Technique Optimization in Digital Mammography

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1. Introduction to Optimization in Mammography
2. Characteristics of S/F vs. Digital Mammography
3. Technique Optimization Methodology
4. What does this mean to me in the Clinic?
Part 1

Introduction to Technique Optimization in Mammography
Technique

Acquisition Parameters

1. X-RAY BEAM SPECTRUM
   - target material
   - filter material and thickness
   - tube kilovoltage (kVp)

2. EXPOSURE LEVEL
   - beam current x time (mAs)
Optimization

“Any process or procedure which ensures that doses due to appropriate medical exposure for radiological purposes are kept as low as reasonably achievable (ALARA) consistent with obtaining the required diagnostic information ..”

IAEA-TECDOC-1447  May 2005”
Implications

A mammography image of adequate to superior image quality is NOT acquired using an optimal technique if the dose to the patient was higher than necessary to yield a diagnostic image.

Must find optimum balance between dose & image quality
Optimization in Mammography

“In mammography, the objective is to produce images that provide maximum visualization of breast anatomy and the signs of disease without subjecting the patient to unnecessary radiation”

- IAEA
Normal Breast Anatomy

1. Chest wall
2. Pectoralis muscles
3. Lobules
4. Nipple
5. Areola
6. Duct
7. Fatty tissue
8. Skin

www.wikipedia.com
Features of Breast Cancer in Mammography Imaging

- Increased Density (relative to prior exam)
- Architectural Distortion
- Micro-calcifications
- Masses
1. DIAGNOSTIC OBJECTIVES

- Detect and characterize microcalcification cluster patterns and morphology
- Visualize breast parenchyma and subtle architectural distortions
- Detect soft tissue masses and assess shape, size, degree of local invasion
II. CHALLENGES

A. NORMAL BREAST DENSITY VARIATIONS
   - Age, Genetics, Menstrual cycle (premenopausal women)

For adequate SNR^2 choice of radiographic technique must be patient- and context-specific

Source: McGill University Department of Medicine Online Mammography Tutorial
Optimized Imaging of the Breast

II. CHALLENGES

B. HIGH TISSUE CONTRAST RESOLUTION REQUIRED

Fibro-glandular and tumor tissue have similar attenuation properties

Optimize beam quality to maximize differential absorption and ...

Source: Bushberg, The Essential Physics of Medical Imaging
Use COMPRESSION

Craniocaudal (CC)  Mediolateral (MLO)

Breast Thicknesses: 2 cm - 8 cm

Scatter Fraction:
- 0.8 – 1.0 uncompressed
- 0.4 – 0.5 compressed

Source: Basset LW, Imaging the Breast, Cancer Medicine, 6th ed
Source: Bushberg, The Essential Physics of Medical Imaging
C. NEED FOR DEVICE-SPECIFIC OPTIMIZATION

Different:
- Technology, i.e. Receptor Sensitivity
- Target/Filter options
- Exposure and other controls
- Image Processing

May require different imaging protocols & techniques for different technologies & systems, i.e. SF versus CR, CR versus DR, Direct DR versus Indirect DR, etc…
Optimized Imaging of the Breast

III. IMAGING SYSTEM REQUIREMENTS

- High Receptor Sensitivity → DOSE
- High Spatial Resolution
- High Contrast Resolution
- Low Noise
- Reproducibility
  - Consistent image quality & exposure
# Optimized Imaging of the Breast

## IV. PRIMARY QUALITY FACTORS

<table>
<thead>
<tr>
<th>RESOLUTION</th>
<th>Focal Spot Size &amp; Blur</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Magnification,</td>
</tr>
<tr>
<td></td>
<td>Pixel Pitch</td>
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<tr>
<td></td>
<td>Patient Motion Blur</td>
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<table>
<thead>
<tr>
<th>CONTRAST</th>
<th>Tissue Density, Thickness</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>X-Ray Beam Quality (Target/Filter/kVP)</td>
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<table>
<thead>
<tr>
<th>NOISE</th>
<th>Receptor Sensitivity</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>mAs / Exposure</td>
</tr>
</tbody>
</table>
Optimized Imaging of the Breast

