- **Performed by specially qualified personnel**
- **Dedicated breast imaging equipment**
- **Goal: Produce high quality images of breast at *adequate* radiation dose**

Mammography Physics



X-ray Tube

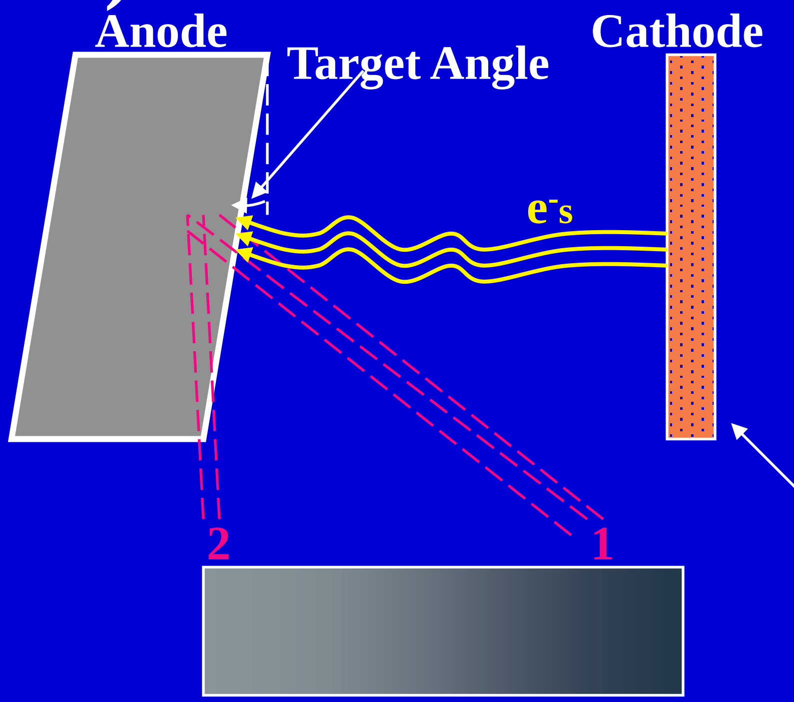
1. Focal Spot Size
   - 0.3 mm, 0.1 mm
   - improved resolution of microcalcifications (phantom 150-160 μm)

2. Dual track anode:

   Mo, Rh - photon energies appropriate for imaging breast tissue

X-ray Tube

3. (Anode) Heel Effect



1. X-rays emerging toward cathode side of x-ray tube and penetrate small amount of anode material.
2. X-rays emerging on anode side of tube penetrate through greater amount of anode material.

Closest to chest wall
Breast thickness greatest

X-ray beam gradient (decrease intensity) from cathode to anode side of tube

X-ray Tube

4. Tube port

   a. Collimator – automatic, adjustable field sizes:

      Small - 19x23 cm

      Large - 24x31 cm

      MAG/Spot compression - 10x12 cm, 13x18 cm

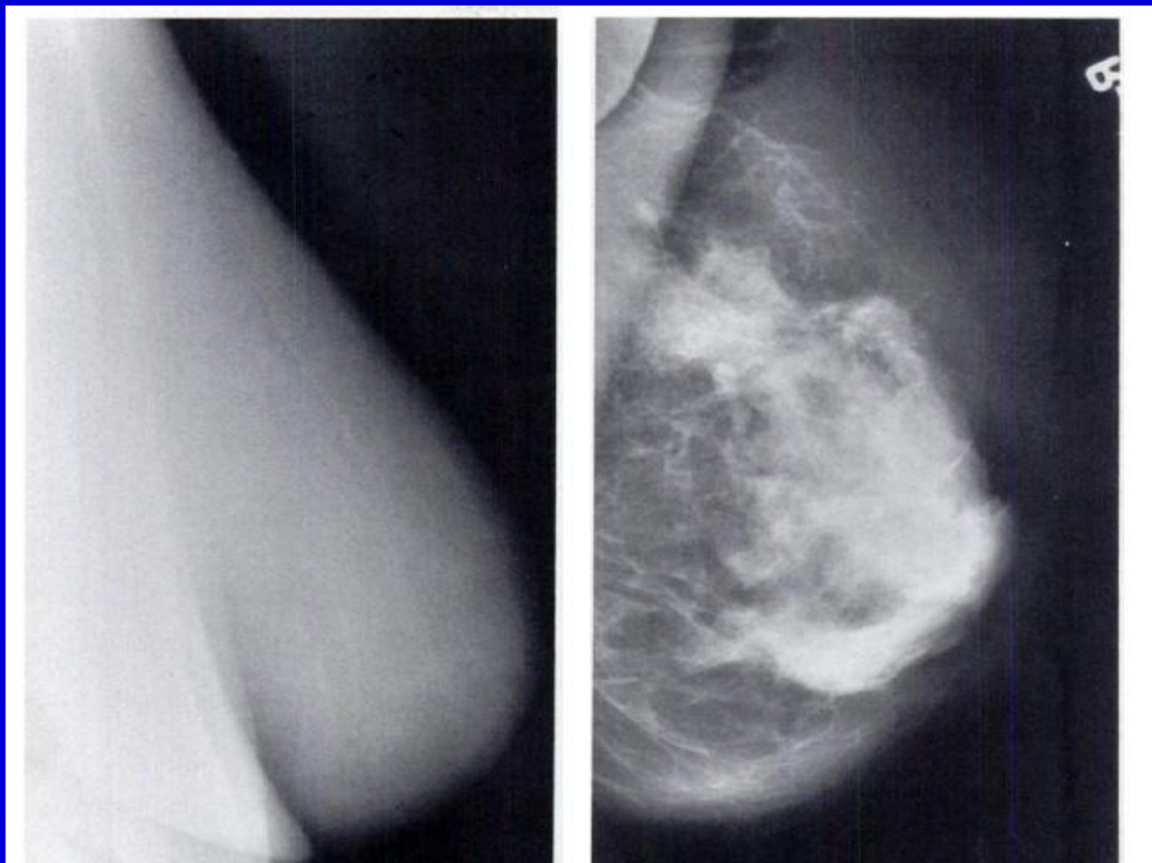
   b. Window – Be (thin layer); not glass

