Innovations and Applications of Tomosynthesis

Andrew D. A. Maidment, Ph.D.
University of Pennsylvania
Department of Radiology
Acknowledgements of Support

- Grant support from the Komen Foundation, DOD, NIH, and Hologic.
- Dr. Maidment is a scientific advisor to and shareholder of Real Time Tomography, LLC.
- Dr. Maidment is a member of the Scientific Advisory Board of Gamma Medica, Inc.

FDA Statement

- This presentation will include off-label uses and applications and devices not yet approved for human use in the United States.
Tomosynthesis Pedigree
Linear Tomography
Simple Tomosynthesis

Acquisition geometry

Backprojection image formation
Computed Tomography
Tomosynthesis Reconstruction

Sampling geometry

- sampling is incomplete (in Fourier space)
- approximative inversion only
- artifacts
B.3 - 3D spatial frequency domain

CT
Modern Multi-slice VCT scanners have nearly isotropic response with maximum spatial frequencies of .8 to 1.0 cycles/mm

Courtesy M Flynn
B.3 - 3D spatial frequency domain

**TS vs CT**
Unsampled frequencies along the $\omega_y$ axis make TS and CT complimentary.

Courtesy M Flynn
Images Courtesy J. Boone
Tissue Imaging

Angular Spacing, $\Delta \theta = 2^\circ$

Courtesy M.J. Yaffe
Dose Determines Lesion Detectability

For an ideal detector, the dose for tomosynthesis should be equal to or less than the dose for digital mammography.
Determinants of Dose

X-ray Beam Quality
- kVp
- Filtration
- Total mAs

Angular Exposure
- Change in SID
- Collimation
- Dose Depth Dependence

Projection Factors
- Number of projections
- mAs per projection
- Technical Limitations (det./gen.)
Tomosynthesis

Mammogram

Breast CT
Clinical applications

- Breast
- Chest
- Muskuloskeletal
- Head and Neck
- Angiography
- Dental imaging
- Radiation therapy
Breast Imaging
Hologic Selenia Dimensions Tomosynthesis

- 2D and 3D Imaging under same compression
- W Tube with Rh, Ag and Al Filtration
- 15 degree continuous sweep, 15 images, 3.7 s acquisition
- 200 mA generator, 0.1/0.3 mm focal spot
- 70 cm source-to-detector distance
- Retractable High Transmission Cellular grid
- 24 x 29 cm Selenium Direct Detector, 70 μm pixels
GE Senoclaire Tomosynthesis

- 2D or 3D Imaging under one compression
- Mo/Rh Tube with Mo and Rh Filtration
- 15 degree step and shoot sweep, 9 images, 9 s acquisition
- Grid to reduce scatter
- 24 x 30 cm CsI Indirect Detector, 100 \( \mu \)m pixels
- Iterative Reconstruction
Siemens Mammomat Inspiration
With True-Breast Tomosynthesis

- Mo/W Tube with Mo and Rh Filtration
- 50 degree continuous sweep, 25 images, 25 s acquisition
- Retractable grid, with optional digital scatter removal software (mammo)
- 24 x 30 cm Selenium Direct Detector, 85 μm pixels
Case 1:
Potential to reduce false-negative diagnoses

Invasive Carcinoma

Tomosynthesis Slice (Z = 24mm)

Invasive Carcinoma

Courtesy of Tao Wu, Ph.D.
Tomosynthesis Mammography Reconstruction Using a Maximum Likelihood Method
Invasive Ductal Carcinoma

Images courtesy of Dr. Jelle Teertstra
NKI-AVL, The Netherlands
Case 2:
Potential to reduce false-positive diagnoses

Courtesy of Tao Wu, Ph.D.
Case 2:
Potential to reduce false-positive diagnoses

Z = 0 mm
Z = 10 mm
Z = 15 mm
Z = 20 mm
Z = 25 mm
Z = 30 mm
Z = 35 mm
Z = 40 mm
Pooled ROC curves for 2 reader studies

Using probability of malignancy scores; curves represent average ROC performance for 12 readers in study 1 and 15 in study 2.

