History, Theory and Operation of Digital Breast Tomosynthesis Systems

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Disclosure

Research Collaboration with GE Global Research

Tomosynthesis

- 3-D method of imaging that reduces or eliminates tissue overlap problem of conventional x-ray imaging.
- Involves acquisition of multiple projections over a limited angle.
- Reconstruction produces many image slices.
- Reference:

Digital x-ray tomosynthesis:
Current state of the art and clinical potential

James T. Dobbins III & Devon J. Godfrey

Phys Med Biol 48 (2003) R65-R106

Tomosynthesis

- Is a refinement of conventional tomography.
- Generates an arbitrary number of in-focus planes from a series of projection radiographs taken during a single motion (sweep) of the x-ray tube.
- Unlike conventional tomography, the various in-focus planes are produced without additional exposure.
- Can be considered “limited angle” CT.

Shift & Add Tomosynthesis Reconstruction

Dobbins & Godfrey - Phys Med Biol 2003; 48: R65-R106

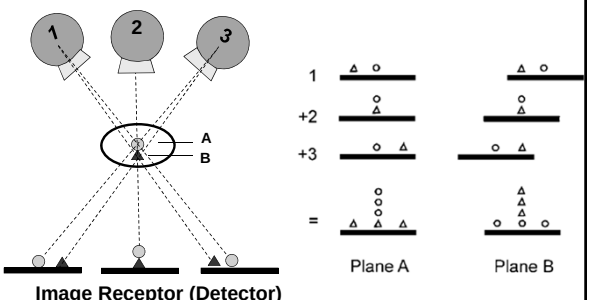
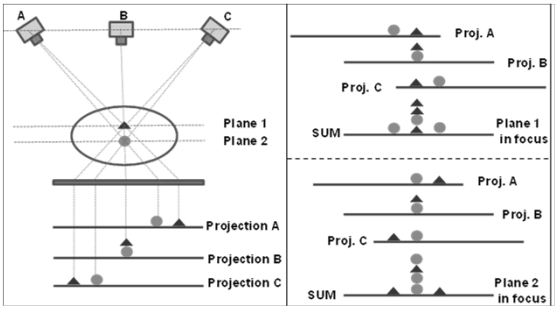


Image Receptor (Detector)

Acquisition **Reconstruction**

Shift and Add Tomosynthesis Stationary Detector



Acquisition **Reconstruction**

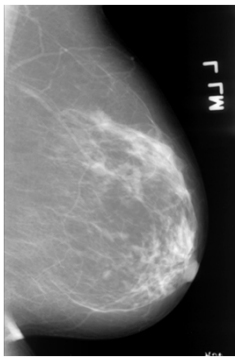
Inventor of Tomosynthesis

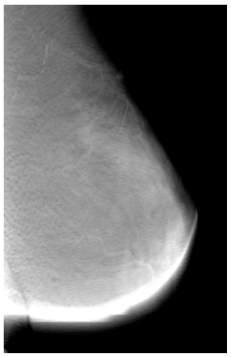
George Ziedses des Plantes (1902-1993)

- Dutch neuroradiologist & electrical engineer
- 1932: developed 1st prototype planigraphy (tomography) system
- 1936: developed photographic subtraction angio – precursor to DSA
- 1935 paper [Ned. Tijdschr. Geneesk 51 5852-6]: "Seriescopy, a Roentgenographic method which allows an infinite number of successive parallel planes of the test object to be considered separately " (translated) = TOMOSYNTHESIS

Other Inventor: Julius Kaufman, MD Brooklyn, NY

- Published 4 papers on "planeography" (1st in 1936)
- Stated with this method, "it is possible to demonstrate any plane in space, parallel to the plane of the plate from two (or more) roentgenograms (films) properly taken."
- Stressed localization and depth measurement capabilities of method.

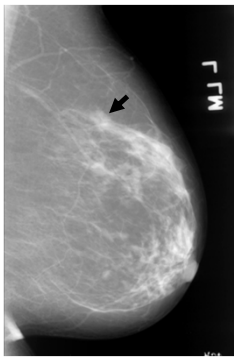




Tomo: GE research system at Univ of Michigan

Invasive ductal carcinoma

Mammogram **Tomosynthesis**



Mammogram **Tomosynthesis**

Digital Breast Tomosynthesis late 1990's

1) LT Niklason, BT Christian, LE Niklason, DB Kopans, et al, Radiology 1997; 205: 399-406

GE Gen I Tomo Unit

Flat panel digital detector

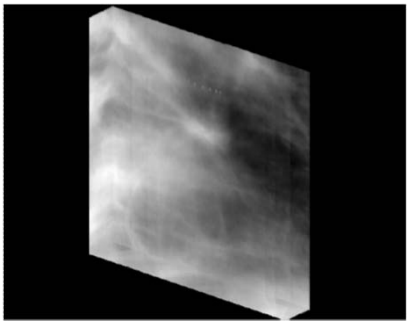
40° angle, 9 views

2) Instrumentarium TACT (Tuned Aperture CT)*

- Introduced at 1997 RSNA
- 5 cm x 5 cm CCD for 3D digital spot imaging (Gd_2O_2S phosphor)
- TACT recon uses reference point on compression paddle
- Images acquired at 7 angles
- 50 micron pixel pitch
- FDA 510 K approved for digital 3D spot imaging - 2000

*** Richard L Webber, US Patents 1994, 1997**

Instrumentarium 3D volume Display



Mari Lehtimaki et al White Paper, Instrumentarium, Finland

Reconstruction Methods

- Shift and Add = unfiltered backprojection. Brings in-plane objects in focus while blurring out-of-plane features.
- Tuned Aperture CT (Webber et al) = shift & add with fiducial markers. Allows images to be acquired at random angles & orientations & reconstructed in arbitrary planes.
- Matrix Inversion (MITS) (Dobbins et al) Uses linear algebra to solve/correct for out-of-plane blur using known blurring functions of all other planes when a given plane is reconstructed.