      Less attenuation of beam => ↑ subject contrast

Energy Spectrum

- **Mammography requirement:**
  - Low beam energy (decreased penetration):
    - Enhance subject contrast
  - High beam energy (increased penetration):
    - Reduce breast dose
    - Reduce tube heat loading
    - Shorter exposure time, especially thick/dense breast
- **Thus, need spectrum that provides balance between <u>high image contrast</u> and <u>adequate radiation dose</u>**

Tube Potential



Chest radiograph
using high kVp

Mammogram using
low kVp

Image contrast significantly increased when low x-ray energy used to maximize photoelectric interaction in breast tissue

http://dx.doi.org/10.1148/radiographics.9.4.2667052

Energy Spectrum

Spectrum determined by:

1. Anode material – Mo, Rh W (Tomosynthesis)
2. Filter material – Mo, Rh Ag, Al (Tomosynthesis)
3. Tube potential – Typical, 25 – 32 kVp (max. energy of spectrum)

X-ray Beam:

Continuous radiation (Bremsstrahlung) – range of energies; max. (kVp)

Characteristic radiation – discrete energies; determined by anode

Anode material	k-edge (keV)	Char. X-ray en. (keV)	
Mo	20.0	K_α: 17.9	K_β: 19.5
Rh	23.2	K_α: 20.2	K_β: 23.2

X-ray Tube

5. Filter Material

a. Mo filter used w/Mo target th. = 0.03 mm

b. Rh filter also can be used w/Mo target

b. k-edge = 20 keV, Mo characteristic enhanced

c. Low energy (< 15 keV), high energy (> 20 keV) removed

- Increased subject contrast
- Decreased entrance breast dose from low energy photons

d. Excessive filtration reduces beam intensity:

- longer exposure, motion blur

Technique

- **X-ray Absorption Differences:**
  - Adipose tissue Density = 0.95 g/cm^3
  - Glandular tissue Density = 1.02 g/cm^3
- **<u>Differential attenuation</u> between materials $\Rightarrow$**
  Image Contrast
- **Calcifications**
  - High Z
  - Maximize Photo. Elec. Absorption
  - P.E. $\propto Z^3$ dominates in diagnostic energy range
  - At low en. (20 keV) P.E. interaction dominates

Technique

Target/Filter material:

- Mo/Mo combination:
  - Attenuates continuous spectrum above k-edge (20 keV)
  - Typically used for thin or breast of average thickness
  - Low/medium dense breast
- Mo/Rh combination:
  - Shift spectrum to higher energies: 20 keV< photons < 23.2 keV
  - Typically used for thicker/more dense breast
- Rh/Rh combination:
  - Allows Rh characteristic (20.2, 23.2 keV); more penetrating beam
  - Shift spectrum higher energies
  - Typically used for very thick/very dense breast

Technique

- **Tube Potential (kVp, max. energy of spectrum)**
  - Typical 25 - 32 kVp Diag. X-ray (60 - 100 kVp)
  - Ave. breast 25 – 29 kVp optimal
  - Decrease kVp:
    - increase contrast, increase dose
    - decrease scatter
- **Tube current-exposure time (mAs)**
  - mA constant large f.spot (100-200 mA) small f. spot (30-50 mA)
  - exp. time varies 30 msec. – 6 sec.
    - long exposure times ⇒
    - increase motion blur, reduces noise (improves image quality)
    - increases radiation dose

Compression

- **Firm compression decreases breast thickness:**
  - structures spread out more uniformly
  - structures closer to receptor $\Rightarrow$ improve sharpness
  - x-rays travel through less tissue $\Rightarrow$ decrease dose
  - less scatter radiation $\Rightarrow$ increase image contrast
- **Immobilize breast $\Rightarrow$ reduce motion blur**
- **Improves image quality, reduces radiation dose**

Magnification

- Contact mammography: SID = 66 cm, SOD = 61 cm, M = 1.08
- MAG stand used to place breast close to x-ray tube:
  - SID = 66 cm, SOD = 37 cm M = 1.8; SOD = 44 cm M = 1.5
  - Air gap technique (air gap between object and image receptor); reduces scatter
  - Grid removed: Compensate for dose increase
- 0.1 mm focal spot use
  - Improve spatial resolution
  - Longer exposure time: lower mA with 0.1 mm focal spot
- Dose increase: breast tissue closer to focal spot
- Improved effective resolution: smaller object magnified

