Advanced Imaging for Breast Cancer: Screening, Diagnosis, and Assessing Response to Therapy

The Role of Tomosynthesis

Andrew Karellas, PhD

Department of Radiology

University of Massachusetts Medical School
Worcester, MA

Andrew.Karellas@umassmed.edu

AAPM 2013 Indianapolis
WE-A-141-01

Acknowledgments

NIH NCI grant R21 CA 134128 (Karellas, UMass)
NIH NCI grant R01 CA128906 (Vedantham, UMass)
R01 CA139449-01 (Paulsen-PI, Dartmouth)

The contents are solely the responsibility of the authors and do not necessarily represent the official views of the NIH or the NCI.

- Mark Williams, PhD, University of Virginia
- Otto Zhou, PhD, University of North Carolina
- Andrew Tucker, graduate student, University of North Carolina
- Bob Liu, PhD, Massachusetts General Hospital

Disclosures

- University based NIH funded collaboration with Dartmouth College. Hologic, Inc. is involved in this research.

Collaborators

UMass Medical School

- Srinivasan Vedantham, PhD
- Linxi Shi, MS
- Stephen Glick, PhD
- Gopal Vijayaraghavan, MD
- Sarwat Hussain, MD

Thayer School of Engineering at Dartmouth

- Keith Paulsen, PhD
- Brian Pogue, PhD
- Venkat Krishnaswamy, PhD
- Kelly Michaelsen (med student, PhD candidate)

Objectives

1. Rationale for the use of breast tomosynthesis
2. Evolution of breast tomosynthesis from digital mammography
3. Technical requirements
   - ✓ Projection geometry
   - ✓ X-ray generation, kVp, mA, x-ray spectra
   - ✓ Hardware, acquisition modes, spatial resolution
4. Image characteristics, clinical applications
5. Future applications
   - ✓ Fusion with molecular imaging
   - ✓ Stationary x-ray sources
   - ✓ Combination with optical imaging

- Why do we need breast tomosynthesis?
- Didn’t digital mammography deliver on its objectives?
- What were these objectives?

Health care objectives

- Improved sensitivity
- Improved specificity
- Dose reduction

Technological objectives

- Improved contrast
- Improved penetration in dense tissue
- Dynamic range
- Archival, communication, CAD

Digital Mammography

- Increased sensitivity (dense breasts)
- Improved contrast
- Reduced dose

but .....

It is still limited by superposition of tissues, particularly in the dense breast.

How can this limitation be overcome?
Develop tomographic capability

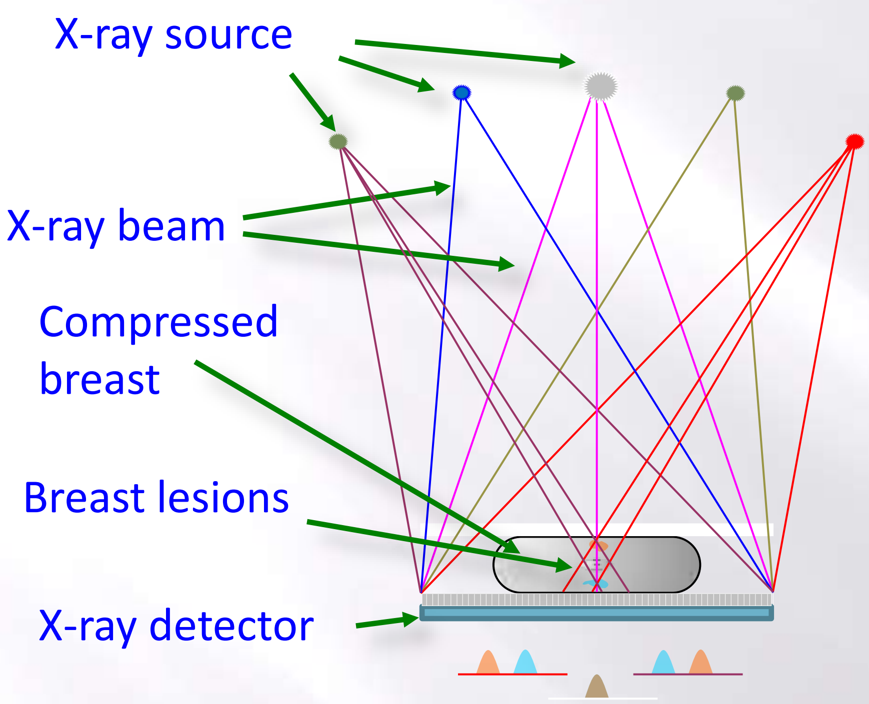
Digital Breast Tomosynthesis

Loren T. Niklason, PhD • Bradley T. Christian, PhD • Laura E. Niklason, MD, PhD • Daniel B. Kopans, MD
Donald E. Castleberry, PhD • Beale H. Opsahl-Ong, PhD • Cynthia E. Landberg, PhD
Priscilla J. Slanetz, MD • Angela A. Giardino, MD • Richard Moore, BS • Douglas Albagli, PhD
Michael C. DeJule, MS • Paul F. Fitzgerald, AAS • David F. Fobare, MS • Brian W. Giambattista, PhD
Robert F. Kwasnick, PhD • Jianqiang Liu, PhD • Stanley J. Lubowski, AAS • George E. Possin, PhD
James F. Richotte, AAS • Ching-Yeu Wei, PhD • Reinhold F. Wirth, MS

Digital Tomosynthesis in Breast Imaging[1]

Radiology 1997; 205:399–406

Digital Breast Tomosynthesis



- 4 mastectomy specimens
- 7 - 9 views, 30˚ – 40˚ total arc of tube motion
- Mo target, Mo filter, 26 kVp, 126 mAs
- Dose: up to 1.74 times of mammography technique

First digital breast tomosynthesis study. Niklason LT et al.
Digital tomosynthesis in breast imaging. Radiology. 1997 205(2):399-406.

Subsequent Study on Breast Tomosynthesis

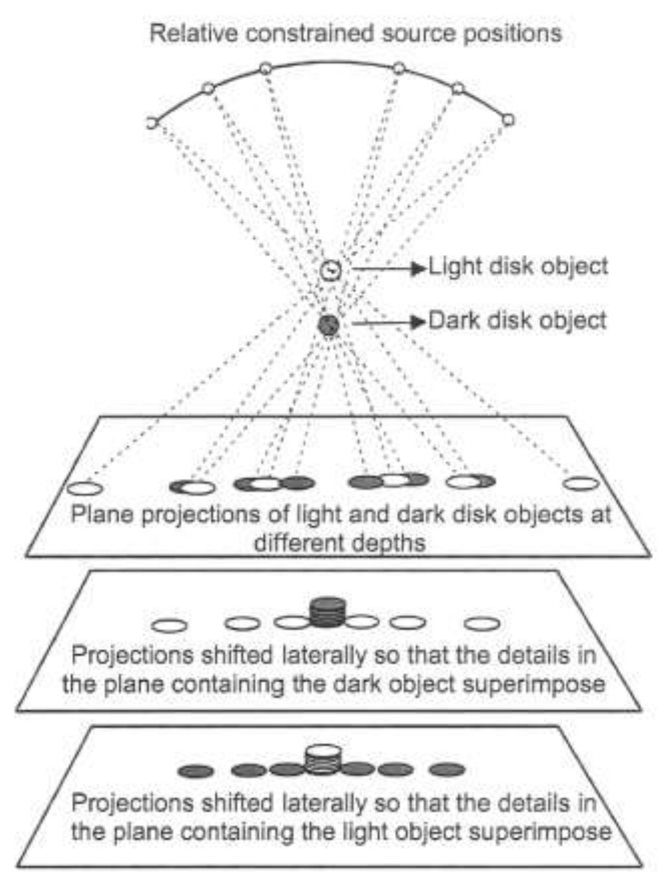


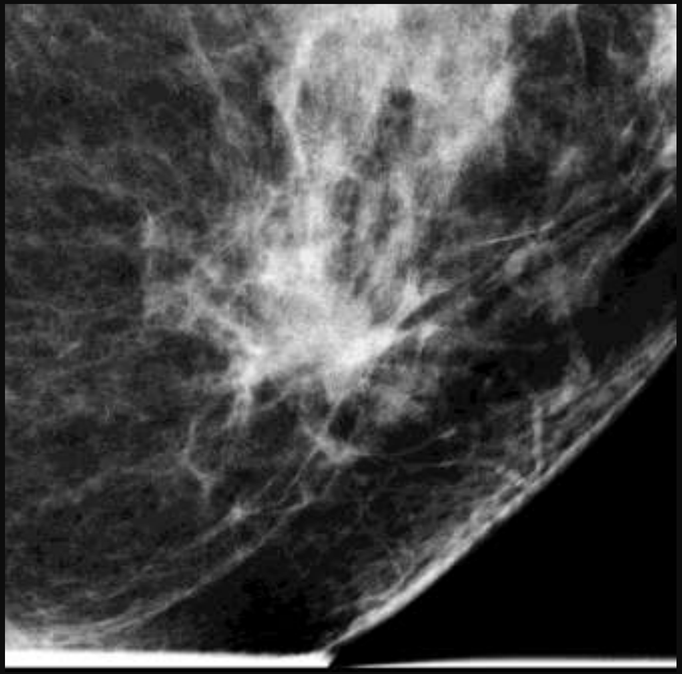
Figure 3. Diagram of constrained tomosynthesis geometry shows how the projections were shifted and added to form different sections.

