Digital Mammography Update: Design and Characteristics of Current Systems

Kalpana M. Kanal, Ph.D., DABR
Assistant Professor
Department of Radiology
University of Washington
Seattle, Washington

AAPM Annual Meeting 2009 – Anaheim, CA

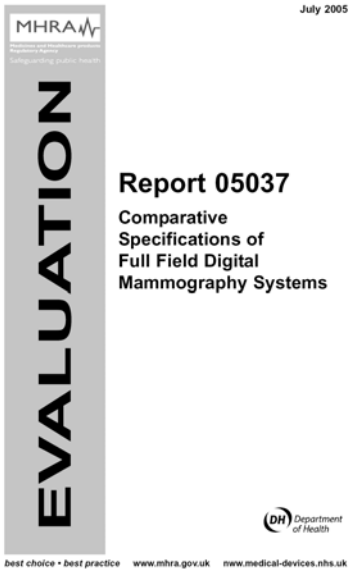
Educational Objectives

- Understand the physics of digital detector technology
- Recognize that vendors use varying detector technology in FFDM systems
- Appreciate the advantages and disadvantages of digital mammography systems
- Understand briefly the image quality metrics such as DQE and MTF

Kanal 2

Resources

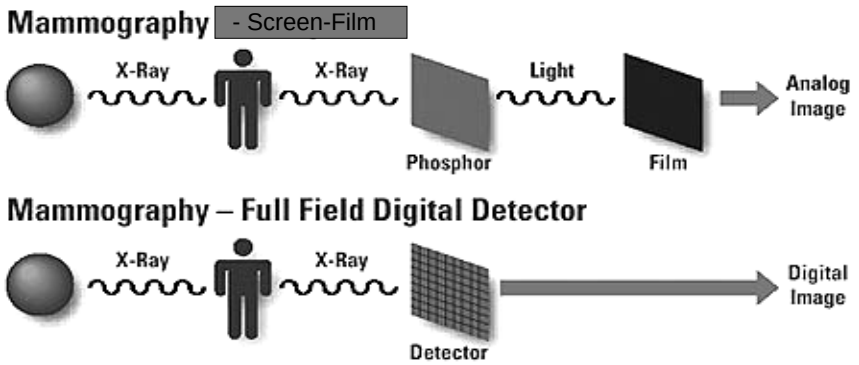
- *Doug Pfeiffer*, MS, DABR
- Digital Mammography: An overview – *Dr. Mahesh* (Radiographics 2004;24:1747-1760)
- Fundamentals of Digital Mammography Primer – *Dr. Smith* (Hologic Inc)
- Digital Mammography – *Pisano and Yaffe* (Radiology 2005; 234:353-262)
- Bloomquist and Yaffe – Med Phys 33 (3), 2006



Kanal 3

Introduction

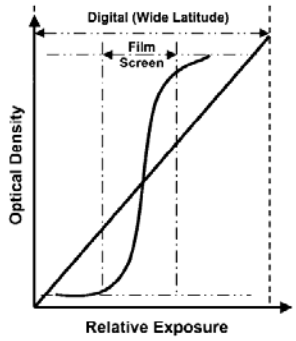
Full-Field Digital Mammography (FFDM)

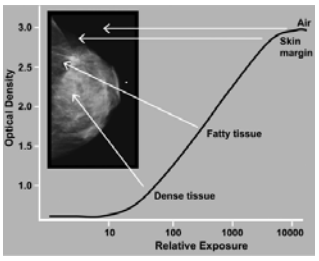


c.f. www.gehealthcare.com/rad/xr/education/dig_xray_intro.html

Kanal 5

Full-Field Digital Mammography (FFDM)

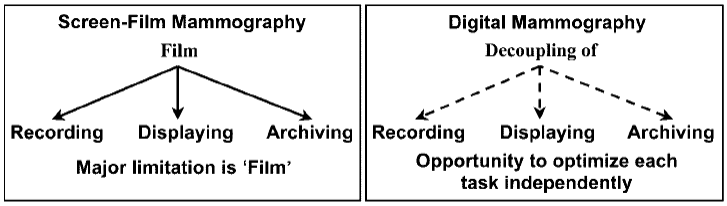




- Wide dynamic range (1000:1) compared with SFM (40:1)
- Dynamic image manipulation
- Ability to post-process
- Soft-copy read accompanied by computer-aided-diagnosis (CAD)
- 3D imaging

Kanal Radiographics 2004:24,1749 6

Full-Field Digital Mammography (FFDM)