Recall rates for individual readers

Non-Cancers

Cancers

Recall Rates (Average of Readers)

<table>
<thead>
<tr>
<th>Case Type</th>
<th>Reader Study</th>
<th>DM</th>
<th>DM plus Tomo</th>
<th>DM</th>
<th>DM plus Tomo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Cancer</td>
<td>1</td>
<td>55.1%</td>
<td>22.3% - 79.8%</td>
<td>16.3%</td>
<td>16.7%</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>48.8%</td>
<td>28.2% - 69.1%</td>
<td>12.3%</td>
<td>30.1%</td>
</tr>
<tr>
<td>Cancer</td>
<td>1</td>
<td>87.2%</td>
<td>77.0% - 100%</td>
<td>6.5%</td>
<td>80.4%</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>84.8%</td>
<td>76.0% - 92.2%</td>
<td>6.1%</td>
<td>85.7%</td>
</tr>
</tbody>
</table>


©2012 by Radiological Society of North America
University of Pennsylvania

2010: 2D Mammo

Sept 2010-Sept 2011: 10814 patients

Call-Back Rate: 10.33%

Cancer Detection Rate: 4.25/1000

2011: Combo-Tomo

Sept 2011-Sept 2012: 11115 patients

Call-Back Rate: 8.77%

Cancer Detection Rate: 5.58/1000

Courtesy Emily Conant,
Group Call-Back Rates (CBR) by Month

Courtesy Emily Conant,
Cancer Detection Rate (cancers/1000)

Courtesy Emily Conant,
CBRs pre and post Tomo implementation

Courtesy Emily Conant,
Tomosynthesis Screening Outcomes

• **Individual CBR varied significantly**
  - 2010-11 (pre-tomo): from 5.5 to 15.5%
  - 2011-12 (post-tomo): from 4.4 to 12.2%

• **All Readers reduced their CBR**
  - Reduction was not based on initial CBR or years in experience

• **Group CBR went from 10.33 to 8.7%**
  - Largest reduction was from 8.5% to 5.8% (=31.2%)
  - Smallest reduction was from 12.6% to 12.2% (=3.8%)