Reconstruction Methods Cont'd

- Filtered Back Projection Low-pass filters used in spatial frequency domain to compensate for incomplete &/or nonuniform sampling of tomo acquisition in spatial domain & suppress high freq's.
- Algebraic Reconstruction Techniques (ART)
  Iterative solution to set of linear equations ray by ray.
  Variants: SART, SIRT, and ILST
- Statistical Reconstruction
  Maximum Likelihood (ML) – maximize probability of generating projections given a 3-D model of attenuation coefficients.
  Variants: ML-EM, ML-convex

Today's DBT Units

- **Flat Panel Detector, Cone Beam:**
  GE
  Hologic
  IMS Giotto
  Planmed
  Siemens
- **Photon Counting Strip Detectors, Multiple Slot Beam:**
  Philips/Sectra
  XCounter

FDA Approval

Full Field Digital Breast Tomosynthesis

2011 - Hologic Selenia Dimensions (February 11, 2011)

First published paper on the Hologic System: BR Ren, J Stein, A Smith et al, Design and performance of the prototype full field breast tomosynthesis system with selenium based flat panel detector, Medical Imaging 2005: Physics of Medical Imaging, Pts 1 and 2 SPIE, Volume: 5745 Pages: 550-561 (2005)

Hologic Selenia Dimensions
15° angle, 15 views, 24x29 cm, CC & MLO, Continuous tube motion, FBP

Hologic showing motion of x-ray tube

"Combo view" : 2D & Tomo under same compression total dose < MQSA limit (3 mGy)

Selenia Dimensions: Specifications

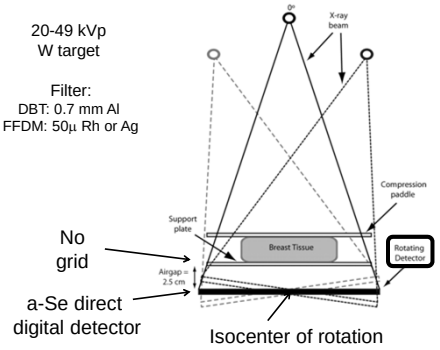
Conventional 2D Imaging	Tomosynthesis 3D Imaging
• a-Se detector, 24×29 cm area	• a-Se detector, 24×29 cm area
• 70 μm pixel size	• 140 μm pixel size (binned 70 μm)
• W anode, Rh and Ag filters	• W anode, Al filter
• HTC grid in contact mode; No grid in magnification mode	• No anti-scatter grid
	• Moving tube, 15° sweep
	• Moving detector
	• 15 projections
	• 3-4 seconds acquisition
	• FBP Reconstruction
	- ~100 μm pixel size
	- 1 mm slice spacing

Specs from Bob Liu, PhD of MGH

Hologic Selenia Dimensions Tomo unit

20-49 kVp
W target

Filter:
DBT: 0.7 mm Al
FFDM: 50μ Rh or Ag



SID=70 cm

AEC:
kVp (DBT&FFDM) & filter (FFDM) determined from thickness.

Test shot at 0° for FFDM, -7.5° for DBT determines mAs

No grid

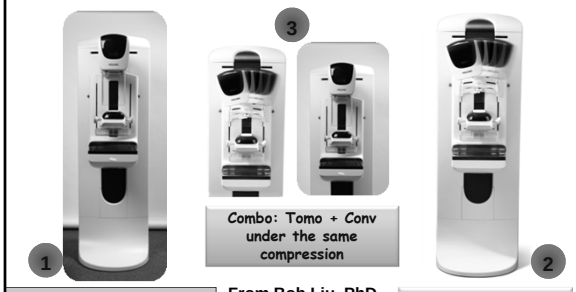
a-Se direct digital detector

Isocenter of rotation

Feng S S J , Sechopoulos I Radiology 2012;263:35-42

Radiology

Selenia Dimensions: Image Acquisition Modes



Conventional FFDM Only

From Bob Liu, PhD of MGH

Tomosynthesis Only

GE Senographe DS DBT – Clinical Trial configuration

DS Gantry

19.2 x 23.4 cm detector (100 μm); Indirect

Stationary indirect detector (CsI a-Si)

Manual Compression

15 Step/Shoot exposures

± 20° Tomo angle

15 s Exam Time

SART reconstruction

GE Review Workstation

With DBT application

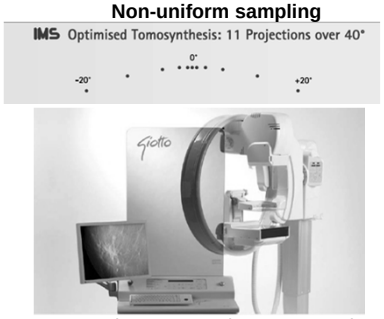
2048 x 2560 pixel display

GE Essential Tomo Unit

25° angle, 9 views, 24 x 30.7 cm
Stationary CsI a-Si Indirect Detector,
Target/filter: Mo/Mo, Mo/Rh, Rh/Rh
Step & Shoot, Iterative Recon

IMS Giotto - Dexela

Non-uniform sampling



Variable angle increment & dose @each angle,

Circular gantry

40° angle, 11 or 13 views, step & shoot,
Stationary 24 x 30 cm Direct a-Se Detector,
Target/filter: W/Rh/Ag, Reconstruction: iterative

Planmed Nuance Excel


30º angle, 15 views, continuous motion,
24 x 30 cm Direct a-Se Detector rotates during exposure,
Target/filter: W/Rh/Ag, Reconstruction: SART

Siemens Mammomat Inspiration

50º angle, 11 to 49 views, continuous motion,
Stationary 24 x 30 cm Direct a-Se Detector,
Target/filter: W/Rh, Reconstruction: FBP

Photon Counting Systems

Multiple scanning slots, each at a different angle, which corresponds with projection (view) angle.

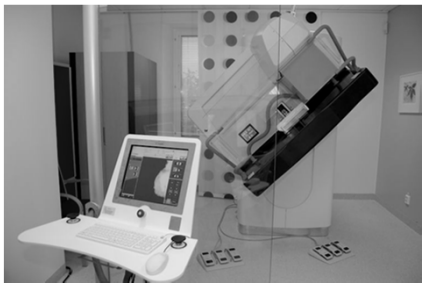
XCounter XCT-3T

Gas detector

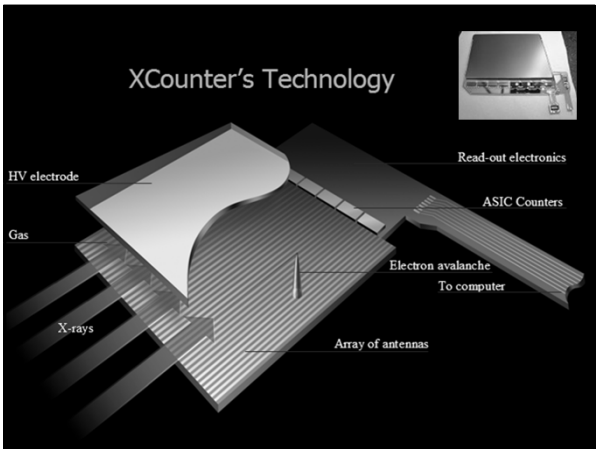
Philips / Sectra

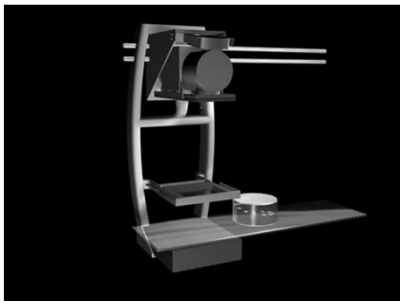
Silicon detector

XCounter XCT-3T



24º angle, 48 views, FBP plus iterative
Tube, pre-patient collimator and detector mounted on E-arm.
Scanning E-arm across breast allows simultaneous acquisition of multiple (48) projection images

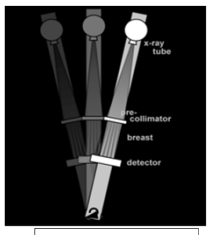




2010: Xcounter decided to focus on photon counting detectors & will not produce this system commercially.