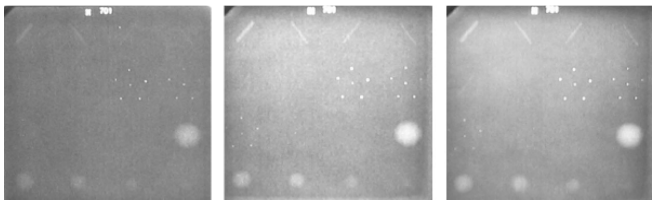


- Advantage
  - Each component of the mammographic process can be optimized with digital mammography

Kanal Radiographics 2004:24,1750 7

SFM vs. FFDM

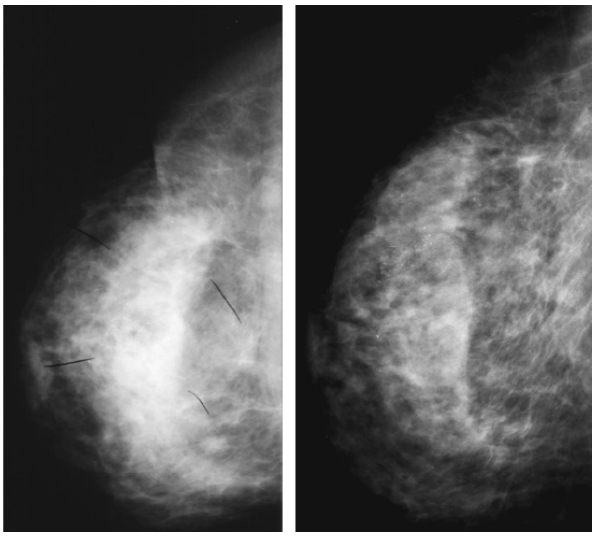
SFM: Half mAs, Automatic exposure control, Double mAs



FFDM: Same technique factors as SFM, W/L adjusted

Kanal Radiographics 2004:24,1750 8

SFM vs. FFDM



Kanal

Radiographics 2004:24,1751

9

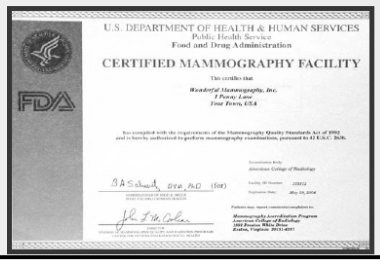
FDA and Digital Mammography

FDA Office of Device Evaluation

- Clears FFDM for sale in US
- GE Senographe 2000D, DS, Essential
- Fischer SenoScan
- Lorad Selenia Amorphous Selenium
- Siemens Mammomat Novation DR
- Fuji FCR*m*
- Approves monitors and printers for sale in US

FDA Office of Communication, Education and Radiation Programs

- Writes and enforces MQSA regulations
- Issues MQSA certificates


U.S. DEPARTMENT OF HEALTH & HUMAN SERVICES
Public Health Service
Food and Drug Administration
CERTIFIED MAMMOGRAPHY FACILITY
This certifies that
Wonderful Mammography, Inc.
1 Pretty Lane
Your Town, USA
FDA

Kanal

Butler - http://www.acr.org/accreditation/mammography/rsna07presentation.aspx

10

MQSA Scorecard

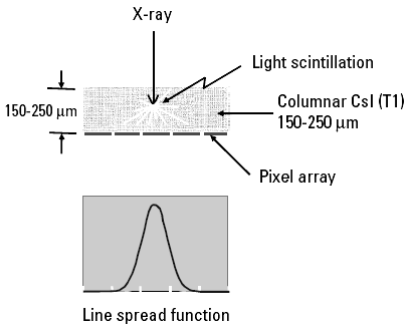
- Certification statistics, as of July 1, 2009
- Total certified facilities / Total accredited units
  - 8,714 / 12,875
- Certified facilities with FFDM units / Accredited FFDM units
  - 4,659 / 6,964
- **53%** certified facilities with FFDM units
- **54%** accredited FFDM units (38% last year)

Kanal http://www.fda.gov/cdrh/mammography/scorecard-statistics.html 11

Technologies for FFDM

Technologies for FFDM
Indirect Capture

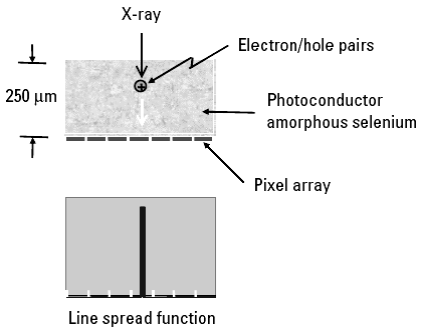
- a scintillator such as cesium iodide (CsI) absorbs x-rays and generates a light scintillation
- detected by an array of photodiodes or charge-coupled devices (CCDs)
- Resolution degradation