S. Suryanarayanan, A. Karellas, S.Vedantham, SJ Glick SJ, CJ D'Orsi, SP Baker, RL Webber RL. Comparison of Tomosynthesis Methods Used with Digital Mammography. Acad. Radiol. 2000; 7:1085-1097.

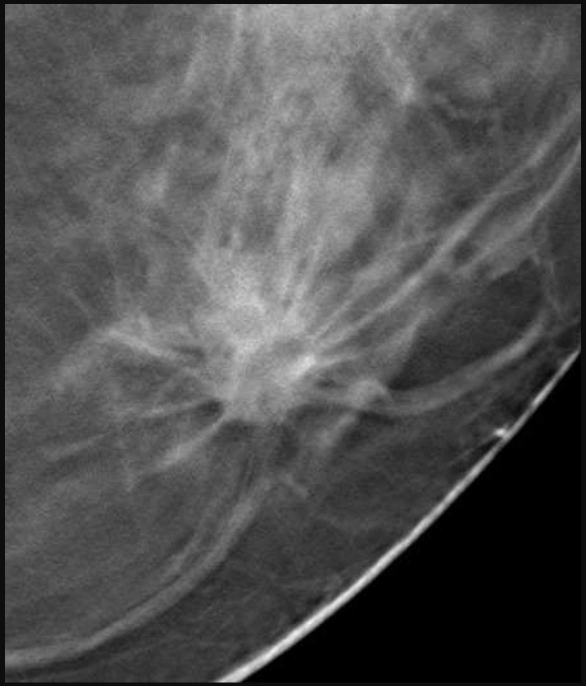
Conclusion

"The contrast-detail trends of all the tomosynthesis methods analyzed in this study were better than those of planar mammography. Further optimization of the algorithms could lead to better image reconstruction, which would improve visualization of valuable diagnostic information"

Digital Mammography LCC



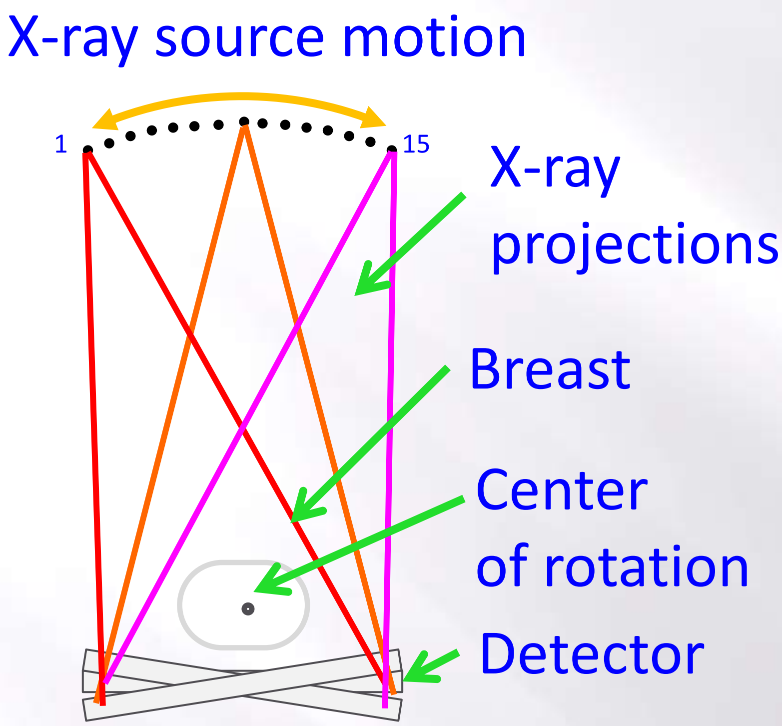
Tomosynthesis LCC



A clinical case showing 1.6 cm low-grade invasive ductal carcinoma with minor ductal carcinoma in situ (DCIS) component.

Courtesy of Steven P. Poplack, Dartmouth Hitchcock Medical Center.
Karellas A, Vedantham S. Med Phys. 2008 Nov;35(11):4878-97.

Tomosynthesis Geometry



- Scan arc 15˚ (± 7.5˚from center) *
- 15 projections
- Antiscatter grid is not used
- Detector tilt (about 5˚)

Other approaches

- 25º (±12.5˚), 9 projections
- 25 projections
- 10 Projections

*Based on the Hologic approach

Tomosynthesis: X-ray Generation

- Tungsten x-ray target and aluminum filtration (W/Al)
- Tube potential: 25 to 49 kVp
- Tube current: 200 mA maximum
- Auto-exposure adjusts kVp and pulse width from 10 – 50 msec
- Total scan angle: 15º arc (±7.5˚), 15 projections, scan in less than 4 seconds
- Intensity (mA) modulation is not used

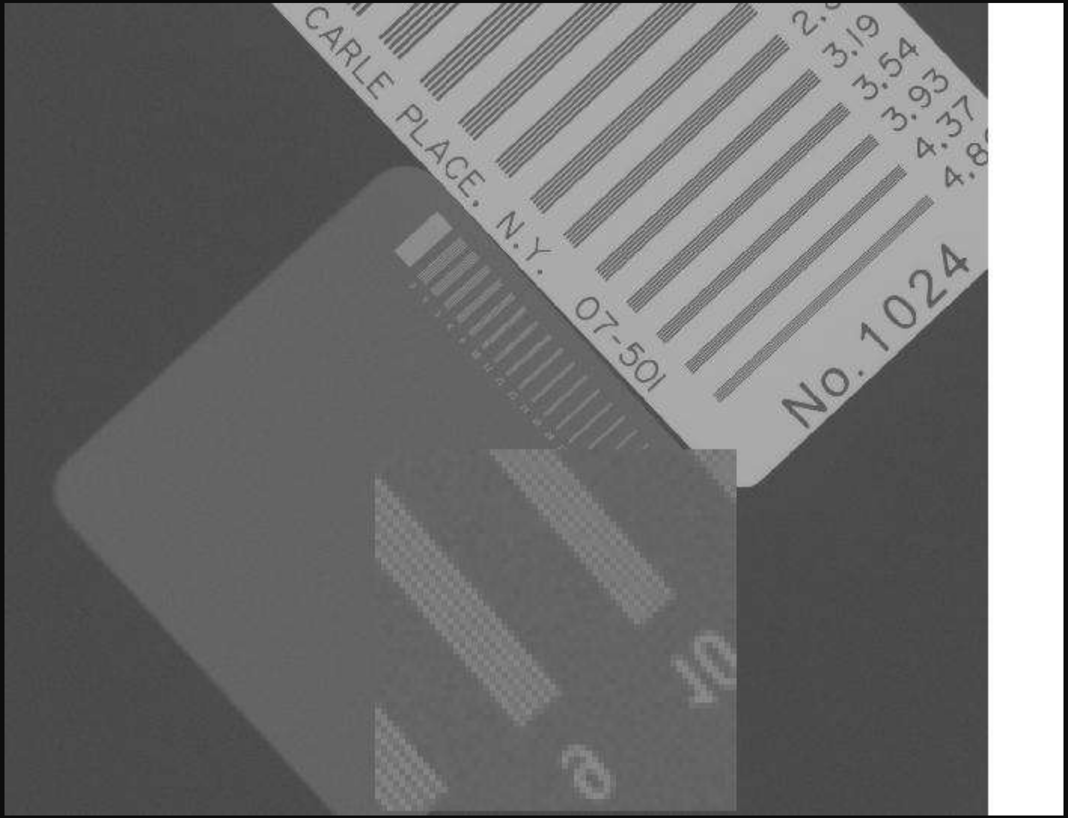
Breast Tomosynthesis : X-ray Detection

- Pixel size 2D: 70 microns
- Detector: a-Se, ~ 24 x 29 cm
- Detector readout: 4 frames/sec 2x2 pixel binning mode (140 micron pixel)
- Detector moves slightly during scan
- Automatic exposure control: 5 x 14 cm, shifted to follow the breast
- Continuous movement with 30 msec – 50 msec per exposure, 15 exposures

