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

Sarah M. McGuire Ph.D., Sumin Zhou Ph.D., Lawrence B. Marks M.D., Mark Dewhirst Ph.D. D.V.M., Fang-Fang Yin Ph.D., and Shiva K. Das Ph.D.

Department of Radiation Oncology Physics
Duke University Medical Center

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.

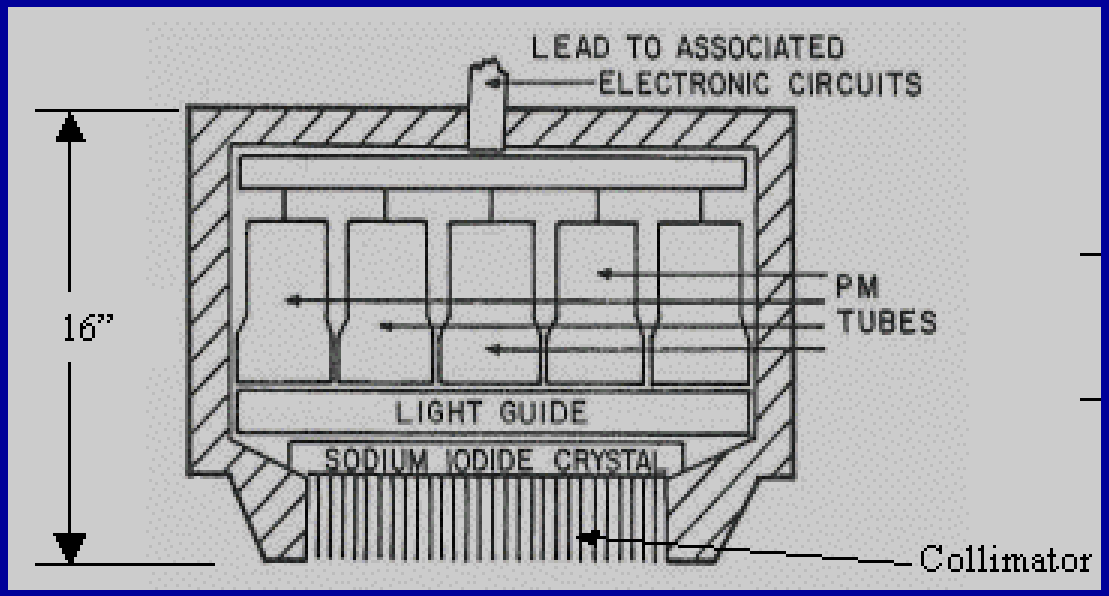
Reduce lung toxicity: reduce dose to higher functioning normal lung $\Rightarrow$ better quality of life!

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° rotation at 3° 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 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

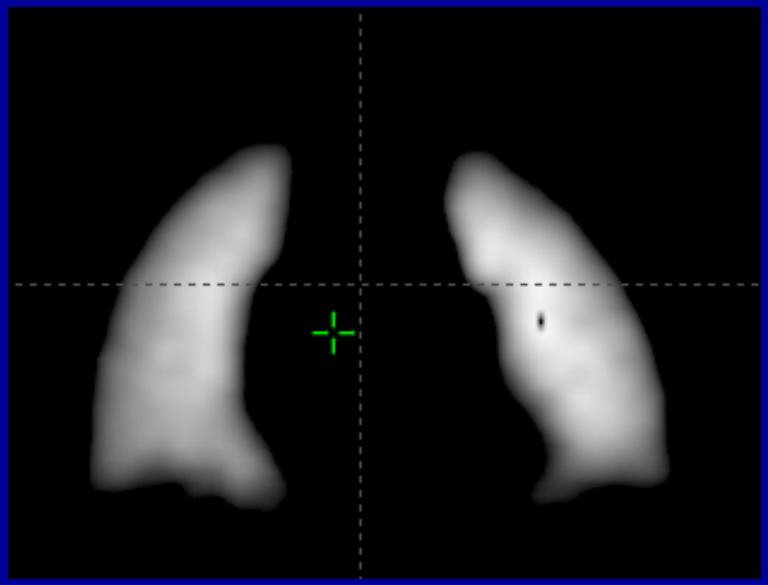
  PTV 40: 100% / 40 Gy (Primary)