Kanal http://www.hologic.com/wh/pdf/R-LM-016_Radiology_Management.pdf 13

Technologies for FFDM
Direct Capture

- X-ray photons are directly captured by a photoconductor such as amorphous selenium (a-Se), which converts the absorbed x-rays directly to a digital signal
- Spatial resolution limited to pixel size



Kanal http://www.hologic.com/wh/pdf/R-LM-016_Radiology_Management.pdf 14

Various Approaches in development of FFDM systems

- **Indirect**
  - A single flat-panel scintillator and an amorphous silicon (a-Si) diode array – *GE*
  - Slot scanning with scintillators and CCD arrays – *Fischer Imaging, now Hologic*
  - Photostimulable phosphor plates - *Fuji*
- **Direct**
  - A flat-panel amorphous selenium (a-Se) array – *Hologic, Siemens*
  - Tiled scintillators with fiberoptic tapers and mosaic CCD arrays – *Hologic Stereotactic*

Kanal 15

Technologies for FFDM – Indirect Capture GE

Fig. Ref: GE DS QC manual

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

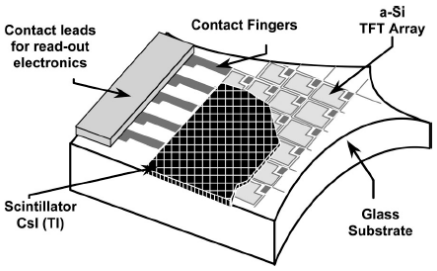
GE Senographe DS Full Field Digital Mammography (FFDM) System - 02/19/04

GE Senographe Essential Full Field Digital Mammography (FFDM) System - 04/11/06 (larger detector)

Kanal 16

Technologies for FFDM – Indirect Capture GE

- In this system, the digital detector array is constructed from an a-Si thin-film transistor (TFT) matrix deposited on a glass substrate
- The CsI scintillator is deposited on the a-Si detector
- Each light-sensitive diode element is connected by TFTs to a control and a data line so that charge produced in the diode is read out in response to light emission from the scintillator



Kanal Radiographics 2004:24,1753 17

Technologies for FFDM – Indirect Capture GE

	2000D	DS	Essential
Detector size	19.2 x 23.0	19.2 x 23.0	24.0 x 30.7
Pixel size	100 µm	100 µm	100 µm
Limiting Spatial Resolution	5 lp/cm	5 lp/cm	5 lp/cm
Image size	1914 x 2294 pixels (9 MB)	1914 x 2294 pixels (9 MB)	2394 x 3062 pixels (14 MB)
Bit Depth	14	14	14

Kanal Radiographics 2004:24,1753 18

Technologies for FFDM – Indirect Capture
GE – Advantages and Disadvantages

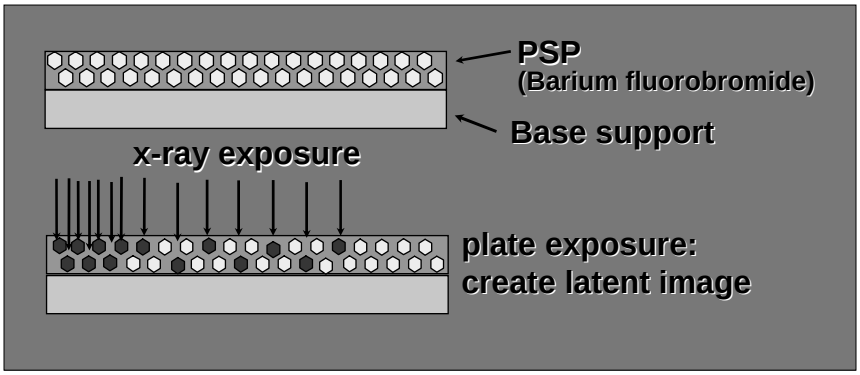
- Close bonding between CsI and a-Si ensures minimal light loss
- Strong signal from the Si diode array yields higher detective quantum efficiency
- Detector is linear over a wide range (10^5) of exposures

- Limiting factor is the large pixel size (100 μm)
- Smaller pixel sizes improve spatial resolution but at the cost of increased image noise and decreased SNR for the same breast dose
- Possibility of ghosting in images