Data sampling

- Reconstruction size: ~ 100 microns
- Reconstructed slice thickness: ~ 1 mm

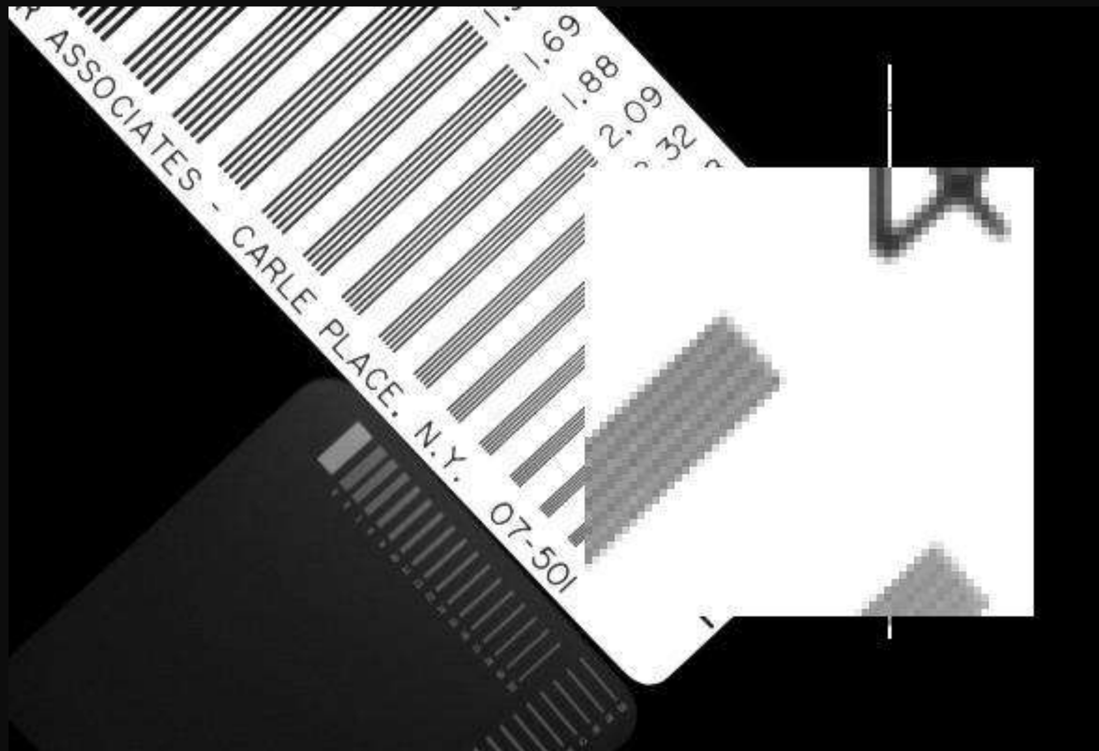
X-Y Plane Resolution - 2D Acquisition



Performance:

- ✓ 9 lp/mm can be resolved
- ✓ No depth information

X-Y Plane Resolution - 3D Acquisition



Performance:

- ✓ 4 lp/mm pattern can be resolved
- ✓ Depth information available

Courtesy of Dr. Bob Liu

Dose using ACR Phantom

AGD ~ 1.2 mGy (2D)
AGD ~ 1.4 mGy (Tomo)

Courtesy of Dr. Bob Liu

In agreement with S. Feng and I. Sechopoulos: Radiology: 2012; 263: 35-42

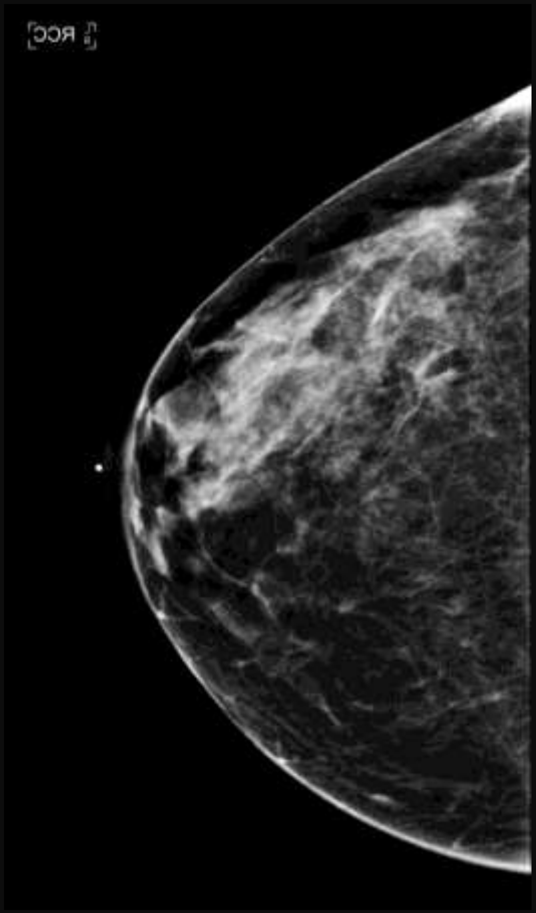
Tomosynthesis is an extension of digital mammography.

It is commonly called “3D” imaging.

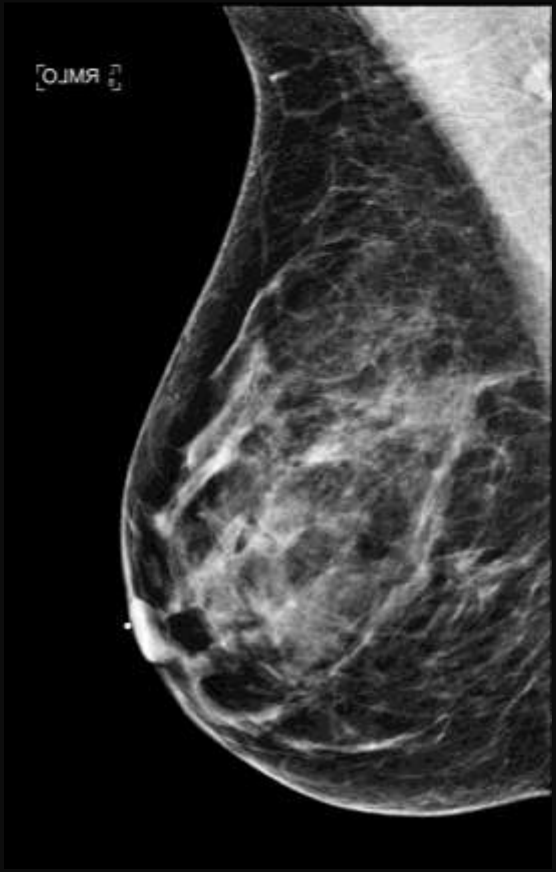
Is it fully 3D imaging? Does it matter?