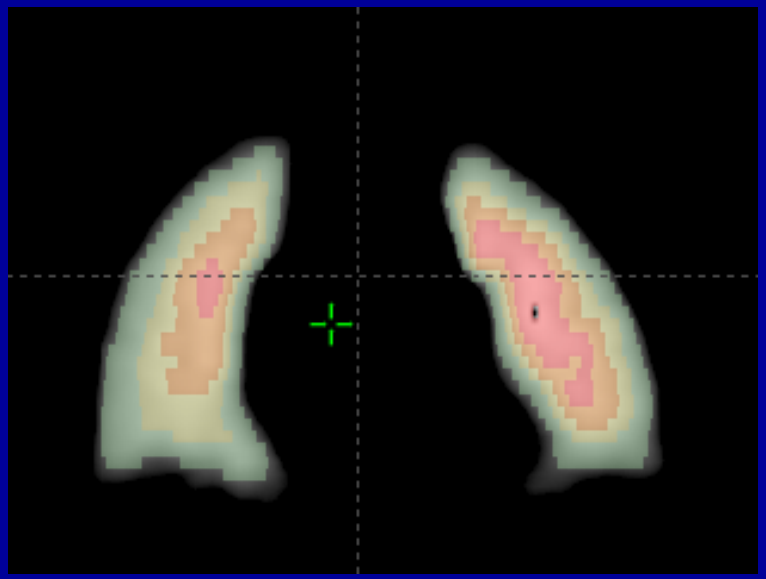
  PTV 66: 100% / 66 Gy (Boost)