Kanal Radiographics 2004:24,1753 19

Technologies for FFDM – Indirect Capture
Computed Radiography – Fuji (7/10/2006)

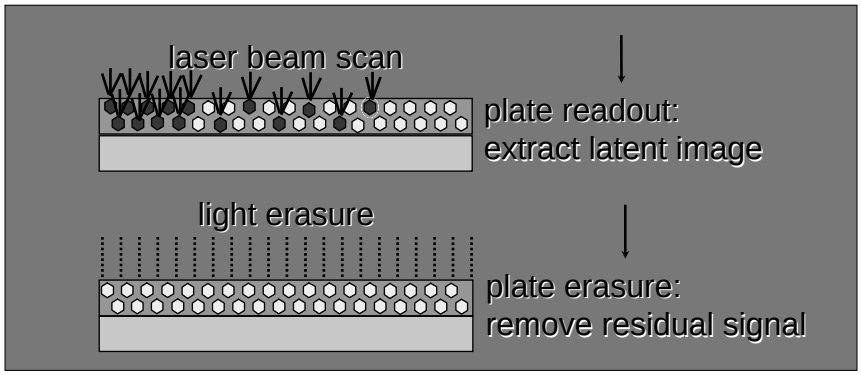
Technology introduced in 1981



Kanal Pfeiffer 20

Technologies for FFDM – Indirect Capture
Computed Radiography – Fuji

Technology introduced in 1981



Kanal Pfeiffer 21

Technologies for FFDM – Indirect Capture
Computed Radiography – Fuji

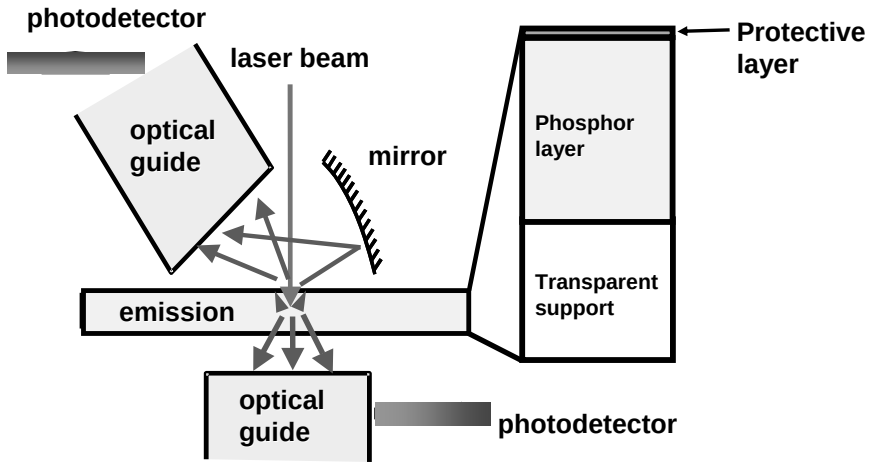
- Fuji FCR*m*, Dual-side reader

Detector size	18 x 24 24 x 30
Pixel size	50 µm
Image size	3328 x 4096 pixels (24 MB)
Spatial Resolution	10 lp/mm
Dynamic Range	14 bits

http://www.fujimed.com/

Kanal 22

Fuji - Dual Side Readout



Kanal

Image courtesy: Doug Pfeiffer

23

Technologies for FFDM – Indirect Capture
Fuji – Advantages and Disadvantages

- Advantage of the CR mammo system is that film-screen cassettes can be replaced by CR cassettes without replacing the entire system
- Both small and large cassettes can be accommodated by the reader
- Dual side reader, 50 μm pixel size

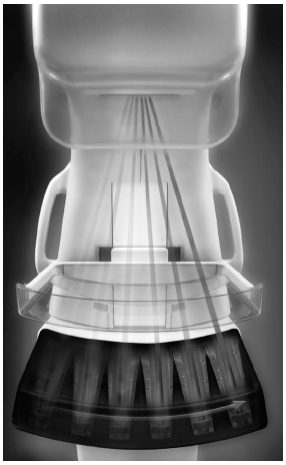
- Disadvantage - Effective pixel size influenced by phosphor thickness, light diffusion within phosphor, laser light scatter & diameter of laser beam
- Technologist time on processing of images
- Noise associated with the low collection efficiency of emitted light