*When controlled for variable reader volumes, OR = 1.24 (p=0.004)*

*Therefore, the call-back rate decreased by 24% with DBT*
<table>
<thead>
<tr>
<th>Radiologist</th>
<th>Years of Experience*</th>
<th>False-Positive Rate†</th>
<th>Cancer Detection Rate‡</th>
<th>No. of Known Cancers¶</th>
<th>Detected Cancers (%)§</th>
<th>No. of Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
<td>110.7 (80)</td>
<td>6.9 (5)</td>
<td>6</td>
<td>83.3</td>
<td>723</td>
</tr>
<tr>
<td>2</td>
<td>21</td>
<td>62.2 (175)</td>
<td>4.6 (13)</td>
<td>24</td>
<td>54.2</td>
<td>2812</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>83.3 (131)</td>
<td>4.5 (7)</td>
<td>12</td>
<td>58.3</td>
<td>1573</td>
</tr>
<tr>
<td>4</td>
<td>31</td>
<td>39.5 (64)</td>
<td>11.1 (18)</td>
<td>24</td>
<td>75.0</td>
<td>1622</td>
</tr>
<tr>
<td>5</td>
<td>29</td>
<td>45.2 (106)</td>
<td>4.7 (11)</td>
<td>19</td>
<td>57.9</td>
<td>2346</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
<td>53.8 (78)</td>
<td>6.2 (9)</td>
<td>15</td>
<td>60.0</td>
<td>1451</td>
</tr>
<tr>
<td>7</td>
<td>20</td>
<td>71.8 (67)</td>
<td>4.3 (4)</td>
<td>5</td>
<td>80.0</td>
<td>933</td>
</tr>
<tr>
<td>8</td>
<td>6</td>
<td>60.3 (70)</td>
<td>8.6 (10)</td>
<td>16</td>
<td>62.5</td>
<td>1161</td>
</tr>
<tr>
<td>All</td>
<td></td>
<td>61.1 (771)</td>
<td>6.1 (77)</td>
<td>121</td>
<td>63.6</td>
<td>12621</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Radiologist</th>
<th>Years of Experience*</th>
<th>False-Positive Rate†</th>
<th>Cancer Detection Rate‡</th>
<th>No. of Known Cancers¶</th>
<th>Detected Cancers (%)§</th>
<th>No. of Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
<td>73.6 (46)</td>
<td>11.2 (7)</td>
<td>8</td>
<td>87.5</td>
<td>625</td>
</tr>
<tr>
<td>2</td>
<td>21</td>
<td>68.3 (119)</td>
<td>7.5 (13)</td>
<td>15</td>
<td>86.7</td>
<td>1743</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>55.3 (82)</td>
<td>4.7 (7)</td>
<td>9</td>
<td>77.8</td>
<td>1483</td>
</tr>
<tr>
<td>4</td>
<td>31</td>
<td>44.4 (78)</td>
<td>5.1 (9)</td>
<td>10</td>
<td>90.0</td>
<td>1758</td>
</tr>
<tr>
<td>5</td>
<td>29</td>
<td>52.7 (147)</td>
<td>13.3 (37)</td>
<td>43</td>
<td>86.0</td>
<td>2790</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
<td>50.6 (71)</td>
<td>5.7 (8)</td>
<td>14</td>
<td>57.1</td>
<td>1402</td>
</tr>
<tr>
<td>7</td>
<td>20</td>
<td>52.4 (71)</td>
<td>8.9 (12)</td>
<td>14</td>
<td>85.7</td>
<td>1355</td>
</tr>
<tr>
<td>8</td>
<td>6</td>
<td>38.2 (56)</td>
<td>5.5 (8)</td>
<td>8</td>
<td>100.0</td>
<td>1465</td>
</tr>
<tr>
<td>All</td>
<td></td>
<td>53.1 (670)</td>
<td>8.0 (101)</td>
<td>121</td>
<td>83.5</td>
<td>12621</td>
</tr>
</tbody>
</table>
Pooled ROC by Lesion Type

Calcifications

Non-calcified

Area under the ROC curve

<table>
<thead>
<tr>
<th>Case Type</th>
<th>Reader Study</th>
<th>DM†</th>
<th>DM plus† Tomo</th>
<th>Difference</th>
<th>p-value</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcification</td>
<td>1</td>
<td>80.4</td>
<td>84.0</td>
<td>3.5</td>
<td>0.073</td>
<td>-0.4, 7.4</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>81.7</td>
<td>83.1</td>
<td>1.4</td>
<td>0.082</td>
<td>-0.2, 2.9</td>
</tr>
<tr>
<td>Non-Calcification</td>
<td>1</td>
<td>80.7</td>
<td>91.2</td>
<td>10.4</td>
<td>&lt;0.001</td>
<td>4.7, 16.1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>84.2</td>
<td>93.0</td>
<td>8.8</td>
<td>&lt;0.001</td>
<td>5.1, 12.5</td>
</tr>
</tbody>
</table>


©2012 by Radiological Society of North America
ROC curves for average probability of malignancy

Masses

Sensitivity (TPF)

1−Specificity (FPF)

Conventional (AUC=0.83)

Tomosynthesis (AUC=0.87)


©2012 by Radiological Society of North America
Digital mammography image of an invasive ductal carcinoma.

Tomosynthesis image of an invasive ductal carcinoma.

Pooled ROC by Lesion Type

Calcifications

Non-calcified

Area under the ROC curve

<table>
<thead>
<tr>
<th>Case Type</th>
<th>Reader Study</th>
<th>DM†</th>
<th>DM plus‡</th>
<th>Difference</th>
<th>p-value</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcification</td>
<td>1</td>
<td>80.4</td>
<td>84.0</td>
<td>3.5</td>
<td>0.073</td>
<td>-0.4, 7.4</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>81.7</td>
<td>83.1</td>
<td>1.4</td>
<td>0.082</td>
<td>-0.2, 2.9</td>
</tr>
<tr>
<td>Non-calcification</td>
<td>1</td>
<td>80.7</td>
<td>91.2</td>
<td>10.4</td>
<td>&lt;0.001</td>
<td>4.7, 16.1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>84.2</td>
<td>93.0</td>
<td>8.8</td>
<td>&lt;0.001</td>
<td>5.1, 12.5</td>
</tr>
</tbody>
</table>


©2012 by Radiological Society of North America
Visualization of micro-calcifications

Conventional mammography:
- Clustered $\mu$Ca are projected onto a 2-D plane.
- The pattern of $\mu$Ca distribution is obvious.
- The pattern of $\mu$Ca distribution contains important diagnostic information.

Simulated pattern of clustered $\mu$Cas (Pattern: Big Dipper and Pole Star)

Distribution along z-direction
The pattern of μCa cluster is lost.
Visualization of micro-calcifications

“Slab View” for showing clustered μCa:
- Combine multiple slices into a “slab”
- Maximum intensity projection (MIP) within the slab
- Slide the “slab window” through the reconstruction
Visualization of micro-calcifications

DBT reconstruction (1 mm slice)
Visualization of micro-calcifications

Slab View: 10 mm slab
Average Glandular Dose in Digital Mammography and Breast Tomosynthesis

Mittlere Parenchymdosis bei der digitalen Mammografie und der Brusttomosynthese

Authors
T. Olgar¹, ², T. Kahn¹, D. Gosch²

Affiliations
¹ Faculty of Engineering, Department of Engineering Physics, Ankara University
² Klinik und Poliklinik für Diagnostische und Interventionelle Radiologie, Universitätsklinikum Leipzig Ä&R

2D: AGD 1.61 mGy
3D: AGD 2.22 mGy

Average Breast Thickness – 55 mm
Results – MGD and Thickness & Glandularity

**Digital Mammography:**
- MGD is dependent on both thickness and glandularity ($p<0.001$)

**Tomosynthesis:**
- MGD is dependent on thickness ($p<0.001$) but not glandularity ($p=0.11$)
2D vs 3Ds

Hologic FDA data:
- 302 subjects
- 15 readers
- 3Ds superior to 2D alone
- $\Delta$AUC = 0.04 (p=0.005)
- Recall Rate reduced by 30.2%

<table>
<thead>
<tr>
<th>Mode</th>
<th>FFDM Views</th>
<th>DBT Views</th>
<th>Synthesized Views</th>
<th>Exam Dose per Breast</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFDM</td>
<td>MLO + CC</td>
<td>-</td>
<td>-</td>
<td>2.4 mGy</td>
</tr>
<tr>
<td>FFDM + 3D MLO</td>
<td>MLO + CC</td>
<td>MLO</td>
<td>-</td>
<td>3.85 mGy</td>
</tr>
<tr>
<td>FFDM + DBT</td>
<td>MLO + CC</td>
<td>MLO + CC</td>
<td>-</td>
<td>5.3 mGy</td>
</tr>
<tr>
<td>DBT + Synthesized 2D</td>
<td>-</td>
<td>MLO + CC</td>
<td>MLO + CC</td>
<td>2.9 mGy</td>
</tr>
</tbody>
</table>
Other Issues

- Reimbursement
- Computer-aided diagnosis (CAD)
- Automated density estimation (Quantra)
- Tomo-guided procedures
Thoracic Imaging
• Computer-controlled tube mover
• GE flat-panel detector
• Matrix inversion tomosynthesis reconstruction algorithm (Duke)
Digital Tomosynthesis

Conventional tomography

Tomosynthesis

Images Courtesy J. Dobbins
Routine follow-up; history of breast Ca with right partial mastectomy

20-degree tube angle, 61 projection images, 5 mm slice spacing
Total tomo exposure ≈ Lateral image exposure (screen film)

8 mm nodule
Analysis of the impact of digital tomosynthesis on the radiological investigation of patients with suspected pulmonary lesions on chest radiography

Emilio Quaia et al.

*Eur. Radiol* 2012

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Dose (in mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CXR</td>
<td>0.06 (0.03 – 0.10)</td>
</tr>
<tr>
<td>Tomosynthesis</td>
<td>0.11 (0.09 – 0.12)</td>
</tr>
<tr>
<td>CT</td>
<td>3.0 (2-4)</td>
</tr>
</tbody>
</table>

Clinical Study of 339 Patients

Tomosynthesis is almost 30 times lower dose than CT
Pulmonary Mycobacterial Disease: Diagnostic Performance of Low-Dose Digital Tomosynthesis as Compared with Chest Radiography

<table>
<thead>
<tr>
<th>Purpose:</th>
<th>To compare the diagnostic performance of a low-radiation-dose digital tomosynthesis (DTS) technique with that of conventional radiography in the detection of lung lesions in patients with pulmonary mycobacterial disease.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials and Methods:</td>
<td>The institutional review board approved this study, and all patients provided informed consent. In this study, 100 patients (65 study patients, 35 control patients) underwent multidetector computed tomography (CT), chest radiography, and low-dose DTS (effective doses: 3.4, 0.02, and 0.05 mSv, respectively). Two radiologists evaluated radiographs and DTS images for the presence of parenchymal lesions and the number of cavities in each patient; CT served as the reference standard. Wilcoxon signed rank and McNemar tests and $\kappa$ statistics were used.</td>
</tr>
<tr>
<td>Results:</td>
<td>The accuracies of DTS and radiography in depicting mycobacterial disease were 97% and 89%, respectively, for observer 1 ($P = 0.039$) and 95% and 93%, respectively, for observer 2 ($P = 0.031$). The accuracies of DTS and radiography in depicting each lesion type were, respectively, 95% and 77% for bronchiolitis, 92% and 70% for nodules, 80% and 70% for consolidation, and 93% and 70% for cavities. Interobserver agreement with DTS ($\kappa = 0.62-0.94$) was superior to that with radiography ($\kappa = 0.46-0.62$). Of a total of 141 cavities found with CT, means of 27 (19%) cavities at chest radiography and 108 (77%) cavities at DTS ($P &lt; 0.01$) were detected by the two observers.</td>
</tr>
<tr>
<td>Conclusion:</td>
<td>DTS performed with a low-dose technique is superior to radiography for the detection of lung lesions in patients with pulmonary mycobacterial disease.</td>
</tr>
</tbody>
</table>

- **Tuberculosis causes ~3 million deaths/yr globally**
- **Leading cause of death in HIV/AIDS population**
- **CXR is routinely used for detection but lacks both sensitivity and specificity**
- **Tomosynthesis showed statistically significant increase in sensitivity compared to CXR, without significant change in specificity**

*Radiol. 2010 257:269-277*
More Dose Studies

• M. Bath, *et al.*,  
  - RPD **139**: 144-152, 2010; RPD **139**: 153-158, 2010  
  - Clinical and simulation studies  
  - Ave. tomosynthesis dose: 0.13 mSv  
  - 2% of average Chest CT dose

• Y. Yamada, *et al.*,  
  - Inv. Radiol **46**: 471-477, 2011  
  - Monte Carlo simulation based on 120 patients  
  - Ave. tomosynthesis dose: 0.22 mSv
Muskuloskeletal Imaging
Muskuloskeletal Imaging

• Like radiology,
  – weight-bearing imaging is possible
  – multiple projections are necessary
  – new projections may be needed
  – Ideal for metal implants and hardware
  – Doses are relatively low

• Like CT,
  – Superposition is largely eliminated
B.1 - Sonialvision / Safire Tomosynthesis

- The Shimadzu Sonialvision / Safire system integrates the digital detector within a radiographic tilt table.