There is still a prototype at Karolinska hospital in Stockholm.

Philips / Sectra Tomo unit



- Photon counting detector with 2 energy bins.
- # projections = # detector lines = 21
- Total tomosynthesis angle = 11°
- continuous motion
- Target/filter: W/Al, Reconstruction: Iterative

Used in EU's HighReX project: tomo alone & combined with spectral imaging w/ &w/o contrast agent. See: www.highrex.eu

Characteristics of Current Breast Tomo Units

Unit	Tomo angle	# views	pixel pitch	2x2 binning	detector	scan time
GE Gen2	60º	21	100 micron	no	CsI-a-Si	7.5 sec
GE DS	40º	15	100 micron	no	CsI-a-Si	11-20 sec
GE Essential	25º	9	100 micron	no	CsI-a-Si	7 sec
IMS Giotto (Dexela)	40º	11-13	85 micron	yes & no	a-Se	12 sec
Hologic	15º	15	70 micron	yes	a-Se	3.7 sec
Planmed	30º	15	85 micron	no	a-Se	20 sec
Sectra (Philips)	11º	21	50 micron	no	silicon	3-10 sec
Siemens	50º	11-49	85 micron	yes &no	a-Se	12-40 sec
XCounter	24º	48	60 micron	no	gas	12-18 sec

***All current DBT systems do not use anti-scatter grid**

DBT image quality depends on:

1) Imaging geometry & accuracy of that geometry
   Tomo angle (range from ~11º to 60º)
   Angular increment (~ 1º to 3º or variable)
2) X-ray tube & detector motion during exposure
   Continuous Motion vs. Step and Shoot
3) Total sweep time (breast motion)
4) X-ray spectrum (anode, filter, kVp) (subject contrast)
5) mAs (quantum noise)
6) Detector DQE (contrast, resolution & noise)
7) Detector lag (artifacts, blur)
8) Detector pixel size, interspace, binning of pixels
9) Reconstruction algorithm (FBP vs. iterative vs. matrix inv.)
10) Image processing (e.g. edge & contrast enhancement)
11) Image display (slice "thickness", slab vs. slice)
12) Artifact & scatter corrections

Examples of some factors that affect DBT image quality

A) Effect of Imaging Geometry

University of Michigan Studies:

The effects of total acquisition angle and angular increment on the detection of :

1) masses and perception of contrast-detail test objects

2) microcalcification clusters

in digital breast tomosynthesis

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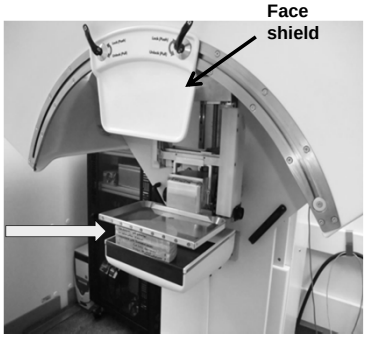
Advanced Mode – DBT System

- GE prototype
- Step and shoot design
- X-ray source and detector stationary during exposure
- Variable tomographic angle
- Variable increments
- Variable # of projections

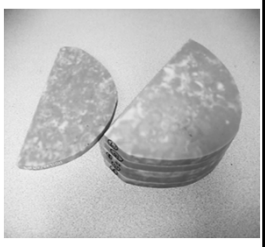
Advanced Mode – DBT System

- a:Si/CsI flat panel detector
- 0.1 mm x 0.1 mm pixel pitch



Modular Breast Phantom

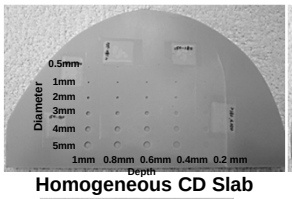
- Six 1-cm-thick slabs of breast-tissue-equivalent material (~ 50% fibroglandular/50% adipose) (CIRS, Inc.)
- Heterogeneous structured background
- Heterogeneous & homogeneous CD slabs
- Slabs arranged in different orders to form 5-cm-thick phantoms
- 4 different phantoms for current study



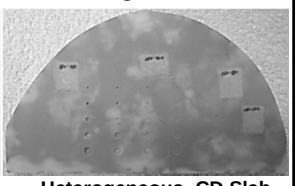
Simulated Microcalcification Clusters

- Calcium carbonate specks
- 3 size ranges:
  - Subtle: 0.15 – 0.18 mm 28 clusters
  - Average: 0.18 – 0.25 mm 29 clusters
  - Obvious: 0.25 – 0.30 mm 24 clusters
- Simulated clusters sandwiched between slabs in random positions at different depths

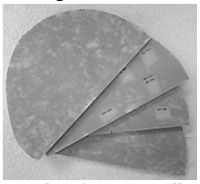
Contrast-Detail and Surrounding Test Slabs



Homogeneous CD Slab



Heterogeneous CD Slab

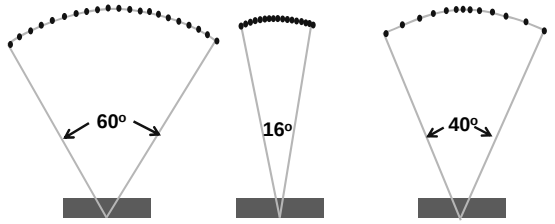


Example of surrounding slabs

Heterogeneous CD phantom imaged in 4 arrangements surrounded by heterogeneous slabs

