Breast Tomosynthesis

Bob Liu, Ph.D.
Department of Radiology
Massachusetts General Hospital
And
Harvard Medical School
Physics aspects of breast tomosynthesis

Quality control of breast tomosynthesis
Limitation of 2D mammography

Performance of 2D Mammography

✓ Sensitivity: 83.55 Good but not ideal.
✓ Specificity: 90.9%

The root cause?

✓ The radiation dose? No. wide dose range in use.
✓ The detector resolution? No. SF resolution more than enough.
✓ The detector dynamic range? No. SF & DM difference small.
✓ The structure noise due to tissue overlaps? Yes
Limitation of 2D systems and solutions

Effects of structure noise

Solution: Tomographic imaging

- Digital Breast Tomosynthesis (DBT)
- Breast CT (BCT)
- Breast MRI
- ...

For a screening modality, it must be low cost, low dose, fast, efficient ... DBT may be the only option
Digital Breast Tomosynthesis

Scan: N projections

New variable affecting IQ
- tube/detector/patient motion
- range of rotation
- number of projections
- scatter intensity

Reconstruction: M slices

New variable affecting IQ
- incomplete data in f space
- selection of recon kernel
- geometric calibration
DBT Performance

Resolution:
- x-y plane: ~ DM (motion/pixel binning/geo calibration/recon)
- z-direction: ~ 1 mm (limited data in f space)

Calcification detection:
- Conflicting reports (DBT better if no detector pixel binning)
- 2D image is required for Hologic for better cal. visualization

Mass detection:
- sensitivity and specificity improved, recall rate dropped
DBT Performance

Artifacts:

High density objects in multiple slices (due to limited sampling)

Dose (ACR phantom, Hologic DBT):

Combo (DBT+2D) acquisition: \( \sim 2.2 \times DM \)
DBT acquisition with synthetic 2D: \( \sim 1.2 \times DM \)

Workflow:

\( \sim DM \), reading time longer

Cost:

\( \sim 2 \times DM + \) cost for more storage
## Characteristics of DBT Systems

<table>
<thead>
<tr>
<th></th>
<th>GE Essential Hologic Selenia Dimensions</th>
<th>IMS Giotto TOMO</th>
<th>Planmed Nuance Excel DBT</th>
<th>Siemens MAMMOMA T Inspiration</th>
<th>Philips MicroDose</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>X-ray tube target</strong></td>
<td>Mo/Rh</td>
<td>W</td>
<td>W</td>
<td>W</td>
<td>W</td>
</tr>
<tr>
<td><strong>X-ray tube filters</strong></td>
<td>Mo/Rh</td>
<td>Al</td>
<td>Rh/Ag</td>
<td>Rh/Ag</td>
<td>Rh</td>
</tr>
<tr>
<td><strong>X-Ray Tube motion</strong></td>
<td>Step&amp;shoot</td>
<td>Continuous</td>
<td>Step&amp;shoot</td>
<td>Continuous</td>
<td>Continuous</td>
</tr>
<tr>
<td><strong>Detect type</strong></td>
<td>CsI-Si</td>
<td>a-Se</td>
<td>a-Se</td>
<td>Csi-a-Si</td>
<td>a-Se</td>
</tr>
<tr>
<td><strong>Detector size (cm)</strong></td>
<td>24x30</td>
<td>24x29</td>
<td>24x30</td>
<td>24x30</td>
<td>24x30</td>
</tr>
<tr>
<td><strong>Detector pixel (µm)</strong></td>
<td>100</td>
<td>70/140</td>
<td>85</td>
<td>85</td>
<td>85</td>
</tr>
<tr>
<td><strong>Detector motion</strong></td>
<td>Static</td>
<td>Rotating</td>
<td>Static</td>
<td>Rotating</td>
<td>Static</td>
</tr>
<tr>
<td><strong>Air gap (cm)</strong></td>
<td>2.2</td>
<td>2.5</td>
<td>2.2</td>
<td>2.38</td>
<td>1.7</td>
</tr>
<tr>
<td><strong>Grid</strong></td>
<td>Trial</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td><strong>Angular range (deg)</strong></td>
<td>25</td>
<td>15</td>
<td>40</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td><strong>Number of projections</strong></td>
<td>5</td>
<td>15</td>
<td>13</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td><strong>Scan time (s)</strong></td>
<td>7</td>
<td>3.7</td>
<td>12</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td><strong>Reconstruction</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Optimization of DBT System

Phantoms:

- Uniform background with embedded features (ACR)
- Anthropomorphic phantom (CIRS)
- Mathematic phantom

Figure of Merit (FOM):

- MTF/DQE
- CNR, CNR/MGD, CNR/ASFW
- Signal difference noise ratio (SDNR)
Optimization of DBT

X-Ray sources:
- Target: Mo/Rh/W, more systems with W
- Filter: Mo/Rh/Ag/Al
- kVp: up to 49 (> DM)
  
  High output is desirable for short acquisition time and contrast is enhanced by structure noise reduction, for same breast thickness, higher kVp is used in DBT

X-Ray Detectors:
- Material: CsI-Si (indirect), a-Se (direct)
- Minimal lag and ghosting
- Fast reading time
- May be running in the binning mode to speed up data acquisition

X-Ray Grid
- Not use with most DBT, GE is developing one for DPT
- Primary ray may be cutoff
- Dose may be double
Optimization of DBT

X-Ray tube motion:
  - Step-and-Shoot: no focal spot motion blurring, but longer $t$
  - Continuous: focal spot motion blurring, but short $t$

Angular range: $\alpha$
  - Large $\alpha$ → better $z$-resolution,
  - Large incident angle → lower detector MTF and DQE for high $f$ signal
  - Large incident angle → more attenuation
  - Optimal: 45 - 60 degree

# of projections: $N$
  - For fixed $\alpha$, IQ improves as $N$ increases until $N$ reaches a certain #
  - High $N$ → higher noise in projection images
  - Optimal: 15-20
QC of DBT System

There is no QC standard for all DBT systems.