Kanal

24

Technologies for FFDM – Indirect Capture
SenoScan; Fischer Imaging – 9/25/01

- A narrow slot-detector and a narrow fan beam of x-rays are scanned synchronously across the full field of view to cover the entire breast
- System consists of phosphor (thallium-activated CsI) with a fiberoptic coupling to a CCD



Kanal

Radiographics 2004:24,1752

25

Technologies for FFDM – Indirect Capture
SenoScan; Fischer Imaging (now Hologic)

	Fischer SenoScan
Detector material and design	Caesium iodide with 4 CCDs
Detector area (cm)	21 x 1 *
Maximum field size (cm)	21 x 29
Image acquisition time (time to display image on workstation) (s)	12 to 15
Image matrix (pixels)	4096 x 5625
Pixel pitch (μm)	25 or 50
High contrast limiting resolution (lp mm^{-1})	13 (at 25 μm) 10 (at 50 μm)

Seibert, AAPM Meeting Handout

Kanal

26

Technologies for FFDM – Indirect Capture

(SenoScan; Fischer Imaging (now Hologic)) Advantages and Disadvantages

- Compact detector that is less expensive compared to others
- Excellent scatter rejection due to small volume of breast exposed at any time
- No grid needed therefore less dose
- Longer compression since scan times are longer (approx. 6 sec)
- Powerful tubes, elaborate signal readout and image reconstruction required

Kanal 27

Comparison – Indirect Capture

	Fischer SenoScan	GE Senographe DS	Fuji FCR*m*
Detector material and design	Caesium iodide with 4 CCDs	Caesium iodide / TFT array	PSP plate
Detector area (cm)	21 x 1 *	19 x 23	18 x 24
Maximum field size (cm)	21 x 29	19 x 23	24 x 30
Image acquisition time (time to display image on workstation) (s)	12 to 15	< 15	
Image matrix (pixels)	4096 x 5625	1914 x 2294	3328 x 4096 pixels (24 MB)
Pixel pitch (µm)	25 or 50	100	50 µm
High contrast limiting resolution (lp mm^{-1})	13 (at 25 µm) 10 (at 50 µm)	5	10 lp/mm

Kanal 28

Technologies for FFDM – Direct Capture

a-Se Array (Selenia, Hologic) – 10/2/01

- a-Se, a good photoconductor is deposited directly onto the a-Si TFT substrate enabling direct capture
- The a-Se detector directly converts x-rays to electron-hole pairs
- The a-Si TFT converts the electron-hole pairs to electronic signal

Kanal http://www.hologic.com/wh/digisel.htm 29

Technologies for FFDM – Direct Capture

Flat-Panel a-Se Array (Selenia, Hologic)

Detector size	**24.0 x 29.0**
Pixel size	**70 µm**
Image size	**3328 x 4096 pixels (24 MB)**
Spatial Resolution	**> 7 lp/cm**
Dynamic Range	**14 bits**

Kanal http://www.hologic.com/wh/digisel.htm 30

Technologies for FFDM – Direct Capture

Flat-Panel a-Se Array (Selenia, Hologic) Advantages and Disadvantages

- Advantage is that the detector response function maintains its sharpness even with increasing thickness
- High MTF and DQE can be achieved

- Potential weaknesses are the need for high biasing voltage, drifting of the dark signal and cost of detector
- Inherent sharpness of detector may also increase the severity of aliasing artifacts associated with undersampling on any digital detector

Kanal 31

Technologies for FFDM – Direct Capture

a-Se Array (Mammomat Novation, Siemens – 8/20/04)

Detector size	**24.0 x 29.0**
Pixel size	**70 µm**
Image size	**3328 x 4096 pixels (24 MB)**
Spatial Resolution	**> 7 lp/mm**
Dynamic Range	**14 bits**

