Pitfalls in SBRT
Treatment Planning for
a Moving Target

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I have no conflicts of interests to disclose

In memory of Lynn

• Lynn Verhey, mentor and boss
• 7th medical physics resident at UCSF
• Stayed on as Cyberknife physicist – SBRT
treatment planning
Outline

• Brief summary of SBRT Treatment Planning
  – Dose Constraints
  – What other matrices to check, 10/20 Gy isodose line? D_{2cm}?
  – Calculation Algorithms
• Pitfalls in Lung/Liver SBRT Treatment Planning:
  – Motion Management Methodologies
    • Which method to use?
    • What planning CT to use?
    • What PTV margins?

Basics of SBRT Treatment Planning

• Goal of SBRT: ablate tissues within PTV
• Minimize normal tissues receiving high dose - sharp dose fall off outside PTV
• Dose conformity more important than dose homogeneity (potentially more advantageous).

\[ CIP_{addick} = \frac{TV_{PTV}}{TV \times PV \times RI} \] or \[ CI_{Lomax} = \frac{TV_{PTV}}{TV} \]

\[ HI = \frac{I_{max}}{RI} \]

Dose Constraints: TG101 Table III

• RTOG protocols - Spine 0631
Basics of SBRT Treatment Planning

• Dose Constraints based on RTOG protocols
  – Lung: 0813 and 0915

Basics of SBRT Treatment Planning

• Dose Constraints based on RTOG protocols
  – Liver: 0438 and 1112
Basics of SBRT Treatment Planning

- CT slice thickness 1-3 mm per TG101
- Typical scan length extends at least 5–10 cm superior and inferior beyond the treatment field borders
- Non-coplanar 15 cm
- Calculation Grid Size: 2 mm or less
- Calculation algorithms
  - CSA/AAA perform better than PBAs
  - EPL overestimated dose compared with MC for SBRT of lung tumors

Pitfalls of SBRT treatment planning for a moving target

- What CT scans to use?
- What margins to use with specific CT?

Motion management methodologies

<table>
<thead>
<tr>
<th>Encompassing</th>
<th>Gating</th>
<th>Tracking</th>
<th>Suppression</th>
</tr>
</thead>
<tbody>
<tr>
<td>GTV/ITV</td>
<td>Free breathing or breath hold</td>
<td>CyberKnife</td>
<td>Abdominal compression</td>
</tr>
</tbody>
</table>

Animation adapted from Jason Chan
Different Platforms for Lung/Liver SBRT

- Cyberknife
  - Synchrony
  - Lung Optimized Treatment (LOT)
- Linac – Based SBRT
  - Free Breathing
  - Gating
  - Breath Hold
  - Abdominal Compression

CT & Target Contouring for Lung on CK

Internal target position

- The internal target position can be extracted based on gold markers or large/dense tumors visible on 2 cameras or just 1 camera

Fiducial

Tumor visible on 2 cameras: 2 views

Tumor visible on 1 camera: 1 view A or 1 view B
1-view tracking

- Tumors visible in only 1 projection image
- The component of motion in the image plane is tracked
- Partial ITV expansion in the un-tracked direction

Sup-Inf motion is tracked (principal component of motion)

Planning CT for Linac-Based Lung SBRT

- Free breathing CT does not record the average target position
- Severe geometric distortion could result, lengthen or shorten the target in random fashion
- Center of the imaged target could be displaced as much as the amplitude of the motion
- Breath hold CT or average phase CT (from 4D CT) should be used as the baseline CT

Free Breathing CT Only Represents a Snapshot of GTV location

Courtesy of Ping Xia, Ph.D.
Difference in FBCT and 4DCT volume

<table>
<thead>
<tr>
<th>Scan/phase</th>
<th>Liver tumor volume (cm³)</th>
<th>Lung tumor volume (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helical CT, light breathing</td>
<td>296.68</td>
<td>24.35</td>
</tr>
<tr>
<td>4D-CT 0%</td>
<td>246.38</td>
<td>19.10</td>
</tr>
<tr>
<td>4D-CT 20%</td>
<td>275.46</td>
<td>21.20</td>
</tr>
<tr>
<td>4D-CT 40%</td>
<td>248.53</td>
<td>19.65</td>
</tr>
<tr>
<td>4D-CT 60%</td>
<td>257.22</td>
<td>23.94</td>
</tr>
<tr>
<td>4D-CT 80%</td>
<td>253.68</td>
<td>24.91</td>
</tr>
</tbody>
</table>

Abbreviation: 4D-CT = four-dimensional computed tomography.

Rietzel E, et. al. Red J. Vol. 61, 1535-1550 (2005)

COM Shifts Between FBCT and BHCT

Potential Misalignment Between CBCT and FBCT

• If align to tumor between the CBCT and FBCT, the isocenter could be potentially misaligned, depending on which breathing phase of the tumor was captured in FBCT.

NM Woody et al, J Radiat Oncol, 2015
Free Breathing CT Only Represents a Snapshot of GTV location

Planning CT for Lung SBRT

• How to align patient using kV-CBCT?
• If align to Free breathing CT, the iso-center could be misaligned
  – Depending on which phase the FBCT was acquired
• AIP should be used for planning CT
• What is AIP?
  – A synthetic CT derived from 4DCT using average intensity projections

How Big Are Intra-fractional Margins?

