Treatment Planning of Lung Cancer: Dosimetric Considerations

Indrin J. Chetty, PhD
Henry Ford Health System
Disclosure

My department receives research support from:

• NIH/NCI
• Varian Medical Systems
• Philips HealthCare
Learning Objectives/Outline

To discuss the physics related to lung tumor dose coverage, with special emphasis on small tumor sizes and location

To review dose calculation accuracy with different algorithms for lung planning/dose calculation

To present approaches to improve plan quality especially when using simplistic calculation algorithms for lung cancer planning

To review example volumetric arc therapy plans and discuss technical issues
Pre Test Question

1. For the treatment of small lung tumors located peripherally, which dosimetry algorithm is contra-indicated for SBRT-based treatment planning:

A. 1-D Pencil Beam  
B. 3-D Pencil Beam  
C. Superposition/Convolution  
D. Monte Carlo  
E. Both A and B
The Primary Issue: Underdosage of the PTV

Comparison of the 100% IDLs, Pencil beam (dashed) and MC (solid)
Lateral Scattering of electrons: Monte Carlo simulation, 10 MV pencil beam
Impact of electron scattering on beam penumbra: conformal lung plan

Note the differences in dose gradient due to penumbral broadening
Loss of Charged Particle Equilibrium (CPE)

CPE exists in a volume if each charged particle (electron) leaving the volume is replaced by an identical electron entering the volume.

In narrow field, CPE is lost and dose reduction can be severe.
“Build down effect” – severe dose reduction caused by scattering of electrons into the lung tissue. Dose builds up in the tumor resulting in underdosage at tumor periphery.
Implications for “island” tumors

Ring” of underdosage gets larger for smaller tumors (as size approaches the e’ range) and higher energies due to larger e- range.
The Energy Effect (low vs. high MV)

Pencil Beam (6 MV)

Pencil Beam (18 MV)

C-S (6 MV)

C-S (18 MV)
PTV DVHs (PB vs. AAA), 6 MV

PB: mean = 70.2 Gy
AAA: mean = 68.9 Gy

Diff. in min. PTV dose = 11%
PTV DVHs (PB vs. AAA), 18 MV
PB: mean = 70.5 Gy
AAA: mean = 64.7 Gy
Diff. in min. PTV dose = 16%
Accuracy of dose calculations for lung SBRT

PTV diam. = 3.2 cm
PTV vol. = 14.6 cc

PTV diam. = 3.2 cm
PTV vol. = 14.6 cc
DVH comparison for the PTV
MC plan recomputed using MUs from PB plan

MC
PB

58%
98%
PTV mean dose diff. vs. PTV diam. (mm): 100 patients

PTV diam. (mm)

PTV mean dose diff.%

MC-PB]
MLD (MC) as a function of MLD (PB): 50 patients

\[ y = 0.9093x - 0.0755 \]

\[ R^2 = 0.9948 \]
Comparative Dose Calculation Study

Purpose: To investigate dosimetric differences between treatment plans computed with:

- 1-D Pencil beam (PB) – (iPlan BrainLAB)
- 3-D Pencil beam – (Eclipse, Varian)
- Anisotropic Analytic Algorithm (AAA, convolution-type, Eclipse)
- Pinnacle – Collapsed Cone Convolution (CCC, convolution-type, Pinnacle, Philips)
- Monte Carlo (iPlan BrainLAB)
6X, central tumor: MU for the 1D-PB plan
6X, peripheral tumor: 12 Gy x 4
% difference in PTV min. dose vs. MC, 11 lung cancer plans

<table>
<thead>
<tr>
<th>% diff. $D_x - D_{mc}$</th>
<th>1D-PB</th>
<th>3D-PB</th>
<th>AAA</th>
<th>CCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ave</td>
<td>29.2</td>
<td>21.6</td>
<td>1.5</td>
<td>-2.0</td>
</tr>
<tr>
<td>STD Dev</td>
<td>12.1</td>
<td>12.8</td>
<td>4.6</td>
<td>5.1</td>
</tr>
<tr>
<td>Max Diff.</td>
<td>63.2</td>
<td>48.5</td>
<td>12.7</td>
<td>8.7</td>
</tr>
</tbody>
</table>
What can be done to improve the plan?

Increase the prescription dose – non-uniformity in target

Increase the PTV margin and hence the field size – will not fix the lateral scattering problem but will help restore CPE - increases unintended dose to healthy lung tissue

Use beams with smallest path length through lung and low energies (choose 6X over higher MV)
What can be done to improve the plan?

Non-coplanar beams may be helpful depending on location – electron lateral scattering is cylindrically symmetric; adding more co-planar beams will not improve the coverage.

One size does not fit all!

Each case must be judged by location and field size.
VMAT (RapidArc) Example Case
RapidArc (2 partial arcs)

IMRT
DVHs for normal lung and R peripheral PTV

V20 (RA) = 26.4%; MLD = 14.2 Gy
V20 (IMRT) = 27.5%; 14.7 Gy
**VMAT vs. IMRT Case: Summary**

Target coverage was somewhat better with RA vs. IMRT

<table>
<thead>
<tr>
<th></th>
<th>Lungs MLD (Gy)</th>
<th>Esophagus Mean (Gy)</th>
<th>Heart Mean (Gy)</th>
<th>Cord Max (Gy)</th>
<th>MU and (Beam-on Time)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RA</strong></td>
<td>14.7</td>
<td>17.5</td>
<td>11.3</td>
<td>35.8</td>
<td>475 (0.8 min)</td>
</tr>
<tr>
<td><strong>IMRT</strong></td>
<td>14.2</td>
<td>20.3</td>
<td>8.2</td>
<td>36.5</td>
<td>1563 (2.6 min)</td>
</tr>
</tbody>
</table>
VMAT and the Interplay Effect

Describes the interaction between organ motion and MLC leaf motion.

Interplay effect in IMRT is generally small (~1%) especially for highly fractionated treatments.

VMAT and the Interplay Effect

- Motion amplitude: 1.3 cm in S/I, 0.2 cm in R/L, 0.4 cm in A/P
- Rapid Arc (RA) plan – two 180 deg. Arcs; IMRT plan
- Interplay effect incorporated and compared to “static case” for both RA and IMRT plans
Tumor Motion: Exhale and Inhale States
DVHS (PTV and normal lung) with and without interplay
IMRT plan

with interplay
DVHS (PTV and normal lung) with and without interplay
RapidArc plan

with interplay
Overall Summary

Simulation, planning and delivery of lung cancer is confounded by motion and heterogeneity in tissue density.

Lung tissue density impacts tumor dose deposition significantly requiring accurate dose algorithms.

Tumor size is important – pay special attention to small tumors with field sizes close to the electron range.

Location! Location! Location! Location!

Convolution/superposition or MC-based methods should be used for lung cancer treatment planning.
Overall Summary

High energy photon beams (> 6 MV) should be avoided.

VMAT/RapidArc offers an efficient solution to RT delivery, particularly in the context of SBRT.

Interplay effects tend to be small in the context of IMRT or VMAT, however, further investigation is needed to fully understand these effects in the VMAT setting.
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E. Both A and B
E: Under small field conditions, and lower density lung tissue, electron scattering becomes the dominant factor influencing dose to the tumor. Pencil beam algorithms (1-D or 3-D) do not properly account for electron scattering either implicitly or explicitly and have been shown to be quite inaccurate under such circumstances. Therefore pencil beam algorithms are contra-indicated in the context of SBRT planning.

References: