Video–Based Positioning for Breast Radiotherapy

Hania Al–Hallaq, Ph.D.
The University of Chicago
Radiation & Cellular Oncology

Disclosures

I am employed by the University of Chicago.
I receive royalties from the University of Chicago for software licensed for computer aided detection of breast cancer.
Learning Objective

- Discuss the use of video–based surface imaging (SI) of breast cancer patients for:
  - Initial positioning
  - Real–time tracking during deep–inspiration breath hold (DIBH) treatments

Outline

- Clinical rationale: Cardiac dose
- DIBH techniques: ABC, RPM, Surface Imaging (SI)
- Verifying DIBH: MV ports, MV cine, CBCT
- Absolute versus relative positioning with SI
- Real–time tracking with SI: Surveillance, DIBH
- Clinical issues for DIBH with SI: Patient selection, Field matching, Reconciling with x–ray
- Challenges when using SI for breast RT
- Example workflows of SI for breast RT
- Future Directions of SI
Clinical Rationale

Cardiac Dose

- Population-based study in Sweden & Denmark
- Breast RT from 1958–2001:
  - 963 major coronary events
  - 1205 controls
- Heart dose estimated:
  - “CT scan of a woman with typical anatomy”
NSABP B–51 Sets De Facto Standard

Ipsilateral lung:
- Arm 1 Group 1A:
  - \( \leq 15\% \) of the ipsilateral lung should receive \( \geq 20\,\text{Gy} \)
  - \( \leq 25\% \) of the ipsilateral lung should receive \( \geq 10\,\text{Gy} \)
  - \( \leq 50\% \) of the ipsilateral lung should receive \( \geq 5\,\text{Gy} \)

Arm 3 Groups 3A and 3B:
- \( \leq 20\% \) of the ipsilateral lung should receive \( \geq 20\,\text{Gy} \)
- \( \leq 50\% \) of the ipsilateral lung should receive \( \geq 10\,\text{Gy} \)
- \( \leq 5\% \) of the ipsilateral lung should receive \( \geq 5\,\text{Gy} \)

Contraindicated lung:
- \( \leq 10\% \) of the contralateral lung should receive \( \geq 15\,\text{Gy} \)

Heart:
- Arm 1 Group 1A:
  - \( \leq 5\% \) of the whole heart should receive \( \geq 10\,\text{Gy} \) for left-sided breast cancers, and \( 0\% \) of the heart should receive \( \geq 15\,\text{Gy} \) for right-sided breast cancers
  - \( \leq 20\% \) of the whole heart should receive \( \geq 10\,\text{Gy} \) for left-sided breast cancers, and \( \leq 10\% \) of the heart should receive \( \geq 15\,\text{Gy} \) for right-sided breast cancers
  - Mean heart dose should be \( \leq 400\,\text{cGy} \)

- Arm 2 Groups 2A and 2B:
  - \( \leq 5\% \) of the whole heart should receive \( \geq 20\,\text{Gy} \) for left-sided breast cancers, and \( 0\% \) of the heart should receive \( \geq 25\,\text{Gy} \) for right-sided breast cancers
  - \( \leq 20\% \) of the whole heart should receive \( \geq 15\,\text{Gy} \) for left-sided breast cancers, and \( \leq 10\% \) of the heart should receive \( \geq 20\,\text{Gy} \) for right-sided breast cancers
  - Mean heart dose should be \( \leq 600\,\text{cGy} \)

Cardiac dose reduction strategies

1. Increase distance from target to heart:
   - Prone positioning
   - Exploit advantages of breathing cycle
2. Reduce dose to heart
   - IMRT/VMAT
   - Proton

DIBH Techniques

- ABC, RPM, SI

Advantages of DIBH

- Freeze organ/tumor motion
- Separate heart from target (breast, IMN)
- Increase total lung volume

Active Breathing Control (ABC) with Spirometer at William Beaumont

- Largest U.S. institutional experience:
  - 87 patients with ≤T2 disease
  - 50% treated with simple tangents only (FIF)
  - Median dose of 46Gy + 16Gy boost

- Compared to free-breathing (FB), moderate DIBH significantly decreased:
  - Mean heart dose (4.23Gy vs. 2.54Gy)
  - Mean left lung dose (9.08Gy vs. 7.86Gy)
  - All dosimetric parameters (V5, V10, V15, V20) for lung/heart


Voluntary Breath Hold vs. ABC

- 23 patients receiving 40 Gy in 15 fractions:
  - Randomized to v_DIBH or ABC_DIBH for 7 fractions & vice versa
  - Daily portal imaging & CBCT for 6 fractions

- No significant Δ: setup errors, normal tissue doses

- Patients & therapists significantly preferred v_DIBH!