http://www.medical.siemens.com

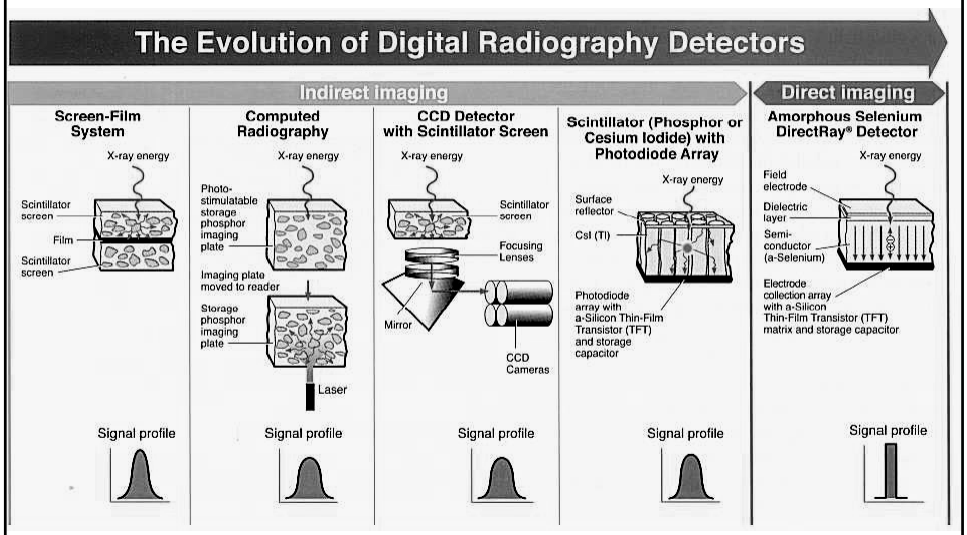
Kanal 32

Comparison – Direct Capture

	Selenia	Siemens Mammomat NovationDR
Detector material and design	Amorphous selenium / TFT array	Amorphous selenium / TFT array
Detector area (cm)	24 x 29	24 x 29 †
Maximum field size (cm)	24 x 29	18 x 23 (small format), 23 x 29 (large format)
Image acquisition time (time to display image on workstation) (s)	10 to 15	40 to 50
Image matrix (pixels)	3328 x 4096 (24x30) 2560 x 3328 (18x24)	3328 x 4096
Pixel pitch (μm)	70	70
High contrast limiting resolution (lp mm^{-1})	> 7	> 7

Kanal 33

Technologies for FFDM



Fuji/Kodak/ Agfa/Philips | **Fischer (Hologic)** | **GE** | **Hologic Siemens**

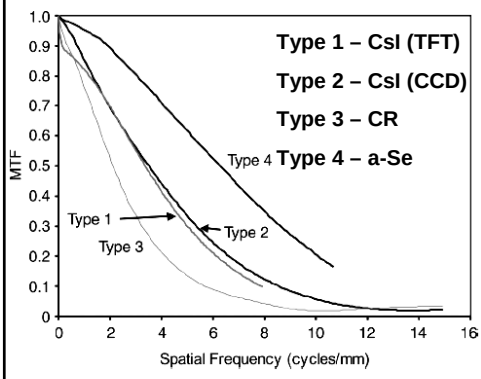
Kanal http://www.hologic.com/oem/pdf/DROverviewR-007_Nov2000.pdf 34

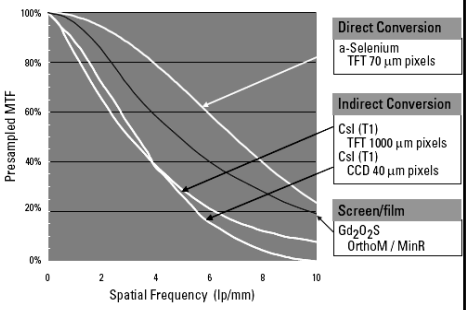
MTF, DQE, DOSE

Kanal 35

MTF

- MTF is a measure of signal transfer over a range of frequencies and quantifies spatial resolution





