Optimizing Dose and Image Quality in Digital Mammography

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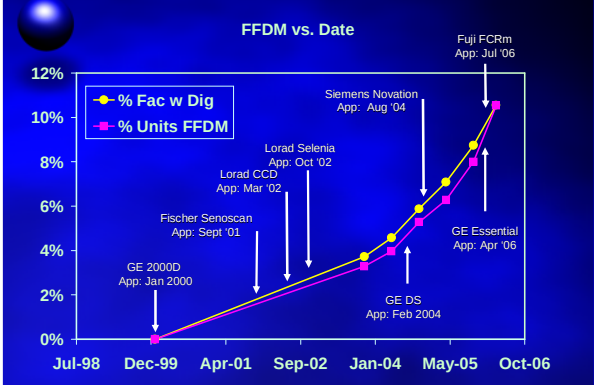
Introduction

Certified Statistics – 15 Months			
	April 1, 2005	August 1, 2006	Difference
Total Certified Mammo Facilities	8,929	8,829	-100
Total Accredited Mammo Units	13,640	13,556	-84
Certified Facilities with FFDM units	607	1,130	+523
Accredited FFDM units	819	1,604	+785



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)

Equipment

GE Senographe 2000D

Equipment

GE Senographe DS

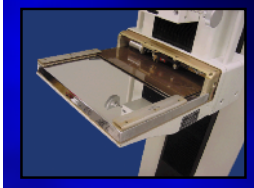
Equipment

GE Senographe Essential

Equipment

- <u>GE Senographe 2000D & DS & Essential</u>
  - FOV: 19.2 x 23.0 cm & 24.0 x 31.0 cm
  - Spatial resolution: 100 microns (5.0 lp/mm)

Equipment



Lorad Selenia

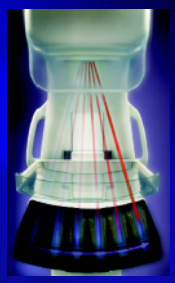
Equipment

Siemens Mammomat *Novation*^{DR}

Equipment

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

Equipment



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

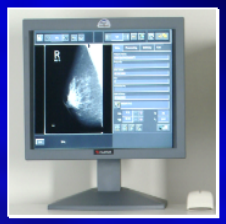
Equipment

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

Equipment

FCS*m*

Fuji FCRm



Flash Plus IIP*m*

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

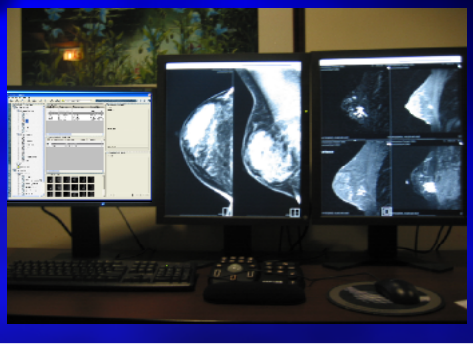
- FDA-Approved Laser Imagers ~ 40 μm spot
  - •Agfa LR5200 Laser Imager (Wet Chemistry)
  - •Agfa DS4500M
  - •Kodak 8600 Laser Imager
  - •Kodak 8610 Laser Imager
  - •Kodak 8900
  - •Fuji Drypix 4000, 5000, 7000
  - •Fuji Drypix FM-DP L
  - •Codonics Horizon Ci, GS, SF
  - •Konica Minolta DryPro 793

Workstations

- 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.)

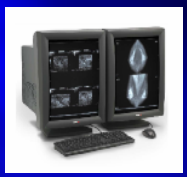
Workstations

- What is a Multimodality Review Workstation?



Multimodality Workstations

- FDA Approved Multimodality Workstations
  - AGFA IMPAX MA3000
  - Sectra IDS5/mx
  - Kodak DirectView PACS System
  - McKesson's PACS Mammo Station
  - iCad Second Look 500M
  - Cedara I-ReadMammo
  - Fuji Synapse
  - GE Seno Advantage & Seno Adv. 2
  - Fischer Senoview Plus (Cedara)
  - Hologic SecureView DX
  - Siemens MammoReportPlus

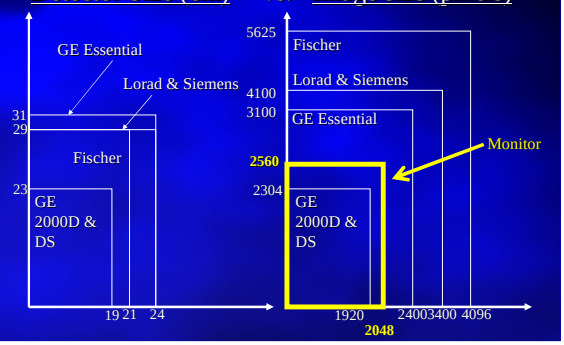


Workstations

- <u>Current challenges</u>
  - Device to device connectivity
  - DICOM incompatibilities between acquisition and displays
    - Can result in image degradation
  - PACS connectivity

Workstations

Detector Size (cm) vs. Image size (pixels)



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

- 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?

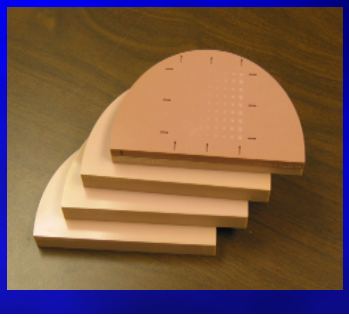
3 AOP Modes: Contrast +
Standard O
Dose -