Breast/Chest Wall Surface vs. ABC

- Surface displacement studied in 7 patients with IR markers:
  - During a single DIBH
  - Intra-fraction (between DIBH/same treatment)
  - Inter-fraction


Breast/Chest Wall Surface vs. ABC

- “Spirometer-based control does not guarantee a stable and reproducible position of the external surface in left-breast DIBH”

Surface Imaging (SI) for Breast Cancer

- **Advantages:**
  - 3D modality
  - Real-time monitoring
  - No radiation dose

- **Disadvantages:**
  - Variations with ROI used for registration
  - Tissue deformation can lead to low correlation with MV films
  - Results difficult to interpret


Voluntary DIBH with AlignRT

- Surface variability (2–3 mm) comparable to spirometry–controlled in 20 patients
- 7/20 did not require additional reference surfaces

Voluntary DIBH with AlignRT (8th fraction)

Real–Time Position Management (RPM) vs. AlignRT

- Chestwall excursion offset between DRRs and MV portal films or cine

Real-Time Position Management (RPM) vs. AlignRT

- Chestwall excursion & RPM: no correlation
- Chestwall excursion & SI: correlation = 0.52


Verification of DIBH

Using Surface Imaging
Comparison of MV Port Films to DRR

Mean heart dose reduced from 4.8 Gy (FB) to 1.2 Gy (vDIBH)


Comparison of MV Cine to DRRs

- Chestwall excursion offset between DRRs and MV portal films or cine

Consistent Differences Between MV Port and DRRs

- Inherent differences in image resolution?
- More dose to the heart than planned?

\[ d_{OAR} vs. d_{OAR} \text{ scatter plot} \]


---

CBCT vs. SI: Geometric Uncertainty of Heart

- Planning OAR margins recommended when setting up to surface: 1.1mm (LR), 6.7mm (CC), 2.5mm (AP)
- SI: “Harder to distinguish whether a setup error ...is caused by anatomic changes or by a change in BH”

---

**Table 2:** The mean and maximum dose for the heart and left coronary artery averaged over all patients for planning, offline, and online protocol situations

<table>
<thead>
<tr>
<th>Dose (Gy)</th>
<th>Planned</th>
<th>Offline</th>
<th>Online</th>
<th>Planned vs. Offline</th>
<th>Planned vs. Online</th>
<th>Offline vs. Online</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart (D_{max})</td>
<td>1.9</td>
<td>2.3</td>
<td>2.1</td>
<td>0.64</td>
<td>0.71</td>
<td>0.62</td>
</tr>
<tr>
<td>Heart (D_{mean})</td>
<td>19.2</td>
<td>25.5</td>
<td>25.5</td>
<td>0.02</td>
<td>0.01</td>
<td>0.26</td>
</tr>
<tr>
<td>Left coronary artery (D_{max})</td>
<td>6.5</td>
<td>7.5</td>
<td>7.1</td>
<td>0.05</td>
<td>0.53</td>
<td>0.02</td>
</tr>
<tr>
<td>Left coronary artery (D_{mean})</td>
<td>26.6</td>
<td>25.9</td>
<td>25.0</td>
<td>0.37</td>
<td>0.00</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Abbreviations: \(D_{max}\) = maximum dose; \(D_{mean}\) = mean dose.

For offline and online protocols, the dose was first accumulated over all breathing phases and then over all fractions. Wilcoxon signed-rank test was calculated to determine statistical significance dose difference between the protocols.

**Dose Between Breath-Holds**

<table>
<thead>
<tr>
<th></th>
<th>DIBH1</th>
<th>DIBH2</th>
<th>FB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart Mean Dose (Gy)</td>
<td>1.8</td>
<td>2.5</td>
<td>8.7</td>
</tr>
<tr>
<td>Lung V20 (%)</td>
<td>24%</td>
<td>29%</td>
<td>39%</td>
</tr>
</tbody>
</table>

**Surface Imaging for Breast RT**

Using Video-Based Systems
Absolute vs. Relative Positioning?

- **Absolute:**
  - Register to same reference surface
  - Reduce systematic errors?
  - Reduce frequency of filming?

- **Relative:**
  - Capture new reference surfaces
  - Reduce intra-fraction errors?
  - Relies on use of “other” IGRT modality

“If there was a discrepancy between the patient position determined by surface and MV imaging, then a new set of initial setup and/or BH reference surfaces was generated and used for subsequent treatments.”

**Patient selection:**
- Compliance
- Breast size or pendulous shape
- Dosimetric threshold for use of DIBH?

**Technical:**
- Field matching during DIBH
- Bolus placement obstructs surface
- Dependencies of registration on ROI selection
- Reconciling discrepancies between SI and MV/kV?