Automatic Exposure: AEC (Phototiming), AOP

- AEC – Select kVp, mAs automatic
- AOP (Auto. Optimize parameters):
  - Pre-exposure samples breast tissue
  - kVp, mAs selected automatically
- Consistent optical density on film or digital signal
- Reduce motion blur due to long exp. times
- Must account for variation in kVp, breast thickness

Grid

- Position
  - Receptor Bucky
  - Reciprocating: moves during exposure to blur grid lines
- Purpose
  - Important for scatter removal
  - Improvement in contrast
  - Increase in patient dose (approx. factor of 2 - 3)
  - Speed determines phototimed mAs => dose/noise tradeoff
  - Increase speed $\Rightarrow \downarrow$ dose, $\downarrow$ motion blur, $\uparrow$ noise
  - Decrease speed $\Rightarrow \uparrow$ dose, $\uparrow$ motion blur, $\downarrow$ noise

Image Receptor: Film/Screen

X-ray Film Components:

1. Base - support, shape
2. Emulsion - coating; silver halide, latent image formation
   light sensitive material (crystal grains)

Latent Image Formation

- Exposure of silver grains to light (or x-rays) ⇒ atomic silver
  Exposure ⇒ Latent image formation ⇒ Development

Processing

1. Development
2. Fixing
3. Washing

Image Receptor: Film/Screen

Photographic Characteristics

Response of film to exposure: mAs => density

kVp => contrast (gamma)

Optical Density - measurement of film "blackness"

O.D. = log (opacity) = log (I_0/I_t) I_0 = incident I_t = transmitted

- log units; thus differences (orders of magnitude)
- physiological response of eye is differences in brightness that are logarithmic
- diagnostic (useful) range of O.D. ~ 0.25 to 3.0

Characteristic Curve (H&D Curve)

