 disclosure

- Our department has research collaborations with:
  - Elekta Oncology Systems
  - Philips Radiation Oncology Systems
  - Ray Search Laboratories

- Our department licenses software to:
  - Elekta Oncology Systems

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Content

- CBCT versus portal image analysis
- Geometrical Uncertainties in breast RT
- IGRT for deep inspiration breath-hold
- IGRT for pre-operative partial breast irradiation
- Adaptive RT for breast cancer
Cone Beam CT
Guided Breast RT
@ NKI-AvL

Geometrical Variability in Breast Radiotherapy

Protocol
- Patients are treated in 28 fractions with
- 50.7 Gy to the whole breast and 64.4 to the boost area
- Registration on bony anatomy
- Correction using a shrinking action level protocol with $N=3$ and initial action level $\alpha=9$ mm

Image Registration
Introduction

- 20 breast cancer patients, treated in a supine position
- CBCT scans were regularly acquired for a shrinking action level (SAL) setup correction protocol
- The EPID images were obtained during the same fraction from the opposing oblique treatment beams and manually registered to the DRRs in the 2D coordinate system of the EPID (U,V).
- For both EPID and CBCT the registrations were performed on the ribs

Study
Study

- Analyze position variability based on CBCT in three orthogonal directions
  - Without corrections
  - For offline correction protocol (SAL)
- Compare portal image analysis with CBCT analysis in the EPID coordinate system (U,V)

### Bony Anatomy Position Variability CBCT

<table>
<thead>
<tr>
<th></th>
<th>No-correction</th>
<th>Offline</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CC</td>
<td>LR</td>
</tr>
<tr>
<td>M (mm)</td>
<td>-1.1</td>
<td>-2.1</td>
</tr>
<tr>
<td>Σ (mm)</td>
<td>3.8</td>
<td>3.1</td>
</tr>
<tr>
<td>σ (mm)</td>
<td>2.8</td>
<td>2.2</td>
</tr>
<tr>
<td>Margin</td>
<td>11.5</td>
<td>9.2</td>
</tr>
</tbody>
</table>

Margin = $2.5Σ + 0.7σ$

2D versus 3D imaging

- Portal image – DRR fusion
- CBCT-planning CT fusion
Geometrical Uncertainties for Tumor Bed Boost

- 20 breast cancer patients
- Three registration methods:
  - Bony anatomy
  - Breast surface
  - Tumor bed
- Compare residual geometric uncertainties
Improved image quality

Boost position variability – Surrogate accuracy

<table>
<thead>
<tr>
<th>No-correction</th>
<th>Bone</th>
<th>Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC LR AP</td>
<td>CC LR AP</td>
<td>CC LR AP</td>
</tr>
<tr>
<td>M (mm)</td>
<td>1.4 0.2 -3.1</td>
<td>0.5 -0.9 0.9</td>
</tr>
<tr>
<td>Σ (mm)</td>
<td>3.0 3.8 2.7</td>
<td>2.0 2.3 1.5</td>
</tr>
<tr>
<td>σ (mm)</td>
<td>2.6 3.2 2.9</td>
<td>1.8 2.3 1.9</td>
</tr>
<tr>
<td>Margin</td>
<td>8.3 10.6 7.7</td>
<td>5.6 6.5 4.5</td>
</tr>
</tbody>
</table>

Margin=2.5Σ + 0.3σ

Topolnjak et al. IJROBP 2008

Relative Surface surrogate benefit

Image Guidance for Deep Inspiration Breath-hold

Topolnjak et al. IJROBP 2008
**Introduction**

- Left-sided breast cancer radiation
  - Increased risk for long term heart disease

- To decrease the irradiated heart volume
  - Voluntary deep inspiration breath hold (DIBH)

**Treatment planning**

- **Planning:**
  - IMRT plan
  - Max.1 3 segments per beam
  - 1 open en 2 IMRT segments
Patient set-up

- Under kV fluoroscopy guided imaging the patient was instructed for 2 deep in- and expirations before the DIBH position was taken.

- During the DIBH position a CBCT was performed (30 sec.)

Free breathing vs Breath hold CBCT
Procedure: step V - irradiation

- During the first part of the second DIBH, the medial segments were given and guided by kV fluoroscopy imaging (green).

Procedure: step VI - irradiation

- Hereafter, the open medial fields were given and registered by online EPID images.
- This procedure was repeated for the lateral fields during the third DIBH.