Homogeneous CD phantom imaged in 1 arrangement surrounded by heterogeneous slabs

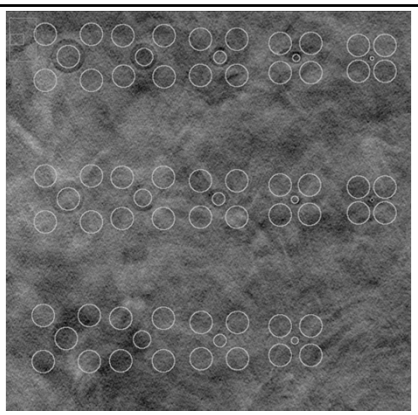
Examples of Acquisition Geometries



60 degrees
21 projection views
60d 21p

16 degrees
17 projection views
16d 17p

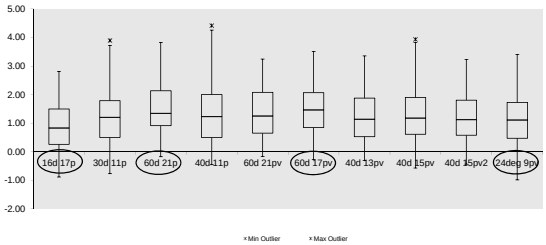
40 degrees
13 projection views
variable increment
40d 13pv



Target and background ROIs (16d 17p)

RESULTS
CNR vs. Acquisition Geometry

All disks
All 4 heterogeneous CD phantom arrangements



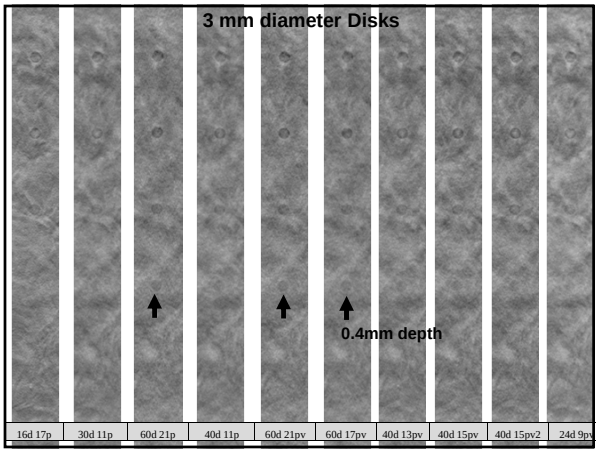
Summary CNRs for all disks heterogeneous CD phantom, all arrangements

Labels	16d 17p	30d 11p	60d 21p	40d 11p	60d 21pv	60d 17pv	40d 13pv	40d 15pv	40d 15pv2	24d 9pv
Median	0.83	1.21	1.35	1.23	1.25	1.46	1.14	1.18	1.12	1.11
mean	0.87	1.17	1.48	1.30	1.40	1.51	1.20	1.25	1.18	1.07
Stdev	0.85	0.94	0.87	0.97	0.91	0.86	0.87	0.89	0.86	0.91

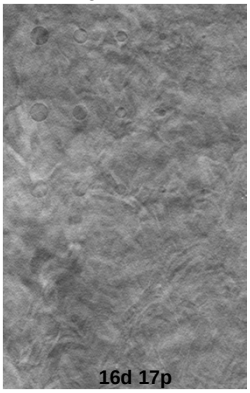
Statistically significant differences (paired t-test) for multiple comparisons ($p<0.05/45 = 0.0011$ Bonferroni correction)
45 = combination of 10 categories taken 2 at a time

16d 17p vs. 60d 21p ($p<10^{-5}$)
16d 17p vs. 60d 21pv ($p<10^{-4}$)
16d 17p vs. 60d 17pv ($p<10^{-6}$)
60d 17pv vs. 24d 9p ($p<10^{-3}$)

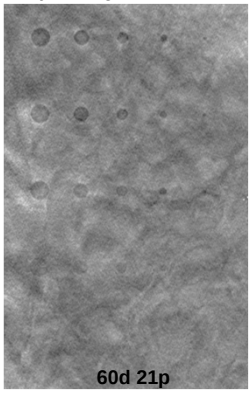
CD: 16d 17p < (60d 21p, 60d 21pv & 60d 17pv)
24d 9p < 60d 17pv



Heterogeneous CD slab surrounded by heterogeneous slabs

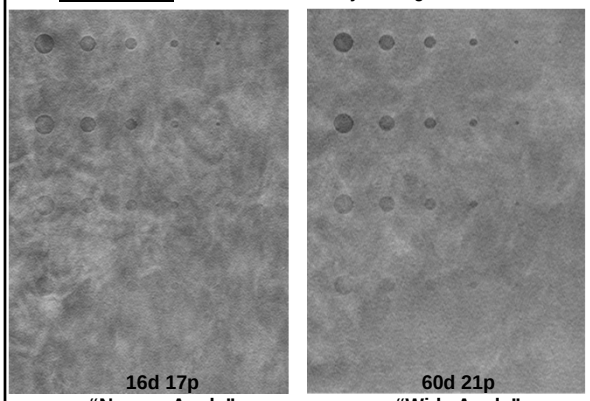


"Narrow Angle"



"Wide Angle"

Homogeneous CD slab surrounded by heterogeneous slabs

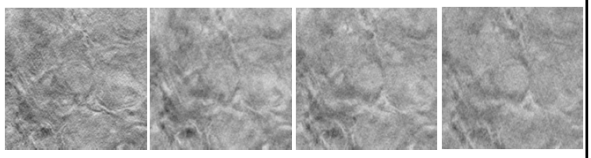


16d 17p
"Narrow Angle"

60d 21p
"Wide Angle"

Visibility of Small Mass

16°-Δ1°-17 **24°-Δ3°-9** **40°-var-13** **60°-Δ3°-21**

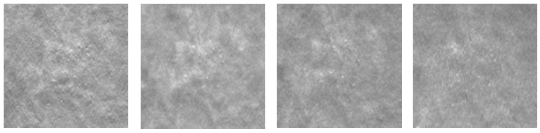


Narrow Angle

Wide Angle (SUPERIOR)

Examples – Subtle Cluster

16°-Δ1°-17 **24°-Δ3°-9** **40°-var-13** **60°-Δ3°-21**

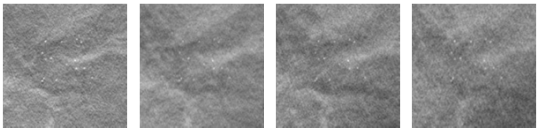


Narrow Angle (SUPERIOR)

Wide Angle

Examples – Average Cluster

16°-Δ1°-17 **24°-Δ3°-9** **40°-var-13** **60°-Δ3°-21**

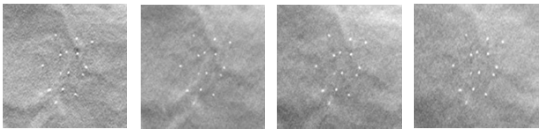


Narrow Angle (SUPERIOR)