- Shown in the tilt position for a lateral knee tomosynthesis acquisition (60°), the detector translates up and the x-ray tube moves downward.

- The x-ray central beam is directed at the joint surface with an angle that varies from -20 to +20 degrees.
B.3 - Frozen Cadaver - Tibial Plateau

Nearly matched coronal planes from reformatted 3D CT (GE)

GE VCT

standard

Shimadzu TS
B.3 - Frozen Cadaver - Tibial Plateau

Nearly matched coronal planes from reformatted 3D CT (GE)

GE VCT

Shimadzu TS
Radiograph shows no obvious osteophyte in the right lateral femur (arrow).

Tomosynthesis demonstrates osteophyte

MRI also shows focal cartilage defect

B.3 - Proximal Femur - ? Fx

reformatted coronal planes
3D CT (GE VCT, 64)

Standard

Bone
Multiple TS views are often used to obtain detail in planes of different orientation.
B.3 - Reduced metal artifacts

Coronal CT

Coronal Tomosynthesis

Delayed Union, Femoral Fractures
63-year-old man with RA show three erosions (arrows) of the second metacarpophalangeal joint

Canella C et al. Radiology 2011;258:199-205
Other Tomosynthesis Dose Studies

Gislasson, King, Elbakri, and Reed, Winnipeg Children's Hospital:
- Tomosynthesis in pediatric spine, knee, facial, imaging
- 2-10 times dose of radiographic exam dose
- ~2-16% of CT exam dose
- Tomosynthesis dose less than total DR dose for some exams

R.E. Gazaille, M. Flynn et al. Henry Ford Hospital:
- Monte Carlo simulation of hip tomosynthesis
  0.24 mSv per view, (typical exam of 3 views)
- ~3-4 times dose of radiographic exam dose
- ~10% of CT exam dose

Hayashi, Guermazi et al. Boston University:
- Clinical study of bilateral knee imaging
  0.0072 mSv for DTS (~4X DR)

Mermuys et al.:
- Clinical study of detection of urinary stones
  0.85 mSv for DTS (~1.7 times DR, 7-34% of CT)

Canella et al. Lille FR:
- Clinical study of rheumatoid arthritis of the wrist
  0.1166 μSv (~2.6 times DR)


Hayashi et al., "Detection of Osteophytes and Subchondral Cysts in the Knee with Use of Tomosynthesis" Radiology 263:206–215, 2012


Head and Neck Imaging
Radiation dose of digital tomosynthesis for sinonasal examination: Comparison with multi-detector CT

Haruhiko Machida\textsuperscript{a, *}, Toshiyuki Yuhara\textsuperscript{a}, Mieko Tamura\textsuperscript{a}, Tomokazu Numano\textsuperscript{b}, Shinji Abe\textsuperscript{b}, John M. Sabol\textsuperscript{c}, Shigeru Suzuki\textsuperscript{d}, Eiko Ueno\textsuperscript{a}

\textsuperscript{a} Department of Radiology, Tokyo Women's Medical University Medical Center East, 2-1-10 Nishiogu, Arakawa-ku, Tokyo 116-8567, Japan
\textsuperscript{b} Department of Radiological Sciences, Tokyo Metropolitan University of Health Sciences, Tokyo 116-8551, Japan
\textsuperscript{c} GE Healthcare, 3000 North Grandview Blvd., Waukesha, WI 53188, USA
\textsuperscript{d} Department of Radiology, Saitama Red Cross Hospital, 8–3–30 Kamiochiai, Chuo-ku, Saitama 338-0001, Japan
Acute Maxillary Sinusitis