V. TECHNIQUE FACTORS

Target (Anode): Molybdenum (Mo)
- Rhodium (Rh)
- Tungsten (W)

Filter: Mo, Rh, Al, Ag

Tube Voltage: kVp

Exposure: mAs
VI. BREAST DOSIMETRY

Mean or Average Glandular Dose (MGD/AGD)

\[ \text{MGD} = D_gN \times E \]

\( D_gN \): Exposure normalized glandular dose

(abs. dose / unit exposure)

\( E \): Entrance surface exposure

\( \sim 2.0 \text{ mGy (3.0 mGy ACR limit)} \)

Source: Bushberg, The Essential Physics of Medical Imaging
Part 2

The Advantages of Digital Mammography
Analog Imaging Chain (Screen-Film)

Diagnostic Exposure

Detection/Capture (Latent Image)

Chemical Processing (D-logE* + Chem.)

Output Display (Hardcopy*)

*same S/F system used @ 3 exp. levels
Technique Optimization

**Screen-Film**

- Optimization criteria based on film density
- Typical Target/Filter: Mo/Mo or Mo/Rh
- Dependent on film processor performance
- Impacted by speed and latitude of film
- Film is capture, display and storage medium
Digital Imaging Chain (CR, DR)

Diagnostic Exposure (Latent Image) → Detection/Capture (Latent Image) → Capture (Sampling, Quant.) → Processing → Output Display (Hardcopy/Softcopy) → Output Display (Hardcopy*)

*same system used @ 3 exp. levels
Technique Optimization

**Digital Mammography**

- Optimization criteria can be subjective, semi-objective or objective, e.g. based on a computed figure-of-merit (FOM)
- Prerequisite: Detector calibration & QC
- Typical Target/Filter: W/Rh
- Acquisition, processing and display can and should be optimized separately
Latitude: S/F vs DR

Adapted from: Mahesh M., Radiographics (2004)
## CR System Comparisons

<table>
<thead>
<tr>
<th>Class</th>
<th>Type/Phosphor*</th>
<th>Model</th>
<th>Manufacturer</th>
<th>Pixel Pitch* (mm)</th>
<th>Active Area (cm²)</th>
<th>Target/Filter</th>
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<tbody>
<tr>
<td>CR</td>
<td>PSP BaSrFBrI:Eu</td>
<td>CR35-X</td>
<td>AGFA</td>
<td>0.050</td>
<td>18 x 24</td>
<td>?</td>
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<tr>
<td></td>
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<td>CR85-X</td>
<td></td>
<td>0.050</td>
<td>24 x 30</td>
<td></td>
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<tr>
<td>CR</td>
<td>PSP BaFBrI:Eu</td>
<td>ASPIRE</td>
<td>FUJIFILM</td>
<td>0.050</td>
<td>18 x 24</td>
<td>?</td>
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<td></td>
<td></td>
<td>CLEARVIEW</td>
<td></td>
<td>0.050</td>
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<tr>
<td>CR</td>
<td>PSP BaFBr:Eu</td>
<td>DIRECTVIEW</td>
<td>CARESTREAM</td>
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<td>18 x 24</td>
<td>?</td>
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<td>0.0485</td>
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<td>PSP BaFl:Eu</td>
<td>REGIUS 190</td>
<td>KONICA-MINOLTA</td>
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<td>0.04375</td>
<td>24 x 30</td>
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</tbody>
</table>