Follow Equipment Vendor’s QC manual

The Hologic QC manual MAN-01965 covers:
- Selenia Dimensions 2D FFDM system
- Selenia Dimensions DBT system
Selenia Dimensions: Image Acquisition Modes

1. 2D Only
2. DBT Only
3. Combo: Tomo + 2D under the same compression

! AEC is calibrated independently for each mode
### Selenia Dimensions: Specifications

#### Conventional 2D Imaging
- a-Se detector, 24×29 cm area
- 70 µm pixel size
- Rh and Ag filters
- HTC grid in contact mode; No grid in magnification mode

#### DBT Imaging
- a-Se detector, 24×29 cm area
- 140 µm pixel size (2x2 binning)
- Al filter
- 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

### Approved screening protocol for each breast:
- One CC view DBT and one CC view 2D
- One MLO view DBT and one MLO view 2D
### Selenia Dimensions QC Tests (MP)

<table>
<thead>
<tr>
<th>Quality Control Test</th>
<th>2D</th>
<th>3D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mammographic Unit Assembly Evaluation</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Collimation Assessment</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Artifact Evaluation</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>kVp Accuracy and Reproducibility</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Beam Quality Assessment — HVL</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Evaluation of System Resolution</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Automatic Exposure Control (AEC) Function Performance</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Entrance Exposure, AEC Reproducibility, and Dose</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Radiation Output Rate</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Phantom Image Quality Evaluation</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Signal-To-Noise and Contrast-To-Noise Measurements</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Diagnostic Review Workstation Quality Control</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Detector Ghosting (Troubleshooting Use Only)</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>
FDA approved screening protocol

For each breast:

- One CC view DBT
- One CC view 2D
- One MLO view DBT
- One MLO view 2D

2D image can be acquired

  - In the combo mode
  - Generated from DBT images with C-view software
QC Test: Dose

Objective:
To assess ESE and AGD

Test Method
- Measured ESE of ACR phantom in 2D or DBT or combo mode
- Calculate AGD using the ESE to AGD tables in the manual

Performance criteria:
- 2D: \( \text{AGD} < 3 \text{ mGy}. \)
- DBT: \( \text{AGD} < 3 \text{ mGy} \)
- Combo: \( \text{AGD} < 3 \text{ mGy} \) (can be very close to 3 mGy!)
QC Test: Artifact Evaluation

Objective:
To assess the degree and the source of artifacts

Test Method:
- Acquire projection images with 4 cm acrylic block.
- Check artifacts in the 0 degree projection image.
- Artifacts due to reconstruction is not evaluated.

Performance criteria:
Similar to DM.
QC Test: System Resolution

Objective:

To assess the limiting spatial resolution of the system

Test Method:

- Acquire 2D and DPT images of line pair pattern over 4 cm acrylic
- Determine the highest frequency line resolved in 2D image
- Determine the highest frequency line resolved in focal slice of DBT image set

Performance criteria:

- 2D: 7 lp/mm must be resolved
- DBT: 3 lp/mm must be resolved.
Objective:
To assess the quality and consistency of images

Test Method
- Acquire ACR phantom image in Combo or DBT mode
- Determine the score of fibers, specks and masses in 2D image
- Determine the score of fibers, specks and masses in the focal slice

Performance criteria:
Passing score:
2D: 5 fibers, 4 speck groups and 4 masses.
DBT: 4 fibers, 3 speck groups and 3 masses
For Hologic Dimensions DBT, the measured high contrast resolution in reconstructed slices is typically lower than that measured in 2D mode. Which one of the followings is not the possible reason?

1. X-ray source motion
2. Patient motion
3. Detector pixel binning
4. Al filter used in tomo mode
5. Inaccurate geometric calibration
Answer: 4.

Al filter used in tomo mode

Explanation:
The filter will change the shape of x-ray spectrum, may affect HVL, dose and contrast, but not affect system resolution.

Reference:
For fixed angle range and total mAs, too many projections may degrade the image quality, because

1. Too many points will be in frequency space
2. Acquisition time will be longer
3. Dose will be higher
4. Projection image will be very noisy
5. X-ray tube will be too hot
Answer: 4

Projection image will be very noisy

Explanation:

If there are too many projections, mAs for each projection can be very low, the projection image will be very noisy.

Reference:
For Hologic Dimensions, the total mean glandular dose to ACR mammographic Accreditation phantom in the combo mode (2D+DBT) must not exceed

1. 6 mGy
2. 3 mGy
3. 4.5 mGy
4. 2.5 mGy
5. 3.5 mGy
Answer: 2

3 mGy

Explanation:

Specified in Selenia Dimensions QC manual

Reference:

Selenia Dimensions QC Manual MAN-01965, rev. 007 page 44
Other Optional Tests

✓ Ghosting

✓ Artifacts for reconstructed images

✓ Z-resolution

✓ ...
Thank You!