  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

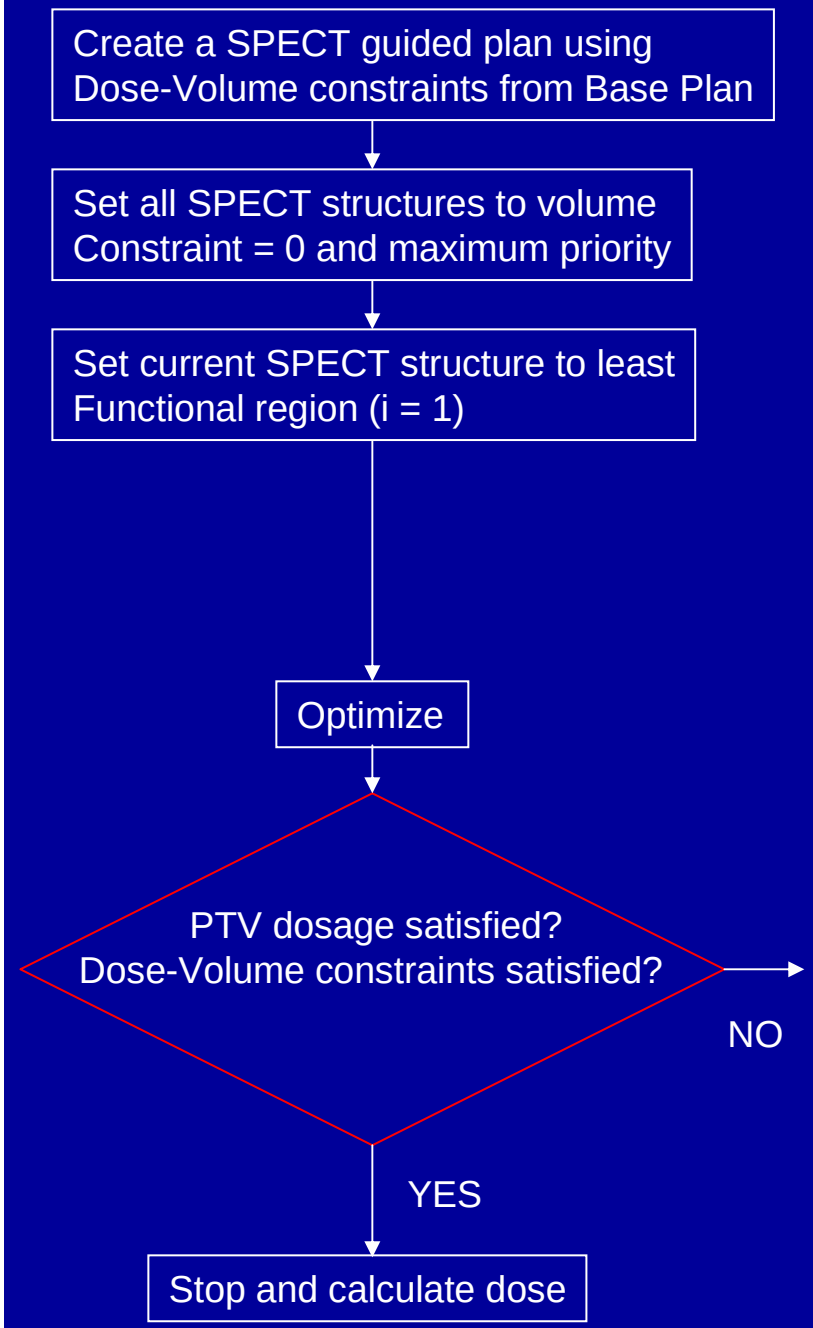
↓