Digital Mammography

RCC

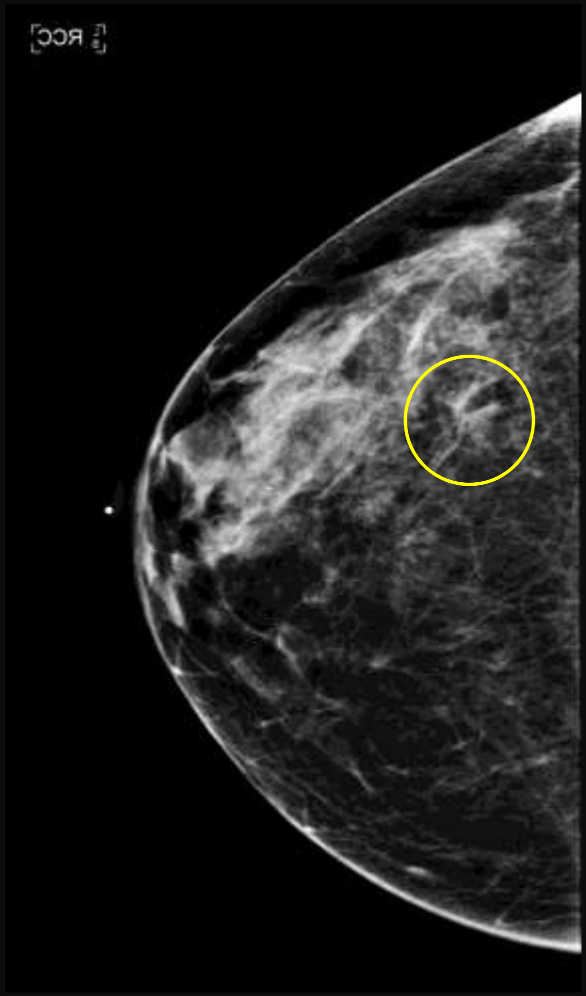


RMLO



Courtesy of Gopal Vijayaraghavan, MD, UMass Radiology

Digital Mammography
RCC



Tomosynthesis
RMLO

Courtesy of Gopal Vijayaraghavan, MD, UMass Radiology

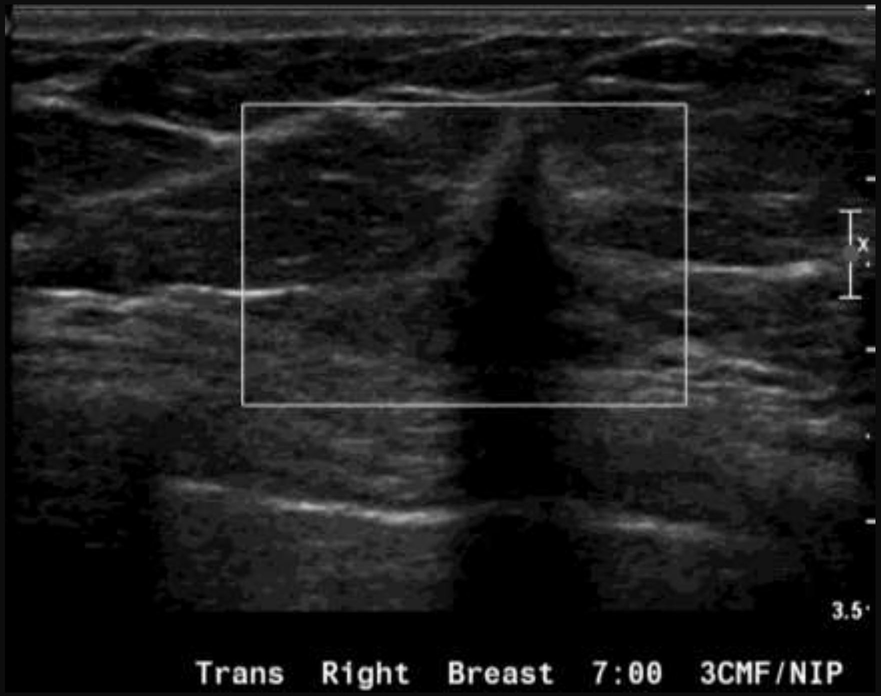
Digital Mammography RMLO

Tomosynthesis RMLO

Diagnosis: Intraductal carcinoma

Courtesy of Gopal Vijayaraghavan, MD, UMass Radiology

Ultrasound



Courtesy of Gopal Vijayaraghavan, MD, UMass Radiology

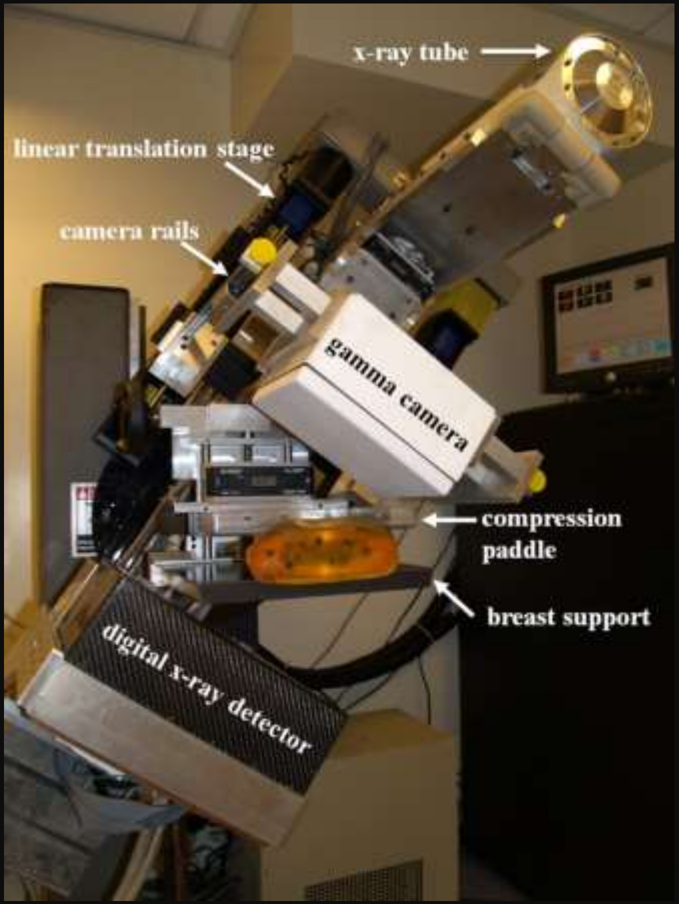
Recent Developments and Future Directions

Synergistic approaches

- Combination with molecular imaging
- X-ray source arrays, stationary x-ray sources
- Combination with optical imaging

Disclaimer: The equipment and techniques described in the slides that follow are experimental and they are not FDA approved

