Innovations in Clinical Breast Imaging

Dedicated breast CT

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Contributors

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Disclaimer

- Mention of any company or product does not constitute as endorsement.
- Dedicated breast CT has not been U.S. FDA approved for clinical use.
Learning objectives

To understand the following topics after this talk:

- Rationale for dedicated breast CT
- Current development and clinical studies of breast CT
- Challenges for dedicated breast CT
- Considerations on quality assurance
Breast CT (bCT)

- Introduction
- Development of bCT
- Patient imaging / clinical studies
- Challenges for bCT
- Quality assurance for bCT
- Summary
Breast cancer facts and figures

About 40,000 deaths from breast cancer in 2011.

About 288,000 women diagnosed with breast cancer in 2011.

12.2% of women will get breast cancer sometime during their lifetime.

Table 1. Estimated New Female Breast Cancer Cases and Deaths by Age, US, 2011*

<table>
<thead>
<tr>
<th>Age</th>
<th>In Situ Cases</th>
<th>Invasive Cases</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 40</td>
<td>1,780</td>
<td>11,330</td>
<td>1,160</td>
</tr>
<tr>
<td>Under 50</td>
<td>14,240</td>
<td>50,430</td>
<td>5,240</td>
</tr>
<tr>
<td>50-64</td>
<td>23,360</td>
<td>81,970</td>
<td>11,620</td>
</tr>
<tr>
<td>65+</td>
<td>20,050</td>
<td>98,080</td>
<td>26,000</td>
</tr>
<tr>
<td>All ages</td>
<td><strong>57,650</strong></td>
<td><strong>230,480</strong></td>
<td><strong>39,520</strong></td>
</tr>
</tbody>
</table>

*Rounded to the nearest 10.

Source: Total estimated cases are based on 1995-2007 incidence rates from 46 states as reported by the North American Association for Central Cancer Registries. Total estimated deaths are based on data from US Mortality Data, 1969-2007, National Center for Health Statistics, Centers for Disease Control and Prevention.

American Cancer Society, Surveillance Research, 2011

Table 5. Age-specific Probabilities of Developing Invasive Female Breast Cancer*

<table>
<thead>
<tr>
<th>If current age is ...</th>
<th>The probability of developing breast cancer in the next 10 years is:</th>
<th>or 1 in:</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.06%</td>
<td>1,681</td>
</tr>
<tr>
<td>30</td>
<td>0.43%</td>
<td>232</td>
</tr>
<tr>
<td>40</td>
<td>1.45%</td>
<td>69</td>
</tr>
<tr>
<td>50</td>
<td>2.38%</td>
<td>42</td>
</tr>
<tr>
<td>60</td>
<td>3.45%</td>
<td>29</td>
</tr>
<tr>
<td>70</td>
<td>3.74%</td>
<td>27</td>
</tr>
</tbody>
</table>

Lifetime risk 12.15%

*Among those free of cancer at beginning of age interval. Based on cases diagnosed 2005-2007. Percentages and “1 in” numbers may not be numerically equivalent due to rounding.

Probability derived using NCI DevCan Software, Version 6.5.0.

American Cancer Society, Surveillance Research, 2011
Mammography: standard of care
Major limitation of mammography

Tissue overlapping – “Anatomical noise” especially for dense breasts

Breast density in the U.S. (See pie chart)
- 10% of women have almost entirely fatty breasts
- 10% have extremely dense breasts
- 80% are classified into one of two middle categories

http://www.breastdensity.info
"If you have dense breast tissue, the odds of finding a cancer on your mammogram are about equal to a coin toss."

Dr. Stacey Vitiello
Rationale for a tomographic modality

2D vs. 3D
Background Noise

Anatomical Noise

low

high
Digital Subtraction Angiography (Temporal Subtraction)

Reduces Anatomical Noise

Dual Energy Chest Radiography (Energy Subtraction)

Reduces Anatomical Noise
Rationale for a tomographic modality

Mammography

Breast CT (bCT)

70 μm × 70 μm × 50,000 μm  ~0.25 mm³

230 μm × 230 μm × 250 μm  ~0.013 mm³
Breast CT (bCT)

Introduction

Development of bCT

Patient imaging / clinical studies

Challenges for bCT

Quality assurance for bCT

Summary
**Dedicated breast CT - Timeline**

### 1970’s-80’s
- Chang et al., Univ. of Kansas Med Ctr.
- 127 Xe detectors
- 1.56 x 1.56 x 10 mm
- 127 x 127 reconstruction
- CT #: -127 to 128 HU
- 1625 patients (78 cancers)
- IV contrast media
- 94% detection rate vs. 77% for mammography

