Virtual and physical breast phantoms that mimic patients

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Background / From 2D to 3D Mammo

- Digital breast tomosynthesis (DBT) or "3D mammography"
- Limited-angle cone beam CT, x-ray tube pivots and takes many shots of compressed breast, reconstruct into quasi-3D volume
**Background | Lesion seen better on 3D than 2D**

![Lesion comparison](image)

**Status quo | Many commercial vendors...**

- Current commercial DBT systems:
  - FDA approved (top row): GE, Hologic, Siemens
  - EU approved (bottom row): IMS, FUJIFILM

![DBT systems](image)

**Status quo | Variability of Systems**

<table>
<thead>
<tr>
<th>GE SenoEclaire</th>
<th>Hologic Selenia Dimensions</th>
<th>Siemens MAMMOGRAPHY Inspiration</th>
</tr>
</thead>
<tbody>
<tr>
<td>target/filter</td>
<td>Rh/Rh</td>
<td>W/N</td>
</tr>
<tr>
<td>detector</td>
<td>indirect Cs</td>
<td>direct aSe</td>
</tr>
<tr>
<td>pixel pitch (µm)</td>
<td>~100</td>
<td>140</td>
</tr>
<tr>
<td>view angle</td>
<td>~30°</td>
<td>15°</td>
</tr>
<tr>
<td>n projection rings</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>mechanism</td>
<td>step-and-shoot</td>
<td>continuous tube</td>
</tr>
<tr>
<td>acquisition time (sec)</td>
<td>~15</td>
<td>~5</td>
</tr>
<tr>
<td>reconstruction</td>
<td>IR</td>
<td>FBP</td>
</tr>
</tbody>
</table>
Why focus VCT efforts on DBT?

- Misconception: DBT is a “solved problem”
- Facts:
  - Yes, many large trials have shown improvement in sensitivity and specificity vs. mammography, BUT...
  - DBT adoption is still early
    - ~30% sites have a system, ~10% total systems
  - Reimbursement still mixed while awaiting definitive trials
  - DBT systems vary greatly in implementation and features
  - DBT protocols are not yet established
  - Many variations still to come

Why focus VCT efforts on DBT?

- Unanswered questions:
  - Comparing different acquisition geometries:
    - angular range, # projections, dose distribution across angles
  - Radiographic technique and dose
  - Masses vs. calcifications
  - 1 vs 2 views
  - Real vs. synthetic mammogram
  - Full vs. partial compression
  - Reconstruction algorithm or post-processing modes
  - Other emerging technologies:
    - contrast-enhanced mammogram, dedicated breast CT

What is a virtual 3D phantom?

- Computational model of the breast
- Allows simulation of virtual images with known ground truth under precise control
- No radiation dose!
- Images can be interpreted by human or model observers
- To maximize clinical relevance, new generation of phantoms go beyond uniform or random texture to mimic patients
Virtual tools / AAPM TG 234

- Work in progress: AAPM TG 234 on virtual tools...

AAPM COMMITTEE TREE

Virtual phantoms: Penn VCTworld

- Penn VCTworld environment

Virtual phantoms: FDA Graff / VICTRE
Virtual phantoms: Duke XCAT

- Duke XCAT virtual phantom:
  - "Patient-based" – from breast CT scans of actual human subjects
  - Multi-step process of artifact removal, denoising, and segmentation
  - Voxelized result can be assigned values corresponding to modality, e.g., attenuation coefficients for x-ray
  - PRO: Realistic in appearance
  - CON: (initially) limited in number of cases and resolution
Virtual phantoms: Improving numbers

- Synthesized (left) vs. original (right) phantoms
- Top: mammo projection, bottom: central 250 µm slice

Greg Sturgeon, Duke RAILabs

Virtual phantoms: Improving resolution

Original +Power law +ligaments +ducts+ vessels

Claire Chen, Duke RAILabs

Virtual phantoms: Improving resolution

Tomo reconstructed slice before vs. after adding FDA phantom details

Claire Chen, Duke RAILabs
Virtual phantoms: Virtual lesions

Spiculated
Hilde Bosmans

Irregular
Kevin Wells

Circumscribed
Justin Solomon
Virtual to Physical Phantoms

- **Virtual phantoms:**
  - Infinite variability and control
  - Cannot reproduce proprietary hardware and software

- **Physical phantoms:**
  - Limited in number
  - Can reproduce all x-ray physics and acquisition h/w and s/w

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**Physical Phantoms | AAPM TG 245**

- Work in progress: AAPM TG 245 on tomo QC...
Physical phantom: Penn

- Anthropomorphic shape and interior:
  - 3D printed glandular/Coopers ligaments
  - Filled with adipose-equivalent resin

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Physical phantom: Duke “Doublet”

... scanned on 5 commercial DBT systems

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Andrew Maidment & Predrag Bakic, Univ of Penn

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Andrew Maidment & Predrag Bakic, Univ of Penn
Conclusions

- DBT shows great clinical promise and is entering clinical practice
- VCTs enable optimization and evaluation of new DBT technologies
- Realistic phantoms should maximize clinical relevance
- Virtual phantoms provide great diversity and computational control
- Physical phantoms directly assess proprietary system h/w and s/w

Thank You! | Joseph.Lo@duke.edu

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