Combination with molecular imaging



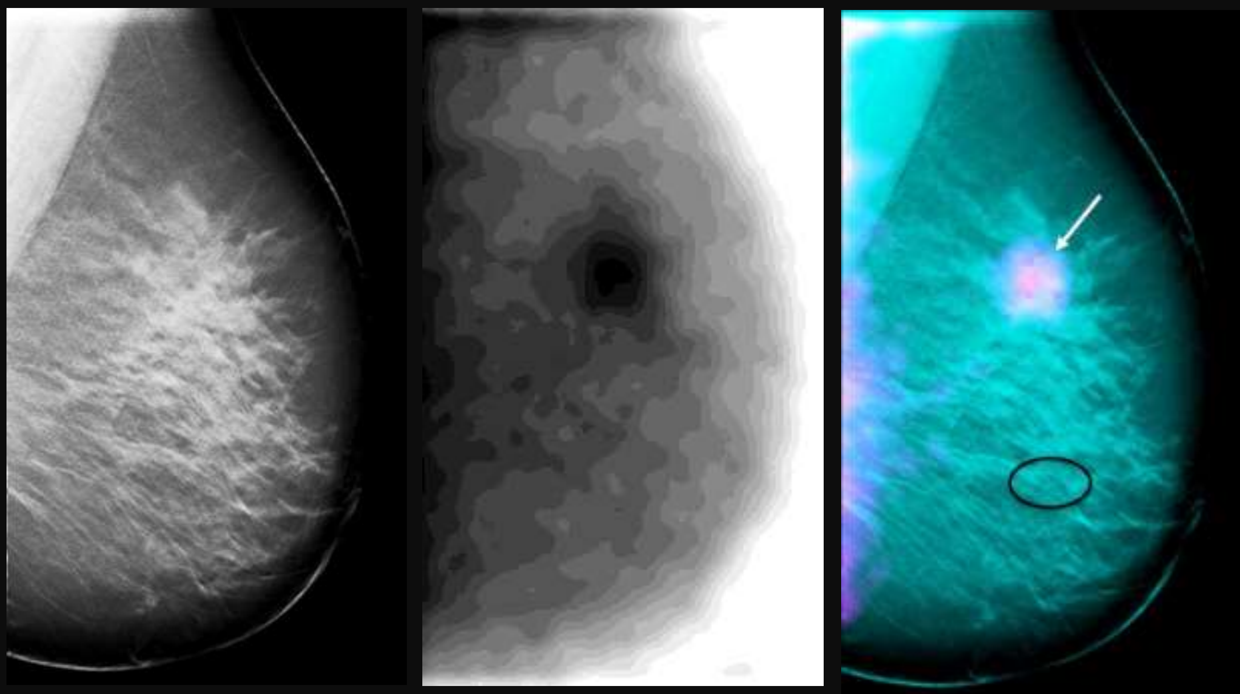
Radiology

Courtesy of Mark Williams , PhD
Williams M B et al. Radiology 2010;255:191-198

Tomosynthesis

Molecular Breast Imaging

Merged

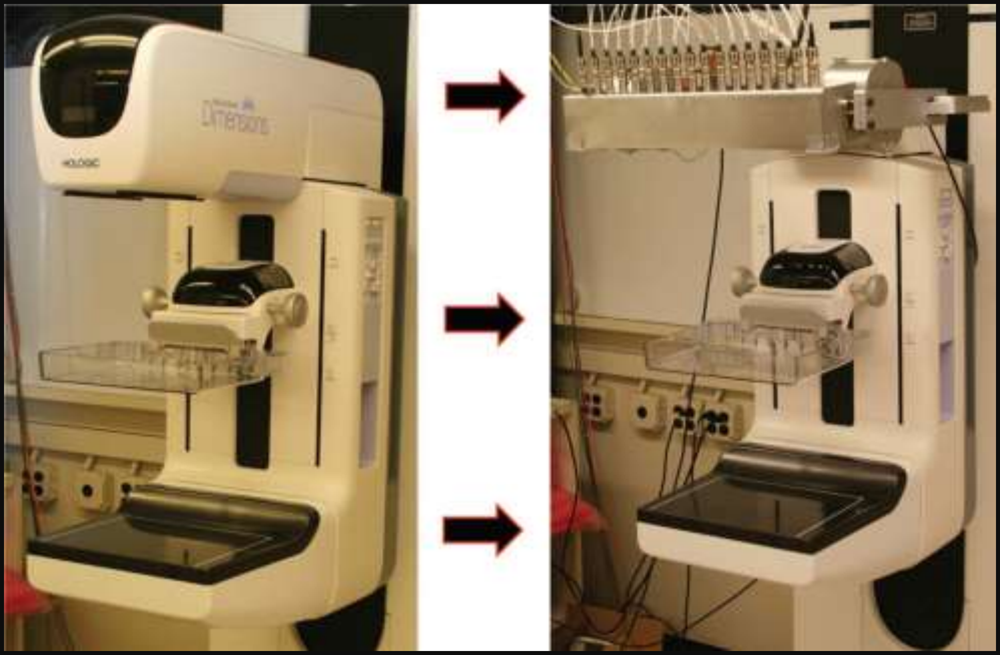


High grade DCIS

Radiology

Courtesy of Mark Williams , PhD
Williams M B et al. Radiology 2010;255:191-198

Stationary Digital Breast Tomosynthesis

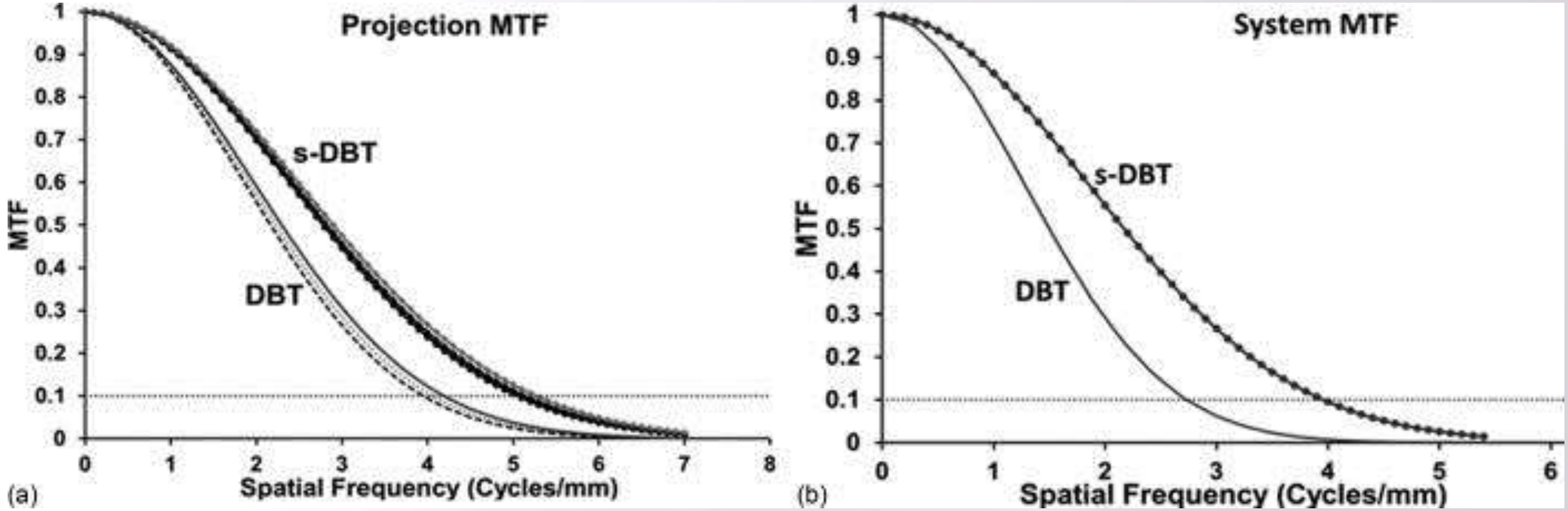


LEFT: Hologic Selenia Dimensions Unit Digital Breast Tomosynthesis system with single rotating x-ray source

RIGHT: Stationary digital breast tomosynthesis system with integrated CNT x-ray source array (XinRay Systems Inc. Research Triangle Park, NC). There are 31 x-ray generating focal spots; each x-ray beam can be electronically controlled to turn on/off instantaneously.

Tucker AW, Lu J, Zhou O. Med Phys. 2013 Mar;40(3):031917.
Courtesy of Dr. Otto Zhou, University of North Carolina

Stationary x-ray sources: Spatial Resolution

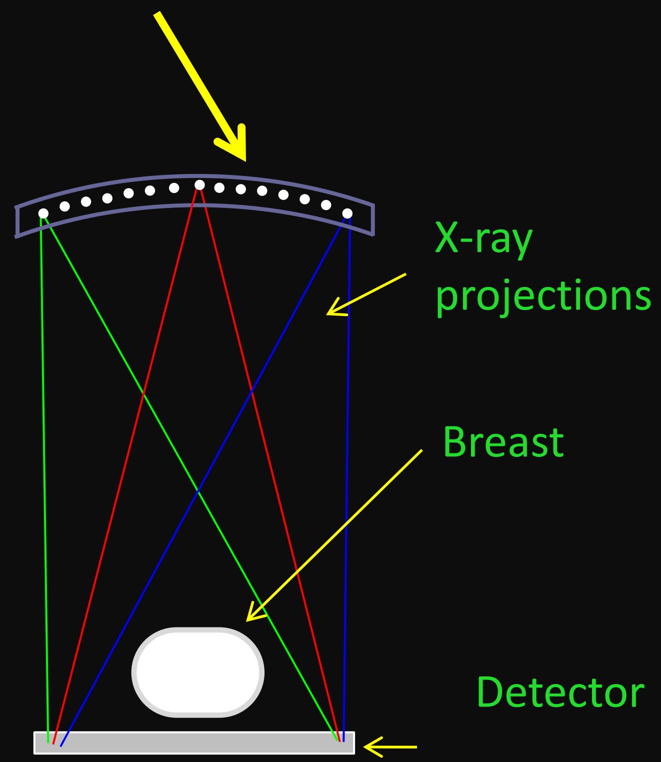


(a) The projection MTFs of the stationary and rotating gantry DBT systems along the scanning direction. (b) The system MTF obtained using reconstructed in-focus slice.