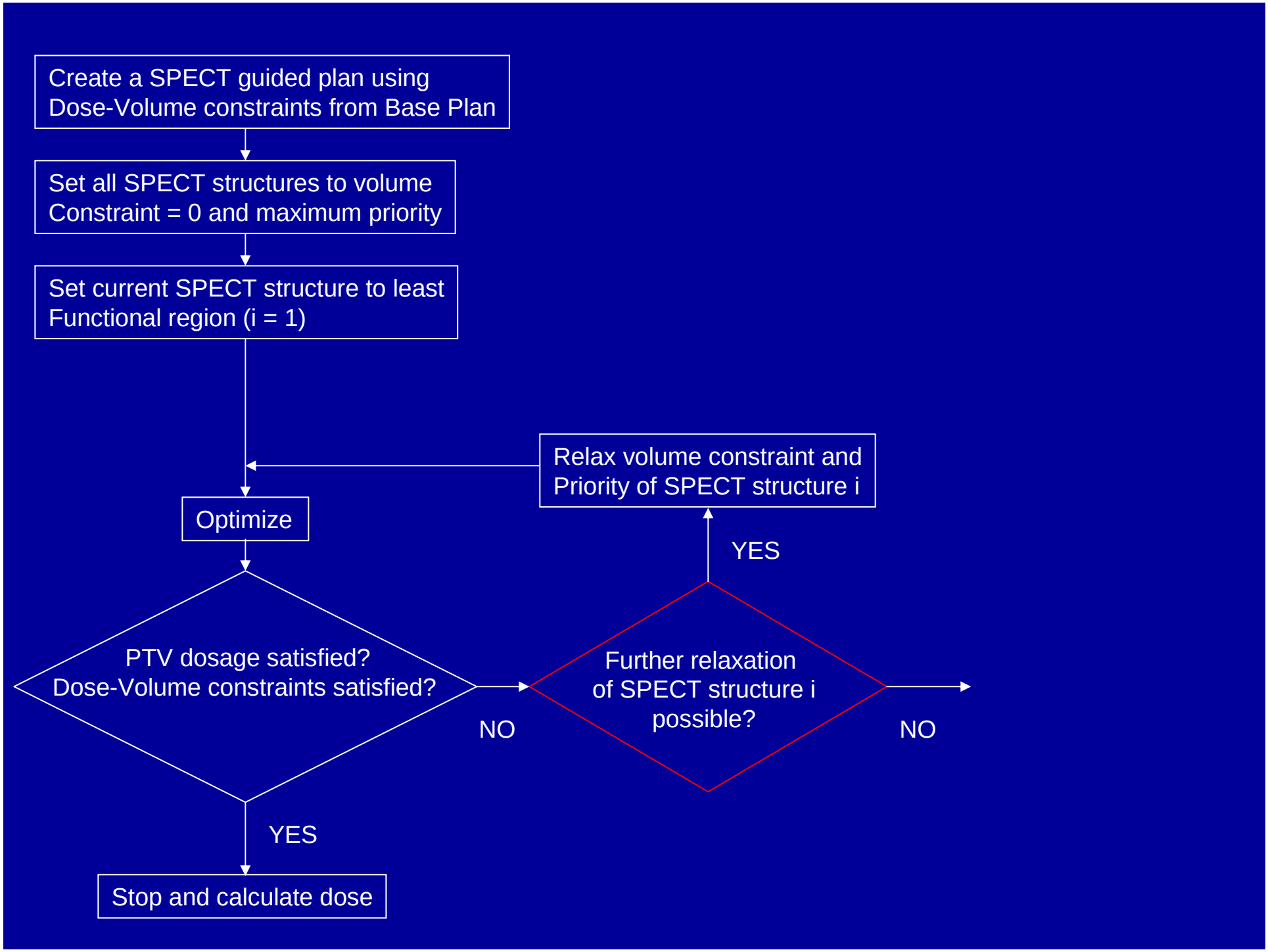
Set all SPECT structures to volume Constraint = 0 and maximum priority

