Digital Breast Tomosynthesis

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Talk Overview

• Breast Cancer Statistics
• Screen-Film Issues
• Tomosynthesis
  – Need
  – Clinical Examples
  – Scientific Studies on DBT vs. FFDM
  – How does it work?
  – Image Display
Acronyms in Digital Imaging

- FFDM – Full Field Digital Mammography
  – Also called Digital Mammography
- DBT – Digital Breast Tomosynthesis
  – Also called Tomosynthesis
- FDA “jargon”
  – PMA – Pre Market Approval
  – 510K
BREAST CANCER STATISTICS

• Estimated cases of Breast Cancer in 2010: 210,000
• Estimated Deaths from Breast Cancer in 2010: 40,000
• Lifetime Risk for Breast Cancer: 1 in 9
BREAST CANCER STATISTICS

- 30% of all cancers are Breast Cancer
- 17% of all cancer deaths are from Breast Cancer
- Breast Cancer is the leading cause of death in women 40 - 44 years
- Only 45% of women get Screening Mammograms
High Quality Mammography

• **CONTRAST** for Mass Identification

• **RESOLUTION** for Calcification Identification

• **Low** Patient **Dose**
Primary Signs of Breast Cancer

- Mass
- Calcifications
- Mass and Calcifications
Secondary Signs of Breast Cancer

- Skin Thickening
- Nipple Inversion
- Adenopathy
- Developing Density
- Architectural Distortion
Performance of Screen/Film

- S/F mammography may have a miss rate of 20 – 30% for breast cancer

- Sensitivity decreases as breast density increases
Disadvantages of Screen-Film

- Short dynamic range
  - Low contrast
  - Under penetration of dense tissue
- Signal strength (screen thickness) compromises image quality (image blur)
- Film Processing
  - Time required – 5 to 10 min
  - Artifacts
- Film grain noise
Disadvantages of Screen-Film

- Can’t enhance or alter the image
- Large amount of physical storage space
- Must be physically transferred; only one place at a time
- Information irretrievable if lost
DIGITAL MAMMOGRAPHY
• Rembrandt Painting
  “Rembrandt’s Wife”
FFDM – Clinical Advantages

- No “film-type” artifacts
- Can see skin line without loss of contrast
- Faster Image acquisition
  - Images are available “immediately” after exposure
  - Increased patient throughput
  - Reduce patient discomfort
- Decrease in BIRADS Category 0
- Post-Processing
  - Avoid call-backs for under exposure
DIGITAL MAMMOGRAPHY

Summary of Benefits

- Improved Image CONTRAST
- FLEXIBLE Display
- Improved Patient THROUGHPUT
- Easier Image Storage
Tomosynthesis

• Designed to improve detection and characterization of breast lesions
  – Non-fatty breasts
• Multiple projections are reconstructed
• Allows visual review of thin breast sections
  – Potential to unmask cancers obscured by normal tissue above or below lesion
Why is There a Need for Tomosynthesis?

- In 2D FFDM:
  Tissue superimposition hides pathologies in 2D

  Tissue superimposition mimics pathologies in 2D
Better Sensitivity

- ACR Phantom insert imaged with 4 cm cadaverous breast
- Phantom has low contrast fibers, masses, and calcifications
- Overlying breast tissue obscures object visibility

Digital Mammogram 1X dose

Tomosynthesis 1X dose

Better Sensitivity

Slice at plane of phantom insert

Tomosynthesis shows improved low contrast visibility over digital mammography
Lower Dose

Digital Mammogram 4X dose

Tomosynthesis 0.5X dose

Slice at plane of phantom insert

Tomosynthesis shows improved low contrast visibility over FFDM, even at much lower dose
Digital Breast Tomosynthesis (DBT) — Visualization

A DBT reconstruction
- 30-80 slices parallel to the detector plane
- 1mm slice thickness
- 100 µm in-plane pixel size

Visualization software functions
- Paging through DBT slices
- Window level
- Zoom in / zoom out
- Field of view magnifier

The knowledge for interpreting conventional mammography is valid for DBT

Courtesy of Tao Wu, Ph. D and Massachusetts General Hospital
Breast Tomosynthesis

A three-dimensional mammographic examination that can minimize the effects of structure overlap within the breast
Breast Tomosynthesis

<table>
<thead>
<tr>
<th>Benefits</th>
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<tbody>
<tr>
<td>Preserves the very high resolution of 2D FFDM</td>
</tr>
<tr>
<td>Multiple images of the breast are acquired at different angles during a sweep of the x-ray tube</td>
</tr>
<tr>
<td>Allows radiologists to see around overlapping structures</td>
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</table>
Hologic Selenia Dimensions DBT

- 2D or 3D imaging
  - 2D only
  - 3D only

- Combo mode
  - 3D image
  - Return to 0 degrees for 2D image
  - Single compression for both images
How Does Hologic’s Tomosynthesis Work?