**Training:**
- Steep learning curve/difficult to interpret SI
Implementing SI for Breast RT/DIBH

- Patient selection:
  - Compliance
  - Breast size or pendulous shape
  - Dosimetric threshold for use of DIBH?

- Technical:
  - Field matching during DIBH
  - Bolus placement obstructs surface
  - Dependencies of registration on ROI selection
  - Reconciling discrepancies between SI and MV/kV?

- Training:
  - Steep learning curve/difficult to interpret SI

Surface Imaging with AlignRT

- Functionality
Reference Surface & ROIs for Registration

- 3D Surface from CT data
- ‘Entire’ ROI
- ‘Breast’ ROI

Rigid Registration Yields Translations & Rotations
Surface Imaging with AlignRT

Registration Variations with ROI Selection

Registration of ‘Entire’ ROI Identifies Roll

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VRT mm</td>
<td>-1.1</td>
</tr>
<tr>
<td>LNG mm</td>
<td>3.7</td>
</tr>
<tr>
<td>LAT mm</td>
<td>-0.4</td>
</tr>
<tr>
<td>MAG mm</td>
<td>3.9</td>
</tr>
<tr>
<td>Yaw °</td>
<td>-0.2</td>
</tr>
<tr>
<td>Roll °</td>
<td>-3.2</td>
</tr>
<tr>
<td>Pitch °</td>
<td>-1.5</td>
</tr>
</tbody>
</table>
Registration of ‘CW’ ROI Misinterprets Roll as LAT shift

Surface Imaging with AlignRT

Reconciling SI with kV/MV
Verification with Weekly MV Imaging

Digitally-Reconstructed Radiograph (DRR)

Verification with Weekly MV Imaging

MV Image
Verification with Weekly MV Imaging

Following Adoption of kV Imaging
Following Adoption of kV Imaging

kV Orthogonal Films
Breast Surface & Bony Anatomy Do Not Always Correlate

Surface Imaging with AlignRT

Steep Learning Curve
WBRT Example: Setup Variability Day 7

Potential breast swelling?

WBRT Example: AlignRT Detects $\uparrow$ Pitch & VRT on Day 7

- VRT: 3.6 mm
- LNG: 1.9 mm
- LAT: -1.0 mm
- MAG: 4.2 mm
- Yaw: 0.7°
- Roll: -0.3°
- Pitch: 2.0°
WBRT Example: Setup Variability Day 8

Breast matches DRR

WBRT Example: AlignRT No Pitch or VRT on Day 8

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VRT</td>
<td>1.3</td>
</tr>
<tr>
<td>LNG</td>
<td>-1.8</td>
</tr>
<tr>
<td>LAT</td>
<td>-1.6</td>
</tr>
<tr>
<td>MAG</td>
<td>2.8</td>
</tr>
<tr>
<td>Yaw°</td>
<td>0.8</td>
</tr>
<tr>
<td>Roll °</td>
<td>1.7</td>
</tr>
<tr>
<td>Pitch °</td>
<td>-0.5</td>
</tr>
</tbody>
</table>
Surface Imaging with AlignRT

Challenges/Pitfalls

- Changes in patient surface
  - Tissue deformation: swelling, shrinking seroma
  - Skin darkening during throughout treatment
- Non-specific topography
  - Male vs. female
  - Post-matectomy chestwall vs. intact breast
- Accuracy of surface generation from CT
  - Use of slow CT acquisition for FB
  - HU threshold to create DICOM reference surface
- Detecting changes in breathing pattern

Potential Clinical Challenges
Potential Clinical Challenges

- Changes in patient surface
  - Tissue deformation: swelling, shrinking seroma
  - Skin darkening during throughout treatment
- Non–specific topography
  - Male vs. female
  - Post-matectomy chestwall vs. intact breast
- Accuracy of surface generation from CT
  - Use of slow CT acquisition for FB
  - HU threshold to create DICOM reference surface
- Detecting changes in breathing pattern

Surface Imaging with AlignRT

Tissue Deformation
WBRT Example:
First Day Orthogonal kV Films

WBRT Example:
First Day Tangent MV Films
WBRT Example: First Day ‘ Entire’ ROI

WBRT Example: First Day ‘Breast’ ROI
WBRT Example: 24th Treatment Tangent Films

WBRT Example: 24th Fraction ‘Entire’ ROI
WBRT Example: 24th Fraction ‘Breast’ ROI

Surface Imaging with AlignRT

Skin Darkening
Skin Darkening Degrades SI Quality

Skin Darkening Due to Bolus Causes Registration Instability
Skin Darkening Degrades SI Quality