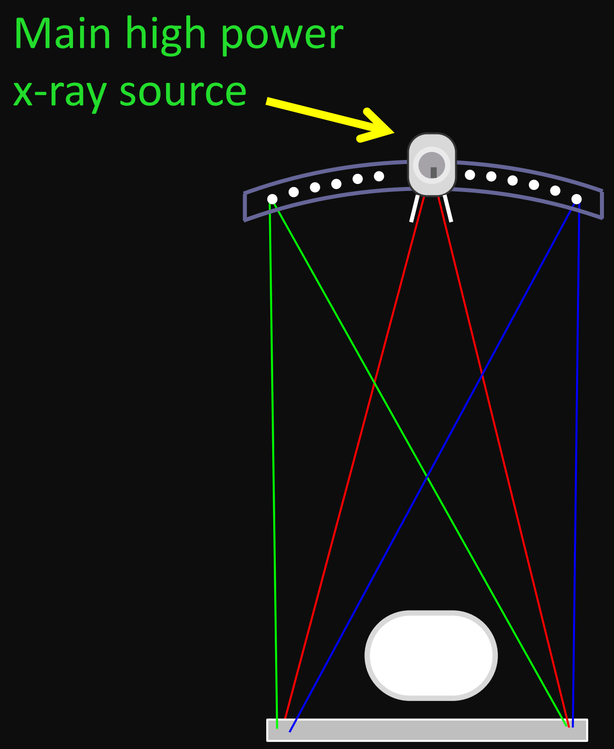
Courtesy of Dr. Otto Zhou, University of North Carolina
Med. Phys. 39, 2090 (2012)

Tomosynthesis with stationary x-ray sources

Multiple stationary x-ray sources



Multiple stationary sources with a main high power x-ray source



Combination with optical imaging

NIR Spectral Tomography (NIRST) and Tomosynthesis

Acknowledgements

Thayer School of Engineering at Dartmouth

Venkat Krishnaswamy
Brian Pogue
Keith Paulsen
Michael Mastanduno
Shudong Jiang
Scott Davis
Optics in Medicine Group

Dartmouth-Hitchcock Medical Center

Steven Poplack
Tracy Frazee
Barbara Van Houten
Joyce Wagner

University of Massachusetts Medical School

Srinivasan Vedantham
Andrew Karellas
Linxi Shi

HOLOGIC

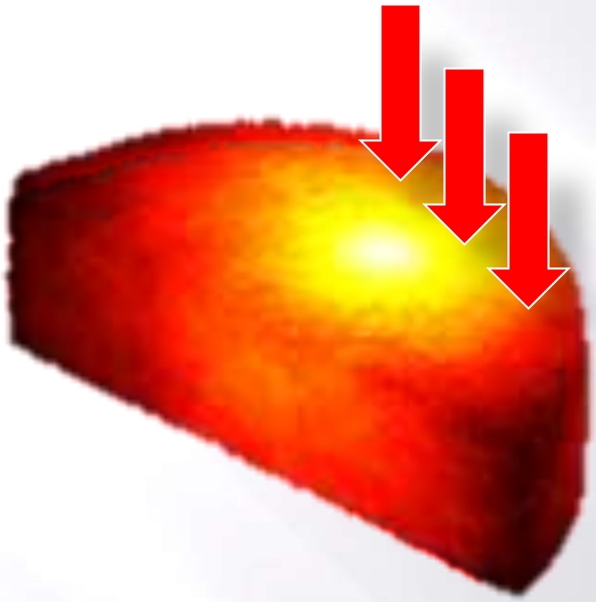
Ian Shaw
Ken Defreitas
Ken Brooks

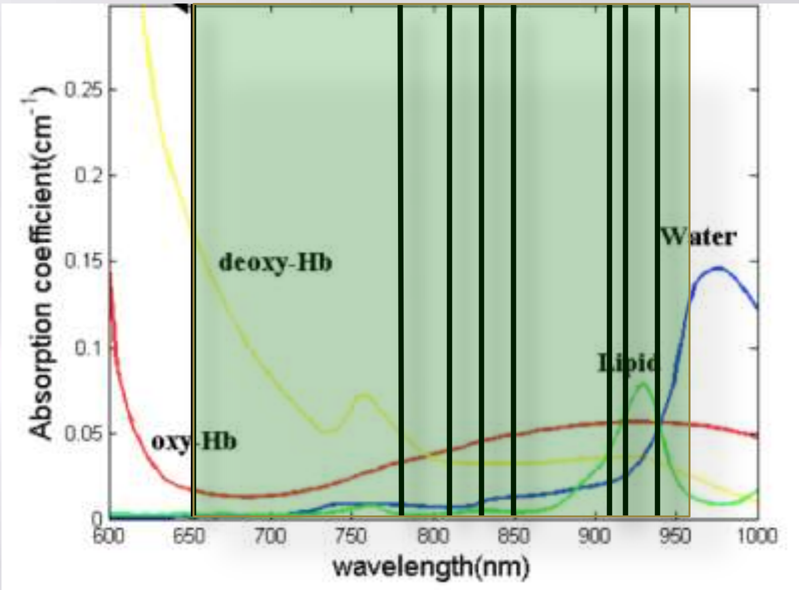
Beckman Laser Institute & Medical Clinic, University of California · Irvine

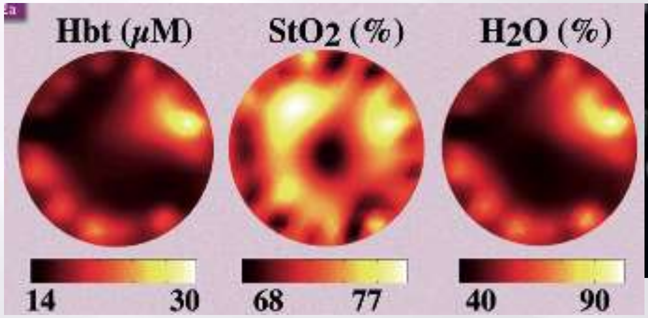
Albert Cerussi
Hosain Haghany
Keunsik No
Brian Hill

Funding Sources:
NIH R01CA139449
NIH F30CA168079

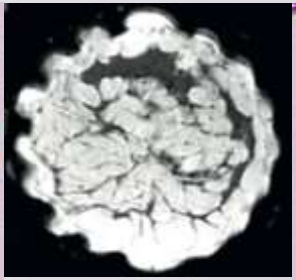
Imaging at multiple wavelengths allows quantification of tissue chromophores