Tomosynthesis in upright position delineates air-fluid level in left maxillary sinus

Tomosynthesis Image

MDCT MPR Coronal Image

Tomosynthesis in upright position delineates air-fluid level in left maxillary sinus
<table>
<thead>
<tr>
<th>Tissue</th>
<th>MDCT (µGy)</th>
<th>DT (µGy)</th>
<th>MDCT/DT dose ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye</td>
<td>32,500 ± 2500</td>
<td>112 ± 6</td>
<td>290</td>
</tr>
<tr>
<td>Skin</td>
<td>20,000 ± 9300</td>
<td>1160 ± 2100</td>
<td>17</td>
</tr>
<tr>
<td>Submandibular gland</td>
<td>17,000 ± 2300</td>
<td>1400 ± 80</td>
<td>12</td>
</tr>
<tr>
<td>Brain</td>
<td>14,300 ± 2200</td>
<td>1770 ± 560</td>
<td>8</td>
</tr>
<tr>
<td>Thyroid gland</td>
<td>1230 ± 160</td>
<td>230 ± 90</td>
<td>5</td>
</tr>
</tbody>
</table>

- Sinusitis prevalence
  - 14% in general public
  - 32% in children
  - 31 million diagnosed each year

- CT is definitive
- CT lens dose is high (33 mGy)
- Cataractogenesis has a deterministic threshold of 0.5 Gy
Comparison of Clinical Dose

- 43 Patients
- X-ray (Caldwell and Water’s views)
- Single AP DTS acquisition
- MDCT standard clinical protocol

<table>
<thead>
<tr>
<th>Average</th>
<th>X-Ray</th>
<th>Tomosynthesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>50%</td>
<td>79%</td>
</tr>
<tr>
<td>Specificity</td>
<td>86%</td>
<td>94%</td>
</tr>
<tr>
<td>Accuracy</td>
<td>76%</td>
<td>89%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Modality</th>
<th>Effective Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-Ray</td>
<td>$29 \pm 6 \mu Sv$</td>
</tr>
<tr>
<td>Tomosynthesis</td>
<td>$48 \pm 10 \mu Sv$</td>
</tr>
<tr>
<td>MDCT</td>
<td>$980 \pm 250 \mu Sv$</td>
</tr>
</tbody>
</table>

Future Directions
Super-Resolution

Acquiring multiple low resolution images at sub-pixel spacing generates a high resolution (i.e., super-resolution) image.
Bar Pattern Phantom

The reconstruction can clearly distinguish frequencies higher than the detector alias frequency $0.5 \sigma^1 (3.6 \text{ lp/mm})$. This ability is not present in acquiring the central projection alone.
Clinical Super-resolution

4x Mag

4x Super-resolution
Oblique Reconstructions

0° to the Detector Plane

30° to the Detector Plane

60° to the Detector Plane
Despite the backprojection artifacts, the reconstruction can clearly resolve the input frequency within the mid-thickness of the sine plate at both pitches.
Clinical MPR

Recon. at 0° Pitch

Recon. with 35 μm voxels at 0° pitch

Recon. at 30° Pitch

Recon. with 35 μm voxels at 30° pitch
Clinical MPR

Recon. at 0° Pitch

Recon. at 30° Pitch

Recon. with 35 μm voxels at 0° pitch

Recon. with 35 μm voxels at 30° pitch

Translation of Recon. Plane at 30° pitch
## Hologic Prototype CE-DBT System

<table>
<thead>
<tr>
<th>Target</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>kVp</td>
<td>49 (HE) / 32 (LE)</td>
</tr>
<tr>
<td>Filter</td>
<td>Cu (HE) / Al (LE)</td>
</tr>
<tr>
<td>SID</td>
<td>70 cm</td>
</tr>
<tr>
<td>Detector</td>
<td>3 fps, 2x2 binning</td>
</tr>
<tr>
<td>Angular Range</td>
<td>15°</td>
</tr>
<tr>
<td>Scan Time</td>
<td>7.3 seconds</td>
</tr>
</tbody>
</table>

