As proposed  
As approved  
As designed  

As manufactured  
As installed  
What the customer really wanted
CenSSIS Multimode Cancer Imaging via Digital Breast Tomosynthesis

RPI Electrical Impedance Laboratory
MGH Diffuse Optical Tomography Laboratory
MGH Breast Imaging Laboratory

Richard Moore

Gordon-CenSSIS Engineering Leadership Program
Aims

What is Digital Breast Tomosynthesis (DBT)?

Review how DBT was developed to solve the problem of superimposition of breast tissue commonly found using conventional 2-view mammography

Highlight new vistas opened by CenSSIS

- Electrical Impedance Tomography (EIT)
- Diffuse Optical Tomography (DOT)
- Ultrafast Computing by Graphical Processing Unit
What is DBT?

What is Conventional Mammography?
What is Conventional Mammography?

Medial Lateral Oblique (MLO)       Cranial - Caudal (CC)

CM is 4 views per patient... 4 compressions
Nature of the screening mammography:

For each 1000 women screened with CTVM:

- About 80 are called back for “additional imaging” X-ray, US, MRI  
  remember this number: 8% callbacks
- About 20 are recommended for some form of biopsy stereo core Bx, open surgical Bx, US guided Bx
- About 3-7 cancers will be discovered on pathology from these biopsies

Overall this yields:

- Reduction in US breast cancer mortality: 30%
- Sensitivity: 75% - 90%
- Specificity: 90% - 95%
- Positive predictive value (biopsy): ~25%
What is DBT?

Original Prototype Acquisition System

- Detector: a-Si (CsI), 23cm $\times$ 18cm area, 100 $\mu$m pixel size
- 11 projections, 50° (30° actual) arc, 7sec acquisition time
- MLO and CC views, patient seated, fixed height
Digital Breast Tomosynthesis (DBT)  
2\textsuperscript{nd} generation GE prototype

Detector:
- amorphous-Si (CsI) epitaxially grown scintillator
- 300msec readout time
- 23cm × 19.2 cm area
- 100 micron pixel size

Acquisition:
- 15 projections
- 40° arc
- 15s acquisition
- Mo and Rh anodes
- same dose as CC+MLO
- 360° gantry rotation
permits all standard views
Digital Breast Tomosynthesis – What do you get?

Conventional 2D

DBT 3D
Digital Breast Tomosynthesis – What do you get?

Direct clinical benefits of DBT for screening:
• Improved specificity, reducing callbacks by 42%
• Likely improved sensitivity in screening
• Reduced exam time and only two compressions per study
• Greater confidence in findings (conspicuity and location)
Digital Breast Tomosynthesis – What do you get?

By removing superimposed tissue, DBT provides more accurate diagnostic information about each finding:
- normal tissue configurations (some mimic lesions)
- benign lesions
- malignant lesions (Overall DBT n > 4100 to date)

3000-women NIH NCI-funded (5R33CA107863-01) DBT screening trial, now completed:
- 42% callback reduction from 80/1000 to 51/1000

A 3D foundation platform on which to build functional imaging such as:
- Electrical Impedance Tomography (208 to date)
- Diffuse Optical Tomography (203 to date)
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Electrical Impedance Tomography (EIT)
Electrical Impedance Tomography (EIT)
Electrical Impedance Tomography (EIT)

Hyalinized Fibroadenoma

Left Breast

Ductal Carcinoma
in-situ

Right Breast

Normal

Carcinoma

Admittance locus -
carcinoma in-situ

Right breast carcinoma
Electrical Impedance Tomography (EIT)
Aims

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Tomographic Optical Breast Imaging (TOBI)

Emerging medical imaging modality based on:
- Illumination of the tissue with **red and near-infrared laser light** of different wavelengths
- Detection of the **highly scattered and absorbed light** that is remitted from the tissue

Spectroscopic light absorption measurements give quantitative information about breast composition:
- Main absorbers: **Oxy-** and **deoxy-hemoglobin** \([HbO] \) and \([HbR]\) ⇒ **Blood volume** and **oxygen saturation**
- With more wavelengths: **lipid** and **water**
- Optical scattering coefficient related to **cell sizes**

- **3D reconstruction of quantitative physiological information**
- **~1cm spatial resolution** (limited by strong light scattering)
- **Low-cost, non-invasive, non-ionizing radiation**
We combined 3D X-ray and near infrared tomographic imaging in a single instrument, to improve the fusion of anatomic and physiologic data.

**X-Ray Mammography**
- **Clinical standard** for screening of breast cancer.
- Provides **structural** information
- Very good **spatial resolution** (<1 mm)

**Near Infrared Diffuse Optical Tomography**
- Provides complementary **physiological** information (blood volume, oxygen saturation, optical scattering)
- Relatively **low spatial resolution** (~ 1cm)

Why TOBI + X-Ray?

We combined 3D X-ray and near infrared tomographic imaging in a single instrument, to improve the fusion of anatomic and physiologic data.
Tomographic Optical Breast Imaging (TOBI)
Source plate

Support paddle, with source plate to be inserted. The figure also shows the pressure sensors.

Source and detector probes mounted on the TOMO clear paddles.