Wide Angle

Examples – Obvious Cluster

16°-Δ1°-17 **24°-Δ3°-9** **40°-var-13** **60°-Δ3°-21**



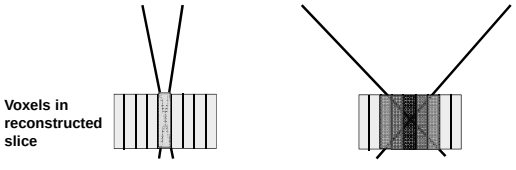
Narrow Angle

Wide Angle

Advantage of Narrow Tomo Angle for Microcalcification Detection - Sharper point spread function (PSF)

Narrow Angle

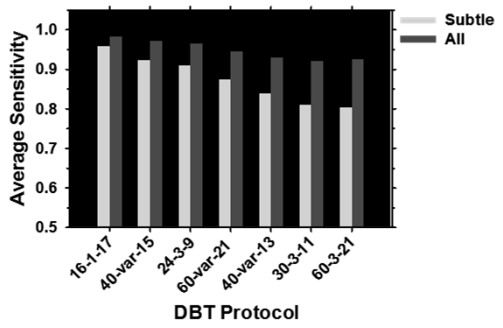
Wide Angle



Narrower PSF

Backprojected rays from wide angles cross more voxels => wider PSF

Comparison of Sensitivity for calcification detection
7 Protocols



P-Values from Paired t-test Microcalcification Detection

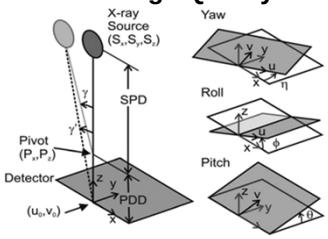
DBT Protocol	16°-Δ1°-17	40°-var-15	24°-Δ3°-9	60°-var-21	40°-var-13	30°-Δ3°-11	60°-Δ3°-21
16°-Δ1°-17	–	0.012*	0.121	0.158	0.061	0.011*	0.000*

*** P < 0.05**

Conclusions

- Wide angle DBT (e.g., 60°-Δ3°-21) is superior to narrow angle DBT (e.g., 16°-Δ1°-17) for visualization of small masses and CD objects.
- Narrow angle scan can provide higher detection sensitivity and conspicuity of subtle MCs than wide-angle scan.
- The optimal acquisition should account for mass as well as calcification perception, DBT artifacts, and scan time.

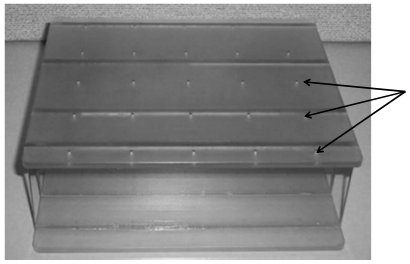
B) Effect of Geometric Accuracy on Image Quality



"Projection mismatches of gantry angle (γ) of 0.14° (standard deviation) can reduce reconstructed lesion intensity by 20%. Also, small offset errors (0.31°) in yaw angle can reduce lesion intensity by 20%."

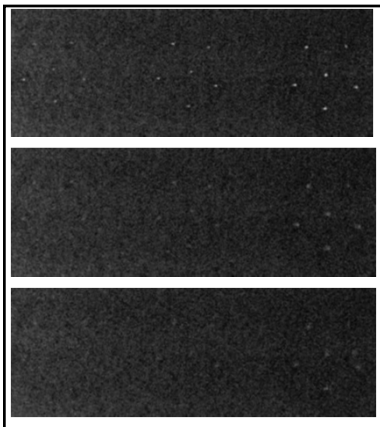
Mainprize J, et al Med. Phys.2011; 38 (6): 3090

Hologic Geometric Calibration Phantom



Note: Technologists perform geometric calibration every 6 months

Phantom used in:
X Li, D Zhang, & B Liu, Medical Physics 2011; 38 (1): 202-9
A generic geometric calibration method for tomo imaging systems with flat panel detectors.



Geometric offset errors: Effect on image quality

No offset

Random central ray offset of projections of 0 mean and std dev of 1 pixel (0.1 mm)

Random central ray offset of projections of 0 mean and std dev of 2 pixels (0.2 mm)

X Li, D Zhang, & B Liu, Medical Physics 2011; 38 **(1): 202-9**

C) Effect of reconstruction algorithms

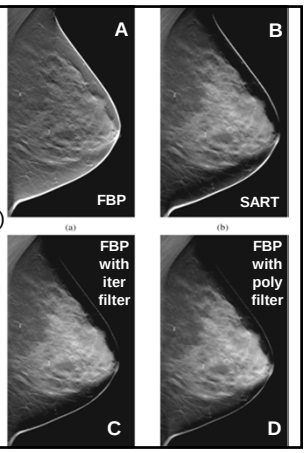
Ludwig & Mertelmeier et al
IWDM 2008, LNCS 5116,
pp. 612–620, 2008

A) Filtered Backprojection (FBP)

B) SART

C) FBP using kernel determined with iterative reconstruction

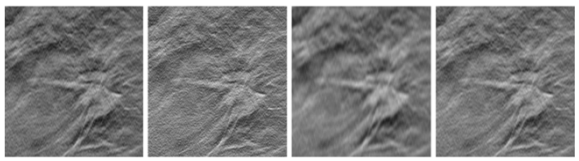
D) FBP using polynomial fit to kernel determined with iterative reconstruction.



Effect of Filter & Pixel Binning on Filtered Back Projection Reconstruction

Mertelmeier et al SPIE Vol. 6142, 61420F, (2006)

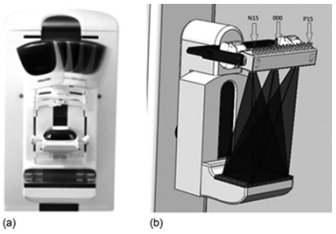
Spiculated Mass



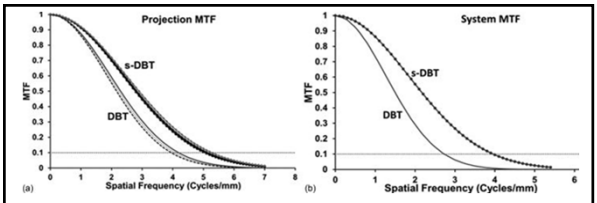
A) FBP | **B) FBP with filter that emphasizes higher freqs.** | **C) (A) with binning** | **D) (B) with binning**

D) Effect of tube motion during exposures.

High resolution stationary digital breast tomosynthesis using distributed carbon nanotube x-ray source array
Qian, Xin; Tucker, Andrew; Gidcumb, Emily; et al.
MEDICAL PHYSICS 2012; 39: 2090-2099



a) Hologic Selenia Dimensions rotating gantry system with the mammo tube in several positions – tube moves continuously.
b) Stationary DBT system with 31 carbon nanotube x-ray source array mounted on the Selenia Dimensions gantry.