• Inconsistent data in the literature
• Tumor size and tumor location dependent
  – Small tumor moves more
  – Tumor in the lower lobe or near diaphragm moves more
• Intra-fraction margins are patient dependent and method/device dependent.
11 SBRT lung patients obtained 3CTs with three separate breath holds during simulation.

Breath Hold Reduces Intra-Fraction Tumor Motion

<table>
<thead>
<tr>
<th>Mean (mm)</th>
<th>3.6</th>
<th>7.7</th>
<th>4.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>SD (mm)</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>


PTV Margin?

- Free Breathing, obtain 4DCT to obtain ITV
- Tumor motion < 1 cm: PTV = 5 mm
- Tumor motion > 1 cm: PTV = 8 mm
- Irregular breathing trace: PTV = 8 mm
- Each direction is determined individually
Dosimetric Implication?

- AIP-based VMAT-SBRT planning approach is practical for lung tumor near diaphragm
- Discrepancy between AIP and 4D plans were less than 3% different
- However, AIP underestimates doses for OARs with large respiratory motion, such as liver and stomach


Planning CT for Liver SBRT

- Multi-Phase IV contrast scans obtained using breath hold should be used for target delineation
- Exhale breath hold CT or average phase CT (from 4D CT) may be used as the baseline CT
- Exhale breath hold more reproducible and is closer to the average position than inhale
- Free Breathing CT are strongly discouraged
  - may be used if breath hold is not possible or if motion is < 5 mm

For a total of 15 patients treated with conventional fractionation, with stent or implant markers.
- Both FBCT and 4DCT were acquired.
- The absolute mean discrepancies in iso-center shifts by aligning the markers between FBCT/CBCT and AIP/CBCT were studied.

Courtesy of Ping Xia, Ph.D.
Magnitude of Liver Motion

Liver/Pancreas SBRT PTV Margins

- Dawson et al, IROBP 2001
  - ABC Breathhold
  - Intrafraction: LR 1 mm, AP 1 mm, SI 2 mm
  - Interfraction: LR 4 mm, AP 4 mm, SI 7 mm
- Case et al, IROBP 2010
  - Free Breathing with/WO abdominal compression
  - RL 2 mm, AP 4 mm, SI 8 mm
  - Liver amplitude consistent during TX
  - Beware of baseline shifts in soft tissue
Liver/Pancreas SBRT
PTV Margins

- Jayachandra et al, IJROBP 2010
  - Free breathing, respiratory gating
  - Align to bony anatomy
  - Shift based on Fiducials
    - AP: 95th percentile, 7 mm
    - LR: 95th percentile, 7 mm
    - SI: 95th percentile, 12 mm
  - Only 20% does not require shifts
- At UCSF, we expand breath hold GTV by 5 mm Axially and 8 mm Superior/Inferior

Pancreatic data

- Fusion between breath hold planning CT and CBCT based on vertebral bodies
- Location of dome and fiducials were measured
- Difference between dome position in relationship to bony anatomy and fiducial position in relationship to bony anatomy is within 1-2 mm S/I direction
- Dome of Diaphragm reasonable surrogate for Fiducial/Tumor position
- One patient has baseline shift, all CBCT are close in position, but differ from planning CT (7.5 – 10.5 mm with only 0.02 L difference in breath hold volume)

Liver data

- Fusion between breath hold planning CT and CBCT based on vertebral bodies
- Location of dome was measured
- SDX breath hold volumes were examined
  - In general, patients breath hold volume deviate from 0.2 L by minute amount, ranging from 0.01 to 0.03 L in most patients.
  - 2 patients have larger breath hold volume deviation, ranging from 0.04 – 0.07 L, generally worse during TX
  - However, this does not translate to larger dome position deviations
  - S/I positions differ from CT ranging from 1.5 – 2.4 mm, A/P < 1 mm and L/R 1 – 2 mm
14 SBRT liver patients obtained 3CTs with three separate breath holds during simulation.

What’s Next?

• Current margins are good for accurate and safe treatments
• Individualized margin might be good for patient whose SDX breath hold volume deviation from 0.2 L by less than 0.02 L
• Baseline shift could be an issue for some patients since S/I margin might need to be increased to 1 cm to account for the inter-fraction difference in dome/fiducial location

Planning CT and Margins for Liver SBRT

• Inter-fractional variation and soft tissue baseline shifts – 5 mm axially and 8 mm Superior/Inferior
IGRT: Avoidance isodose surfaces

- At time of treatment, assess overlap between IGRT_IDL and avoidance OAR
- IGRT_AVOID provides guidance for identifying OAR(s) of interest
- Treatment should be cancelled if significant overlap cannot be avoided
- Consider dietary counselling

Summary

- 4D-CT is useful to understand the profile of the intra-fraction tumor motion.
- Using abdominal compression, or breath-hold treatment to minimize intra-fraction motion.
- Due to interfractional soft tissue baseline shift, margin consideration is important, and could be individual
- Under CBCT guidance, using free breathing CT may introduce a misalignment if directly aligning to the tumor or implant markers.
- AIP CT is a better choice as planning CT under CBCT IGRT.