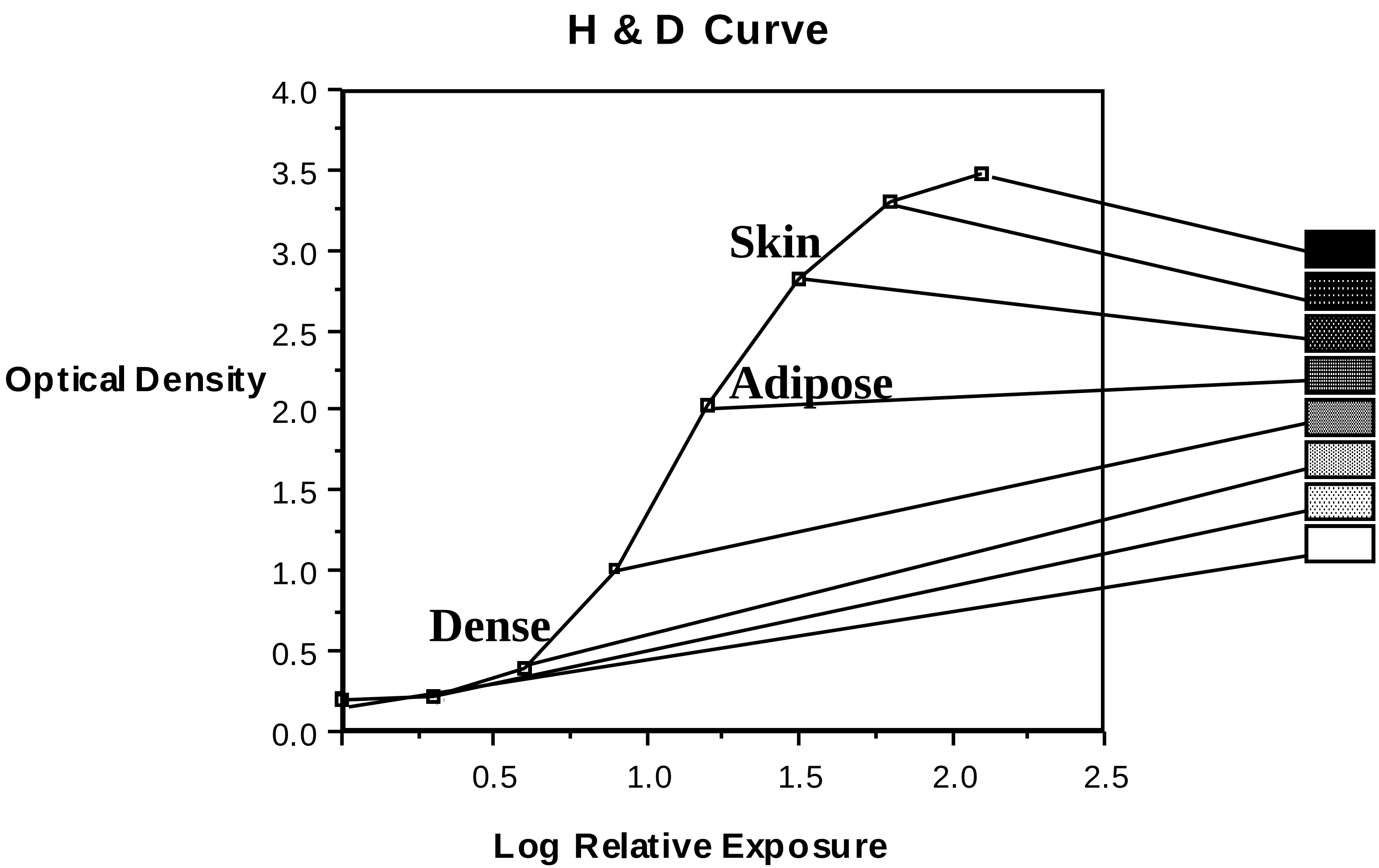


Image Receptor: Film/Screen

1. Response of film to exposure: Contrast Optical Density
2. Contrast
   a. O.D. difference between areas on film; response to variation in exposure
   b. contrast inversely related to film latitude
   c. gamma: max. slope of char. curve
      gamma = $(D_2 - D_1)/(\log E_2 - \log E_1)$
3. Density – O.D. of Film
   a. Slope changes with O.D.; (constant in linear portion)
   b. Shoulder and toe regions: less contrast between steps
4. Speed (sensitivity):
   Reciprocal of Exp. in *R* required to produce O.D. = 1.0 above base+fog
   Speed = 1/Exposure (*R*)
   Ex. Exp. =10 mR Speed = 1/(0.01*R*) = 100 R^{-1}

Image Receptor: Film/Screen

- **Speed inversely related to exposure:**
  - **$\Uparrow$ speed $\Rightarrow$ less exp. required to obtain given O.D.**
  - **$\Downarrow$ speed $\Rightarrow$ more exp. required to obtain given O.D.**
- **Film speed (sensitivity) matched to emission spectra of screen**

  Lanex (screen) $\Rightarrow$ Green   Ortho G (film) $\Rightarrow$ 100 speed

<u>Processing Conditions (time and temp.)</u>

In general, $\Uparrow$ development time or temp:

- **$\Uparrow$ ave. gradient (contrast), then levels off**
- **$\Uparrow$ speed (density), then levels off**
- **$\Uparrow$ fog (decreases contrast)**

Intensifying Screens

Purpose:

- Convert x-ray energy to light which exposes film
- Coupled to one side - single emulsion film

x-rays → light → film exposure

1. Luminescence - emission of light by a material:

   $Gd_2O_2\,S$ (green light emission)

2. Advantages:

   a. Decrease exposure time; reduce blur due to patient motion

   b. Reduce patient & personnel dose

   c. Increase life of x-ray tube

   d. Can choose lower kVp which increases subject contrast

   e. Can choose smaller focal spot size; minimize geometric unsharpness

Intensifying Screens

3. Disadvantages: loss of image information

   a. Poorer resolution – spreading of light; screen/film contact
   b. Noise increased (decrease in no. of x-ray photons used)

<u>Intensification</u>

Screen converts few x-ray photons into many light photons $\Rightarrow$ reduction in patient exposure ~ factor of 50 – 100

Intensification factor:

IF = (exp. required without screen)/(exp. required with screen)

<u>Screen Speed</u>

- Measure of relative light output
- Inversely related to exposure required to produce a given photographic effect

Intensifying Screens

Categories:

- a. **Slow (detail, high resolution)**
- b. **Medium (par)**
- c. **Fast (high speed)**

Conversion of x-ray to light:

1 x-ray photon $\Rightarrow$ 4000 light photons (rare earth, Gd_2O_2S)

Screen Mottle

Speed tradeoff with noise of screens

Depends on no. of photons absorbed by screen

- Fast screens absorb fewer x-ray photons; leads to increased noise

Screen/Film Mammography

- **Advantages**
  - High contrast (inherent film); differentiate small differences in breast tissue
  - High spatial resolution (15 lp/mm); enhance microcalcification visibility
  - Different receptor sizes
  - Control of patient exposure
  - Display multiple films/views; bright light viewbox
  - Storage of film at low cost
- **Disadvantages**
  - Extreme sensitivity of film to changes in exposure; QA maintenance
  - Limited dynamic range – limited visibility of all tissue structures; AEC position
  - Control of patient exposure
  - Dynamic range effect on contrast
  - No post processing; image manipulation
  - Noise due to film grain