**Chang et al., Cancer 46:939-946, 1980.**
© American Cancer Society

### 2000 onwards
- Reported on glandular dose estimates with dedicated breast CT

**Boone et al., Radiology 221: 657-67, 2001**
© 2001 Radiological Society of North America

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Slide contents courtesy: Srinivasan Vedantham, Ph.D., UMass
Dedicated breast CT - an ongoing research

• UC Davis
• U Mass Worcester
• U Nurnberg
• U Rochester
• MD Anderson
• Duke
• Louisiana State University
• Universita di Napoli
• Universitia di Bologna
• UC Irvine
Current clinical breast CT imaging

- Tungsten anode x-ray tube
- Cone beam geometry with flat panel detectors (CsI:TI + a:Si)
- 10~20 seconds scanning time
- 300~512 images across the breast in 360 degrees
- FDK or iterative reconstruction

- Prone patient position
- Breast pendant through a hole
- No compression
- Equal radiation dose to 2-view mammography
<table>
<thead>
<tr>
<th>Parameter</th>
<th>UC Davis (Doheny)</th>
<th>Koning Standard(UMass)†</th>
<th>Duke/Zumat ek</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-ray tube</td>
<td>Varian M-1500</td>
<td>Varian Rad 71SP(M-1500)</td>
<td>Varian (Rad 94)</td>
</tr>
<tr>
<td>Focal spot (mm)</td>
<td>0.3</td>
<td>0.1/0.3 (0.3)</td>
<td>0.4</td>
</tr>
<tr>
<td>kVp/Filtration</td>
<td>60 kVp / Cu</td>
<td>49-60 kVp / Al</td>
<td>65 kVp / Ce</td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; HVL (mm of Al)</td>
<td>~4.15</td>
<td>~1.4@49 kV</td>
<td>~3.0</td>
</tr>
<tr>
<td>X-ray pulsing</td>
<td>Pulsed (3~8 ms)</td>
<td>Pulsed (8 ms)</td>
<td>Pulsed (25 ms)</td>
</tr>
<tr>
<td>No. of projections</td>
<td>500~800</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>Magnification factor</td>
<td>1.39</td>
<td>1.42</td>
<td>1.63</td>
</tr>
<tr>
<td>Detector</td>
<td>Dexela 2923M</td>
<td>Varian PaxScan 4030 CB (4030 MCT)‡</td>
<td>Varian PaxScan 2520</td>
</tr>
<tr>
<td>Detector type</td>
<td>CMOS+ CsI:Tl</td>
<td>a-Si + CsI:Tl</td>
<td>a-Si + CsI:Tl</td>
</tr>
<tr>
<td>Detector‡ pixel size/FPS</td>
<td>75 μm x 2 / 50</td>
<td>194 μm x 2 / 30</td>
<td>127 μm x 2 / 5</td>
</tr>
<tr>
<td>Reconstruction / voxel (mm)</td>
<td>FBP / 110-200</td>
<td>FBP / 155 or 273</td>
<td>OSTR / 254 or 508</td>
</tr>
</tbody>
</table>

† Built to specific request by UMass
‡ Reduced dead-space at chest-wall

Slide contents courtesy: Srinivasan Vedantham, Ph.D., UMass
Breast CT (bCT)

Introduction

Development of bCT

Patient imaging / clinical studies

Challenges for bCT

Quality assurance for bCT

Summary
Ongoing clinical studies (Partial list)

Locations:
- Univ. of California, Davis
- Univ. of Pittsburgh Medical Center
- Univ. of Rochester Medical Center
- UMass Medical School
- M.D. Anderson Cancer Center
- Medical University of South Carolina
- Duke University
- Emory University
- Elizabeth Wende Breast Care

Studies:
- Non-contrast breast CT
- Contrast-enhanced breast CT
- Dedicated breast CT with PET
- Dedicated breast CT with SPECT
BCT (without injected contrast)
Diagnosis: IDC/ILC

Pre-pectoral Saline Implants

BCT (without injected contrast)

UC Davis
January 2005
Breast CT clinical studies

Radiologist Subjective Scoring (N = 69)

BCT (with contrast injection)

mammo
pre
post

Ultrasound
Malignant

pre
post

Benign
Contrast Enhanced bCT DCIS

Coronal

Sagittal

Axial

Rt ML Mag view
Malignant tumors tend to enhance more than benign lesions.