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

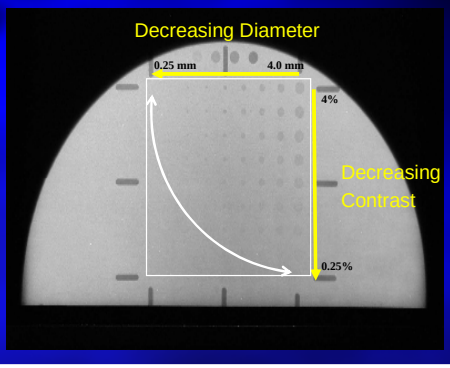
Methods

Contrast Detail Phantoms



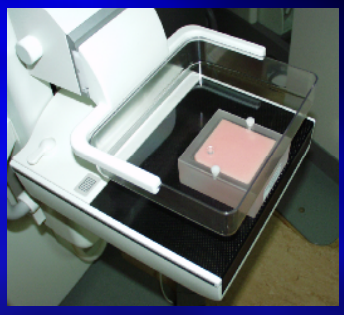
Methods

Methods



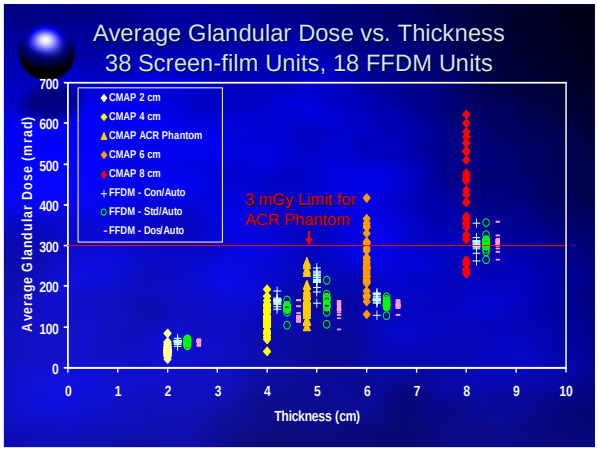
Methods

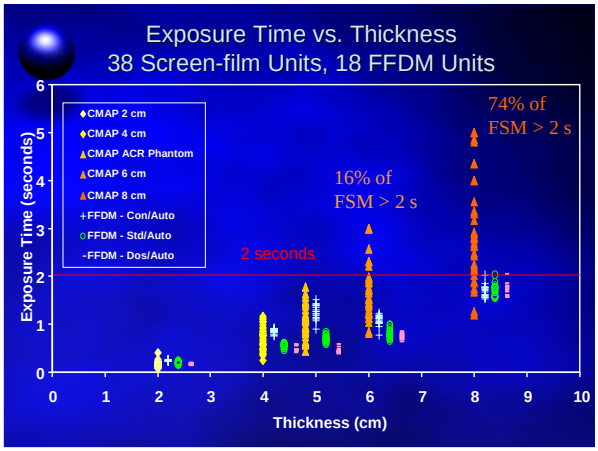
ACR Phantom

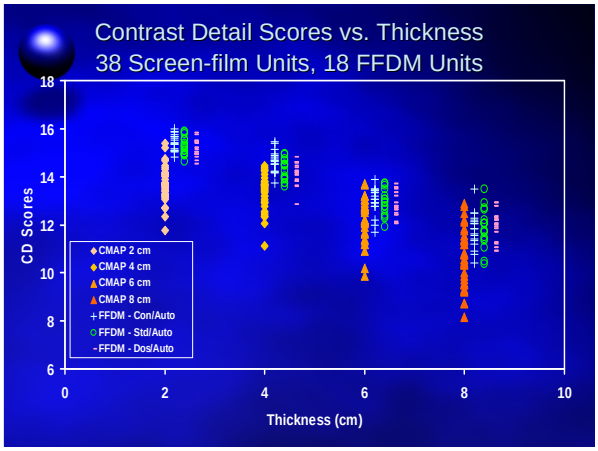


Methods

ACR Phantom

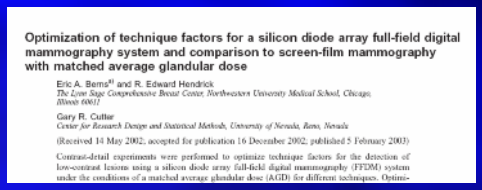






Methods

2002
GE 2000D Opto Data



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

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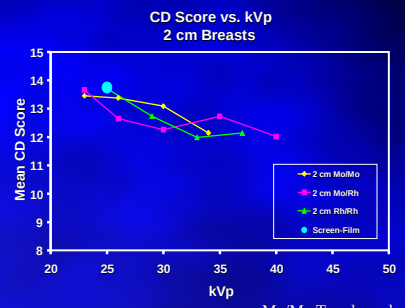
Contrast-detail experiments were performed to optimize technique factors for the detection of low-contrast lesions using a silicon diode array full-field digital mammography (FFDM) system under the conditions of a matched average glandular dose (AGD) for different techniques. Optimi-

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

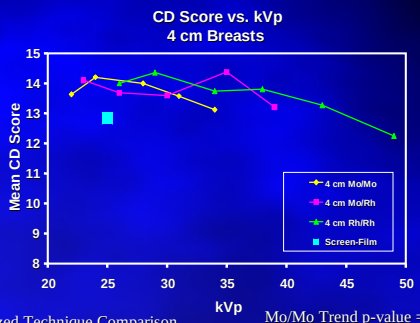
Results



Optimized Technique Comparison
p-value = 0.47

Mo/Mo Trend p-value = 0.0752
Mo/Rh Trend p-value = 0.1369
Rh/Rh Trend p-value = 0.0985

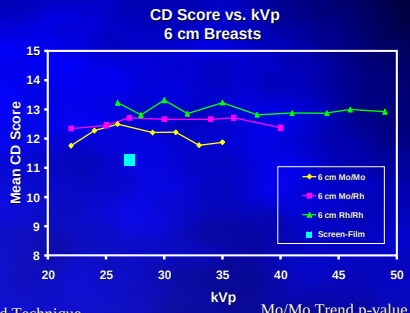
Results



Optimized Technique Comparison
p-value = 0.013

Mo/Mo Trend p-value = 0.2221
Mo/Rh Trend p-value = 0.5691
Rh/Rh Trend p-value = 0.0123

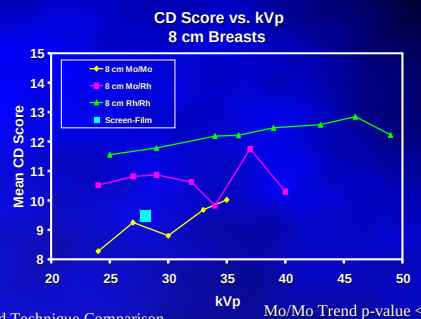
Results



Optimized Technique Comparison
p-value < 0.0001

Mo/Mo Trend p-value = 0.5710
Mo/Rh Trend p-value = 0.6496
Rh/Rh Trend p-value = 0.2735

Results



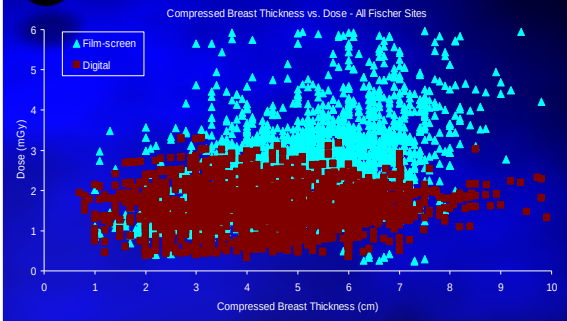
Optimized Technique Comparison
p-value < 0.0001

Mo/Mo Trend p-value < 0.0428
Mo/Rh Trend p-value < 0.9453
Rh/Rh Trend p-value < 0.0121

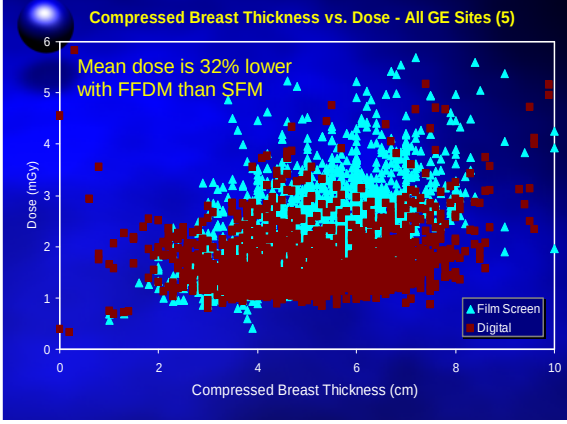
Conclusions

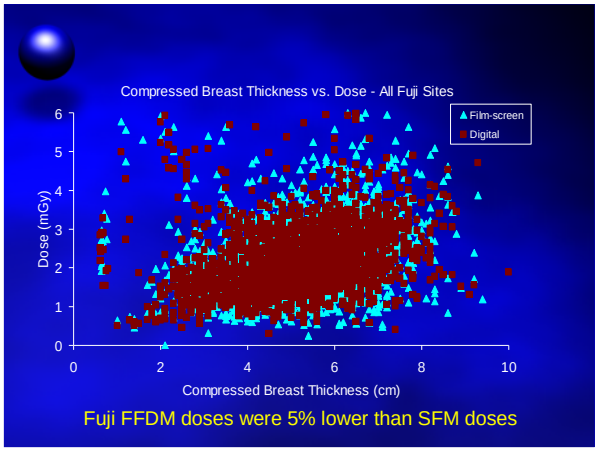
- Low-contrast lesion optimization for FFDM (GE 2000D)
  - Thin breasts (< 2 cm): Mo/Mo with low kVp
  - Intermediate breasts (~4 cm): Insensitive to target-filter and kVp selection
  - Thick breasts (>5 cm): Rh/Rh with higher kVp

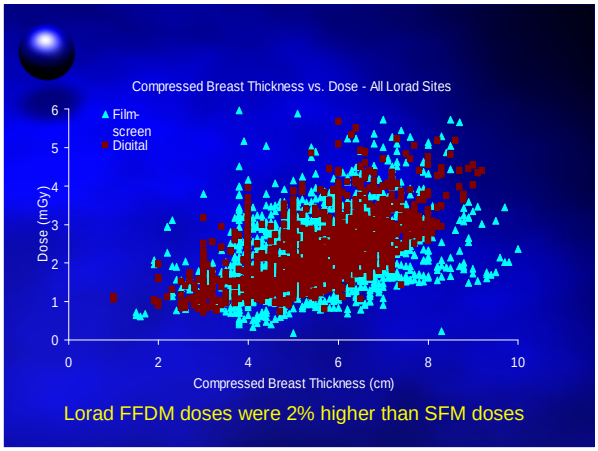
ACRIN Data

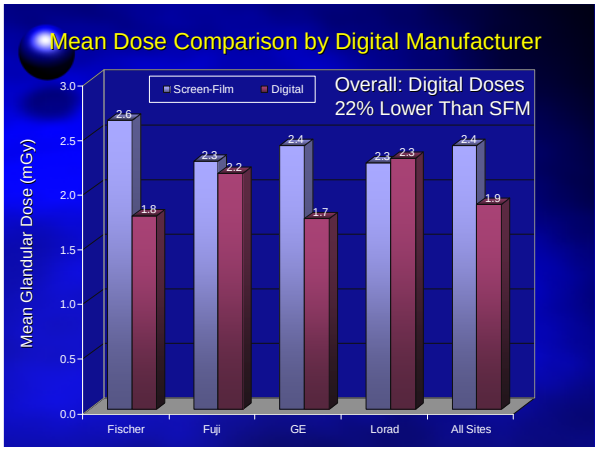


Fischer FFDM doses were 32% lower than SFM doses









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 manufacturers' recommended techniques

Methods

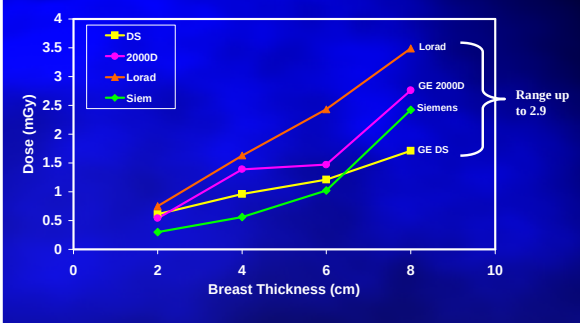
- 4 FDA-approved FFDM systems
  - GE 2000D
  - GE Senographe DS
  - Lorad Selenia
  - Siemens Novation

Methods

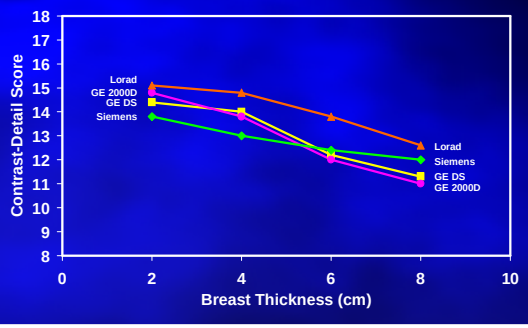
- To acquire images
  - Position the phantom like a clinical acquisition
  - Apply 10 dN compression force
  - Acquire image using manufacturer's recommended technique
  - Record technique factors
  - Measure HVL's and entrance exposures
  - Calculate AGD
  - Measure and calculate Contrast-Detail scores

Results

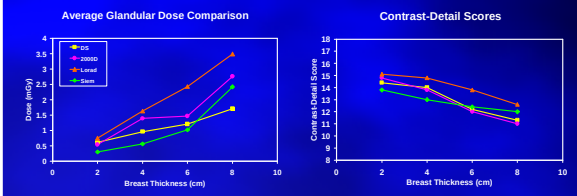
Average Glandular Dose Comparison



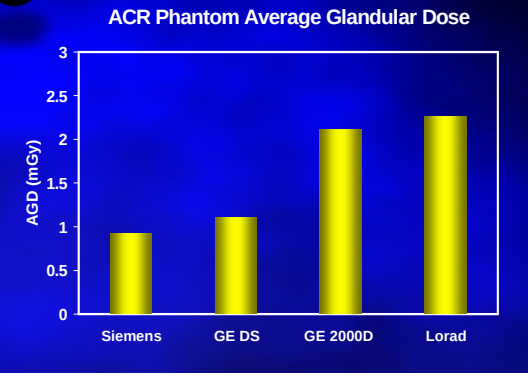
Results



Results



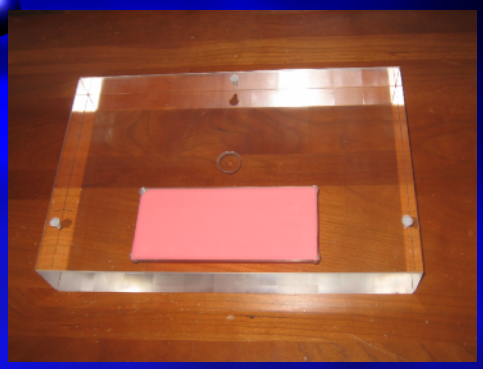
Results

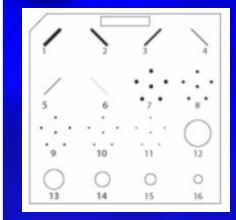


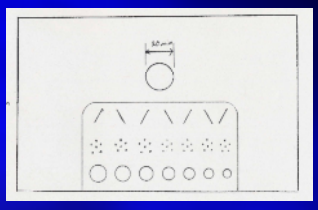
Conclusions

- Results indicate that
  - Average glandular doses varies 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

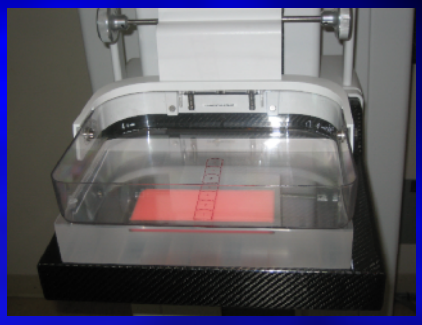
ACR Phantom Object #	ACR Fiber Diameter (mm)	Proposed Fiber Diameter (mm)				
1	1.56					
2	1.12					
3	0.89	0.89				
		0.82				
4	0.75	0.75				
		0.65				
5	0.54	0.54				
6	0.40	0.40				
		0.30				

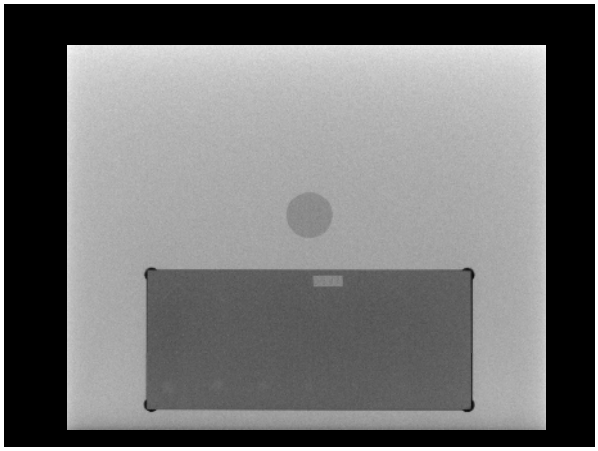
Phantom Comparison

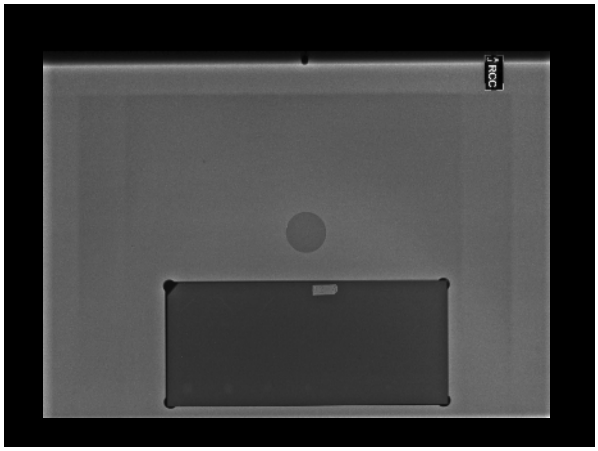
ACR Phantom Object #	ACR	Proposed	ACR	Proposed		
	Fiber Diameter (mm)		Speck Diameter (mm)			
1	1.56		0.54			
2	1.12		0.40			
3	0.89	0.89	0.32	0.32		
		0.82		0.28		
4	0.75	0.75	0.24	0.24		
		0.65		0.20		
5	0.54	0.54	0.16	0.16		
6	0.40	0.40		0.13		
		0.30		0.10		

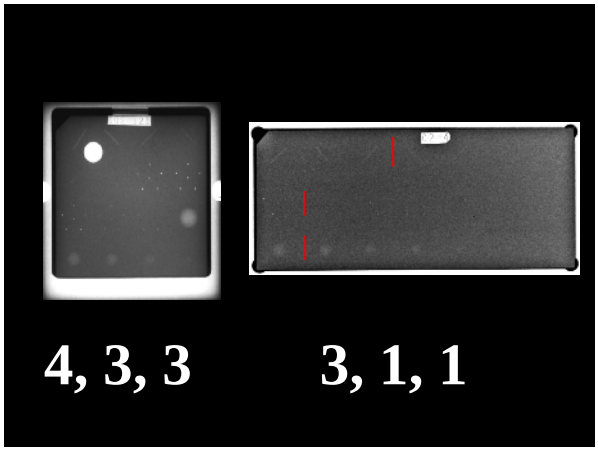
Phantom Comparison

ACR Phantom Object #	ACR	Proposed	ACR	Proposed	ACR	Proposed
	Fiber Diameter (mm)		Speck Diameter (mm)		Mass Thickness (mm)	
1	1.56		0.54		2.00	
2	1.12		0.40		1.00	
3	0.89	0.89	0.32	0.32	0.75	0.75
		0.82		0.28		0.68
4	0.75	0.75	0.24	0.24	0.50	0.50
		0.65		0.20		0.38
5	0.54	0.54	0.16	0.16	0.25	0.25
6	0.40	0.40		0.13		0.20
		0.30		0.10		0.15









Optimization 2006

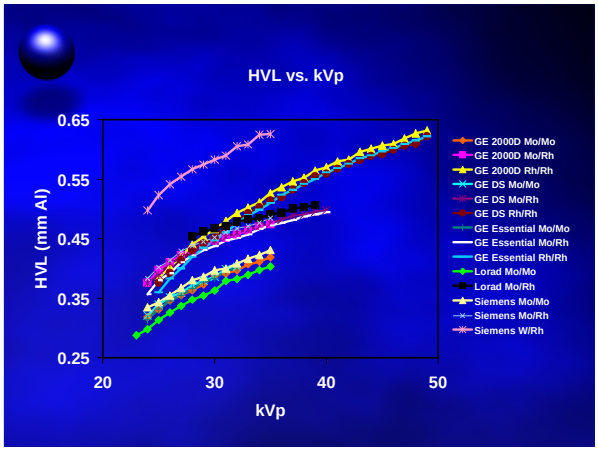
- Objective: To determine optimized technique factors for clinically available full-field digital mammography systems
- On 6 FFDM Units (Siemens counts as 2)
- Using
  - Contrast-Detail Phantoms
  - ACR Phantom
  - Proposed ACR Digital Phantom

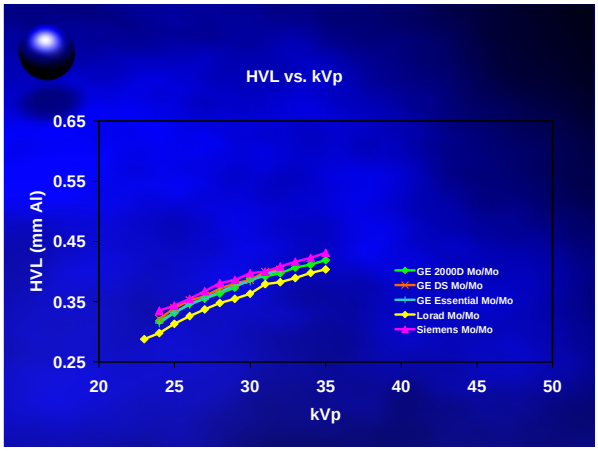
Optimization 2006

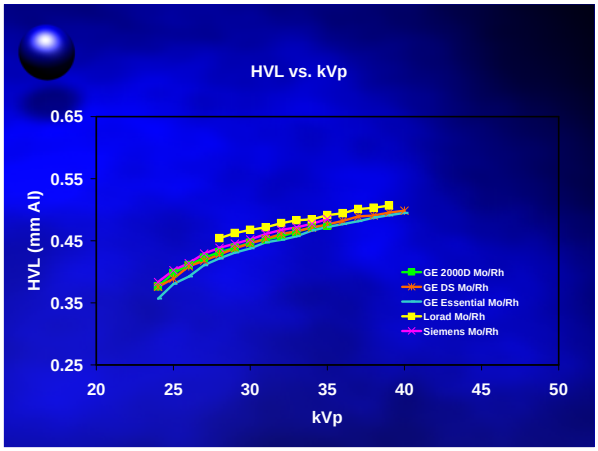
- Measure dose at all recommended techniques and compare to ACRIN doses
- Compare dose and image quality within each system using each mode
- Compare dose and image quality for each system using their recommended mode

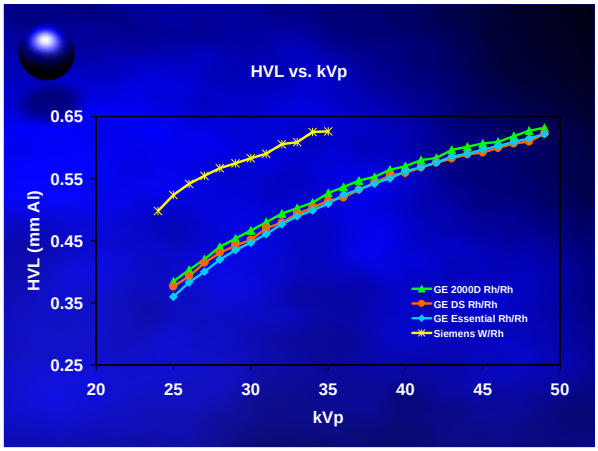
Optimization 2006

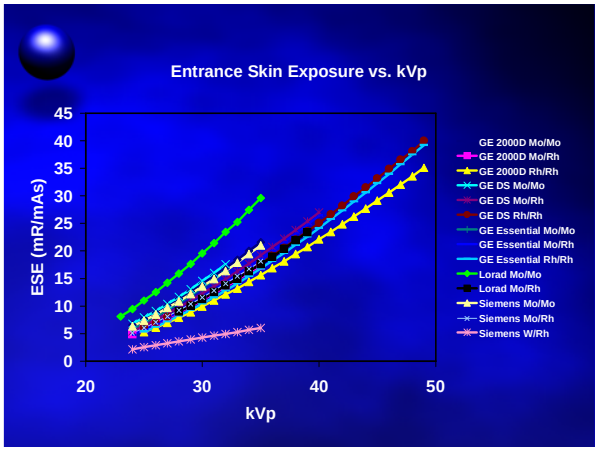
- Evaluate performance of the ACR phantom and compare to our proposed ACR digital phantom
- Evaluate image quality as a function of dose for different modes
- Ultimately find the optimum techniques to provide the highest image quality with the lowest dose

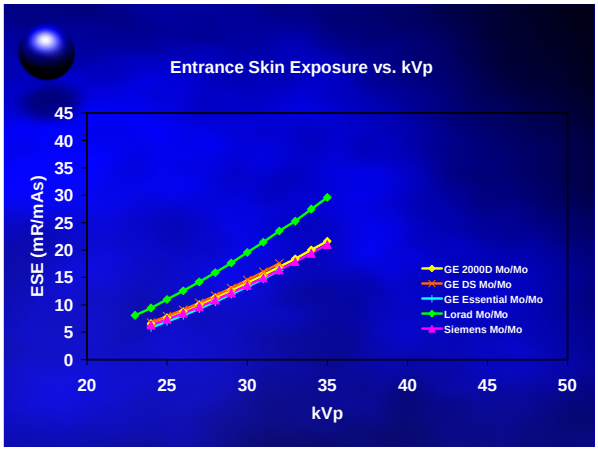


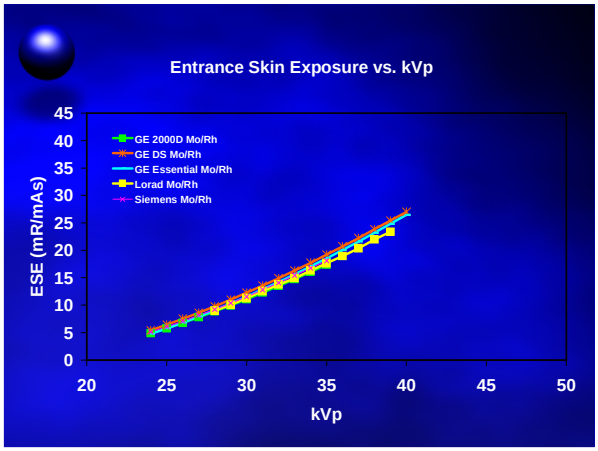


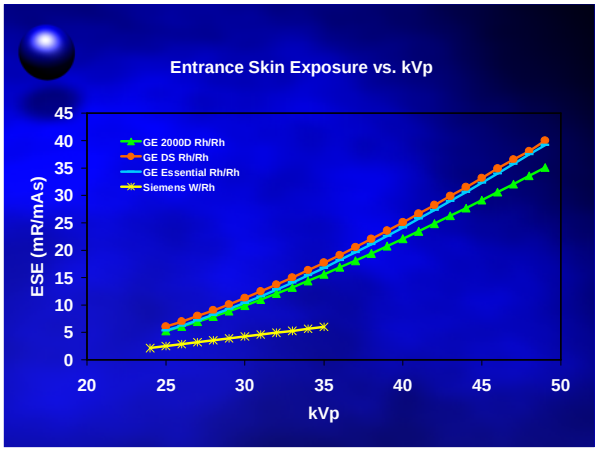

HVL vs. kVp
HVL (mm Al)
0.65
0.55
0.45
0.35
0.25
20
25
30
35
40
45
50
kVp
GE 2000D Mo/Rh
GE DS Mo/Rh
GE Essential Mo/Rh
Lorad Mo/Rh
Siemens Mo/Rh