- Tube moves in a 15° arc

- 15 low dose images are acquired
  - 1 image at each degree
  - Four second sweep
  - Total dose ≈ one 2D mammogram

- Images are reconstructed into 1 mm slices

- In **combo-mode** imaging, 2D and 3D images are taken under the same compression, with no additional patient positioning required. Combo supports both CC and MLO projections.
Potential Benefits of 3D Imaging

• Better imaging
  – Improved lesion margin visibility
  – Precise lesion localization
  – Identification and location of multi-focal cancers

• Higher accuracy
  – Increased breast cancer detection
  – Higher PPV for breast biopsy recommendations
  – Decreased workup rate for non-cancer cases

• Lower recall rates
  – Decreased workup rate for non-cancer cases
Hologic ROC Study for FDA PMA
ROC Study Design

• 1083 women were recruited from 5 clinical centers
  – 856 presented for screening mammography
  – 227 presented for breast biopsy
• All subjects received 2D and 3D images of both breasts in CC and MLO positions
• Radiation dose for a single 2D plus 3D acquisition (either CC or MLO) was less than the MQSA limit for a single 2D mammogram
Overview of Reader Study

- Comparison of 2D to 2D plus 3D
- Two retrospective Independent Reader Studies
- Readers were MQSA qualified
  - Wide range of experience in 2D
- Reader study enriched with:
  - Cancer cases
  - Recalled screening cases
  - Benign biopsy cases
- Major conclusions
  - Improved area under ROC curve
  - Reduced recall rate
Rationale for using 2D plus 3D

• Comparison of current images with prior images is standard mammography practice and critical to perceive subtle changes which may be associated with a cancer.

• Obtaining a 2D exam along with the 3D exam will allow direct comparison of current 2D images with prior 2D images.

• Segmental and clustered calcifications are more easily and quickly appreciated with 2D because they can traverse multiple slices in 3D.

• By minimizing structure overlap, 3D optimally demonstrates masses and architectural distortion.
Reader Study #1

- Pooled ROC Curves for 12 Readers

- Significant increase in performance
  60% increased to 78%
Reader Study 2

- Pooled ROC Curves for 15 Readers
- Identical Results from 2 independent reader studies
- Significant increase in performance
  
  60% increased to 76%
Reader Study 1 & Reader Study 2
Pooled ROC Curves

• Pooled ROC Curves for 2 Reader Studies

• Almost complete overlap between the two studies
Pooled ROC Results

With three points to illustrate trade off between cancer detection and recall rate changes

<table>
<thead>
<tr>
<th>Cancer Detection Increase</th>
<th>Recall Rate Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>16%</td>
<td>0%</td>
</tr>
<tr>
<td>8%</td>
<td>-25%</td>
</tr>
<tr>
<td>0%</td>
<td>-40%</td>
</tr>
</tbody>
</table>

AUC diff 0.072, p-value 0.0001
Reader Study 2: Pooled ROC Curves

Reader Study 2 added a 3D MLO view

Increased sensitivity and decreased recall rate
Performance in Dense Breasts

Tomo improved ROC performance in fatty breasts
In dense breasts, ROC performance increased 3X that of fatty

Conclusion: Tomo useful in fatty breasts, more useful in dense breasts
What are the benefits of Combo-mode *

• The ROC analysis demonstrated that 2D plus 3D is **superior** to 2D alone
• The ROC results showed that for a given sensitivity, the **recall rate should be lower** using tomosynthesis
• The ROC results showed that at a given recall rate, **sensitivity should be higher** using tomosynthesis
• The ROC analysis demonstrated that the **performance of all participating radiologists improved**, regardless of experience

None of these statements could be said for the transition from Analog to Digital Mammography...