Digital Mammography

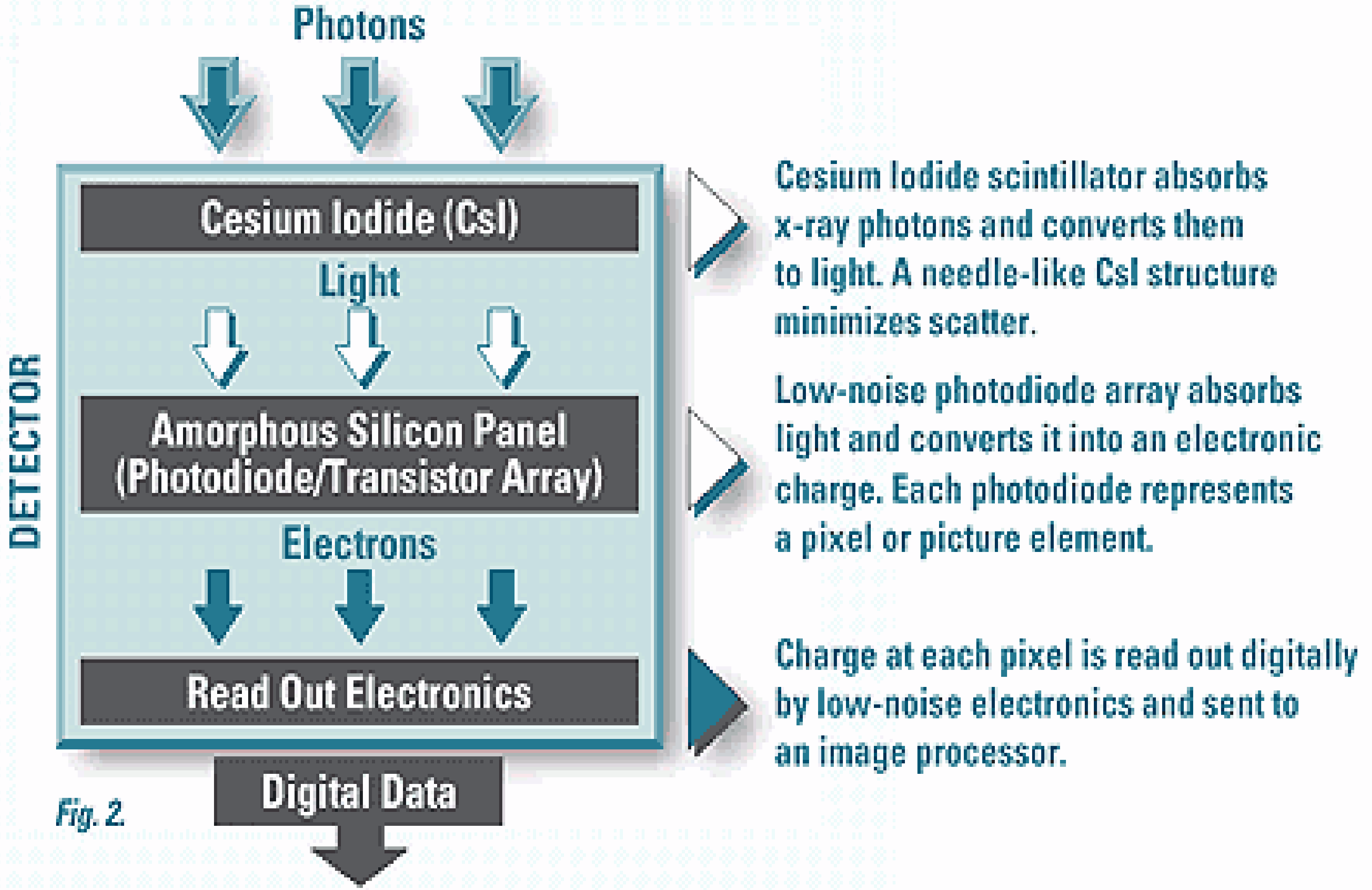
- Digital Detector captures transmitted x-ray distribution pattern   Size: 19x23 cm, 24x31 cm
- Exposure technique of breast same as for screen/film
- X-ray pattern displayed as black and white image on computer screen using specialized electronics
- Image manipulation available to radiologist
  - Brightness
  - Contrast
  - Magnification

Digital Mammography

Digital Detectors

– Indirect: x-rays → light → electronic signal
  (similar to process for screen/film)

– Direct: x-ray → electronic signal



*** Senographe 2000 D** **GE Medical Systems**

Digital Mammography

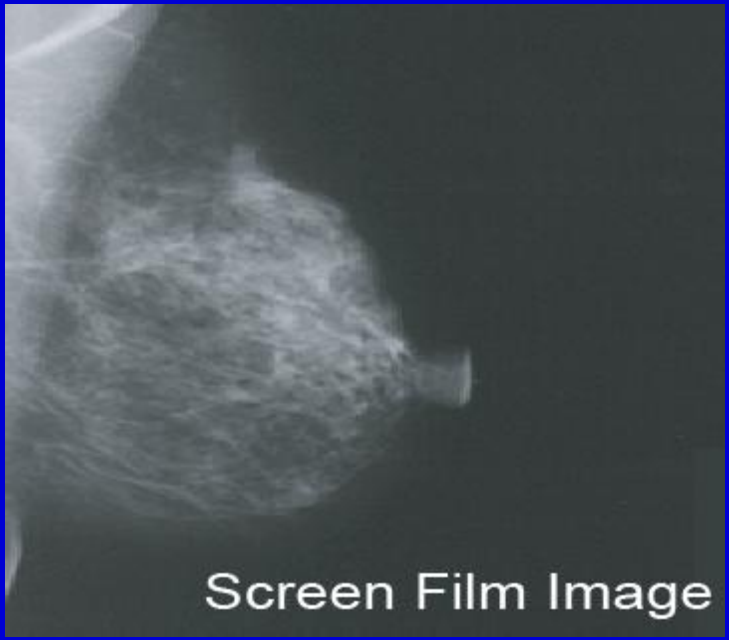
Senographe 2000 D

- 1^{st} FFDM system in U.S.
- a-Si flat panel; 1920 x 2304 detector elements
- 19 x 23 cm area detector
- Pixel resolution 100 µm
- Coupling between CsI crystal structures and photodiode results in some loss of resolution compared with direct capture