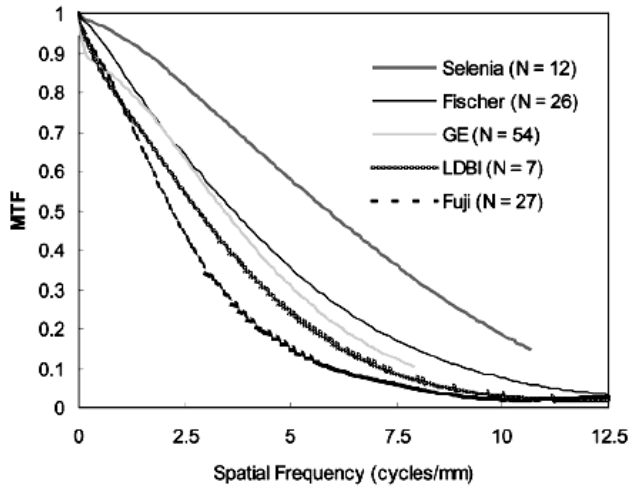
Yaffe - Radiology 2005:234,353

http://www.hologic.com/wh/pdf/R-LM-016_Radiology_Management.pdf

Kanal 36

MTF

- Bloomquist et al - DMIST trial



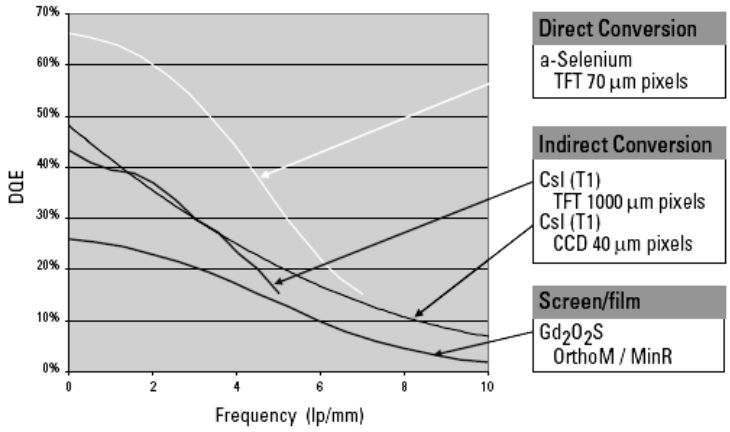
Kanal

Bloomquist – Medical Physics 2006:33 (3), 719

37

DQE

- Detective Quantum Efficiency (DQE) measures SNR transfer through the system as a function of spatial frequency and is a good measure of dose efficiency



Kanal

http://www.hologic.com/wh/pdf/R-LM-016_Radiology_Management.pdf

38

FFDM – Radiation Dose

- Bloomquist et al - DMIST trial

TABLE XIV. Mean glandular dose for the standard breast (N is measurements from separate inspections).

System	N	Entrance exposure μC/kg	Entrance exposure mR	Range mR	MGD mGy	Range mGy
Fischer	26	144	560	400–750	1.31	0.81–1.79
Fuji	25	278	1080	270–1660	1.87	0.79–2.69
GE	46	196	760	410–1410	1.49	0.84–2.53
Lorad DBI	11	294	1140	540–1610	1.98	1.10–2.70
Lorad Selenia	13	273	1060	620–1830	1.85	1.09–2.98
All	121	219	850	270–1830	1.62	0.79–2.98
Screen-film	149	304	1178	708–1810	1.90	1.24–2.72

Kanal Bloomquist – Medical Physics 2006:33 (3), 719 39

Storage and Economics

Kanal 40

Storage of Digital Images

Table 2
Typical Image Sizes and Storage Requirements for FFDM Systems

Manufacturer and Model	Image Matrix (pixels)	Image Size (megapixels)	Storage Requirement (MB)	
			Per Image	Per Examination*
GE Senographe 2000D	1,920 × 2,304	4.4	8.8	35.2
Fischer SenoScan	4,096 × 5,625	23.0	46.1	184.3
Hologic Selenia	3,328 × 4,096	13.6	27.2	110.0
Fuji CR†	1,770 × 2,370	4.2	8.4	33.6
	2,364 × 2,964	7.0	14.0	56.0
Hologic CCD array‡	4,500 × 6,000	27.0	54.0	216.0

*For a typical four-image screening examination.

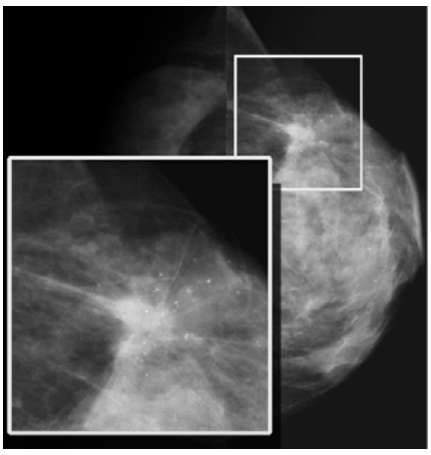
‡No longer commercially available.

Kanal

Radiographics 2004:24,1755

41

Display of Digital Images



Kanal

Radiographics 2004:24,1757

42

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, 5-13 lp/mm vs. 20 lp/mm

Kanal 43

Economics of FFDM

- SFM systems cost well under $100,000
- FFDM systems cost in the range of $300,000 - $450,000
- Reimbursement rates approved by Medicare are decreasing every year

Plain Film	Screening	2008 - $83.03, 2009 - $81.51
Digital	Screening	2008 - $133.69, 2009 - $129.84
	Diagnostic	2008 - $151.21, 2009 - $152.56
CAD		2008 - $14.86, 2009 - $12.26