## DIGITAL MAMMOGRAPHY

### DR SYSTEM COMPARISONS

<table>
<thead>
<tr>
<th>CLASS</th>
<th>TYPE</th>
<th>MODEL</th>
<th>VENDOR</th>
<th>PIXEL PITCH (mm)</th>
<th>ACTIVE RECEPTOR AREA (cm²)</th>
<th>TARGET/FILTER</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR</td>
<td>Indirect CsI Slot-scan CCD</td>
<td>Senoscan FISCHER/HOLOGIC</td>
<td>0.054 (0.027)</td>
<td>21 x 29</td>
<td>Mo/Mo Mo/Rh Rh/Rh W/Al</td>
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<tr>
<td>DR</td>
<td>Direct aSe (Amulet)</td>
<td>Aspire HD* FUJIFILM</td>
<td>0.050</td>
<td>18 x 24, 24 x 30</td>
<td>Mo/Mo Mo/Rh Rh/Rh</td>
<td></td>
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<tr>
<td>DR</td>
<td>Direct aSe</td>
<td>Selenia LORAD/HOLOGIC</td>
<td>0.070</td>
<td>25 x 29</td>
<td>Mo/Mo Mo/Rh</td>
<td></td>
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<tr>
<td>DR</td>
<td>Indirect aSi:CsI Nuance Nuance Excel PLANMED</td>
<td>0.085</td>
<td>17 x 24, 24 x 30</td>
<td>W/Ag W/Rh</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* NOT FDA APPROVED IN U.S.
## DIGITAL MAMMOGRAPHY

<table>
<thead>
<tr>
<th>CLASS</th>
<th>TYPE</th>
<th>MODEL</th>
<th>VENDOR</th>
<th>PIXEL PITCH (mm)</th>
<th>ACTIVE RECEPTOR AREA (cm²)</th>
<th>TARGET/FILTER</th>
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<tr>
<td>DR</td>
<td>Direct aSe</td>
<td>Novation DR</td>
<td>SIEMENS</td>
<td>0.070</td>
<td>18 x 23</td>
<td>Mo/Mo</td>
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<tr>
<td></td>
<td>Novation S</td>
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<td></td>
<td>0.070</td>
<td>24 x 29</td>
<td>Mo/Rh</td>
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<td></td>
<td>Inspiration</td>
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<td></td>
<td>0.085</td>
<td>24 x 30</td>
<td>W/Rh</td>
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<tr>
<td>DR</td>
<td>Indirect aSi:CsI Flat Panel</td>
<td>2000D, DS Essential Senographe</td>
<td>GE</td>
<td>0.100</td>
<td>19.2 x 23</td>
<td>Mo/Mo</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.100</td>
<td>19.2 x 23</td>
<td>Mo/Rh</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.100</td>
<td>24 x 30.7</td>
<td>Rh/Rh</td>
</tr>
</tbody>
</table>
As a class DR systems typically have lower resolution than screen/film.

Source: A. Smith white paper
Why go Digital?

DIGITAL

SCREEN-FILM
Advantages of Digital

- Increased throughput
- Increased sensitivity
- Increased latitude
- Better contrast resolution
- Contrast adjustment
- Image processing
- Advanced applications
- Decreased dose
- Indefinite archival
- Simultaneous access

But ..

- Lower spatial resolution (generally)
Digital is the Future

As of 12/2009:

59% of MQSA certified facilities had 1 or more FFDM units

60% of all MQSA certified units were FFDM

New mammography unit sales in US almost exclusively digital

Source: MQSA website
Part 3

Technique Optimization
Methodology
Technique Optimization Methods

- Spectral Simulation using Monte Carlo methods
- Experimental Studies using Objective Criteria (Figures-of-Merit)
- Clinically-Relevant Task Based Observer Studies
- Prospective or Retrospective Clinical Studies
- *Subjective Evaluation of Image Quality Phantom Data*
Example

Technique Optimization Protocol

- objective figure of merit (FOM)
- quotient of SdNR² to MGD
- computed for masses and calcs
Technique Optimization Protocol