* The Hologic Selenia Dimensions clinical studies presented to the FDA as part of Hologic’s PMA submission that compared Hologic’s Selenia Dimensions combo-mode to Hologic 2D FFDM
Tomosynthesis Technology

Putting it all together
The technology behind tomosynthesis

• Underlying technologies
  – Digital detectors
  – X-ray unit
  – Reconstruction algorithms
  – Image Display
Engineering constraints

- Total radiation dose
- Imaging time
- Patient motion
- Detector performance
- Detector motion
- Ability to image entire breast
- Need to provide for biopsy of lesions only detected by DBT
## Design Approach

<table>
<thead>
<tr>
<th>Design Aspect</th>
<th>Parameters</th>
</tr>
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<tbody>
<tr>
<td>Arc of movement</td>
<td>(11 – 60 Degrees)</td>
</tr>
<tr>
<td>Number of projections</td>
<td>(9 – 25)</td>
</tr>
<tr>
<td>Exposure</td>
<td>Continuous or pulsed</td>
</tr>
<tr>
<td>Detector</td>
<td>Fixed or moved</td>
</tr>
<tr>
<td>Exposure parameters</td>
<td></td>
</tr>
<tr>
<td>Total Dose</td>
<td></td>
</tr>
<tr>
<td>Effective size of pixels</td>
<td></td>
</tr>
<tr>
<td>X-ray source / filter</td>
<td></td>
</tr>
<tr>
<td>Single or binned pixels</td>
<td></td>
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<tr>
<td>Patient position</td>
<td></td>
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IMAGE GENERATION
Projection of Objects in Breast
Reconstruction Algorithms

- Shift-and-add
- Tuned Aperture CT
- Matrix Inversion
- Filtered back projection (FBP)
- Maximum likelihood reconstruction (ML)
- Simultaneous algebraic reconstruction (SART)
- Gaussian frequency blending (GFB)
- Voting strategy
Basic Principle of Slice Recon

Shift each projection left or right then add to get the plane
Basic Principle of Slice Recon

Shift each projection left or right then add to get the plane

Add shifted images to get final slice image
Basic Principle of Slice Recon

Shift each projection left or right then add to get the plane

Shift Left

No Shift

Shift Right

Add shifted images to get final slice image
Shift and Add

Park J M et al. Radiographics 2007;27:S231-S240
Image Display

- Single Slice
- Slab Recon
  - Arithmetic
  - Geometric
  - Cubic
  - Other?
- MIP
MIP of slices showing Calcifications
MIP of slices showing speculated lesions
Clinical Image TOC

- Better Visualization

- Recall Reduction
  - Tissue superimposition – mimicking Cancer

- Invasive Ductal Carcinoma (IDC)

- Micropapillary type Ductal Carcinoma

- Metastasis from endometrioid carcinoma

- Artifacts
Images and data courtesy of:

- Hôpital Privé d’Antony, Paris France
- Massachusetts General Hospital, Boston MA USA
- Netherlands Cancer Institute – Antoni Van Leeuwenhoek Hospital, Amsterdam Holland
- Centre de Radiologie et d’Echographie du Docteur Joussier, Paris France
- Dartmouth Hitchcock Medical Center, Lebanon NH USA
- Magee Women’s Hospital, Pittsburgh PA USA

Slides courtesy of:
- Andy Smith, Ph.D. Hologic, Inc
Better Visualization Example 1
A 2D Mammography Image
A suspicious area in a 2D Mammography Image
The 2D Mammography Image next to one slice of a 3D Image Set

The Difference is Clear
Recall Reduction
Superimposed Tissue Examples
A 2D Mammography Image with a suspicious area next to a 3D image set.
Stepping thru the image set, shows that the suspicious area is nothing more than normal breast structures overlapping.
Recall Reduction – Superimposed Tissue (Case 2)
Invasive Ductal Carcinoma (IDC)
Micropapillary type ductal carcinoma in situ in 65 y/o woman

Adjacent ductal extension

Park J M et al. Radiographics 2007;27:S231-S240

Movie 3
Metastasis from endometrioid carcinoma in 59 y/o woman

3 primary masses (see arrows)

Mass not seen on FFDM

Park J M et al. Radiographics 2007;27:S231-S240
Artifacts
Artifacts due to large Calcification

Artifact from large calcification (white arrow)

On basis of US appearance Mass Dx as Cyst

Park J M et al. Radiographics 2007;27:S231-S240
Needle Artifact

Z = 6mm

Z = 24mm

Z = 42mm

Large Calcification Artifact

Small Calcification Artifact

## Tomosynthesis Status

- Hologic tomosynthesis FDA approved
- Tomosynthesis considered a new modality by FDA
- New modalities require 8 hours of training prior to doing unit surveys.

