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

The Role of Tomosynthesis

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Collaborators

UMass Medical School
• Srinivasan Vedantham, PhD
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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

Breast Imaging

Loren T. Niklason, PhD • Bradley T. Christian, PhD • Laura E. Niklason, MD, PhD • Daniel B. Kopans, MD
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Digital Tomosynthesis in Breast Imaging

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.
Subsequent Study on Breast Tomosynthesis


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

Tomosynthesis Geometry

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

Other approaches
- 25° (±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: 15° 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
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

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

Molecular Breast Imaging

Merged

High grade DCIS

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


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.

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Tomosynthesis with stationary x-ray sources

Multiple stationary x-ray sources

- Breasts
- X-ray projections
- Deteceotor

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

- Main high power x-ray source
Combination with optical imaging

NIR Spectral Tomography (NIRST) and Tomosynthesis
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Hosain Haghany
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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
Effective image segmentation is critically important to preserve edge and circumvent out of slice artifacts.


Related reference
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

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