- Separate calibrations for LE and HE images
- Manual technique, no AEC
- DE subtraction factor $k$ derived from CIRS Model 20 BR3D phantom
Advantages of tomosynthesis

• Improves conspicuity by removing overlying structures
• Permits section imaging with high resolution in coronal view
• Easily performed on the high volume of radiography patients
• Lower radiation dose compared with CT
• Lower cost compared with CT
• Excellent platform for quantitative imaging
Special thanks to

- J. Boone at UC Davis
- E.F. Conant at U of Pennsylvania
- J.T. Dobbins at Duke University
- L. Fajardo at U of Iowa
- M. Flynn at Henry Ford Hospital
- Z. Jing, T. Wu at Hologic
- D. Kopans at Mass. General Hospital
- T. Mertelmeyer at Siemens
- J. Sabol at GE
1. Derive the central slice theorem from first principles
2. Prove that tomosynthesis demonstrates super-resolution using discrete and continuous integration
3. Given the dose at the orthogonal ray, formulate a closed form approximation for the dose at all other obliquities
Q1: How does the radiation dose of tomosynthesis compare to other imaging modalities?

1. Slightly less than radiography
2. Equal to radiography
3. Slightly more than radiography
4. Equal to computed tomography
5. More than computed tomography
3. Radiation dose of tomosynthesis imaging is slightly higher than the dose for a comparable radiograph. The small increase in dose is necessary to overcome the impact of detector readout noise arising from acquiring multiple projection images.

Q2: CT and tomosynthesis images are acquired as a series of projections. How does a projection image sample the Fourier domain of an object?

1. A line in the Fourier domain
2. A plane in the Fourier domain
3. A double-napped cone
4. It fully samples the Fourier domain
2. A projection image samples a single plane in the Fourier domain. The greater the number of projections made, the more completely the Fourier domain is sampled.

J. Zhang, C. Yu, A Novel Solid-Angle Tomosynthesis (SAT) Scanning Scheme, Medical Physics, 37(8), 2010
Q3: How does spatial resolution of tomosynthesis compare to CT?

1. Poorer x, y, and z resolution
2. Poorer x & y resolution; better z resolution
3. Better x, y, and z resolution
4. Better x & y resolution; poorer z resolution
5. Same x, y, and z resolution
4. Like linear tomography, the x and y resolution of tomosynthesis is comparable (or superior) to radiography, and substantially superior to CT. The penalty of tomosynthesis is poorer z resolution than CT.

Q4: The radiation dose in tomosynthesis is determinedly primarily by which factor?

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>18%</td>
<td>1. Body part thickness</td>
</tr>
<tr>
<td>1%</td>
<td>2. Angular range</td>
</tr>
<tr>
<td>27%</td>
<td>3. Number of projections</td>
</tr>
<tr>
<td>0%</td>
<td>4. Number of reconstructed images</td>
</tr>
<tr>
<td>54%</td>
<td>5. Angular range AND number of projections</td>
</tr>
</tbody>
</table>
1. Like radiography, tomosynthesis dose is primarily determined by body part thickness. Dose does NOT depend upon the number of images reconstructed. Dose depends only minimally upon the number of images acquired (detector noise) or angular range (obliquity).

T. Olgar, T Kahn, and D. Gosch, Average Glandular Dose in Digital Mammography and Breast Tomosynthesis, Rofo, 2012
Innovations and Applications of Tomosynthesis

Andrew D. A. Maidment, Ph.D.
University of Pennsylvania
Department of Radiology