### Other Companies working on DBT
- GE
- Siemens
- Philips (Sectra)
- Planmed
- Giotto
Hologic Tomosynthesis Unit

- 15 projections over 15 degrees continuous arc – 3.7 ms scan
  - Rule of thumb is one projection per degree
  - Reduces artifacts from calcification
  - Provides better visualization of spiculations and masses
- During projections, detector moves 5 degrees about CR
  - Angulation corrected in reconstruction
- Using back projection reconstruction because it’s faster
  - Most important are reconstruction filters
- Pixels binned to 140 microns/recon to 95
- Slice thickness of 1mm
GE Tomosynthesis

• Collect 9 projections over 25 degrees
• Use step and shoot exposures
• Reconstruct 0.5 to 1.0 mm slices
• Bin them into 1 cm slabs (overlap 0.5 cm)
• Goal to do screening with MLO view only
  – Use dose equivalent to CC or MLO
• Preparing to submit for FDA approval
Siemens Tomosynthesis

- Collect 25 projections over 50 degrees
- Use step and shoot exposures
- 85 um aSe detector
- Reconstruct to 1 mm slices
Philips (Sectra) Tomosynthesis

One single scan with continuous read-out of the detector to obtain 3D data
Each detector line will obtain data from a different angle

- Photon Counting Detector
- Move axis of rotation pivot point under detector for 3D
Giotto DBT Projections

-20°  0°  +20°
“Coming Attractions”

- New X-ray tube Technology
- Contrast Enhanced DM
- Dual Energy Contrast Enhanced DM
- Spectral Imaging vs. Dual Energy
- Multi-modality Imaging
Carbon Nanotube X-ray Prototype
Contrast Enhanced Digital Mammography- CEDM

- GE Senobright
- FDA approved for sale in the US
- Change filter and algorithms only
- No hardware change required
- Haven’t found uptake kinetics clinically helpful
- Dose 20% higher-1.5 mGy/view
Temporal CEDM

- 3-7 images at high kVp (45-49)
- Dose/image typically 5x lower compared to standard MX
- Mask image before injection

Images courtesy of Dr Diekmann
Charité – Berlin, Germany

Technique:
Mo/Cu, 45kV, 100mAs

$t = 0s$  $t = 60s$  $t = 120s$  $t = 180s$

$T_{60} - T_0$  $T_{120} - T_0$  $T_{180} - T_0$
Temporal CEDM

Case
62 year-old

Physical examination
Non palpable lesion

Mammography
- 1 stellate opacity
- 1 round opacity

Conventional Mammograms

Images courtesy of Dr Dromain, Institut Gustave Roussy – Villejuif, France
Dual Energy CEDM

- 1 image at low kVp, 1 image at high kVp (45-49)
- low kVp image just before high kVp image

Images courtesy of Dr Dromain, Institut Gustave Roussy – Villejuif, France
Case 4

Physical examination
Normal

Mammography
Small mass only visible on CC view
- Low confidence of presence
- Global classification BIRADS 3

Ultrasonography
normal
(performed by referring physician)

Images courtesy of Dr Dromain, Institut Gustave Roussy – Villejuif, France
Spectral Imaging vs Dual-Energy

Spectral imaging:
dual exposures

Photon-counting:
single exposure

Non-overlapping spectra ⇒ better tissue cancellation
Concentrated around K-edge ⇒ improved I-contrast
Spectral imaging an alternative to MR?
Ultrasound / X-ray Data Fusion

Sagittal US

Mammogram

Axial US

Coronal US
Acknowledgements

Thanks for input from:

- Hologic
- GE Healthcare
- Siemens Healthcare
- Philips Healthcare
- Giotto
- Tao Wu, Ph.D.
- Andy Smith, Ph.D.
Thank you for your attention
Don’t let the Sharks BITE!!
Just the Sail Fish
HAVE A WONDERFUL DAY!!
QUESTIONS ??

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