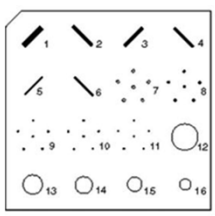
a) "Projection MTFs of stationary (s-DBT) & rotating gantry DBT systems along the scanning direction."
10% MTF:

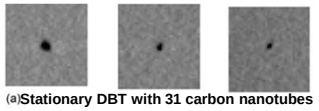
s-DBT 5.1 cycles/mm along scanning direction, 5.2 cycles/mm perpendicular
DBT 4 cycles/mm along scanning direction, 5.4 cycles/mm perpendicular

b) "System MTF obtained using reconstructed in-focus slice."
10% MTF:

s-DBT 4 cycles/mm
DBT 2.7 cycles/mm

Note degradation in MTF of both projections & reconstructed images with tube motion.





(a) Stationary DBT with 31 carbon nanotubes

(b) Conventional Hologic Selenia Dimensions

Tomosynthesis focus plane images of specks in the ACR mammography accreditation phantom.
Zoomed views of central specks in clusters 7, 8, & 9.
Speck diameters left to right: 0.54, 0.40 and 0.32 mm

Spatial Resolution in DBT

Planar (x,y) & Depth (z) Resolution in DBT

A) Planar (x,y) resolution is comparable to FFDM
(e.g. ~ 150-280 microns)

B) Depth (z) resolution is much worse than planar
Due to limited angle acquisition.
Note: Smaller angle yields poorer z-resolution,
e.g., 28-deg angle ~600 microns z-resolution

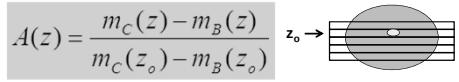
References:
Ren BR, Stein J, Smith A et al, Design and performance of the prototype full field breast tomosynthesis system with selenium based flat panel detector, Medical Imaging 2005; SPIE vol 5745: 550-561

Observation of super-resolution in digital breast tomosynthesis. Acciavatti R J, Maidment ADA, Med Phys 2012;39(12):7518-39

Measurement of depth (z) resolution

Artifact spread function ASF(z)*

$$A(z) = \frac{m_C(z) - m_B(z)}{m_C(z_o) - m_B(z_o)}$$

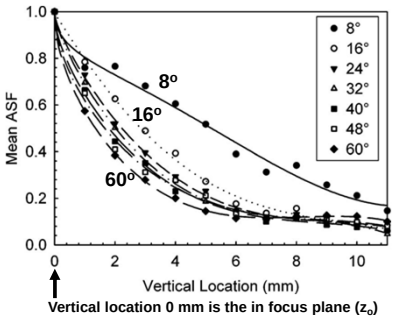


where $m_C(z)$ = mean pixel values of a calcification & $m_B(z)$ = mean pixel value of background in an off-focal plane image at depth z

and $m_C(z_o)$ and $m_B(z_o)$ = corresponding values in focal plane image at depth z_o

*T. Wu, et al, Med. Phys. 2004; **31**: 2636–2647

ASF for Different Tomo Angles using 13 Projection Views in Each Case

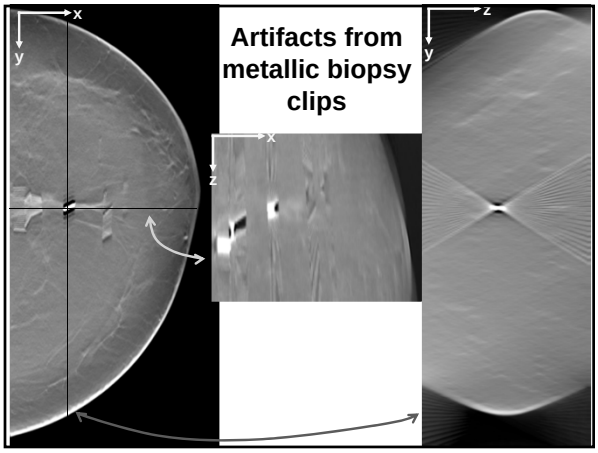


Vertical location 0 mm is the in focus plane (z_o)

Note: Better resolution (narrower ASF) for larger tomo angle.

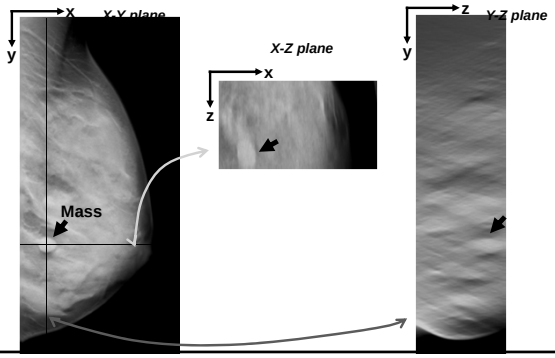
I Sechopoulos & C Ghetti, Medical Physics, Vol. 36, No. 4, April 2009

Artifacts in DBT



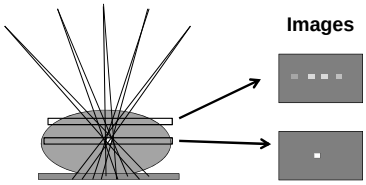
Interplane Artifact

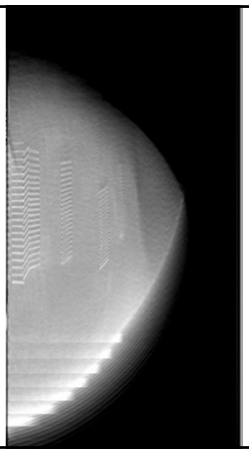
Bright shadow of dense object spreads across slices beyond the physical thickness of the object



"Zipper" artifact

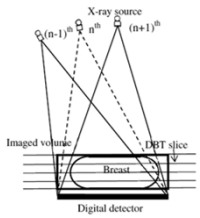
- Due to back projected shadows of a small, high density object (e.g., clip or calc).
- Observed in out-of-focus planes
- Repetitive zipper like appearance

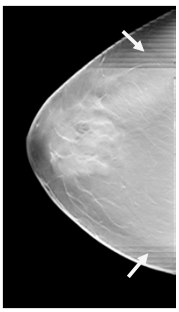




Truncation Artifact

Due to incomplete coverage of entire breast in some projections. (e.g. nth thru (n-1)th , below)

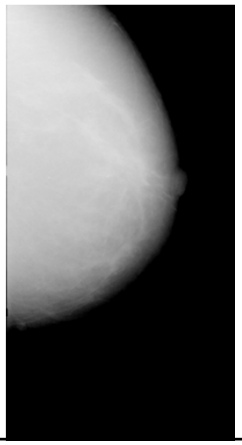




Y Lu, HP Chan, J Wei, LM Hadjiiski Phys. Med. Biol. **58** (2013) 569–587

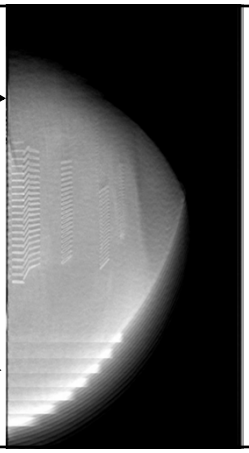
21 projection views obtained with U of Michigan GE research DBT system 60º tomo angle

Note cutoff in projection views at beginning & end of scan.