Breast CT clinical studies

Comparison between modalities

**Mammogram vs. Tomo vs. CE-bCT**

### Malignant Microcalcifications
- **Conspicuity Score**
  - **Mammogram** (N=31): 
  - **Tomo** (N=15): 
  - **CE-bCT** (N=16):

  - *p=NS*

### Malignant Masses
- **Conspicuity Score**
  - **Mammogram** (N=27): 
  - **Tomo** (N=13): 
  - **CE-bCT** (N=23):

  - *p<0.001*

### Benign Microcalcifications
- **Conspicuity Score**
  - **Mammogram** (N=27): 
  - **Tomo** (N=19): 
  - **CE-bCT** (N=25):

  - *p<0.0001*

### Benign Masses
- **Conspicuity Score**
  - **Mammogram** (N=18): 
  - **Tomo** (N=11): 
  - **CE-bCT** (N=15):

  - *p=NS*
Mammograms
Apr 2010: Normal

Mammograms
July 2011: DCIS

2010: CE bCT showing enhancement

2011: DCE MRI showing enhancement

Breast CT (bCT)

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Summary
Demands on breast CT imaging

1. Full 3D capability
2. Good soft-tissue differentiation
3. Dynamic imaging capabilities
4. High isotropic spatial resolution of about 100 μm
5. Low patient dose with an AGD below 5 mGy
6. Patient comfort without breast compression
7. Low cost

## Limitations for breast CT imaging

<table>
<thead>
<tr>
<th></th>
<th>Equal or less than two-view mammo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation dose to the breast</td>
<td></td>
</tr>
<tr>
<td>Patient’s comfort</td>
<td>No breast compression</td>
</tr>
<tr>
<td></td>
<td>Breath hold &lt; 20 seconds</td>
</tr>
<tr>
<td></td>
<td>Natural prone position</td>
</tr>
<tr>
<td>Available technology and the cost</td>
<td>Indirect flat panel detector</td>
</tr>
<tr>
<td></td>
<td>(a-Si TFT or CMOS)</td>
</tr>
<tr>
<td></td>
<td>Pulsed x-ray tube</td>
</tr>
</tbody>
</table>
Challenges for bCT

Mass-lesion detection
  Soft tissue differentiation
  Quantitative information
  Contrast kinetics

Micro-calcification detection

Chest wall coverage
  Patient comfort

Spectrum optimization

Improve the spatial resolution

Improve the image SNR

Improve the accuracy of HU

Table top/gantry design
Challenges for bCT – Spectrum

Dose-normalized CNR (CNRD)

Iodine contrast:

Calcification contrast:

60 kVp + 0.2 mm Cu

Challenges for bCT – μCalcs detection

Spatial resolution
- Flat panel detector – frame rate, MTF, DQE
- X-ray tube – focal spot, pulsed vs. continuous

Contrast resolution
- Relatively high kV (49~80 kV vs. 20~30 kV in mammo).
- Potentially low contrast for calcifications.
- Noise due to dose limit
  - To match the mean glandular dose of two-view mammo.
  - Potentially low SNR in each projection image.
Challenges for bCT – µCalcs detection

Spatial Resolution

<table>
<thead>
<tr>
<th></th>
<th>Breast CT</th>
<th>Mammography</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector pixel size (mm)</td>
<td>388 (150*)</td>
<td>75~100</td>
</tr>
<tr>
<td>X-ray focal spot size (mm)</td>
<td>0.1~0.4</td>
<td>0.1~0.4</td>
</tr>
<tr>
<td>Magnification factor</td>
<td>1.5~2.0</td>
<td>1.0~2.0</td>
</tr>
</tbody>
</table>

* The “Doheny” scanner at UC Davis with a DEXELA CMOS detector.
### UD Davis bCT MTF - system improvement

<table>
<thead>
<tr>
<th>Institution</th>
<th>Focal Spot</th>
<th>Acquisition</th>
<th>Resolution</th>
<th>Frame Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albion Bodega</td>
<td>1.0 mm</td>
<td>Continuous</td>
<td>388x388 μm²</td>
<td>30 fps</td>
</tr>
<tr>
<td>Cambria</td>
<td>0.3 mm</td>
<td>Pulsed</td>
<td>388x388 μm²</td>
<td>30 fps</td>
</tr>
<tr>
<td>Doheny</td>
<td>0.3 mm</td>
<td>Pulsed</td>
<td>150x150 μm²</td>
<td>60 fps</td>
</tr>
</tbody>
</table>