Physical Setup

Siemens Mammomat Novation DR

Mo/Mo vs W/Rh
kVp: 23, 25, 27, 29, 31, 33, 35

Technique Optimization Protocol

**FIGURE – OF – MERIT**

\[
FOM = \frac{SdNR^2}{MGD}
\]

- Quality
- Dose

SdNR\textsuperscript{2}: Signal Difference to Noise Ratio Squared

MGD: Mean Glandular Dose (computed from spectral estimates using Spectra*)

* Boone et al, Radiol 213 (1999)
Technique Optimization Protocol

Characterizing the Beam Quality & Exposure

Measure free-in-air exposure at each beam quality: target/filter & kVp

Extrapolate to phantom surface using inverse square law

Measure HVL at each beam quality using narrow beam geometry and calibrated ion chamber fitted with a Mammo probe.
Technique Optimization Protocol

Computation of $SdNR^2$

With Inclusions

\[ S_i : \text{mean signal in ROI overlying inclusion} \]

Without Inclusions

\[ S_b : \text{mean signal in ROI in background (same location)} \]
Technique Optimization Protocol

**FOM Results**

- **0% Gland**
- **50% Gland**
- **100% Gland**

**MASSES**

**CALCS**
Relative FOM (FOM$^R$) gives the image quality improvement at the new technique (W/Rh) in comparison to the optimized reference technique (Mo/Mo) for the equivalent glandular dose.

$$FOM^R = \frac{FOM_{EVAL}}{FOM_{REF}}$$

Relative Dose SAVINGS $\rightarrow (FOM^R)^{-1}$
Technique Optimization Protocol

Relative Dose Savings

Siemens Novation DR

Dose Reduction Achievable in Migration from Screen-Film Technique Employing Mo-Mo to FFDM Technique Employing W-Rh.

Dose savings likely to be much more conservative ....

WHY?
Breast Density: What is typical or average?

Common misconception that average breast density is 50% adipose tissue to 50% fibroglandular or “50-50”

The myth of the 50-50 breast

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(Received 30 April 2009; revised 23 September 2009; accepted for publication 29 September 2009; published 5 November 2009)

Ref: Yaffe et al, The Myth of the 50-50 Breast
Normal Density Variations

ACR BI-RADS BREAST DENSITY CLASSIFICATION SCHEME

Category 1  Category 2  Category 3  Category 4

ADIPOSE  GLANDULAR

Source: McGill University Department of Medicine Online Mammography Tutorial
Part 4

What does all this mean in the clinic?
Summary Key Concepts

Image quality must be optimized in the context of the COST (RISK) associated with the patient’s EXPOSURE (DOSE) and that is accomplished via Technique Optimization

- Tradeoff between QUALITY and DOSE

- Optimization must be patient- and application-specific, i.e. tailored to patient size, exam type and other relevant factors
Recommendations

1. Automatic exposure (and other controls, e.g. automatic kVp, Target-Filter selection, etc..) controls should be verified as part of routine acceptance testing and checked on a routine basis.

2. AEC cells in conventional mammo units are located beneath the grid. CR cassette structure/sensitivity varies from vendor to vendor. Must calibrate the AEC for the intended CR cassette type and only use those cassettes.

3. Newer FFDM systems employ a virtual AEC in conjunction with a short prescan to determine the exposure termination conditions. Make sure it works as intended.
Recommendations

4. An imaging QA program must include monitoring of the system in the context of its intended clinical use. A PROPERLY OPERATING imaging system is NOT the same as one OPERATED PROPERLY.