The optical probe sensor plate is not in direct contact with the breast (clear layer of the compressions paddle in-between). Both source and sensor can be removed from the system while the breast remains in fixed position for the X-ray mammogram.
TOBI image reconstruction

3D image reconstruction of blood content and blood oxygenation
Boundaries given by TOMO scan

TOMO

TOBI

Absorption coefficient $\mu_a$ at 830 nm

Chest wall

Fibro-glandular tissue (contour obtained from segmentation of the TOMO scan)
Tomographic Optical Breast Imaging (TOBI) -tumor
Tomographic Optical Breast Imaging (TOBI)

- Development of a combined X-Ray / Optical tomographic imager:
  - X-Ray Tomosynthesis ⇒ Structure
  - Near infrared diffuse optical tomography ⇒ Physiology

- X-Ray and optical images recorded with the breast in the same position:
  - Facilitates image comparison
  - Boundaries given by TOMO scan used in optical reconstruction

- 203 women imaged to date

- Pressure distribution due to the mammographic compression induces lower blood volume in the center of the breast

- Tumor was visible on TOBI scan as local higher absorption suggesting high vascularization
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Reconstruction Method
— Iterative Maximum Likelihood Algorithm

Initial 3-D Model

Model volume 800 @ 10Mbytes/ea = 800Mbytes

Forward projection

Measured Projections: \( P \)
15 @ 10Mbytes/ea = 120 Mbytes

Back projection

Calculated Projections: \( P^{(n)} \)
120 Mbytes

\( \Delta \mu^{(n+1)} \)

Optimized Likelihood Function

\( \mu^{(end)} \)

In 2002 these were overwhelming data spaces.
Reconstruction Computing Hardware for MLEM

Ancient history (1997):
- Pentium-4 single thread
- had to reconstruct “sections” of datasets
- 30 GB hard disk!
- “affordable” at $3K
- 28 hours per 8-iteration MLEM reconstruction

MGH reconstructor (2000):
- Dual – processor 1.8 GHz, 2-GB of memory
- 100 GB hard disk
- “affordable” at $4K
- ~5-9 hours per 8-iteration MLEM reconstruction
- but at least it was the whole breast at once!
Cluster computing (generally):
- 128 processors per cluster
- robust toolsets
- needs own power circuit!
- “affordable” at $120K
- 46 seconds per 8-iteration MLEM reconstruction

MGH “budget” cluster (2004):
- 32 cheap-ish computers on storage racks
- 2.8 GHz, 800MHz FSB, 512 MB RAM, 40GB disk
- 100Mbit Ethernet interconnect and switch
- “affordable” at $48K for the cluster itself
- 3 – 20 amp circuits and 2.5 tons extra AC
- ~200 seconds per 8-iteration MLEM reconstruction
- ~200 seconds to load/unload job
GPU computing (today):
- 240 processors per card, 2GB shared memory
- NVIDIA CUDA - C programming environment with multiprocessor software GPU behavior simulation
- still needs own special power circuit! (from PC power supply 750+ watts recommended)
- very affordable $600/ea
- 46 seconds per 8-iteration MLEM reconstruction

Multi-GPU computing (today):
- 4 GPU cards per PC
- 960 processors per PC
- “affordable desk-side Supercomputing” when problem is parallellizable ~ $4K
- 11 seconds per 8-iteration reconstruction, so quite nearly real-time
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Multimode Digital Breast Tomosynthesis

DBT X-Ray
(n > 4100)

Electrical impedance Tomography
(n = 208)

Diffuse Optical Tomography
(n = 203)
Multimode Digital Breast Tomosynthesis
Looking forward

Direct clinical benefits of DBT for screening:
- Improved specificity, reducing callbacks by 42%
- Likely improved sensitivity in screening
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In addition to expected direct clinical benefits, we believe DBT can serve as a foundation for understanding new modalities by acquiring them in registration permitting functional assessment.

Fleshing out the domain of anatomically co-registered functional imaging is a monumental undertaking, complimenting recent advances in genetics and metabolic pathways.
A Hand-held probe layered model for Electrical Impedance Tomography

Rajuta Kulkarni
Gary J. Saulnier
Tzu-Jen Kao
Gregory Boverman
Jonathan C. Newell
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A hand-held probe for combined ultrasound and electrical impedance tomography

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Tzu-Jen Kao
Gregory Boverman
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Combining diffuse optical imaging with X-ray tomosynthesis: clinical results


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Gordon Engineering Leadership Program

Calcification Conspicuity for Digital Breast Tomosynthesis Compared to Conventional Digital Mammography

Daniel Kopans, M.D.
Sarah Chen, M.D.
Richard Moore, A.B.

Second Generation Digital Breast Tomosynthesis (DBT) in the Screening Setting: Reading times for 1487 cases

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Analysis of forward solvers for EIT in a mammography geometry

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Analysis of Admittivity Spectra with Synthesis for Breast Cancer Detection: 49 Breasts Studied

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Utilization of EIT and Digital Tomosynthesis Data for Breast Cancer Detection

Initial Callback Rates for Digital Breast Tomosynthesis Compared to Conventional Digital Mammography in the Screening Setting

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