HVL vs. kVp
HVL (mm Al)
0.65
0.55
0.45
0.35
0.25
20
25
30
35
40
45
50
kVp
GE 2000D Rh/Rh
GE DS Rh/Rh
GE Essential Rh/Rh
Siemens W/Rh

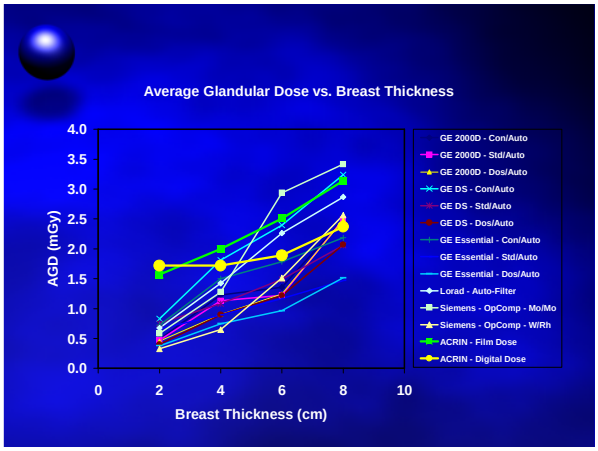

Entrance Skin Exposure vs. kVp
ESE (mR/mAs)
45
40
35
30
25
20
15
10
5
0
20
30
40
50
kVp
GE 2000D Mo/Mo
GE 2000D Mo/Rh
GE 2000D Rh/Rh
GE DS Mo/Mo
GE DS Mo/Rh
GE DS Rh/Rh
GE Essential Mo/Mo
GE Essential Mo/Rh
GE Essential Rh/Rh
Lorad Mo/Mo
Lorad Mo/Rh
Siemens Mo/Mo
Siemens Mo/Rh
Siemens W/Rh

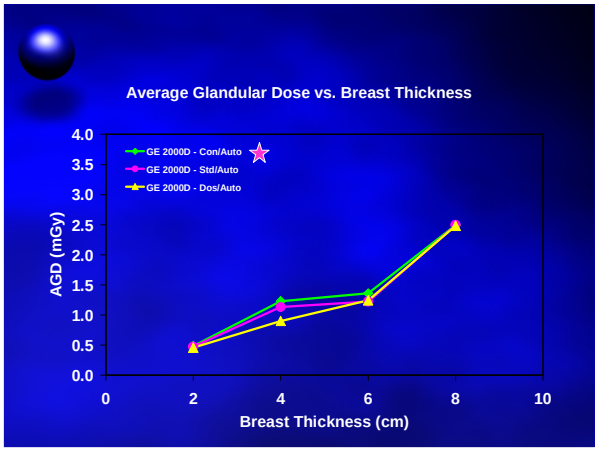

Entrance Skin Exposure vs. kVp
ESE (mR/mAs)
45
40
35
30
25
20
15
10
5
0
20
25
30
35
40
45
50
kVp
GE 2000D Mo/Mo
GE DS Mo/Mo
GE Essential Mo/Mo
Lorad Mo/Mo
Siemens Mo/Mo

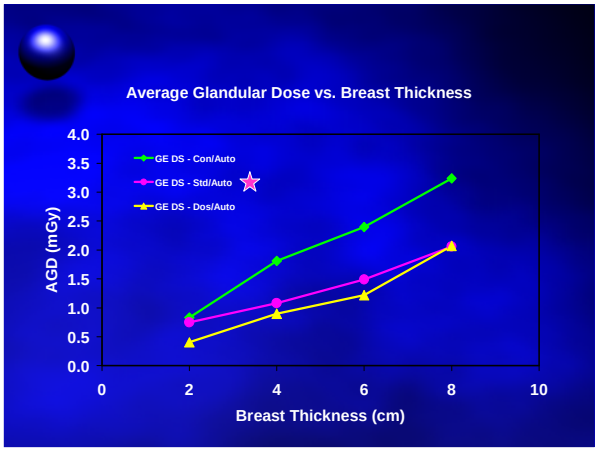

Entrance Skin Exposure vs. kVp
ESE (mR/mAs)
kVp
GE 2000D Mo/Rh
GE DS Mo/Rh
GE Essential Mo/Rh
Lorad Mo/Rh
Siemens Mo/Rh

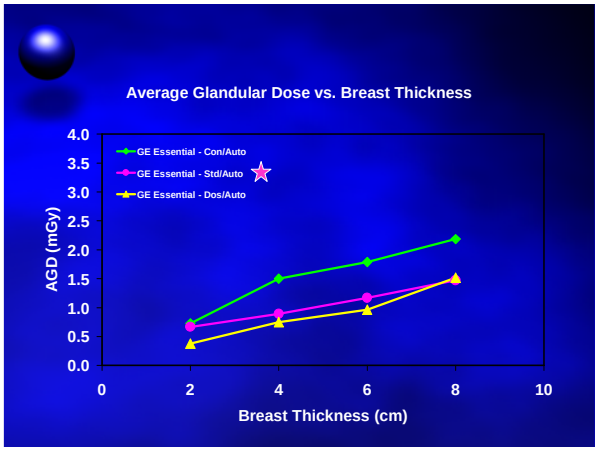

Entrance Skin Exposure vs. kVp
ESE (mR/mAs)
kVp
GE 2000D Rh/Rh
GE DS Rh/Rh
GE Essential Rh/Rh
Siemens W/Rh

Dose

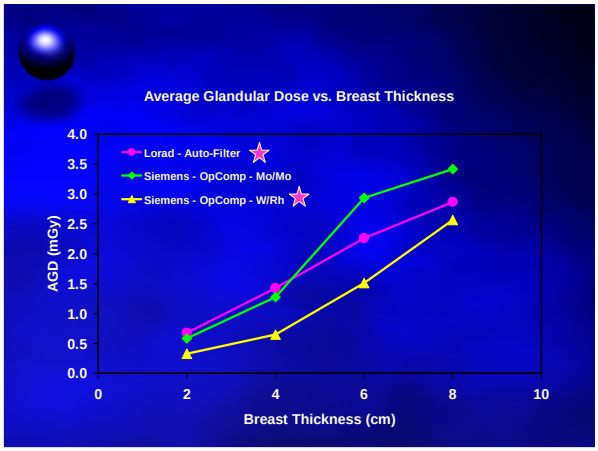

Average Glandular Dose vs. Breast Thickness
AGD (mGy)
Breast Thickness (cm)
GE 2000D - Con/Auto
GE 2000D - Std/Auto
GE 2000D - Dos/Auto
GE DS - Con/Auto
GE DS - Std/Auto
GE DS - Dos/Auto
GE Essential - Con/Auto
GE Essential - Std/Auto
GE Essential - Dos/Auto
Lorad - Auto-Filter
Siemens - OpComp - Mo/Mo
Siemens - OpComp - W/Rh
ACRIN - Film Dose
ACRIN - Digital Dose

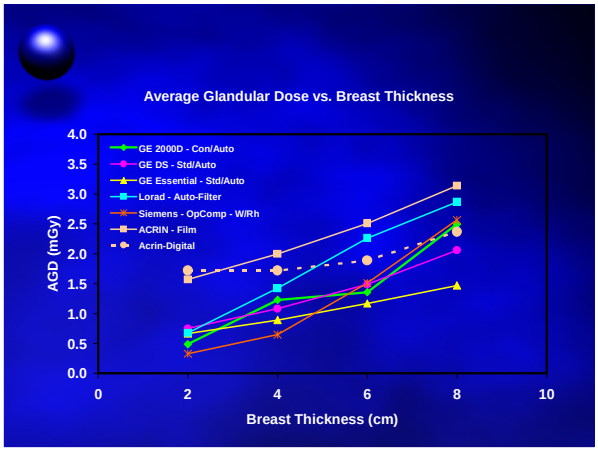

Average Glandular Dose vs. Breast Thickness
GE 2000D - Con/Auto
GE 2000D - Std/Auto
GE 2000D - Dos/Auto
AGD (mGy)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
2
4
6
8
10
Breast Thickness (cm)