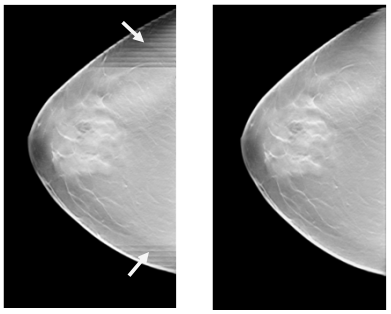


With truncation artifact correction →

Without truncation artifact correction →



Truncation Artifact Correction

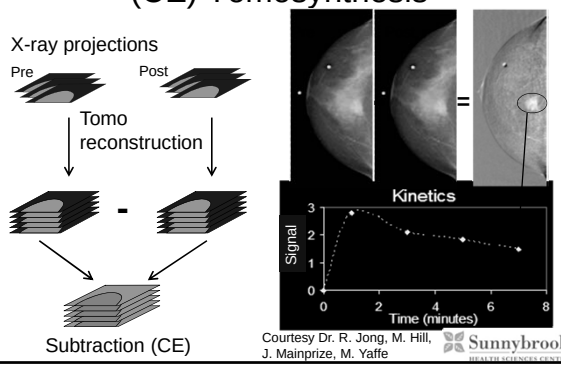


Y Lu, HP Chan, J Wei, LM Hadjiiski Phys. Med. Biol. **58** (2013) 569–587

Contrast Enhanced (CE) Tomosynthesis

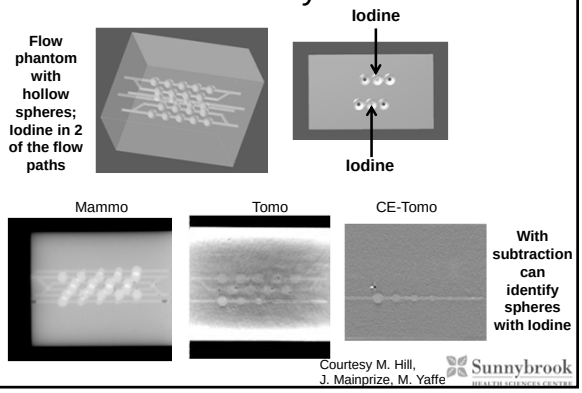
- Single energy: R Jong, M Hill, J Mainprize, & M Yaffe, Sunnybrook Health Sciences Center, Toronto
- Single and Dual energy: A-K Carton, J Currivan, E Conant & A Maidment, University of Pennsylvania

Dynamic Contrast-Enhanced (CE) Tomosynthesis

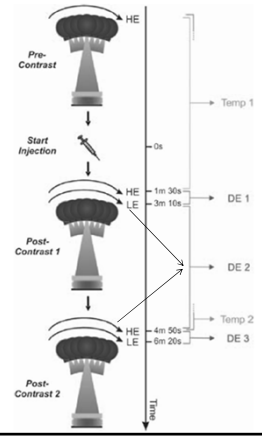


Courtesy Dr. R. Jong, M. Hill, J. Mainprize, M. Yaffe

CE-Tomosynthesis



Courtesy M. Hill, J. Mainprize, M. Yaffe



Dual energy (DE) Tomosynthesis
Andrew DA Maidment, PhD
University of Pennsylvania

Ann-Katherine Carton et al, BJR 2010; 83: 344-350

HE: 49 kVp, Rh target, 25μRh+0.25mmCu filter

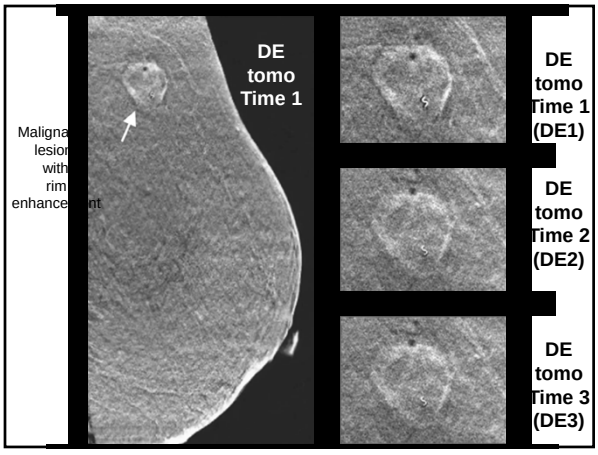
LE: 30 kVp, Rh target, 25μRh filter

7 projection views, 40º arc

Total MGD for 5 cm 50/50 = 6.5 mGy

DE = ln(HE) - 0.21 ln(LE)

DE at 3 different time points after injection (DE1, DE2, DE3)



Multi-Modality Tomo Systems

Combined tomo & automated ultrasound – U of M & GE

UM: P Carson, M Goodsitt, HP Chan, Y Zhang, M Roubidoux, M Helvie, B Booi, S Sinha, G LeCarpentier, B Fowlkes, G Narayanasamy, L Hadjiiski, C Lashbrook, L DeCaussin, X Wang, F Padilla, A Nees, FM Hooi, R Pinski, C Paramagul, B Sahiner, M O'Donnell

GE: J Eberhard, C Landberg, A Kapur, K Thomenius, A Schmitz, A Hall, P Staudinger, A Dattamajumbar

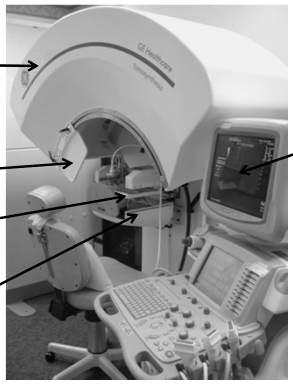
Combined tomo & Nuc Med (SPECT)– U of Virginia

M Williams, P Judy, M More, J Harvey, S Majewski, J Proffitt, J McKisson, A Stolin, B Kross, A Stewart, E Bullard, M Kankaria, R Janer

Combined tomo & optical – MGH

Q Fang, S Carp, J Selb, G Boverman, Q Zhang, D Kopans, E Rafferty, R Moore, E Miller, D Brooks, D Boas