- Validate vendor-recommended techniques/protocols
- Establish written imaging protocols and SOPs
- Mandate ongoing staff training and in-services
- Conduct routine audits to ensure compliance
ACKNOWLEDGMENTS

Information or Assistance Provided by:

**DUKE**
Joseph Y. Lo, PhD
Ehsan Samei, PhD
Jay A. Baker, MD
Anne Jarvis

**SIEMENS**
Thomas M. Mertelmeier, PhD

**OTHER**
Eric Gingold, PhD
SAM Question #1

Which of the following is NOT an advantage of digital mammography over screen film mammography:

- a) improved throughput
- b) improved latitude
- c) higher spatial resolution
- d) decreased dose for comparable image quality
- e) image processing and digital archival
SAM Question #1

Which of the following is NOT an advantage of digital mammography over screen film mammography:

(a) improved throughput
(b) improved latitude
(c) higher spatial resolution
(d) decreased dose for comparable image quality
(e) image processing and digital archival

Answer: (c)

SAM Question #2

The technique factor that has the strongest impact on digital mammography image quality as reflected in a Figure-of-Merit (FOM) computed from the ratio of CNR2 or SdNR2 to MGD is:

- a) focal spot size
- b) mAs
- c) field size
- d) kVp
- e) target / filter combination
The technique factor that has the strongest impact on digital mammography image quality as reflected in a Figure-of-Merit (FOM) computed from the ratio of $\text{SNR}^2$ or $\text{SdNR}^2$ to MGD is:

(a) focal spot size  
(b) mAs  
(c) field size  
(d) kVp  
(e) target / filter combination

**Answer:** (e)


SAM Question #3

In digital mammography, the approximate Mean Glandular Dose (MGD) for a 5 cm thick average density breast imaged using automatic exposure control with a W/Rh target/filter combination would be closest to:

- a) 0.02 mGy
- b) 0.2 mGy
- c) 2.0 mGy
- d) 20.0 mGy
- e) 200.0 mGy
SAM Question #3

In digital mammography, the approximate Mean Glandular Dose (MGD) for a 5 cm thick average density breast imaged using automatic exposure control with a W/Rh target/filter combination would be closest to:

(a) 0.02 mGy  
(b) 0.2 mGy  
(c) 2.0 mGy  
(d) 20.0 mGy  
(e) 200.0 mGy

Answer: (c)

SAM Question #4

For a 4 cm breast with a composition ratio of 50% glandular to 50% adipose, the magnitude of dose reduction achievable for comparable image quality in the transition from screen/film to digital mammography is approximately:

- a) 10%
- b) 20%
- c) 40%
- d) 60%
- e) 80%
SAM Question #4

For a 4 cm breast with a composition ratio of 50% glandular to 50% adipose, the magnitude of dose reduction achievable for comparable image quality in the transition from screen/film to digital mammography is approximately:

(a) 10 %  
(b) 20 %  
(c) 40 %  
(d) 60 %  
(e) 80 %

Answer: (c)

Thank you for your attention.

Email: NicoleTRangerMSc@gmail.com
OLD SLIDES
Source: IMS Giotto 3D brochure
Characterizing Breast Masses

Mass Shape

- Round
- Oval
- Lobulated
- Irregular
- Architectural Distortion

Mass Margins

- Circumscribed
- Obscured
- Micro-lobulated
- Ill-defined
- Spiculated
Characterizing Microcalcifications

Low Probability or Typically Benign

Skin calcifications, lucent, polygonal shape
Vascular calcifications
Coarse, larger calcifications

Intermediate Probability

Indistinct or amorphous microcalcifications

High Probability

Clusters of heterogeneous or pleomorphic calcifications, irregular size & shape & < 0.5 mm diameter are suspicious

Fine linear or branching calcifications < 1 mm in width are associated with necrotic cancer cells

NEED EXAMPLE IMAGES/FIGURES
Need a image quality- & dose-sensitive metric to objectively assess optimization
Typical Calibrations (DR)

Correction for bad detector elements (dels)

Flat-field correction

Correction for radiation field non-uniformity (i.e. Heel Effect)
Gain and offset correction for each del
Correction for velocity variation during scan (CR)