Post Correction Residual Error

- Open field treatment portal used for image registration

<table>
<thead>
<tr>
<th></th>
<th>Inter-fraction</th>
<th>Intra-fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U</td>
<td>V</td>
</tr>
<tr>
<td>M (mm)</td>
<td>0.3</td>
<td>-1.3</td>
</tr>
<tr>
<td>Σ (mm)</td>
<td>1.4</td>
<td>1.6</td>
</tr>
<tr>
<td>σ (mm)</td>
<td>1.6</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Borst et al. IJROBP 2010
Adaptive RT for breast cancer

Dosimetric Impact of Seroma Reduction on Boost Planning Volume

- Seroma reduction during RT

CT1 scan
CT2 scan

CT1: initial planning CT obtained before whole-breast irradiation
CT2: second CT obtained during a patient's RT course

<table>
<thead>
<tr>
<th></th>
<th>SEQ</th>
<th>SIB</th>
<th>SIB-ART</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole breast</td>
<td>CT1</td>
<td>CT1</td>
<td>CT1</td>
</tr>
<tr>
<td></td>
<td>25x2Gy</td>
<td>28x1.81Gy</td>
<td>15x1.81Gy</td>
</tr>
<tr>
<td>Boost</td>
<td>CT3</td>
<td>CT1</td>
<td>CT1</td>
</tr>
<tr>
<td></td>
<td>8x2Gy</td>
<td>28x0.49Gy</td>
<td>15x0.49Gy</td>
</tr>
</tbody>
</table>

- Retrospective comparison between three different boost RT delivery and planning techniques:
  - SEQ: a sequential boost plan
  - SIB: a simultaneous integrated boost plan
  - SIB-ART: a SIB adaptive radiation therapy plan
Dosimetric Impact of Seroma Reduction on Boost Planning Volume

- **21 Patients**

- **Seroma volume reduction:**
  - Significant total reduction during RT ($p<0.001$, one sample t test)
  - Mean (Range): 62 (38~85)%
  - 77% of total reduction in first three weeks of RT

- **Evaluation on CT scans used for planning:**
  - Target coverage: relative volume of \( V_{TV\text{breast}} \) and \( V_{PTV\text{boost}} \) receiving ≥95% of the prescribed dose
  - \( V_{\text{excess-dose}} \): undesired volume (outside \( V_{PTV\text{boost}} \)) receiving ≥95% of the total dose

Dosimetric Impact of Seroma Reduction on Boost Planning Volume

- **Evaluation of total dose distributions on CT5**
  - \( V_{\text{excess-dose}} \)
  - \( V_{107\%\text{(breast-dose)}} \)
  - \( V_{95\%\text{(total-dose)}} \)
  - \( HD_{\text{max}} \): maximum physical heart dose
  - \( LD_{\text{mean}} \): mean physical lung dose

- **Correlation seroma volume / reduction and differences between the treatment plans for**
  - \( V_{\text{excess-dose}} \)
  - \( V_{107\%\text{(breast-dose)}} \)
  - \( V_{95\%\text{(total-dose)}} \)

<table>
<thead>
<tr>
<th>Variable</th>
<th>SEQ mean</th>
<th>SIB mean</th>
<th>SIB-ART mean</th>
<th>Friedman</th>
<th>Wilcoxon</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{107%\text{(breast-dose)}} ) (cm$^3$)</td>
<td>584.5</td>
<td>536.8</td>
<td>485.5</td>
<td>&lt;0.001</td>
<td>SIB-ART&lt;SIB&lt;SEQ</td>
</tr>
<tr>
<td>( V_{\text{excess-dose}} ) (cm$^3$)</td>
<td>272.6</td>
<td>289.4</td>
<td>234.2</td>
<td>&lt;0.001</td>
<td>SIB-ART&lt;SEQ&lt;SIB</td>
</tr>
<tr>
<td>( V_{95%\text{(total-dose)}} ) Planning</td>
<td>134.4</td>
<td>56.3</td>
<td>36.1</td>
<td>&lt;0.001</td>
<td>SIB-ART&lt;SEQ&lt;SIB</td>
</tr>
<tr>
<td>( V_{\text{excess-dose}} ) CT3</td>
<td>134.4</td>
<td>150.1</td>
<td>95.0</td>
<td>&lt;0.001</td>
<td>SIB-ART&lt;SEQ&lt;SIB</td>
</tr>
<tr>
<td>( HD_{\text{max}} ) (Gy) Left</td>
<td>39.9</td>
<td>36.9</td>
<td>35.8</td>
<td>0.001</td>
<td>SIB-ART&lt;SEQ&lt;SEQ</td>
</tr>
<tr>
<td>( LD_{\text{mean}} ) (Gy)</td>
<td>4.2</td>
<td>4.6</td>
<td>4.5</td>
<td>0.001</td>
<td>SEQ&lt;SIB&lt;ART&lt;SEQ</td>
</tr>
</tbody>
</table>

**Summary**

- Considerable geometrical uncertainties limit the precision in breast RT

- Image guided correction strategies effectively manage setup errors

- Adaptive RT has the potential to account for shape and volume changes