Optimizing Dose and Image Quality in Digital Mammography

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Introduction

Certified Statistics – 15 Months

<table>
<thead>
<tr>
<th></th>
<th>April 1, 2005</th>
<th>August 1, 2006</th>
<th>Difference</th>
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<tbody>
<tr>
<td>Total Certified Mammography Facilities</td>
<td>8,929</td>
<td>8,829</td>
<td>-100</td>
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<tr>
<td>Total Accredited Mammography Units</td>
<td>13,640</td>
<td>13,556</td>
<td>-84</td>
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<tr>
<td>Certified Facilities with FFDM Units</td>
<td>607</td>
<td>1,130</td>
<td>+523</td>
</tr>
<tr>
<td>Accredited FFDM units</td>
<td>819</td>
<td>1,604</td>
<td>+785</td>
</tr>
</tbody>
</table>

Introduction

Detector Types

- **Cesium Iodide** with Silicon Diode Array (GE)
- **Selenium** with Silicon Diode Array (Lorad, Siemens, Kodak, Agfa)
- **Slot Scanning CCD Array** (Fischer)
- **Computed Radiology** (Fuji, Kodak, Konica, Agfa)
- GE Senographe 2000D & DS & Essential
  - FOV: 19.2 x 23.0 cm & 24.0 x 31.0 cm
  - Spatial resolution: 100 microns (5.0 lp/mm)
**Equipment**

- **Lorad Selenia & Siemens Novation**
  - FOV: 24 x 29 cm
  - Spatial resolution: 70 microns (7.14 lp/mm)

- **Siemens Mammat Novation OR**

- **Fischer Senoscan**
**Equipment**

- **Fischer Senoscan**
  - FOV: 21 x 29 cm (std), 11 x 15 cm (high res)
  - 54 & 27 microns – 9.3 lp/mm in 54 µm mode
  - Scan time: 5.2 seconds

- **Computed Radiology**
  - Fuji – FDA approved
  - Kodak
  - Konica
  - Agfa

**Equipment**

- **Fuji FCRm**
  - FOV: 18 x 24 and 24 x 30 cm
  - Spatial resolution: 50 microns (10.0 lp/mm)
  - 60 to 80 imaging plates per hour
**Equipment**

**Kodak DirectView CR Mammography System**

**Equipment**

**Sectra Microdose**
- Slot-scanning photon counter detector
- FOV: 24 x 26 cm
- Spatial resolution: 50 microns (10.0 lp/mm)

**Equipment**

**Planmed Nuance – Amorphous Selenium – 85 µm**

**Equipment**

**FDA-Approved Laser Imagers ~ 40 µm spot**
- Agfa LR5200 Laser Imager (Wet Chemistry)
- Agfa DS-8100M
- Kodak 8600 Laser Imager
- Kodak 8610 Laser Imager
- Kodak 8900
- Fuji Drypix 4000, 5000, 7000
- Fuji Drypix FM-DP L
- Codonics Horizon Ci, GS, SF
- Konica Minolta DryPro 793
Until recently, workstations came with acquisition units.

Those days are over.

Spurred by FDA approval of third party RWS, high resolution displays, and PACS.

As a result, FFDM is becoming more a la carte to allow best of each (acquisition, RWS, PACS, etc.).

Multimodality Workstations

- FDA Approved Multimodality Workstations
  - AGFA IMPAX MA3000
  - Sectra IDS/mx
  - Kodak DirectView PACS System
  - McKesson’s PACS Mammo Station
  - iCad Second Look 500M
  - Cedara i-ReadMammo
  - Fuji Synapsee
  - GE Seno Advantage & Seno Adv. 2
  - Fischer Senoview Plus (Cedara)
  - Hologic SecureView DX
  - Siemens MammoReportPlus

Current challenges
- Device to device connectivity
- DICOM incompatibilities between acquisition and displays
  - Can result in image degradation
- PACS connectivity
**Workstations**

<table>
<thead>
<tr>
<th>Detector Size (cm)</th>
<th>v.s. Image size (pixels)</th>
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<tbody>
<tr>
<td>2304</td>
<td>4100</td>
</tr>
<tr>
<td>2304</td>
<td>5625</td>
</tr>
<tr>
<td>2048</td>
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<tr>
<td>2560</td>
<td>2048</td>
</tr>
<tr>
<td>2304</td>
<td>2560</td>
</tr>
<tr>
<td>2304</td>
<td>2048</td>
</tr>
</tbody>
</table>

**AEC System Function**

- GE (2000D, DS, Essential)
- Mo & Rh Targets, Mo & Rh Filters
  - Mo/Mo, Mo/Rh, Rh/Rh
- 3 Modes
  - Con – Thin, less dense (2000D)
  - Std – Intermediate (DS & Essential)
  - Dos – Thick, dense breasts

**AEC System Function**

- Lorad – Mo target, Mo & Rh Filters
  - Mo/Mo, Mo/Rh
- Modes
  - Auto-Filter – AEC sensor, exposure adjustment
  - Auto-kV – Filter, AEC sensor, exposure adjustment
  - Auto-Time – kV, filter, AEC sensor, exposure adjustment
  - TEC – (Tissue Exposure Control) - Breast density
    - Enhanced manual mode
  - Manual
- Recommended Mode – Auto-Filter

**AEC System Function**

- Siemens – Mo & W Targets, Mo & Rh Filters
  - Mo/Mo, Mo/Rh, W/Rh
- Modes
  - OPDOSE Mode (recommended using W/Rh)
    - Compress breast to given compression
  - T/F & kVp pre-selected by vendor lookup tables
  - Manual

**AEC System Function**

- Fischer – Mo target, Mo & Rh Filters
  - Mo/Mo, Mo/Rh, Rh/Rh
- Modes
  - Auto-Filter – AEC sensor, exposure adjustment
  - Auto-kV – Filter, AEC sensor, exposure adjustment
  - Auto-Time – kV, filter, AEC sensor, exposure adjustment
  - TEC – (Tissue Exposure Control) - Breast density
    - Normal mode
  - Manual
- Recommended Mode – Auto-Filter
AEC System Function

• AEC Summary
  – Manufacturer only recommends, user decides
  – Ultimately up to the Radiologist and/or Physicist to decide which mode to use
  – Make mode choice based on knowing effect on dose and image quality

2000 FFDM Variability Data

How Does Digital Compare to Screen-film Mammography in Terms Of:

- Exposure Times?
- Breast Dose?
- Detection of Low-contrast Lesions?

3 AOP Modes: Contrast
- Standard
- Dose

Methods

• Contrast-Detail image analysis
  – Acquire images at recommended techniques
    • 2, 4, 6, 8 cm
    • Calculate Dose
    • Score contrast-detail image for image quality

• ACR Phantom
  – Calculate Dose
  – Scores

• Compare to screen-film data

Contrast Detail Phantoms
Methods

Decreasing Diameter

ACR Phantom

ACR Phantom
Average Glandular Dose vs. Thickness
38 Screen-film Units, 18 FFDM Units

Exposure Time vs. Thickness
38 Screen-film Units, 18 FFDM Units

Contrast Detail Scores vs. Thickness
38 Screen-film Units, 18 FFDM Units

Methods

2002 GE 2000D Opto Data

Optimization of technique factors for a silicon diode array field-of-view digital mammography system and comparison to screen/film mammography with matched average glandular dose

Medical Physics. March 2003. 30 (3) pages 334-340
**Methods**

- **Objective:** To determine optimized technique factors for full-field digital mammography system (GE 2000D) for low-contrast lesion detection
- Optimization done under condition of matched patient dose to screen-film mammography
- Compare full-field digital results to screen-film results

**Results**

**CD Score vs. kVp**

- **2 cm Breasts**
  - Optimized Technique Comparison
  - Mo/Mo Trend p-value = 0.0752
  - Mo/Rh Trend p-value = 0.1369
  - Rh/Rh Trend p-value = 0.0985

- **4 cm Breasts**
  - Optimized Technique Comparison
  - Mo/Mo Trend p-value = 0.013
  - Mo/Rh Trend p-value = 0.2221
  - Rh/Rh Trend p-value = 0.5691

- **6 cm Breasts**
  - Optimized Technique Comparison
  - Mo/Mo Trend p-value = 0.5710
  - Mo/Rh Trend p-value = 0.5691
  - Rh/Rh Trend p-value = 0.0123

**CD Score vs. kVp**

- **2 cm Breasts**
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- **6 cm Breasts**
  - Optimized Technique Comparison
  - Mo/Mo Trend p-value = 0.5710
  - Mo/Rh Trend p-value = 0.5691
  - Rh/Rh Trend p-value = 0.0123
**Results**

- Mean CD Score vs. kVp for 8 cm Breasts

- Optimized Technique Comparison:
  - Mo/Mo Trend p-value < 0.0001
  - Mo/Rh Trend p-value < 0.0428
  - Rh/Rh Trend p-value < 0.0121

**Conclusions**

- Low-contrast lesion optimization for FFDM (GE 2000D)
  - Thin breasts (< 2 cm): Mo/Mo with low kVp
  - Intermediate breasts (~4 cm): Insensitive to target filter and kVp selection
  - Thick breasts (>5 cm): Rh/Rh with higher kVp

**ACRIN Data**

- Fischer FFDM doses were 32% lower than SFM doses

**Compressed Breast Thickness vs. Dose - All GE Sites (5)**

- Mean dose is 32% lower with FFDM than SFM
Fuji FFDM doses were 5% lower than SFM doses

Lorad FFDM doses were 2% higher than SFM doses

ARRS 2006
Comparison of Image Quality and Average Glandular Dose on Four FDA-approved Full-Field Digital Mammography Systems
**Purpose**

- To Measure and Compare
  - Image Quality
  - Average Glandular Dose
    - On 4 FDA-approved FFDM systems
    - Across full range of breast thicknesses
    - Using each manufacturer’s recommended techniques

**Methods**

- 4 FDA-approved FFDM systems
  - GE 2000D
  - GE Senographe DS
  - Lorad Selenia
  - Siemens Novation

**Methods**

- To acquire images
  - Position the phantom like a clinical acquisition
  - Apply 10 dN compression force
  - Acquire image using manufacturer’s recommended technique
  - Record technique factors
  - Measure HVL’s and entrance exposures
  - Calculate AGD
  - Measure and calculate Contrast-Detail scores

**Results**

![Average Glandular Dose Comparison](image)
Results

Contrast-Detail Scores

Results

Average Glandular Dose Comparison

Results

ACR Phantom Average Glandular Dose

Conclusions

- Results indicate that average glandular doses vary by up to a factor of 2.9
- There are significant differences in image quality
- Technique factors and automatic exposure mode selection can play an important role in clinical image quality and patient dose
Digital Proposed Phantom

Phantom Comparison

<table>
<thead>
<tr>
<th>ACR Phantom Object #</th>
<th>Fiber Diameter (mm)</th>
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<tbody>
<tr>
<td>ACR</td>
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<tr>
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<tr>
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<td>0.89</td>
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<td>6</td>
<td>0.40</td>
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<tr>
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<td>ACR Phantom Object #</td>
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<table>
<thead>
<tr>
<th>ACR Phantom Object #</th>
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<th>Mass Thickness (mm)</th>
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<td>0.89</td>
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<tr>
<td>6</td>
<td>0.40</td>
<td>0.13</td>
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Objective: To determine optimized technique factors for clinically available full-field digital mammography systems

- On 6 FFDM Units (Siemens counts as 2)
- Using
  - Contrast Detail Phantoms
  - ACR Phantom
  - Proposed ACR Digital Phantom
**Optimization 2006**

- Measure dose at all recommended techniques and compare to ACRIN doses
- Compare dose and image quality within each system using each mode
- Compare dose and image quality for each system using their recommended mode

**Optimization 2006**

- Evaluate performance of the ACR phantom and compare to our proposed ACR digital phantom
- Evaluate image quality as a function of dose for different modes
- Ultimately find the optimum techniques to provide the highest image quality with the lowest dose
HVL vs. kVp

Entrance Skin Exposure vs. kVp

Slid e 78

HVL vs. kVp

Entrance Skin Exposure vs. kVp

Slid e 80
Entrance Skin Exposure vs. kVp

Dose

Average Glandular Dose vs. Breast Thickness
Average Glandular Dose vs. Breast Thickness

- GE 2000D - Con/Auto
- GE 2000D - Std/Auto
- GE 2000D - Dos/Auto

Average Glandular Dose vs. Breast Thickness

- GE DS - Con/Auto
- GE DS - Std/Auto
- GE ES - Dos/Auto

Average Glandular Dose vs. Breast Thickness

- GE Essential - Con/Auto
- GE Essential - Std/Auto
- GE Essential - Dos/Auto

Average Glandular Dose vs. Breast Thickness

- GE 2000D - Con/Auto
- GE DS - Std/Auto
- GE ES - Std/Auto
Contrast-Detail Score vs. Breast Thickness

ACR Phantom

AGD for the ACR Phantom

Fibers for the ACR Phantom
Fibers for “Proposed” ACR Digital Phantom

Speck Groups for “Proposed” ACR Digital Phantom

Masses for “Proposed” ACR Digital Phantom

Vary Dose from Rec. Techs.
Contrast-Detail Scores vs. % Vendor AGD
For 6 cm Breast Thickness

% Vendor AGD
0% 50% 100% 150% 200% 250%

Contrast-Detail Scores
GE 2000D - Con/Auto
GE 2000D - Std/Auto
GE DS - Con/Auto
GE DS - Std/Auto
GE Essential - Con/Auto
GE Essential - Std/Auto
Siemens - Mo/Mo
Siemens - Rh/Rh

Contrast-Detail Scores vs. % Vendor AGD
For 6 cm Breast Thickness

% Vendor AGD
0% 50% 100% 150% 200% 250%

Contrast-Detail Scores
GE DS - Con/Auto
GE DS - Std/Auto
Rh/Rh – 29 kVp
Rh/Rh – 31 kVp

Contrast-Detail Scores vs. % Vendor AGD
For 6 cm Breast Thickness

% Vendor AGD
0% 50% 100% 150% 200% 250%

Contrast-Detail Scores
GE Essential - Con/Auto
GE Essential - Std/Auto
Rh/Rh – 29 kVp
Rh/Rh – 31 kVp
Contrast-Detail Scores vs. % Vendor AGD
For 6 cm Breast Thickness

Contrast-Detail Scores vs. kVp
At Matched Average Glandular Doses to Film and Digital

Summary

Vary kVp
Conclusions

• What’s responsible for different image quality scores?
  – Better calibration files on some digital manufacturer’s systems → fewer artifacts
  – Different breast doses
  – Different post-processing algorithms

Conclusions

• Better calibration files on some digital manufacturer’s systems

Conclusions

• Dose
  – Digital in general has lower doses than film
  – For the same phantom, dose varies widely by mode
  – Breast thickness makes big contribution to dose
  – Dose by thickness tracks pretty well across all vendors
  – Dose is affected by selection of mode being used

Conclusions

• Image Quality
  – Digital in general has higher image quality scores
  – For the same phantom, image quality varies widely by mode
  – Breast thickness has big effect on image quality
  – Image quality by thickness tracks pretty well across all vendors
  – Image quality is affected by selection of mode being used
Conclusions

- Still to be done
  - Phantom images scored by several readers
  - Analyzed for statistical differences and trends
- What I didn’t mention
  - Viewing conditions
  - Vendor QC
  - Monitor calibration
  - SNR Data

Conclusions

- Take home messages
  - Dose makes more of a difference on image quality than kVp
  - Digital has lower doses than Film
  - Some systems may set dose to low for their recommended mode
  - Pay attention to what mode is used clinically

Conclusions

- Take home messages
  - Digital mammography needs a more sensitive phantom
  - There is a wide range of image quality scores and doses across FFDM systems
  - Evaluate systems the way they are to be used clinically
  - Manufacturer only recommends AEC mode, user ultimately decides how the system is to be used

Thank You