Digital Mammography

- **Dynamic range: signal vs. exposure**
  - Linear vs. Sigmoidal (Screen/Film)
  - Wide range (10^4:1) vs. Screen Film (30:1); eliminates over/under exposure
  - Fewer repeat images => lower patient dose
  - Visibility of all tissue structures (Fat => Skin line)
  - ↓ noise by ↑ exposure
  - Limit control of patient dose
- **Image Processing**
  - Manipulate grey scale (characteristic curve) of pixel values
  - Maximize contrast (gamma)
  - Choose LUT (curves) to maximize image task
  - Window/Level; software algorithms (similar to CT recon. kernels)
  - CAD

Comparison: Digital vs. Film



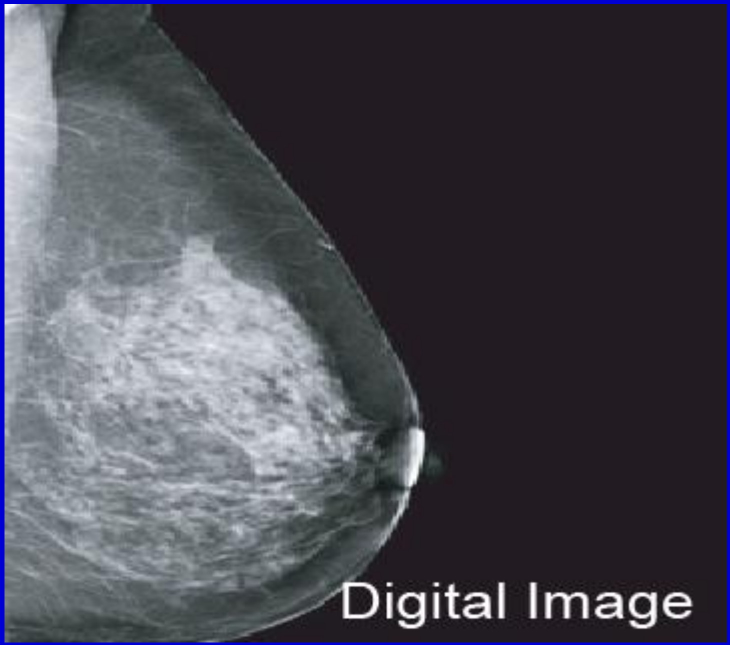


Image Quality: Potential Problems

- Image blur
  - compression, patient motion, exposure time, kVp too low
- Light/dark films
  - exp. time too short/long, penetration, processor unstable
  - darkroom fog
  - review phantom images
- Image blur, resolution
  - compression, film/screen contact
- Artifacts
  - dust from screens/processor, blotchy (filter), streaks (processor)

Stereotactic Breast Biopsy

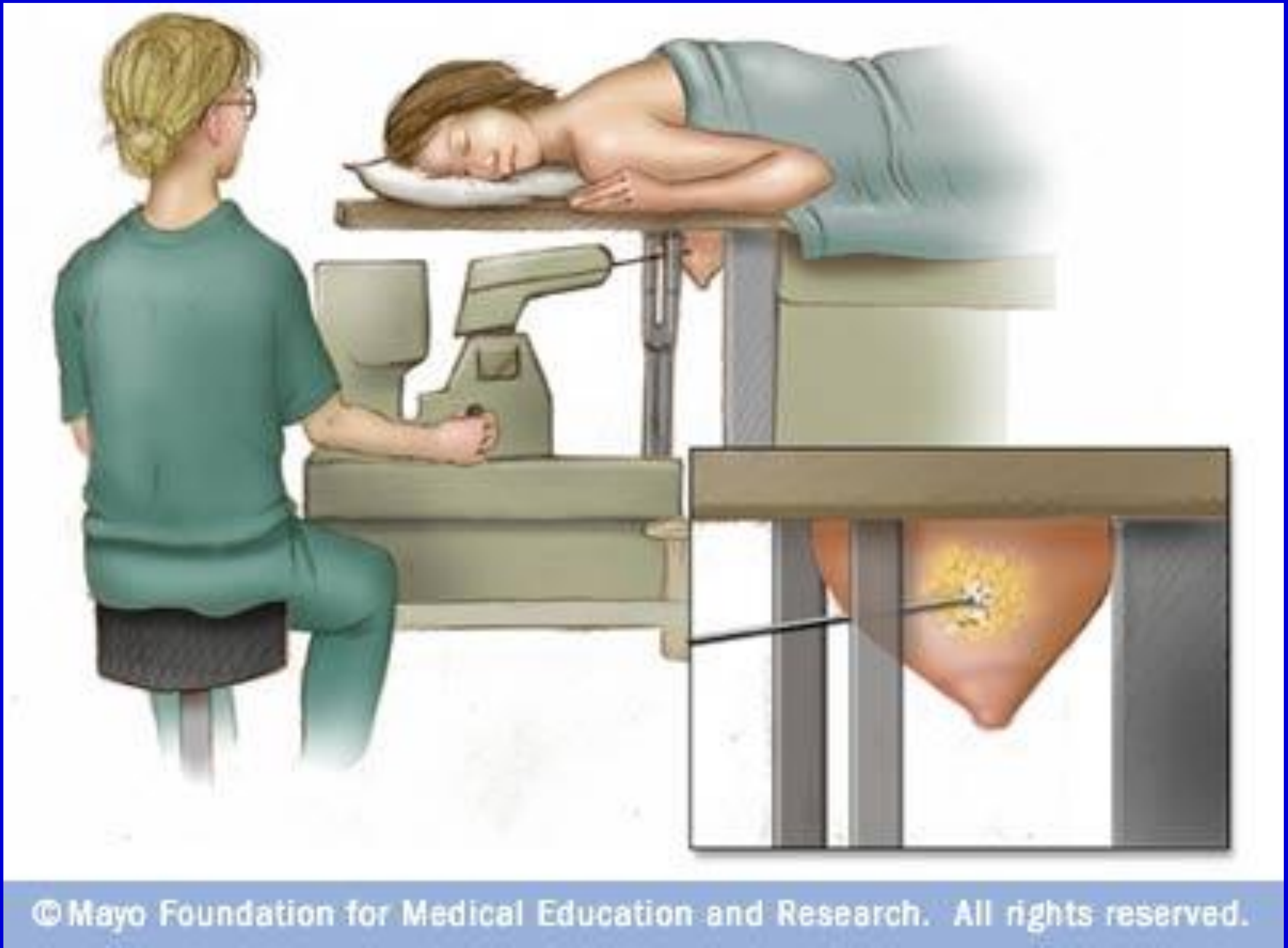
- **Purpose**
  - Analyze tissue cells usually performed after abnormal mammogram
  - Invasive procedure using needle (gun) to excise small tissue sample of breast
  - Sample analyzed in lab for abnormalities
  - Determines follow up testing/treatment