Correction for geometric distortion *

* Primarily in CCD lens-based imaging systems
study published in September 2005 in the New England Journal of Medicine compared digital mammograms to film mammograms. The study involved 49,000 women in North America with no known signs of breast cancer. The women were screened using both digital and film mammograms at the beginning of the study and again one year later. Breast cancer was found in 335 of the women. The researchers determined that digital mammograms were superior to film mammograms for three groups: women under 50 years of age, women with dense breasts, and women who have not yet gone through menopause, or who have been in menopause less than one year. Digital mammograms did not prove to be more beneficial for post-menopausal women over age 50 that do not have dense breasts. Additionally, both forms of mammogram had the same rate of false positives.
Recommendations

• Take advantage of the free resources available
• Invest in a high quality IEC-compliant edge device
• Use lower purity “legacy” Al not the $\geq 99.9\%$ purity Al specified by the standard (test Al before use)
• Review the fundamentals of DQE physics
• Study the body of literature on DQE testing
• Obtain the IEC standards for reference
• Recruit a “DQE Mentor”
Thank you for your attention.

Email: nicole.ranger@duke.edu
EXTRA STUFF
ACKNOWLEDGMENTS

Information &/or Assistance Provided by:

**DUKE**

Joseph Y. Lo, PhD
Ehsan Samei, PhD
Jay A. Baker, MD
Anne Jarvis

**SIEMENS**

Thomas M. Mertelmeier, PhD
Introduction

CONTEXT

1 in 8 women (13%) will be diagnosed with breast cancer in their lifetime

In 2006, 191,410 new breast cancer cases

In 20__, __ screening mammography exams were conducted in the US and ___% were performed using a digital mammography imaging system
Characteristic Photons:

Moly: 17.9, 19.5
Rhodium: 20.2, 22.7

Best spectra with kVp set 5-10 kVp above K-edge
Source: IMS Giotto 3D brochure
## Radiographic Characteristics of Breast Tissue

<table>
<thead>
<tr>
<th>Tissue Type</th>
<th>Density</th>
<th>Atomic #</th>
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<tbody>
<tr>
<td>Adipose</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glandular</td>
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<tr>
<td>Calcification</td>
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</tbody>
</table>
Breast Imaging Statistics

Breast cancer #___ cause of death in women aged XX-YY

Lifetime risk: 1 in 8 women will be diagnosed

In 2006, ____ new cases of breast cancer were diagnosed; approx. half of which were diagnosed as a result of screening mammography

Risk of inducing a breast cancer as a result of exposures associated with lifetime of screening mammography: ____

In 20__, ____ screening mammography exams were conducted in the US and ____% of those studies were performed using a digital mammography imaging system

Sources: http://apps.nccd.cdc.gov/uscs/
Measure free-in-air exposure at each beam quality: target/filter & kVp

Extrapolate to phantom surface using inverse square law

Measure HVL at each beam quality using narrow beam geometry and calibrated ion chamber fitted with a Mammo probe.
CR: PSP

Indirect DR: Cs(I) TFT

Direct DR: aSe TFT

Indirect vs. Direct Detection

- Indirect: scintillator converts x-rays to light photons → causes scattering/image blur → "smooth" image
- Direct: no scintillator → detector converts x-rays to electrons directly - no intermediate steps → "sharper", "edge enhanced"

Indirect Conversion

GE Senographe

Hologic Selenia

Screen-Film

Indirect Digital

Direct Digital
CR: PSP

Indirect DR: Cs(I) TFT

DIRECT DETECTION

GE Senographe

Hologic Selenia

Direct DR: aSe TFT

DIRECT DETECTION
Computed Radiography

Source: Basset LW, Imaging the Breast, Cancer Medicine, 6th ed
Indirect DR

Cs(I) TFT Array

Source: Basset LW, Imaging the Breast, Cancer Medicine, 6th ed
Direct DR

aSi TFT Array

Source: Basset LW, Imaging the Breast, Cancer Medicine, 6th ed