Average Glandular Dose vs. Breast Thickness
GE DS - Con/Auto
GE DS - Std/Auto
GE DS - Dos/Auto
AGD (mGy)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
2
4
6
8
10
Breast Thickness (cm)

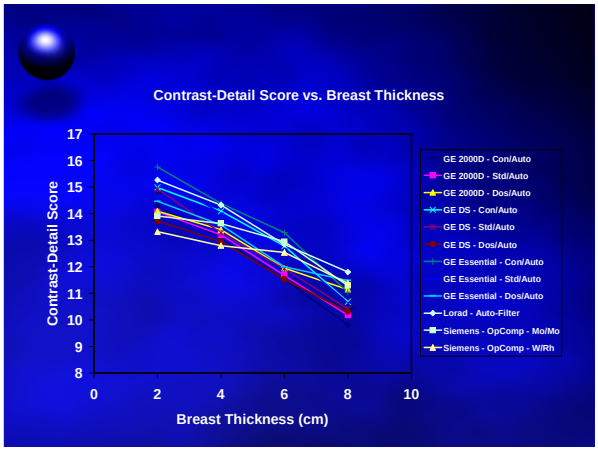

Average Glandular Dose vs. Breast Thickness
GE Essential - Con/Auto
GE Essential - Std/Auto
GE Essential - Dos/Auto
AGD (mGy)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
2
4
6
8
10
Breast Thickness (cm)

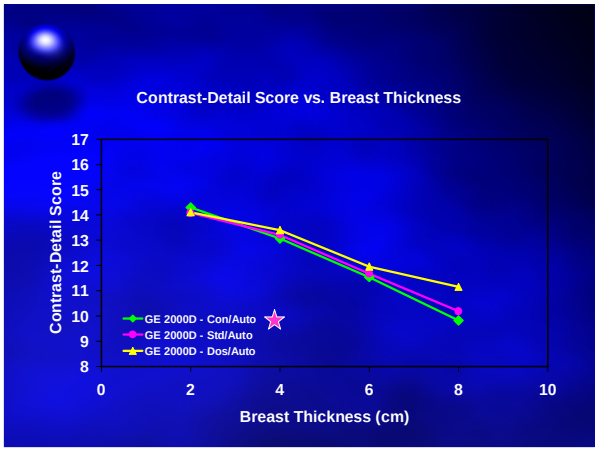

Average Glandular Dose vs. Breast Thickness
GE 2000D - Con/Auto
GE DS - Std/Auto
GE Essential - Std/Auto
AGD (mGy)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
2
4
6
8
10
Breast Thickness (cm)

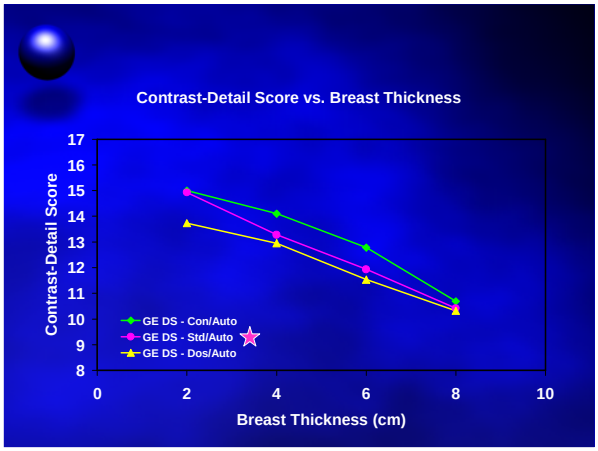

Average Glandular Dose vs. Breast Thickness
Lorad - Auto-Filter
Siemens - OpComp - Mo/Mo
Siemens - OpComp - W/Rh
AGD (mGy)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
2
4
6
8
10
Breast Thickness (cm)

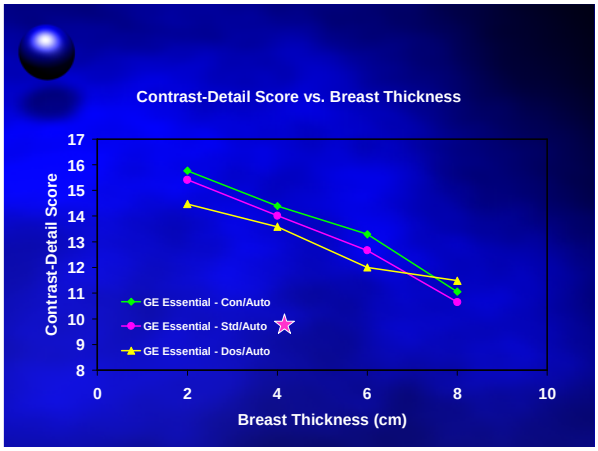

Average Glandular Dose vs. Breast Thickness
GE 2000D - Con/Auto
GE DS - Std/Auto
GE Essential - Std/Auto
Lorad - Auto-Filter
Siemens - OpComp - W/Rh
ACRIN - Film
Acrin-Digital
AGD (mGy)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
2
4
6
8
10
Breast Thickness (cm)

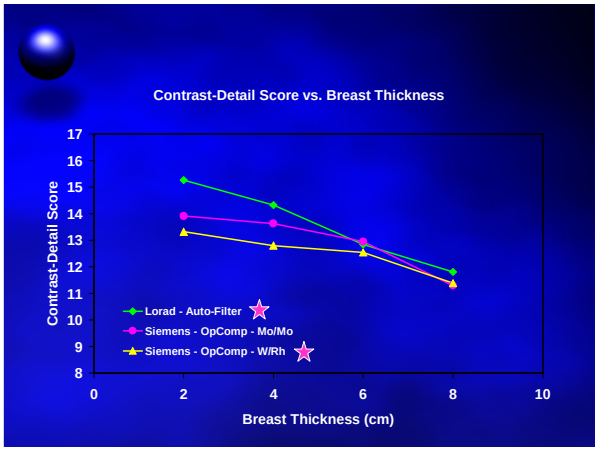
CD Scores

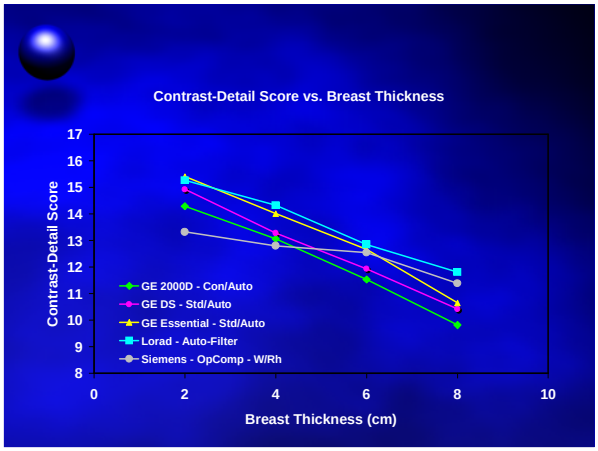

Contrast-Detail Score vs. Breast Thickness
Contrast-Detail Score
17
16
15
14
13
12
11
10
9
8
0
2
4
6
8
10
Breast Thickness (cm)
GE 2000D - Con/Auto
GE 2000D - Std/Auto
GE 2000D - Dos/Auto
GE DS - Con/Auto
GE DS - Std/Auto
GE DS - Dos/Auto
GE Essential - Con/Auto
GE Essential - Std/Auto
GE Essential - Dos/Auto
Lorad - Auto-Filter
Siemens - OpComp - Mo/Mo
Siemens - OpComp - W/Rh


Contrast-Detail Score vs. Breast Thickness
Contrast-Detail Score
17
16
15
14
13
12
11
10
9
8
0
2
4
6
8
10
Breast Thickness (cm)
GE 2000D - Con/Auto
GE 2000D - Std/Auto
GE 2000D - Dos/Auto

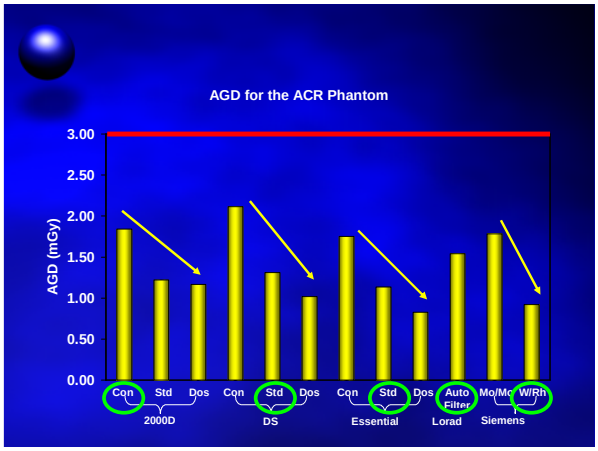

Contrast-Detail Score vs. Breast Thickness
Contrast-Detail Score
17
16
15
14
13
12
11
10
9
8
0
2
4
6
8
10
Breast Thickness (cm)
GE DS - Con/Auto
GE DS - Std/Auto
GE DS - Dos/Auto

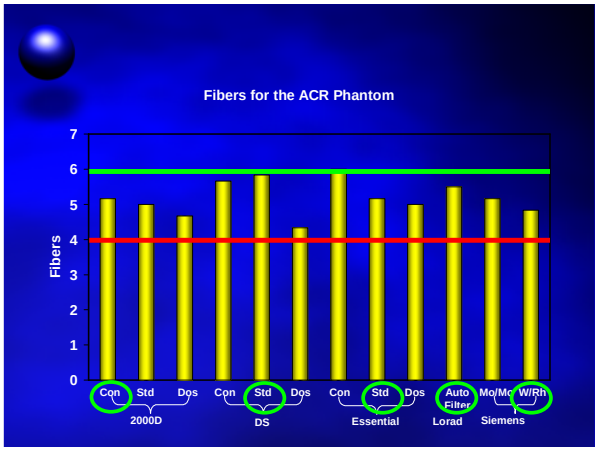

Contrast-Detail Score vs. Breast Thickness
Contrast-Detail Score
17
16
15
14
13
12
11
10
9
8
0
2
4
6
8
10
Breast Thickness (cm)
GE Essential - Con/Auto
GE Essential - Std/Auto
GE Essential - Dos/Auto

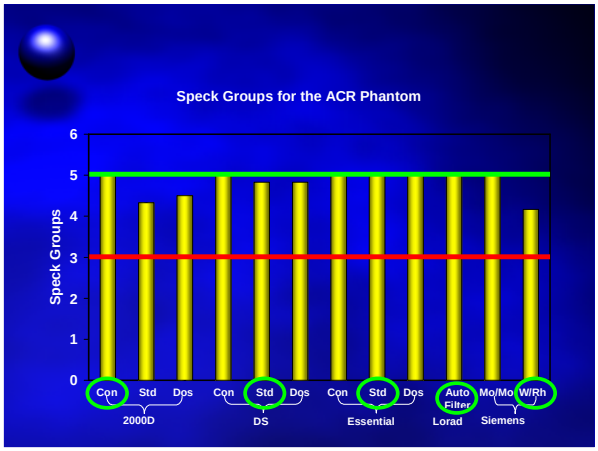

Contrast-Detail Score vs. Breast Thickness
Contrast-Detail Score
17
16
15
14
13
12
11
10
9
8
0
2
4
6
8
10
Breast Thickness (cm)
Lorad - Auto-Filter
Siemens - OpComp - Mo/Mo
Siemens - OpComp - W/Rh

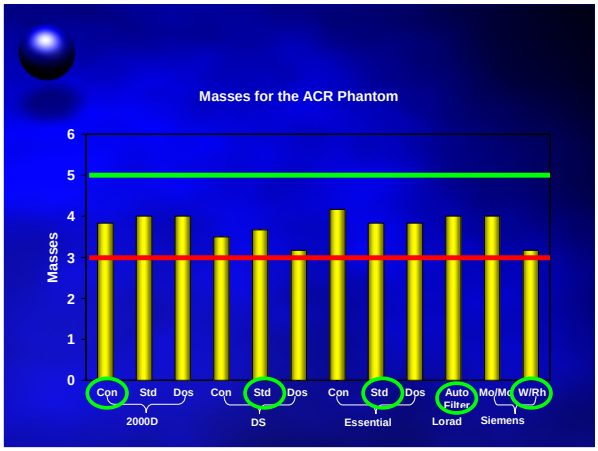

Contrast-Detail Score vs. Breast Thickness
Contrast-Detail Score
17
16
15
14
13
12
11
10
9
8
0
2
4
6
8
10
Breast Thickness (cm)
GE 2000D - Con/Auto
GE DS - Std/Auto
GE Essential - Std/Auto
Lorad - Auto-Filter
Siemens - OpComp - W/Rh

ACR Phantom

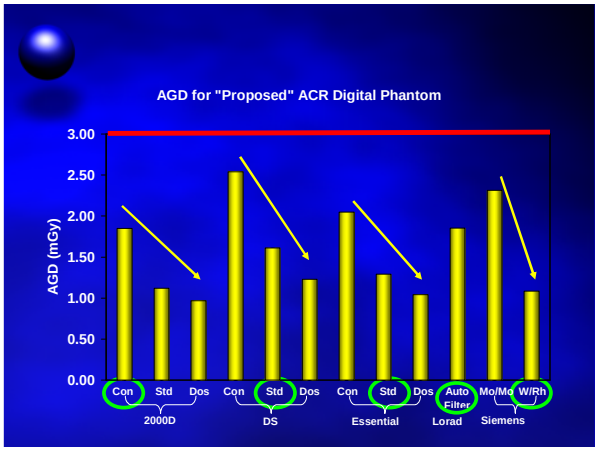

AGD for the ACR Phantom
AGD (mGy)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Con
Std
Dos
Con
Std
Dos
Con
Std
Dos
Auto Filter
Mo/Mo
W/Rh
2000D
DS
Essential
Lorad
Siemens

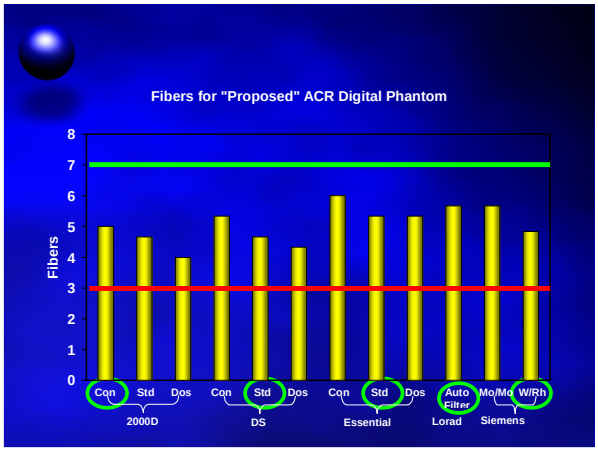

Fibers for the ACR Phantom
Fibers
7
6
5
4
3
2
1
0
Con
Std
Dos
Con
Std
Dos
Con
Std
Dos
Auto Filter
Mo/Mo
W/Rh
2000D
DS
Essential
Lorad
Siemens