- **Procedure**
  - X-ray tube and DAQ below table; patient prone on table
  - Breast compressed between 2 plates with small window for needle access
  - 2 Stereo views obtained at 15^0 on either side of breast
  - Using computer and digital stereo views lesion coordinates identified
  - Localization accuracy usually within 1 mm
  - Needle gun fired into lesion and sample removed

Stereotactic Breast Biopsy

Hologic, The Women's Health Company; Breast Biopsy

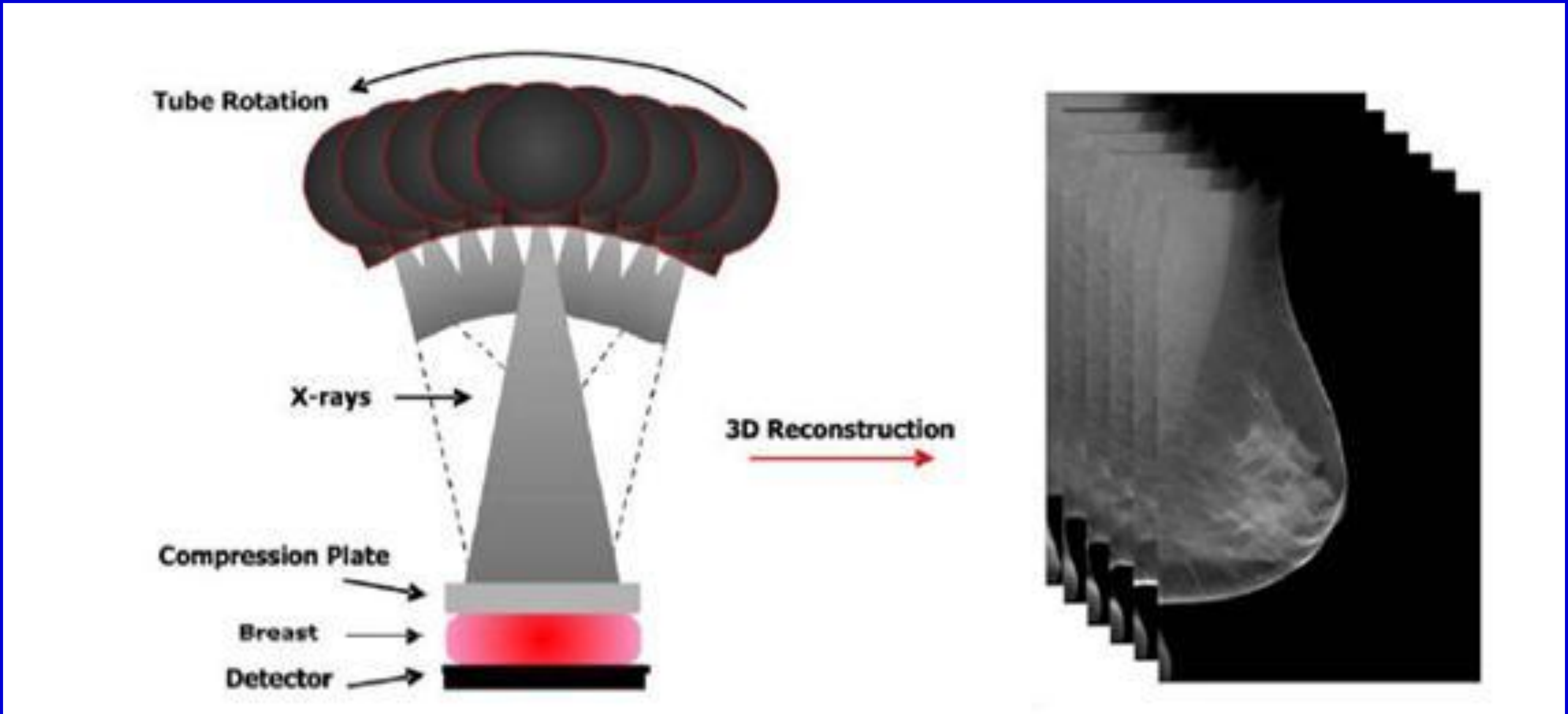
Stereotactic Breast Biopsy



Digital Breast Tomosynthesis (DBT)

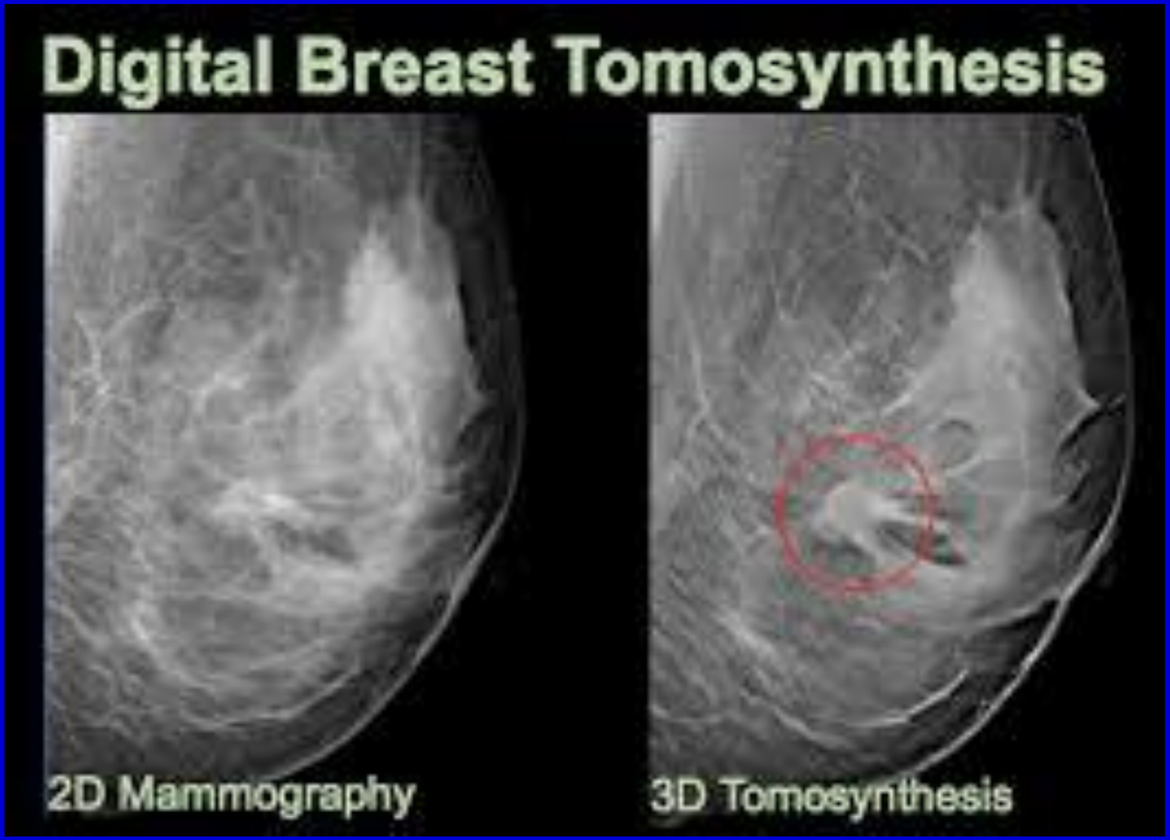
- **Imaging technique**
  - Breast firmly compressed as it is during conventional mammography
  - Several low dose x-ray exposures used to create a 3D image of breast sometimes called 3D imaging
  - X-ray tube rotates around the breast through 15 degrees; 1 exposure taken at every degree
  - Image slices created with 1 mm interval between slices
  - Images viewed on high resolution workstations slice by slice
- **Radiation Dose**
  - Comparable to that of 2D conventional mammography
  - Sum of several low dose x-ray exposures
- **3D Imaging**
  - 3D representation of breast tissue
  - Unlike 2D mammography overlapping tissue removed; problem of superposition eliminated
  - Tumor visibility enhanced with improved resolution of structures within each slice
  - DBT/mammography comparison similar to CT/radiography comparison
  - Due to increased accuracy, DBT may replace mammography within next 10 years

Digital Breast Tomosynthesis (DBT)



Reference: Kontos, D. et al (2009): “Parenchymal Texture Analysis in Digital Breast Tomosynthesis for Breast Cancer Risk Estimation: A Preliminary Study”; Academic Radiology; v.16:283:298

Digital Breast Tomosynthesis (DBT)



References: hca.wa. Gov; Washington State Health Care Authority