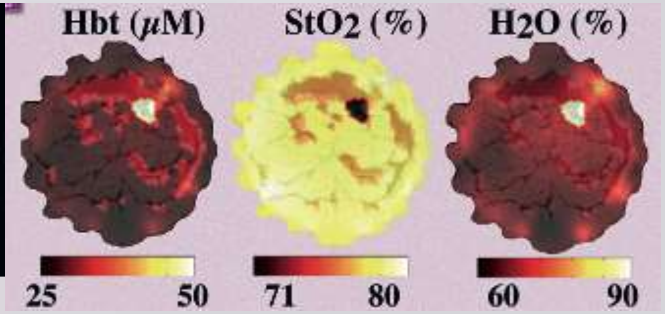






Diffuse Imaging

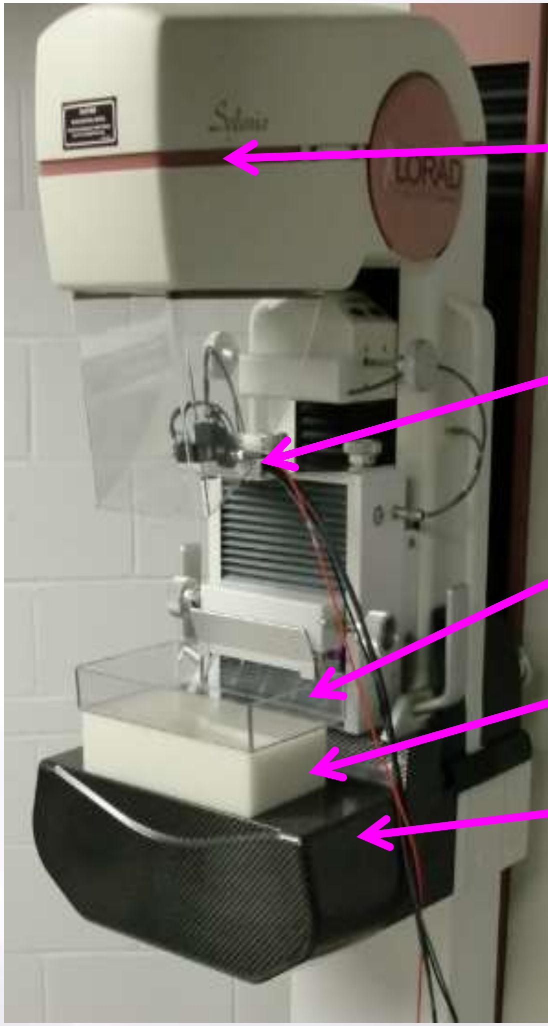




MRI Guided Imaging

Carpenter et al,MedicaMundi, 2009

Tomosynthesis with near-infrared



X-Ray Source

NIR Scanning Source

Compression Paddle

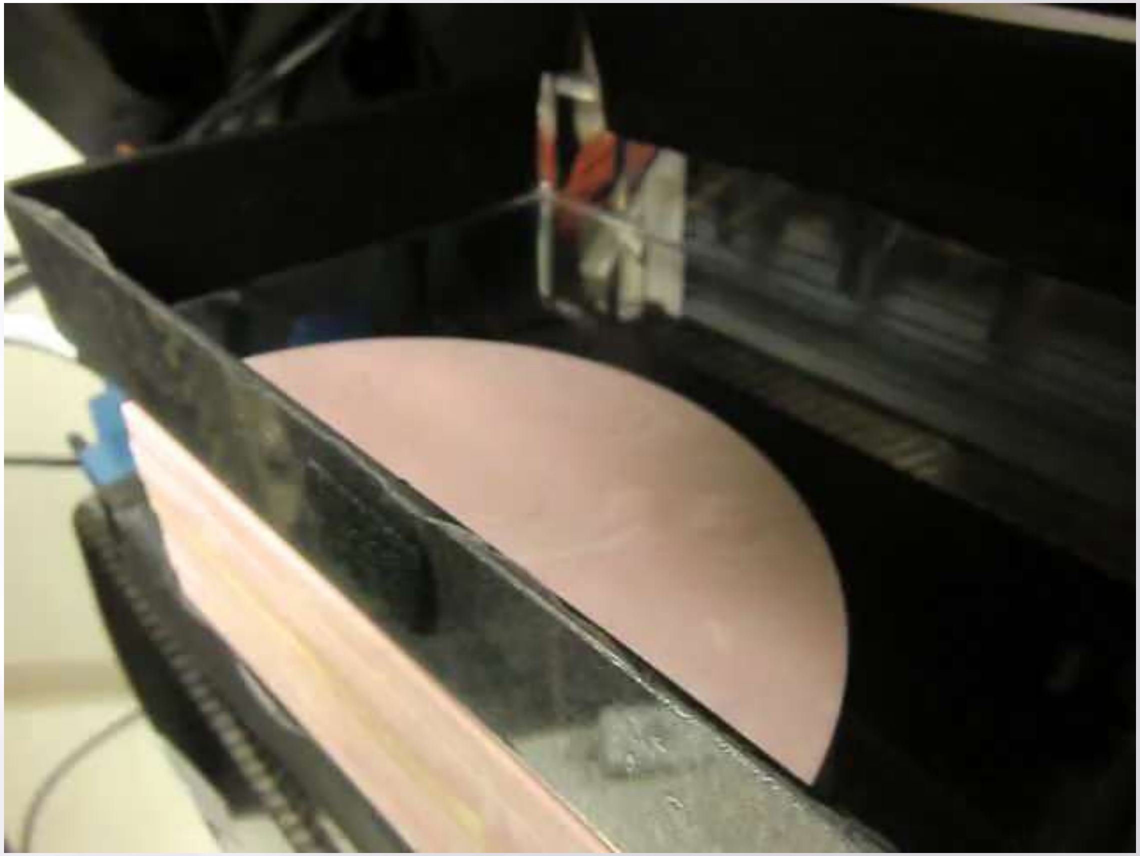
Breast phantom

X-Ray Detectors

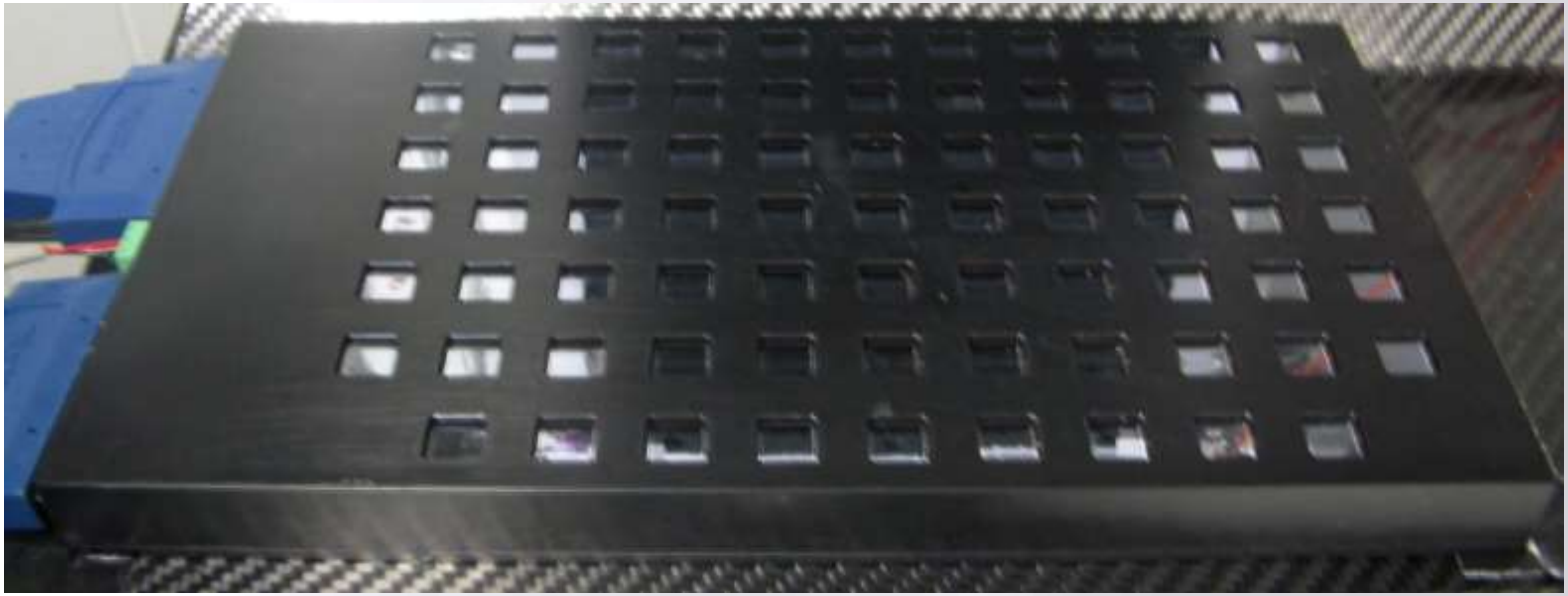
Hologic, Inc. Older Experimental, not current clinical system

Thayer School of Engineering at
Dartmouth and UMass Collaboration
Courtesy of Kelly Michaelson, Venkat Krishnaswamy
Brian Pogue, Keith Paulsen.