P Gazi*, TU-F-18C-7 Tuesday 4:30PM - 6:00PM Room: 18C
Continuous Fluoro [388 μm pixels]

Pulsed Fluoro [388 μm pixels]

Pulsed Fluoro [150 μm pixels]

>3X Spatial Resolution

UD Davis bCT MTF - system improvement

P Gazi*, TU-F-18C-7 Tuesday 4:30PM - 6:00PM Room: 18C
Challenges for bCT - μCalcs detection

Radiation Dose vs. Noise

<table>
<thead>
<tr>
<th>Table V. The minimum detectable MC sizes for various conditions for the small and the large breast phantoms.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Threshold</strong></td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td>50%</td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td>75%</td>
</tr>
<tr>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

14 cm diameter $f_g = 0.15$ breast-equivalent phantom; Calcifications located at $r = 3.5$ cm.

Can visualize 220 µm calcifications @ AGD matched to diagnostic mammography (12 mGy)
Challenges for bCT – \(\mu\)Calcs detection

BCT Denoise – Projection domain (PDEtomo)

without denoise

with denoise

Challenges for bCT – μCalcs detection

BCT Denoise – Projection domain (PDEtomo)

without denoise

with denoise

Challenges for bCT – μCalcs detection

BCT Denoise – CT image domain (iterative reconstruction).

FDK vs. ASD-POCS images showing differences in noise reduction and detail enhancement.

Challenges for bCT – μCalcs detection

BCT Denoise – CT image domain (iterative reconstruction).

FDK
PICCS

Zhihua Qi, et al AAPM Annual Meeting 2010
Challenges for bCT – Scatter

Scatter correction approaches (Partial list)

- **CT image processing based**

- **Monte Carlo simulation based**

The absolute accuracy of HU is equally important as the image uniformity!
Scatter Correction – The BPA Approach

\[
\frac{(P+S) - P}{P} = \text{SPR}
\]

SPR defined at various points

SPR Interpolated to entire image

Scatter Correction – Cupping Correction

with scatter  after scatter correction  difference image
Scatter Correction – HU Accuracy

With scatter
After scatter correction
Calculated for 80 kV

Breast tissue equivalent phantoms
Polyethylene phantoms
Challenges for bCT – Chest wall

Tabletop design
Patient comfort level
Physical limitations
Focal spot location
Detector dead space
Challenges for bCT – Chest wall
Improving chest wall coverage

If using ideal tube/detector – breast CT would miss at the most 9 mm compared to mammography in 95% of women studied.

Optimal swale depth, $s_d^*$ depends on x-ray tube/detector dead-space and magnification [B - corresponds to the geometry with UMass prototype (3.2 cm)].

Slide contents courtesy: Srinivasan Vedantham, Ph.D., UMass
Breast CT (bCT)

Introduction

Development of bCT

Patient imaging / clinical studies

Challenges for bCT

→ Quality assurance for bCT

Summary
Quality assurance for bCT

A combination of CT and Mammo?
Quality assurance for bCT

**Mammo Style**
- Mechanical stability and safety
- kV accuracy, filtration and tube output linearity
- Focal spot size
- Collimation and field coverage
- Detector uniformity and lag

**CT Style**
- Geometrical calibration (spatial accuracy)
- Image quality – MTF and NPS
- HU accuracy
- Cone beam artifact
- Chest wall coverage

**CT + Mammo**
- Radiation dose
- Image quality – μCalcs, mass

One consolidated phantom? ACR phantom?
BCT QA – Radiation Dose

- **Metric: Average Glandular Dose (AGD)**
- **Measure of radiation dose to “at-risk” glandular tissue**
- **Facilitates direct comparison with mammography**
- **Method:**
  - Measure air kerma (mGy) at axis of rotation (AOR) without object (e.g., dosimetry phantom) over entire scan
  - Multiply by Monte Carlo-derived conversion factor \( D_g N^{CT} \) in units of (mGy/mGy)

Slide contents courtesy: Srinivasan Vedantham, Ph.D., UMass
BCT QA – Radiation Dose

radiation dose is size dependent!