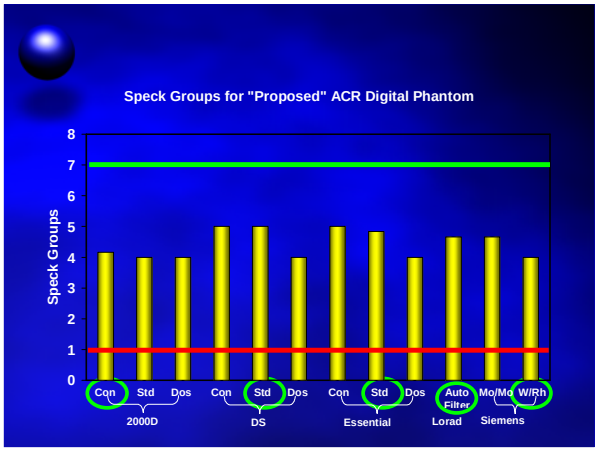


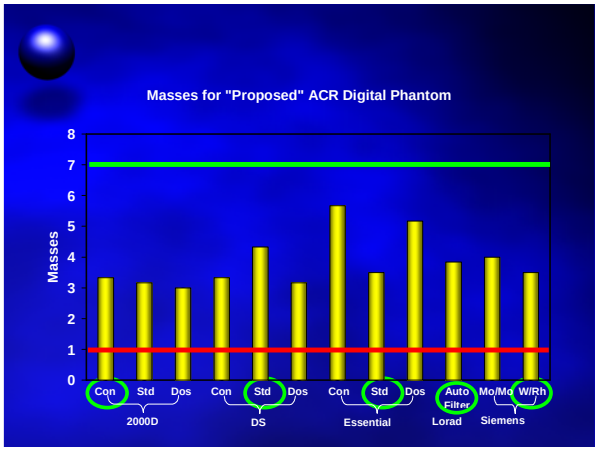


Proposed ACR Digital Phantom

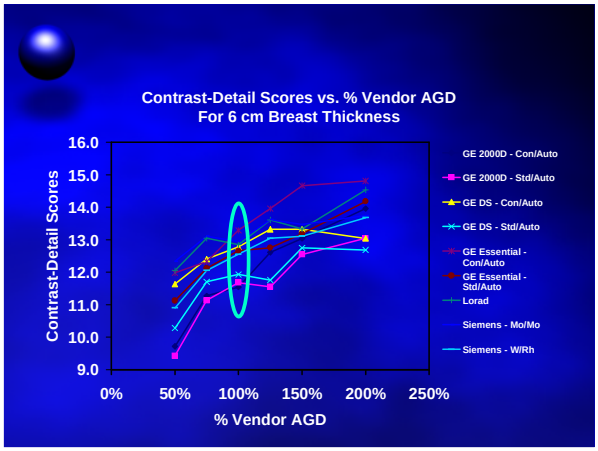


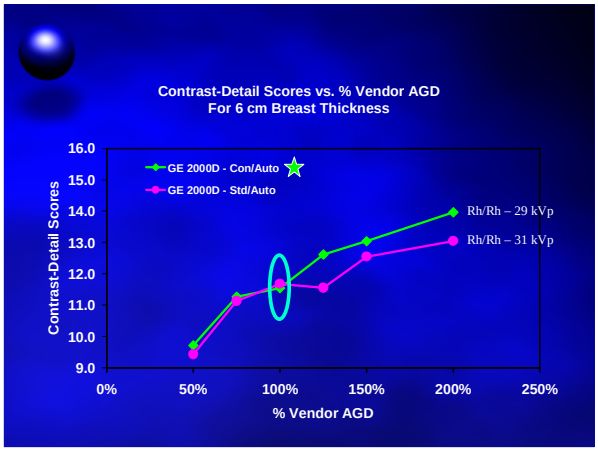


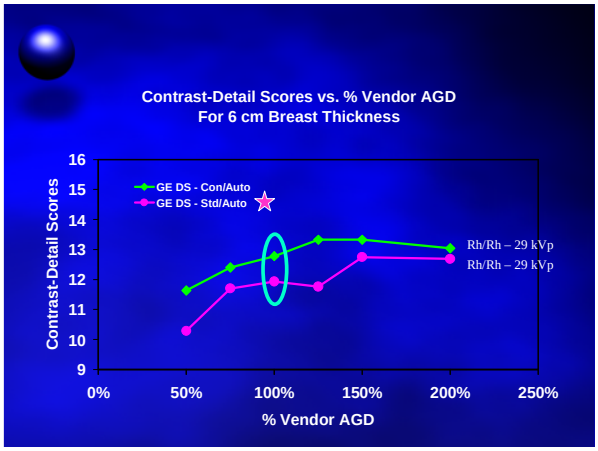


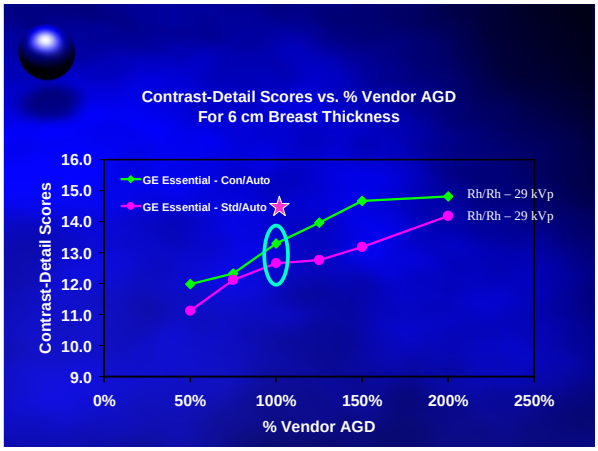


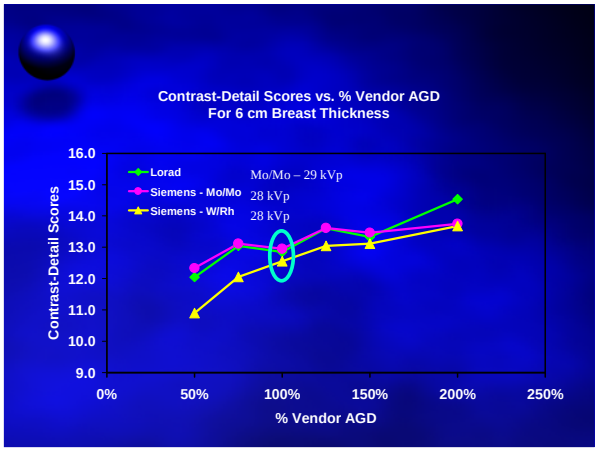
Vary Dose from Rec. Techs.


Contrast-Detail Scores vs. % Vendor AGD
For 6 cm Breast Thickness
Contrast-Detail Scores
16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
0%
50%
100%
150%
200%
250%
% Vendor AGD
GE 2000D - Con/Auto
GE 2000D - Std/Auto
GE DS - Con/Auto
GE DS - Std/Auto
GE Essential - Con/Auto
GE Essential - Std/Auto
Lorad
Siemens - Mo/Mo
Siemens - W/Rh

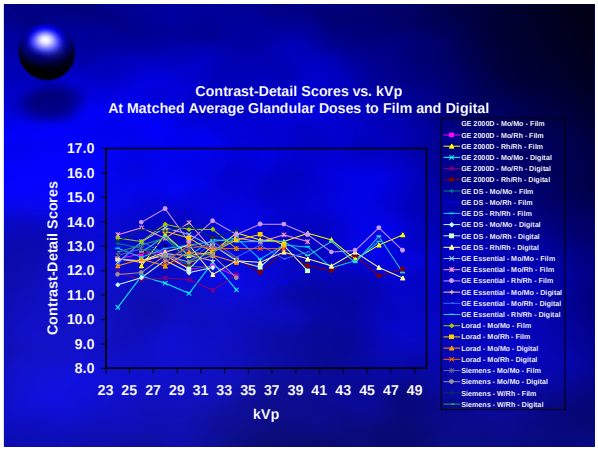

Contrast-Detail Scores vs. % Vendor AGD
For 6 cm Breast Thickness
Contrast-Detail Scores
16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
0%
50%
100%
150%
200%
250%
% Vendor AGD
GE 2000D - Con/Auto
GE 2000D - Std/Auto
Rh/Rh – 29 kVp
Rh/Rh – 31 kVp


Contrast-Detail Scores vs. % Vendor AGD
For 6 cm Breast Thickness
Contrast-Detail Scores
16
15
14
13
12
11
10
9
0%
50%
100%
150%
200%
250%
% Vendor AGD
GE DS - Con/Auto
GE DS - Std/Auto
Rh/Rh – 29 kVp
Rh/Rh – 29 kVp

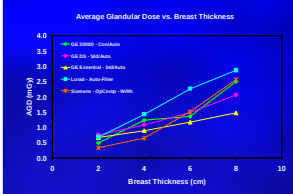

Contrast-Detail Scores vs. % Vendor AGD
For 6 cm Breast Thickness
Contrast-Detail Scores
16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
0%
50%
100%
150%
200%
250%
% Vendor AGD
GE Essential - Con/Auto
GE Essential - Std/Auto
Rh/Rh – 29 kVp
Rh/Rh – 29 kVp

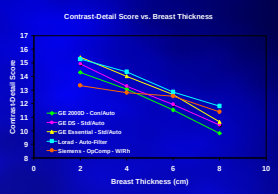


Vary kVp



Summary



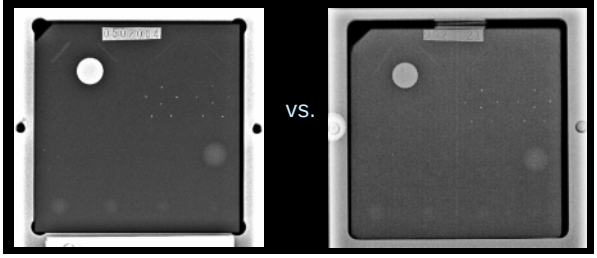


Conclusions

- 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