Deep Inspiration Breath-Hold Techniques: a review of voluntary and controlled breath-hold maneuvers for left-side breast radiation therapy

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Outline

• Background on whole-breast RT
• Dosimetric benefit of DIBH
• Clinical options for DIBH
  – Voluntary DIBH systems
  – Controlled DIBH systems
• UF clinical investigation on Controlled DIBH
• Future direction of DIBH clinical care
• Conclusions
Background on whole-breast RT
Breast Cancer Occurrence

- Breast cancer is the most common cancer for female in U.S., about 29% of all sites
- Breast cancer survival rates:
  - 89% at 5 years after diagnosis
  - 82% after 10 years
  - 77% after 15 years
  - 95% at 5 years for early stage breast cancer

Treatment options for breast

- **Surgery** - to remove the cancer from the breast
  - Lumpectomy - only cancerous tissue plus bordering normal tissue is removed
  - Mastectomy - removal of entire breast

- **Radiation therapy** - to destroy cancer cells remaining in the breast, chest wall, or underarm area after surgery

- **Systemic therapy** - chemotherapy, hormone therapy and etc.

*Post-lumpectomy whole-breast radiotherapy (RT) has become the standard treatment option for early-stage breast cancer.*

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Whole Breast Radiation Therapy @ UF

- 42.4Gy/16 fractions or 50.4Gy/28 fractions to PTV
  - Delivered under DIBH for left breast
- 10 Gy boost in 5 fractions to lumpectomy cavity for all patients
  - Delivered under FB
- Achieve uniform whole breast coverage using opposing tangential fields with field-in-field and/or wedge technique
Radiation Induced Toxicity

- Acute toxicity: skin discoloration
- Pneumonitis
  - 1% at 2 to 3 months post RT
- Lymphedema
  - Fluid buildup due to damage to lymphatic drainage
  - Weeks to years post RT
- Cardiac toxicity
• Cardiac toxicity
  – 4456 women follow up post RT (median follow up 28 years)
  – Treated between 1954 and 1984
  – 1.76 fold increase with surgery + RT compared to surgery alone
  – 1.56 fold increase for left versus right breast RT
Cardiac toxicity

- Investigated rate of major coronary event (i.e., myocardial infarction, coronary revascularization, or death from ischemic heart disease)
- 2168 women treated between 1958-2001 in Sweden and Denmark
- Mean dose to whole heart 4.9 Gy (range, 0.03 to 27.72 Gy)
- Rates of major coronary events increased linearly with mean dose to heart by 7.4%/Gy (95% confidence interval) with no apparent threshold
Clinical solutions to reduce cardiac toxicity:

- Prone positions
- Breath hold techniques
  - Voluntary BH
  - Controlled BH
Clinical solutions to reduce cardiac toxicity: Prone Positions

- **PROS**
  - Target position more reproducible
  - Simple patient setup
  - Reducing the contact between breast tissue and chest walls (large breast patients)

- **CONS:**
  - Patient comfort
  - Variability in contralateral breast
  - Less advantage for small breast patients
Dosimetric benefit of DIBH
BH is used to reduce cardiac toxicity
BH is used to reduce cardiac toxicity
Literature review:
DIBH reduces irradiated cardiac volume

- 5 patients decreased heart volume irradiated by 1-12%
Literature review: DIBH reduces irradiated cardiac volume

- 5 patients achieved mean absolute reduction of 3.6% in heart volume
Things to keep in mind when selecting DIBH treatment option:

• Workflow resources @ CT sim and LINAC
  – Time
  – Staff

• Is the patient a good candidate for DIBH?
  – Can patient perform consistent breath hold?
  – Can patient hold breath long enough?

• Patient compliance and education is critical

• Is it anatomically beneficial over FB?
Clinical options for DIBH: Voluntary (patient comfort)
Voluntary DIBH: ionizing imaging systems

**EPID**

**PROS**
- Direct view of targets and field edge

**CONS**
- Hard to view the heart
- Image quality poor

Betgen et al. (Radiothera Oncol 2013)
Voluntary DIBH: ionizing imaging systems

**Kv**

**PROS**
- Better view of Internal anatomy

**CONS**
- No direct view of targets overlaid with beam (geometry is orthogonal to treatment beam)

*Betgen et al. (Radiothera Oncol 2013)*
Voluntary DIBH: ionizing imaging systems

CBCT

**PROS**
- Volumetric imaging

**CONS**
- limited to pretreatment DIBH

Topolnjak et al. (IJROBP 2011)
Voluntary DIBH: Optical tracking systems

- Provides real time imaging through the whole treatment
- Offers a more quantitative measure compared to ionizing imaging methods
- Optical tracking systems have emerged as the leading alternative to controlled DIBH
VisionRT system

- Projects a pseudo-random optical pattern onto the patient’s skin through a speckle projector
- 3 camera pod array
VisionRT system

- CT skin rendering or captured one for the reference
- Speckle pattern is used for 3D reconstruction of surface anatomy at treatment
DIBH workflow with VisionRT

1. BH screening and training
2. CT scans for patient
3. Treatment planning
4. Treatment setup verification: Portal image guidance during setup BH
5. Treatment:
   Beam gated with VisionRT

Determine threshold for real-time delta monitoring from BEV

Setup tattoos and ask patient to take BH, move couch until real-time delta are in alignment

Shortest distance between beam edge to heart is the threshold for DIBH (~2-3 mm)

Courtesy of VisionRT
VisionRT system

• Pros
  – Not require markers
  – No extra radiation
  – Directly tracking whole breast contours

• Cons:
  – Camera occlusion with gantry or couch rotation
  – Problematic with bolus, due to reflectivity. Overcome with elasto-gel (non-reflective material)
  – Registration accuracy for pendulous breast patients is low
Summary for voluntary DIBH

- Patient comfort during breath hold
- Breath hold reproducibility is low, which can cause low efficiency of the treatment
Clinical options for DIBH: Controlled
Controlled DIBH: tidal volume-guided systems

- **ABC (Active breathing coordinator)**
  - Control lung expansion at user-defined volume, usually 75% of max inspiration for 20 seconds or less

- **SDX**
  - Similar to ABC with addition of real-time feedback to patient through goggles

- **PROS**
  - No extra radiation
  - Immobilize patient’s BH safely
  - More Efficient treatment
ABC system comprises:

- The patient feedback to therapist through a switch. Patient decides when to engage the treatment BH.

- A disposable mouth piece, a breathing tube, a turbine cartridge to measure volume flow, a balloon valve to control the volume flow, and a nose clamp to prevent nasal respiration.

- A dedicated workstation displays the patient’s breathing cycle for the therapist to monitor.
ABC system for treatment

1. Once the patient has initialized a BH, the ABC device measures the tidal volume of air intake.

2. The valve shuts off at the predetermined volume set. The patient is prevented from further inhalation or exhalation until the valve reopens.

3. The valve then reopens when the patient lets go of the switch at the end of the BH procedure.
   - The max time allotted for individual patient’s BH is determined in CT simulation and is displayed on the therapist’s workstation to monitor during each treatment BH.
Challenges with spirometer-guided DIBH:

- Breathing maneuver (abdominal vs. thoracic) can change chest wall expansion with same tidal volume
  - Average difference in chest wall was 1.9 cm from thoracic to abdominal breathing.
  - Plathow et al. (IJROBP, 2005)

- The patient can inhale a larger air volume than the set limit if the air-flow rate is too high
  - Remouchamps et al. (IJROBP, 2003)
Our clinical investigation of ABC-assisted DIBH

Study goals

• We used IR-based OTS to evaluated the dosimetric effect on breast coverage and cardiac toxicity using ABC-assisted DIBH technique.

• Since the application of optical tracking system (OTS) with Infrared (IR) markers can accurately acquire the patient surface information in real time.

Prevention of gross setup errors in radiotherapy with an efficient automatic patient safety system

Guanghua Yan, Kathryn Mittauer, Yin Huang, Bo Lu, Chihray Liu, Jonathan G. Li
Study Overview

- IR Marker on xiphoid process
- 2 CT scans/patient
- Determine Correlation Equations

7 patients
~Analyzed 860 BHs

Optical Tracking at Treatment

Retrospective Treatment Plan for Delivered Dose

BH #1
BH #6

BH during port film 1
BH during port film 2
FB

Dose Volume Histogram

Dose (cGy)
Study Overview

- **Determine BH reproducibility: Inter- and intra-fraction**

  - Week 0: 1 CT simulation REFERENCE
  - Week 1: 6 BHs per treatment, 5 treatments per week
  - Week 2: 6 BHs per treatment, 5 treatments per week
  - Week 3: 6 BHs per treatment, 5 treatments per week
  - Week 4: 6 BHs per treatment, 5 treatments per week
  - Week 5: 6 BHs per treatment, 5 treatments per week

  ~16-28 total treatment days
  ~150 total BH per patient

UF Health Cancer Center

J. Crayton Pruitt Family Department of Biomedical Engineering
Study workflow and objectives

**Standard Clinical Flow**

1. **ABC screening and training**
2. **2 CT scans per patient:**
   - Free breathing and BH CT
3. **Treatment planning**
4. **Treatment setup verification:**
   - Portal image guidance during setup BH
5. **Treatment:**
   - Beam gated with ABC guidance only

**Research Investigation**

- **IR tracking of marker on xiphoid process for study’s baseline**
- **Determine correlation equations of IR marker to breast**
- **IR tracking during setup verification**
- **IR tracking at treatment for 7 patients**
  - ~6 BHs per treatment
  - ~16-28 treatments per patient
  - ~860 BHs in total
- **Quantify BH maneuver differences detected by OTS**
- **Retrospective dose calculation for breast targets**
- **Retrospective dose calculation for cardiac organs**

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Treatment BH verification: EPI

- portal imaging, double exposure
- Align to chest wall
- Couch shift applied and re-portal for verification
Breast-Marker Correlation

- Found from Pinnacle TPS comparing centroid of breast and marker contour

IR Marker

- No LR correlation

\[ \text{Breast}_{AP} = 1.1761(\text{Marker}_{AP}) + 4.1039 \quad r^2 = 0.95 \]

\[ \text{Breast}_{CC} = 0.6557(\text{Marker}_{CC}) + 2.0261 \quad r^2 = 0.93 \]

\[ \text{Breast}_{ML} = -0.2804(\text{Marker}_{ML}) - 0.2525 \quad r^2 = 0.02 \]
Estimation of Breast Positions

- Assumption: portal film guided setup will guarantee the accurate alignment of the breasts (relative to the beam edges) between CT and setup.

Account for portal image guidance

marker displacement difference (MDD)

\[ \text{MDD} = \text{position of marker at BH}\#n - \text{average position of marker during portal correlation} \]

Breast displacement difference (BDD)

Isocenter of delivered dose = BDD + original isocenter of beam

We performed 860 isocenter shifts to recalculate dose to breast targets!
Estimation of Heart position

- Heart shifts only 2 mm with respect to ribs/sternum among different BH
  - McIntosh et al. (IJROB 2011)
- Then we can assume heart position is relatively stable to the back of the patient
- So we evaluated heart position change from CT to treatment by measuring the change of the distance between isocenter and couch position.

Validated our method by comparing OTS with EPID registrations

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Intra/inter-fraction BH variation

- Mean intrafraction BH variation < 3 mm
- Mean interfraction BH variation -5.0 mm

• **Patient 2**: consistent treatment BH but not same as CT BH
  Inter-BH: -12.6± 1.8 mm (AP)

• **Patient 5**: nervous patient
  Inter-BH: -5.2± 5.9 mm (AP)
6 of 7 patients performing BH undershoot:

How does BH undershoot effect heart dose?

- Similar results reported by Tang et al. (PRO, 2014) – voluntary DIBH for breast patients (max undershoot 1.2 cm)
### Delivered Dose

**Planned versus delivered cardiac and target dose.**

<table>
<thead>
<tr>
<th>Patient</th>
<th>Planned/delivered cumulative dose (Gy)</th>
<th>% difference in daily delivered dose from planned dose (mean, range)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heart mean dose</td>
<td>LAD mean dose</td>
</tr>
<tr>
<td>1</td>
<td>1.1/1.4</td>
<td>6.1/13.2</td>
</tr>
<tr>
<td>2</td>
<td><strong>1.3/2.8</strong></td>
<td>4.5/20.3</td>
</tr>
<tr>
<td>3</td>
<td>1.7/2.9</td>
<td>16.0/28.2</td>
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<tr>
<td>4</td>
<td>1.2/1.5</td>
<td>11.0/18.8</td>
</tr>
<tr>
<td>5</td>
<td>1.4/2.6</td>
<td>4.5/18.4</td>
</tr>
<tr>
<td>6</td>
<td>1.7/1.9</td>
<td>4.6/5.3</td>
</tr>
<tr>
<td>7</td>
<td>1.5/1.5</td>
<td>5.3/5.3</td>
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<tr>
<td><strong>Average</strong></td>
<td>1.4/2.1</td>
<td>7.4/15.7</td>
</tr>
<tr>
<td><strong>p value</strong></td>
<td>0.026</td>
<td>0.013</td>
</tr>
</tbody>
</table>

- Significant cardiac dose increase, breast coverage adequate
- Max differences: heart (1.5 Gy) LAD (26 Gy)
Summary

By using ABC assisted DIBH technique to treat breasts

- **Breast coverage was adequate** since online corrections
- **Cardiac sparing can be degraded** due to the inconsistency of the breathing pattern from simulation to treatment
Future direction of DIBH clinical care
Real-time visual feedback

- Patient sees simple bar line for BH threshold goals
- Give patient ability to control their BH in real-time
MRI-guided therapy for real-time tracking of DIBH
Conclusions

- DIBH is a beneficial tool for left-sided whole breast RT
- Reduction in cardiac toxicity is limited to the techniques used in DIBH and patient physiology
- Patient feedback system can improve the reproducibility
- Developments in real-time imaging can improve the treatment efficacy for DIBH breast treatments.
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