2001 tape measure results (N = 200)

2008 assessment on bCT images (N = 137)

X = 13.4 cm
σ = 2.0 cm
Median = 13.6 cm

2001 tape measure results (N = 200)
Monte Carlo Assessment of Dose Deposition

breast modeled as a cylinder

monoenergetic functions

uGy per million photons

X-ray Energy (keV)

SIC=45 cm  FOV=20 cm
50% glandular/50% adipose

10 cm dia

18 cm dia

58
Mean Glandular Dose in Breast CT

spectral model*


polyenergetic functions

Thacker, SC & Glick, SJ (2004). PMB, 49(24), 5433.
Dose in breast CT is set to be **EQUAL** to the dose of two-view mammography for that women.
BCT Radiation dose: diagnostic studies

Median of MGD from diagnostic breast CT is similar to diagnostic mammography with smaller range.

Median MGD from diagnostic breast CT is equivalent to 4-5 mammography views. Mean number of diagnostic mammography views in study: 4.53

Slide contents courtesy: Srinivasan Vedantham, Ph.D., UMass
BCT QA – Image Quality

Prionas, et al., PMB 57 2012: 4293
Breast CT (bCT)

Introduction

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Challenges for bCT

Quality assurance for bCT

Summary
Summary

• BCT can be performed in a dose efficient manner

• BCT almost certainly outperforms mammo for masses

• BCT might be possible for screening / need CALCS

• Needs to solve the challenges:
  Resolution, SNR, Micro-Calcification, HU accuracy, and Chest wall

• BCT QA is a combination of CT and Mammo.
Question #1:
Compared to mammography, current available clinical data showed that dedicated bCT_____

20% 1. takes shorter time for the exam.

20% 2. requires same amount of compression.

20% 3. has a better coverage of the chest wall.

20% 4. can detect micro-calcifications better.

20% 5. can detect mass-lesions better.
Question #1: Compared to mammography, current available clinical data showed that dedicated bCT _____.

1. takes shorter time for the exam.
2. requires same amount of breast compression.
3. has a better coverage of the chest wall.
4. can detect micro-calcifications better.
5. can detect mass-lesions better.

Answer: 5. can detect mass-lesions better.

Question #2:
From one study mentioned in this talk, which of the following spectrum provides the highest dose-normalized CNR (CNRD) for bCT?

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>20%</td>
<td>1.</td>
<td>40 kV + 1.5 mm Al</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20%</td>
<td>2.</td>
<td>60 kV + 1.5 mm Al</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20%</td>
<td>3.</td>
<td>60 kV + 0.2 mm Cu</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20%</td>
<td>4.</td>
<td>60 kV + 0.2 mm Sn</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20%</td>
<td>5.</td>
<td>80 kV + 0.2 mm Cu</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Question #2:
From one study mentioned in this talk, which of the following spectrum provides the highest dose-normalized CNR (CNRD) for bCT?

1. 40 kV + 1.5 mm Al
2. 60 kV + 1.5 mm Al
3. 60 kV + 0.2 mm Cu
4. 60 kV + 0.2 mm Sn
5. 80 kV + 0.2 mm Cu

Answer: 3. 60 kV + 0.2 mm Cu

Question #3:
As described in this talk, the radiation dose to the breast from a dedicated bCT scan is _____.

20% 1. not related to the detection of micro-calcs.
20% 2. independent to the size & density of the breast.
20% 3. determined by the CTDI with a phantom.
20% 4. proportional to the air kerma at isocenter.
20% 5. unable to match mammographic procedures.
Question #3: As described in this talk, the radiation dose to the breast from a dedicated bCT scan is _____.

1. not related to the detection of micro-calcs.
2. independent to the size & density of the breast.
3. determined by the CTDI with a phantom.
4. proportional to the air kerma at isocenter.
5. unable to match mammographic procedures.

**Answer:** 4. proportional to the air kerma at isocenter.

Acknowledgement

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Junguo Bian
Ingrid Reiser
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Hong Zhou
Whit Miller
Kai Yang
Orlando Velazquez
Clare Huang
Nathan Packard
Katie Methaney
Dandan Zheng
Shonket Ray
Anita Nosratieh
Lin Chen
Sarah McKenny
Nicolas Pronas
Peymon Gazi

Varian Imaging Systems

The Breast Tomography Project
University of California, Davis

UC Davis
University of California, Davis