Surface Imaging with AlignRT

Changes in Breathing Pattern
Heart Position Mis-Match Detected

Repeat CT Simulation Following Changes in Breathing Pattern
Project Plan onto New CT Scan Following Changes in Breathing Pattern

Mean Heart Dose
- Before: 0.5 Gy
- After: 1.4 Gy
- Further After: 2.7 Gy

Lung V20Gy
- Before: 15%
- After: 17.7%
- Further After: 23%

MV Ports Pre & Post Re-simulation

Before

After
Surface Imaging with AlignRT

Workflows

AlignRT LEFT DIBH Workflow: V-sim & Film Days

- On V-sim day; page Physics
- Index cradle & align to marks
- 3-point patient
- Shift patient to isocenter with AlignRT: "FB Entire" ROI
- Correct roll, hips, pitch, arm, chin to match AlignRT: "FB Entire" ROI
- Instruct patient to take deep breath to check match AlignRT: "DIBH CW or Breast" ROI
- Take treatment DIBH capture
- Take films at DIBH & shift accordingly
- Take treatment DIBH capture
- Does DIBH CW or Breast ROI match within 7mm, 3°?
  - Yes
  - No
    - Physics sets threshold at: 5mm or 7mm, 2° or 3°
    - Take treatment DIBH capture & generate IGRT report
  - No
    - Page MD
    - Physics changes threshold or captures VRT surface per MD instructions
Benefits of SI other than DIBH?

- Improve intra-fraction positioning
  - Real-time monitoring throughout treatment
- Improve patient safety
  - Particularly for multiple isocenter treatments
- Reduce filming frequency
  - Requires absolute positioning?
- Improve throughput?

<table>
<thead>
<tr>
<th>n=50</th>
<th>Before AlignRT</th>
<th>After AlignRT</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of Patients with shifts &lt; 1cm</td>
<td>64%</td>
<td>92%</td>
</tr>
<tr>
<td>% of Patients with shifts &lt; 1cm; total time &lt; 30mins</td>
<td>44%</td>
<td>72%</td>
</tr>
</tbody>
</table>

AlignRT FB Workflow: Treatment Days

Index cradle & align to marks
3-point patient
Shift table to ARIA coordinates (±3mm)
Correct roll, hips, pitch, arm, chin to match AlignRT - *Entire* ROI
Take treatment capture
Verify that skin marks are within 3mm

YES
Continue treatment
NO
Take medial port film
Shift greater than 3mm?

YES
Proceed to Vital workflow
NO
Treat at AlignRT position
FUTURE DIRECTIONS

IMRT, VMAT, Protons

Inverse–Planned IMRT

- Optimizes radiation intensity levels in many non–opposing beam angles (e.g., 9 beams)
- **Advantages:**
  - Create concave dose volumes
  - Control placement of steep dose gradients
- **Disadvantages:**
  - Low dose spillage to heart, contralateral lung
  - Longer treatment time
Conclusions: “IMRT significantly improved conformity and homogeneity for plans when the breast + IMNs were in the CTV. Heart and lung volume receiving high doses were decreased, but more healthy tissue received low doses.”

Discussion: “Current practice is to use conformal IMRT if the plan results in an absolute reduction in heart V30 of 10% or greater compared to MWT or DIM technique.”


VMAT Mimics IMRT with ↓ Delivery Time

Ongoing Research: Protons

- Prospective clinical trial
  - 12 patients
  - Acceptable skin toxicity
  - Heart Mean = 0.1 – 1.2Gy
  - Lung Mean = 2.4 – 10.1Gy
  - Lung V20 = 4.4 – 22.1%


Collision prediction software for radiotherapy treatments

Laura Padilla
Virginia Commonwealth University Medical Center, Richmond, Virginia 23298

Erik A. Pearson
Techna Institute and the Princess Margaret Cancer Center, University Health Network, Toronto, Ontario M5G 2M9, Canada

Charles A. Pelizzari
Department of Radiation and Cellular Oncology, The University of Chicago, Chicago, Illinois 60637

SI for Breast RT: Take–Home Points

Advantages:
- No radiation dose
- 3D & real–time monitoring
- Cardiac sparing using DIBH
- Highlights surface changes (absolute positioning)

Disadvantages:
- Variations with ROI used for registration
- Variability in surface (swelling, skin darkening) can lead to registration errors
- Discrepancy with kV/MV films
- Steep learning curve

Acknowledgements

Colleagues:
- Steven Chmura, M.D., Ph.D.
- Yasmin Hasan, M.D.
- Hyejoo Kang, Ph.D.
- Martha Malin, Ph.D.
- Maxine Washington, RTT