Using SPECT-Guidance to Reduce Intensity Modulated Radiation Therapy (IMRT) Dose to Functioning Lung

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In a recent retrospective study at our institution: 34/172 lung cancer patients diagnosed with Grade 2+ radiation-induced pneumonitis (initiation/increase in steroids, oxygen).

Asumption: all areas of normal lung have equal function.
Reality: lung function is spatially heterogeneous.

Reduce lung toxicity: reduce dose to higher functioning normal lung ⇒ better quality of life!

Purpose: Develop a manual algorithmic methodology for integrating SPECT-guidance into the ECLIPSE treatment planning optimization process.
Single Photon Emission Computed Tomography (SPECT) at DUMC

- 4 mCi $^{99m}$Tc-MAA administered intravenously
- 3 camera system equipped with low energy, high resolution collimators
- 3 cameras are rotated through a $360^\circ$ rotation at $3^\circ$ intervals using a step and shoot technique
- Each camera acquired 40 angular views in approximately 25-30 min
- 128 x 128 resolution, pixel size = 0.356 cm
Design ... of SPECT Cameras
**Why use SPECT images in RT?**

- SPECT intensity is directly proportional to perfusion as shown in phantom and animal studies.

- Perfusion in lung is a reasonable measure of function based on % perfused lung resected correlated to % loss of function (perfusion vs. ventilation).

- The combination of functional lung information and IMRT technology allows sparing of the ‘best’ parts of the lung.
Methodology

- 9 6MV beams oriented at 30 degree spacing on predominant tumor side. Primary tumor to 40 Gy, boost to 66 Gy.

- Constraints:
  
  - Lung: 20% / 20 Gy
  - Spinal Cord: 0% / 40 Gy
  - Esophagus: 30% / 55 Gy
  - Heart: 50% / 45 Gy
  - PTV 40: 100% / 40 Gy (Primary)
  - PTV 66: 100% / 66 Gy (Boost)
  - Body: 0% / 40 or 66 Gy
Methodology

- Initial IMRT plan generated without SPECT-guidance. Dose-volumes obtained in this plan are used in SPECT-guided plan.
- SPECT image is segmented into 4 areas from low to high intensity.
Create a SPECT guided plan using Dose-Volume constraints from Base Plan

Set all SPECT structures to volume Constraint = 0 and maximum priority

Set current SPECT structure to least Functional region (i = 1)
Create a SPECT guided plan using Dose-Volume constraints from Base Plan

Set all SPECT structures to volume Constraint = 0 and maximum priority

Set current SPECT structure to least Functional region (i = 1)

Optimize

PTV dosage satisfied? Dose-Volume constraints satisfied?

NO

YES

Stop and calculate dose
Create a SPECT guided plan using Dose-Volume constraints from Base Plan

Set all SPECT structures to volume Constraint = 0 and maximum priority

Set current SPECT structure to least Functional region (i = 1)

Optimize

PTV dosage satisfied? Dose-Volume constraints satisfied?

Further relaxation of SPECT structure i possible?

YES

NO

YES

NO

Stop and calculate dose

Relax volume constraint and Priority of SPECT structure i
Create a SPECT guided plan using Dose-Volume constraints from Base Plan

Set all SPECT structures to volume Constraint = 0 and maximum priority

Set current SPECT structure to least Functional region (i = 1)

Optimize

PTV dosage satisfied? Dose-Volume constraints satisfied?

Relax volume constraint and Priority of SPECT structure i

Further relaxation of SPECT structure i possible?

YES

Set current SPECT structure to next higher Region i = i + 1

NO

NO

YES

Stop and calculate dose
How can we measure benefit?

- Dose map
- Dose-Function Histogram (DFH) vs. Dose-Volume Histogram (DVH)
  - DVH measures % volume above a particular dose
  - DFH measures % function above a particular dose
- $F_{20}$ and $F_{30}$ vs. $V_{20}$ and $V_{30}$
  - $V_D$ is the % volume that receives dose above D Gy
  - $F_D$ is the % function that receives dose above D Gy
Dose distribution

Non SPECT-guided plan

SPECT-guided plan
DVHs of targets

- Primary
- Boost

Graphs showing dose-volume histograms (DVHs) with percentage volume plotted against dose (Gy) for Base Plan and SPECT Plan. The graphs illustrate the distribution of doses received by different volumes of tissue.
**DVHs and volume sparing above 20Gy for whole lung**

![Graph showing DVHs for whole lung](image)

**Table: V20 Reductions**

<table>
<thead>
<tr>
<th>Patient</th>
<th>Base (%)</th>
<th>SPECT (%)</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>55.9</td>
<td>49.3</td>
<td>11.8</td>
</tr>
<tr>
<td>B</td>
<td>49.7</td>
<td>47.9</td>
<td>3.7</td>
</tr>
<tr>
<td>C</td>
<td>48.2</td>
<td>42.6</td>
<td>11.5</td>
</tr>
<tr>
<td>D</td>
<td>32.0</td>
<td>30.5</td>
<td>4.7</td>
</tr>
<tr>
<td>E</td>
<td>43.1</td>
<td>41.2</td>
<td>4.5</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>7.2 ± 4.0</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Dose Function Histograms: SPECT Structures**

*(one patient)*

![Graphs showing dose function histograms for different intensity structures of SPECT regions IDFH.](image)

- **Highest intensity SPECT region DFH**
- **2nd Highest intensity SPECT region DFH**
- **3rd Highest intensity SPECT region DFH**
- **Lowest intensity SPECT region DFH**
Lung Dose-Function Histograms (5 patients)
## Lung function sparing above 20 Gy, 30 Gy

<table>
<thead>
<tr>
<th>Patient</th>
<th>$F_{20}$ Base (%)</th>
<th>$F_{20}$ SPECT (%)</th>
<th>% Reduction</th>
<th>$F_{30}$ Base (%)</th>
<th>$F_{30}$ SPECT (%)</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>60.6</td>
<td>51.0</td>
<td>15.8</td>
<td>37.9</td>
<td>32.0</td>
<td>15.6</td>
</tr>
<tr>
<td>B</td>
<td>56.3</td>
<td>51.1</td>
<td>9.2</td>
<td>37.2</td>
<td>35.1</td>
<td>5.6</td>
</tr>
<tr>
<td>C</td>
<td>52.0</td>
<td>44.6</td>
<td>14.2</td>
<td>29.0</td>
<td>27.3</td>
<td>5.9</td>
</tr>
<tr>
<td>D</td>
<td>17.2</td>
<td>13.6</td>
<td>20.9</td>
<td>8.9</td>
<td>7.3</td>
<td>18.0</td>
</tr>
<tr>
<td>E</td>
<td>46.1</td>
<td>42.4</td>
<td>8.0</td>
<td>26.5</td>
<td>24.5</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>13.6 ± 5.2</td>
<td></td>
<td>Average</td>
<td>10.5 ± 5.8</td>
<td></td>
</tr>
</tbody>
</table>
SPECT distribution can be very spatially heterogeneous

- $F_{20} = -14.3\%$  $F_{30} = -5.9\%$

- $F_{20} = -20.9\%$  $F_{30} = -18.0\%$
Conclusions

- Incorporating SPECT-guidance into IMRT planning for thoracic tumors reduces irradiated functioning lung volumes $\Rightarrow$ reduced toxicity.

- Algorithm was manually fine-tuned. Currently working on automating the procedure via ECLIPSE API.

- Number of SPECT segments may affect avoidance. Also currently working on finding the optimal number of SPECT segments.
Acknowledgments

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