Near Infrared Light Source Scans Tissue Surface



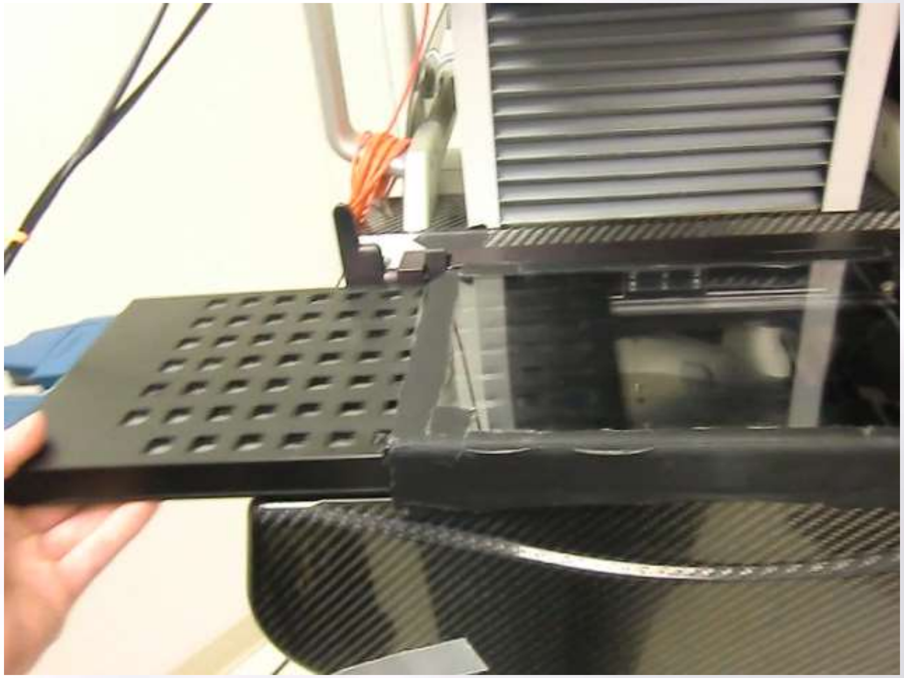
Courtesy of Kelly Michaelson, Venkat Krishnaswamy, Brian Pogue, Keith Paulsen. Thayer School of Engineering at Dartmouth



NIR Detector- Made up of 75 cm by cm silicon photodiodes from Hamamatsu, Many detector measurements made at each source position.

Courtesy of Kelly Michaelson, Venkat Krishnaswamy, Brian Pogue, Keith Paulsen. Thayer School of Engineering at Dartmouth

Near Infrared Light Detectors Detect Signal Beneath the Breast



Detector panel can be easily slid underneath the breast before the patient arrives and then removed in a couple of seconds prior to the X-ray imaging. This detector cover was designed in conjunction with Hologic to maintain clinical quality dbt scans.

A number of breast mimicking phantom studies were performed to characterize the ability of the system to recover changes in hemoglobin, after which we began our first patient imaging scans.

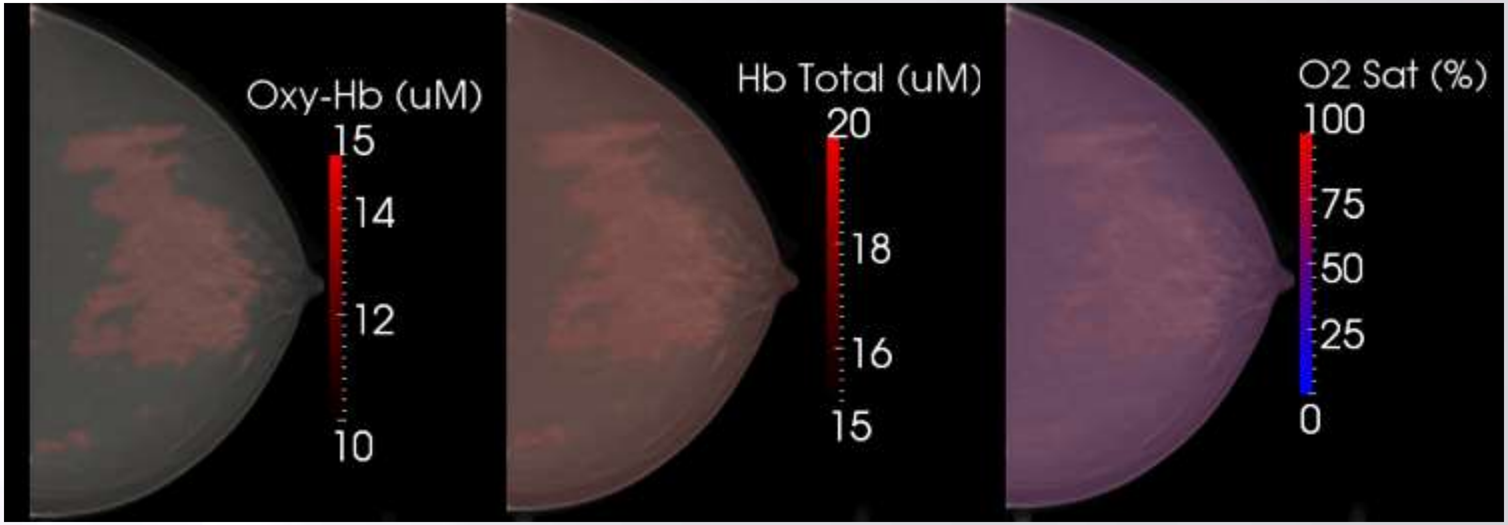
Courtesy of Kelly Michaelson, Venkat Krishnaswamy, Brian Pogue, Keith Paulsen. Thayer School of Engineering at Dartmouth

NIR Spectral Tomography (NIRST) and Tomosynthesis

Near Infrared Scan → NIR Detector Panel Removed → DBT Scan

IRB-approved study

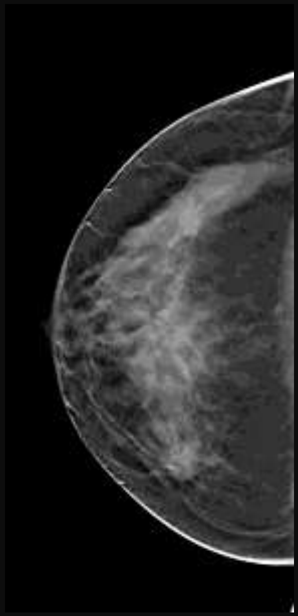
Metabolic Properties in Normal Subjects Show Expected Physiological Values

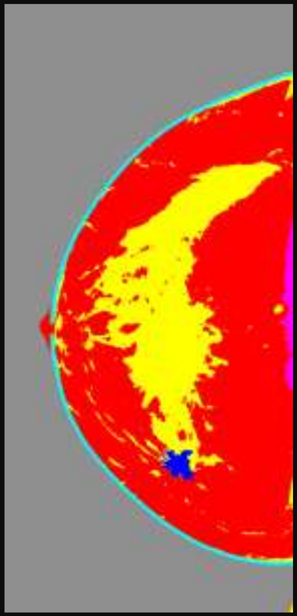


Normal Subject

Courtesy of Kelly Michaelson, Venkat Krishnaswamy, Brian Pogue, Keith Paulsen. Thayer School of Engineering at Dartmouth

Lesion segmentation





Effective image segmentation is critically important to preserve edge and circumvent out of slice artifacts

Srinivasan. Vedantham, Linxi Shi, et al. Conf Proc IEEE Eng Med Biol Soc. 2011;2011:6188-91. Edge preserving out of slice artifact reduction using a Kernel Fuzzy c mean(KFCM) algorithm.

<u>Related reference</u>

- W. Chen, M. L. Giger, and U. Bick, " Academic Radiology, vol. 13, pp. 63-72, Jan 2006.

Conclusions on Breast Tomosynthesis

- Provides limited but clinically useful tomographic detail
- Spatial resolution in the z-direction is limited (concern about detection of subtle microcalcifications)
- Currently it cannot be used without mammography
- “3D” information is not fully 3D. Reconstruction in arbitrary planes is not available.

Conclusions on Breast Tomosynthesis

- Average glandular dose is comparable to mammography and about 2x mammography in combination with mammography
- Convenient platform for molecular imaging (radionuclide or optical)
- Challenge: Insurance may not pay
- Future: Stationary x-ray sources

Thank you

Cone beam x-ray CT will be superior to digital x-ray tomosynthesis in imaging the breast and delineating cancer

Andrew Karellas, Ph.D.
Radiology Department, University of Massachusetts Medical School, Worcester, Massachusetts 01655
(Tel: 508-856-1238, E-mail: Andrew.Karellas@umassmed.edu)

Joseph Y. Lo, Ph.D.
Radiology Department, Duke University Medical Center, Durham, North Carolina 27705
(Tel: 919-684-7763, E-mail: joseph.lo@duke.edu)

Colin G. Orton, Ph.D., Moderator

Med. Phys. 35(2) p. 409 February 2008