Combined Tomo & Automated Ultrasound – U of Michigan with GE Global Research



GE Gen II Research Tomo Unit at U of Michigan

60º angle
21 projections
7.5 sec

Movable face shield

Dual-modality compression paddle

Stationary digital x-ray detector

GE Logiq 9 US system

Automated US (AUS) Scanning System

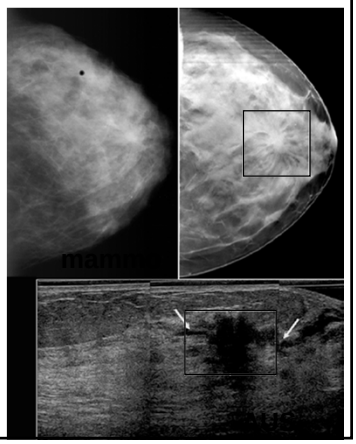
xy translator

US transducer

Mesh paddle

- Translator & transducer out of field for tomo acquisition
- Tilt down for US acquisition
- 0.4 mm spacing between images, 5 frames/sec (2 mm/sec)

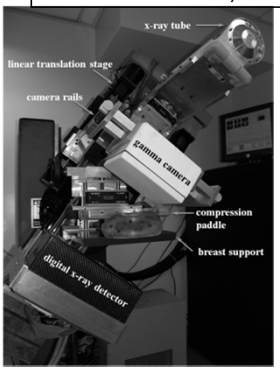
Invasive Cancer: Combined Tomo & AUS



- AUS-suggested ductal extension ↘

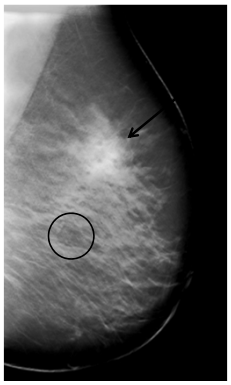
Combined X-ray & Molecular Breast Tomo Imaging - UVa

Mark Williams et al, Radiology 2010; 255; 191-198



1) The patient is seated. Mild, pain-free compression is used.
2) X-ray views are acquired. The total radiation dose is less than or equal to that of regular 2-D mammography. Typically 13 views over ± 12º. Del size is 90 microns.
3) Molecular breast imaging views are acquired. The total scan time is ~ 10 minutes per breast. Typically 5 evenly spaced views over ± 20º. Del size is 2.2 mm. (Molecular breast tomo)

DCIS Not Detected in Clinical Exam

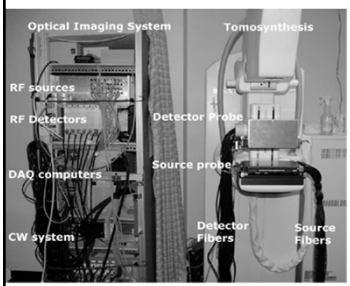


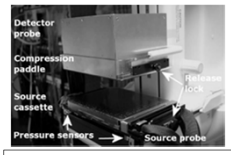
Merged image (x-ray blue, molecular image purple).

DCIS visible as region of focal uptake in molecular image (red arrow).

Black circle indicates region biopsied based on subject's screening exam. That biopsy was negative.

Combined X-ray Tomo & Diffuse Optical Tomo System - MGH





TOMO: 45° swing angle (±22.5°), 15 projections
Image Resolution: 0.1mm x 0.1mm x 1 mm

Procedure:
- Position breast
- Compression
- Take optical measurements (45 s)
- Remove optical probes
- Take DBT scan (20 s)
- Done

Duration: Data acquisition ~1 min, total ~5-10 min

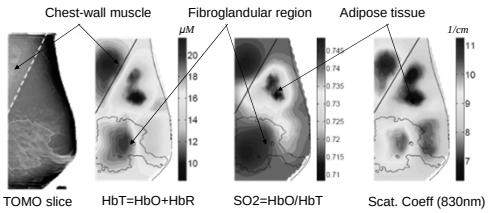
Fang Q, et al., IEEE Trans. Medical Imaging, vol. 28, issue 1, pp. 30 – 42, Jan. 2009.

Diffuse Optical Tomography

- Multi-spectral Near Infrared Measurements (685, 810 & 830 nm)
- Generate 2D & 3D maps of total hemoglobin, oxygen saturation, & scattering coefficient.
- Characterize tissue angiogenesis & metabolism.
- Functional overlay on DBT structural images.
- May reduce unnecessary biopsies.

Results for healthy subject

37 yr old woman, R-breast



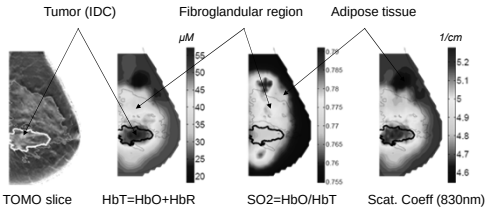
	HbT=HbO+HbR	SO2=HbO/HbT	Scat. Coeff (830nm)
fibroglandular/adipose:	1.42	1.02	1.28

* image slices from 3D reconstructions; HbO: oxy-hemoglobin, HbR: de-oxy hemoglobin, SO2 = O_2 saturation

Fang Q, et al., "Combined Optical and X-ray Tomosynthesis Breast Imaging," Radiology 2011;358:89-97

Results for breast with tumors

45 yr old woman, R-breast



	HbT=HbO+HbR	SO2=HbO/HbT	Scat. Coeff (830nm)
fibroglandular/adipose:	1.55	1.00	1.04
tumor/adipose:	2.07	0.99	1.09
Healthy patient fib/adip	1.42	1.02	1.28

Fang Q, et al., "Combined Optical and X-ray Tomosynthesis Breast Imaging," Radiology 2011;358:89-97

Comprehensive DBT References

1) Sechopoulos, Ioannis , A review of breast tomosynthesis. Part I. The image acquisition process. MEDICAL PHYSICS 40 (1) JAN 2013 On Line only: http://dx.doi.org/10.1118/1.4770279

2) Sechopoulos, Ioannis, A review of breast tomosynthesis. Part II. Image reconstruction, processing and analysis, and advanced applications MEDICAL PHYSICS 40 (1) JAN 2013 On Line only: http://dx.doi.org/10.1118/1.4770281

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GE: Luke Delaney of GE and Bob Liu of MGH

Sectra: Magnus Aslund and Mats Danielsson

X-Counter: Christer Ullberg

CE Tomo: James Mainprize & Roberta Jong of Toronto

DE Tomo: Andrew Maidment of U of Penn

Combined Tomo SPECT: Mark Williams of U of Virginia

Combined Tomo Optical: Qianqian Fang of MGH