Kanal 44

Benefits

Kanal 45

Expected Benefits of FFDM

- The costs of FFDM systems should be compared along with the inherent benefits of the digital technology prior to the purchase:
  - Reduced recall rates
  - Increased patient throughput
  - Increased early detection of breast cancer
  - Decreased false-negative biopsy results
  - Decreasing film and processing costs
  - Increasing the caseload of each mammography room

Kanal 46

Clinical Trials and Phantom Studies

- Large screening study screened 49,500 women
- *Digital Mammographic Imaging Screening Trial* (DMIST), funded by NCI and conducted by ACRIN (http://www.acrin.org/6652_protocol.html)

The NEW ENGLAND JOURNAL of MEDICINE

ESTABLISHED IN 1812 OCTOBER 27, 2005 VOL. 353 NO. 17

Diagnostic Performance of Digital versus Film Mammography for Breast-Cancer Screening

CONCLUSIONS

The overall diagnostic accuracy of digital and film mammography as a means of screening for breast cancer is similar, but digital mammography is more accurate in women under the age of 50 years, women with radiographically dense breasts, and premenopausal or perimenopausal women. (ClinicalTrials.gov number, NCT00008346.)

Kanal 47

Future Developments

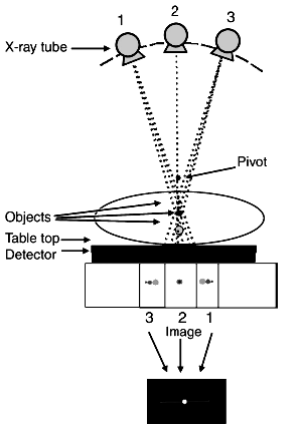
Kanal 48

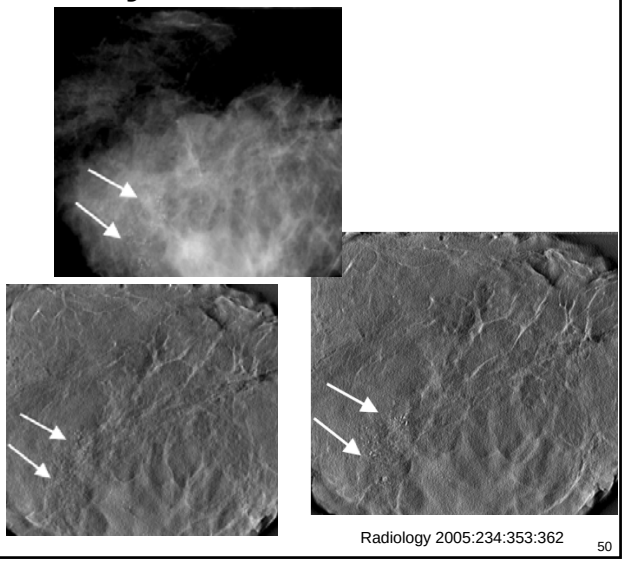
Future Developments

- Dual energy
- CAD integration
- Telemammography
- Tomosynthesis
- Contrast enhanced digital mammography

Kanal 49

Future Developments
Tomosynthesis

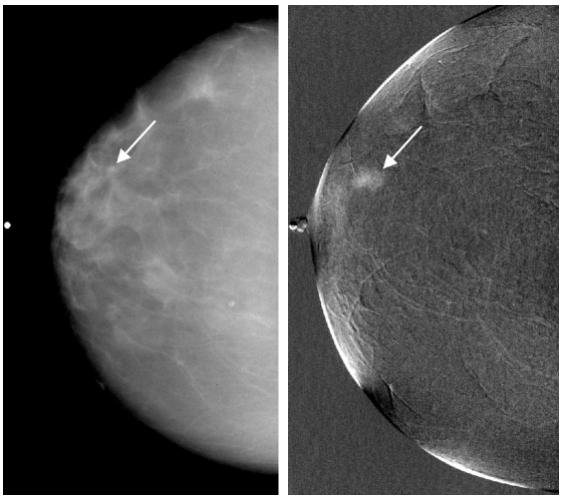




Radiology 2005:234:353:362

Kanal 50

Future Developments
Contrast Enhanced Digital Mammography



Radiology 2005:234:353:362

Kanal 51

TAKE HOME POINTS

- Different technologies exist for digital systems – indirect and direct
- Commercially available FFDM systems vary in technology
- Many advantages exist for FFDM in comparison to FSM
- MTF and DQE are typically used to characterize FFDM systems
- Dose is lower with FFDM compared to FSM
- Advanced applications of FFDM include tomosynthesis, contrast enhanced mammography etc

Kanal 52

THANK YOU

Kanal 53