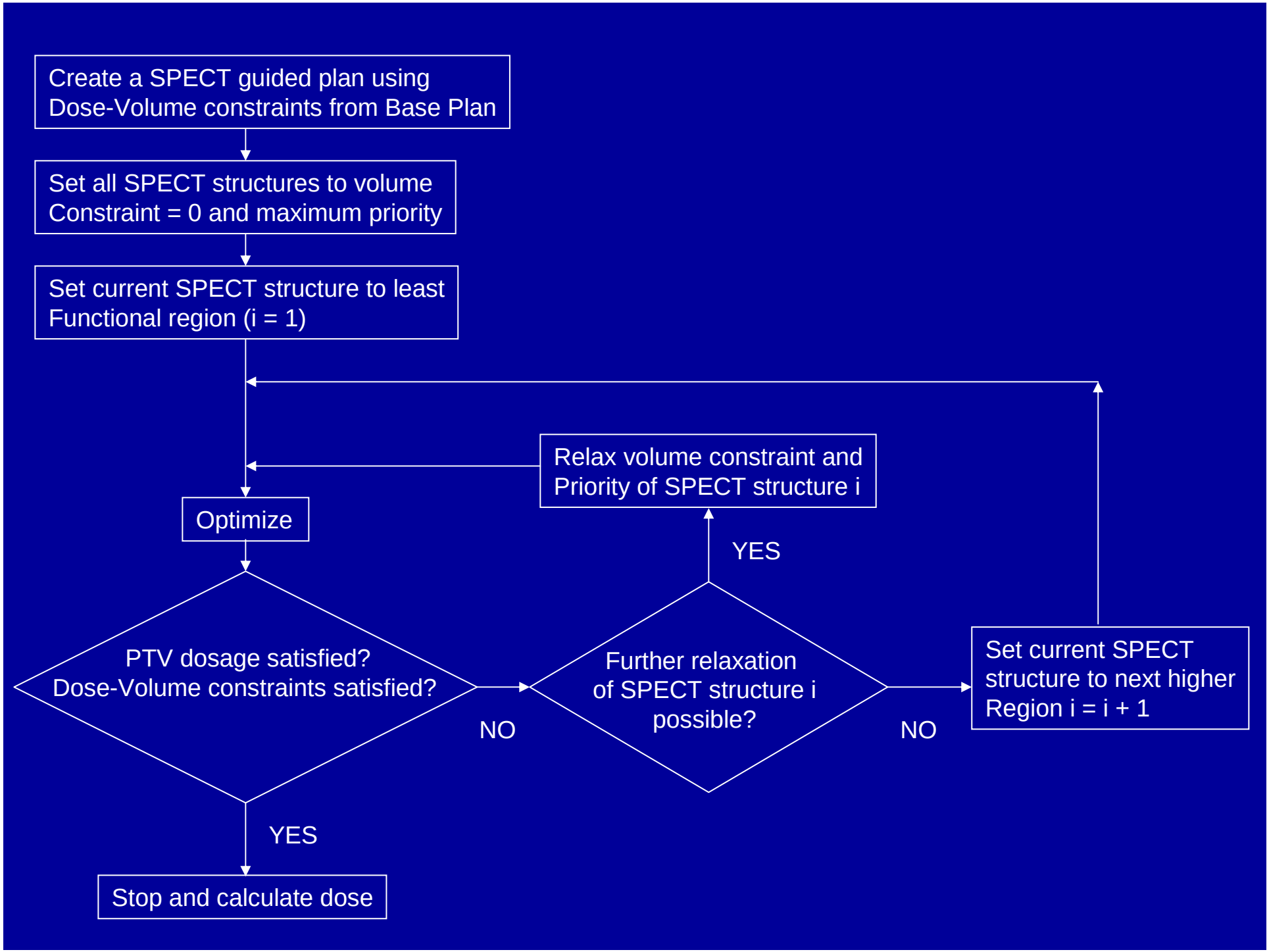
↓

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)
Relax volume constraint and Priority of SPECT structure i
Optimize
YES
PTV dosage satisfied? Dose-Volume constraints satisfied?
Further relaxation of SPECT structure i possible?
NO
NO
YES
Stop and calculate dose

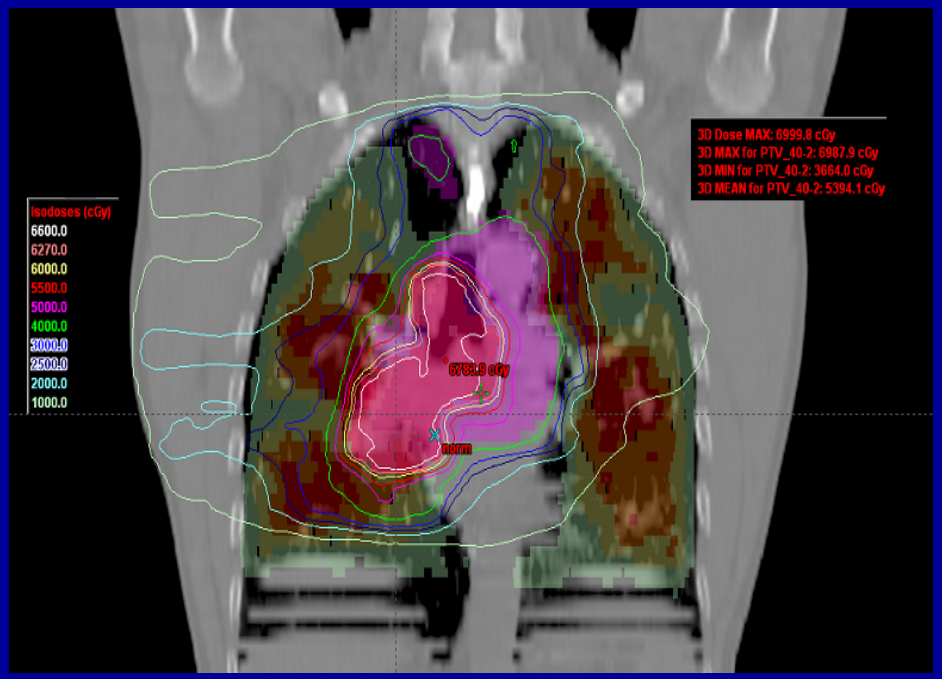

Create a SPECT guided plan using Dose-Volume constraints from Base Plan
Set all SPECT structures to volume Constraint = 0 and maximum priority
Set current SPECT structure to least Functional region (i = 1)
Relax volume constraint and Priority of SPECT structure i
Optimize
YES
PTV dosage satisfied? Dose-Volume constraints satisfied?
NO
Further relaxation of SPECT structure i possible?
NO
Set current SPECT structure to next higher Region i = i + 1
YES
Stop and calculate dose

How can we measure benefit?

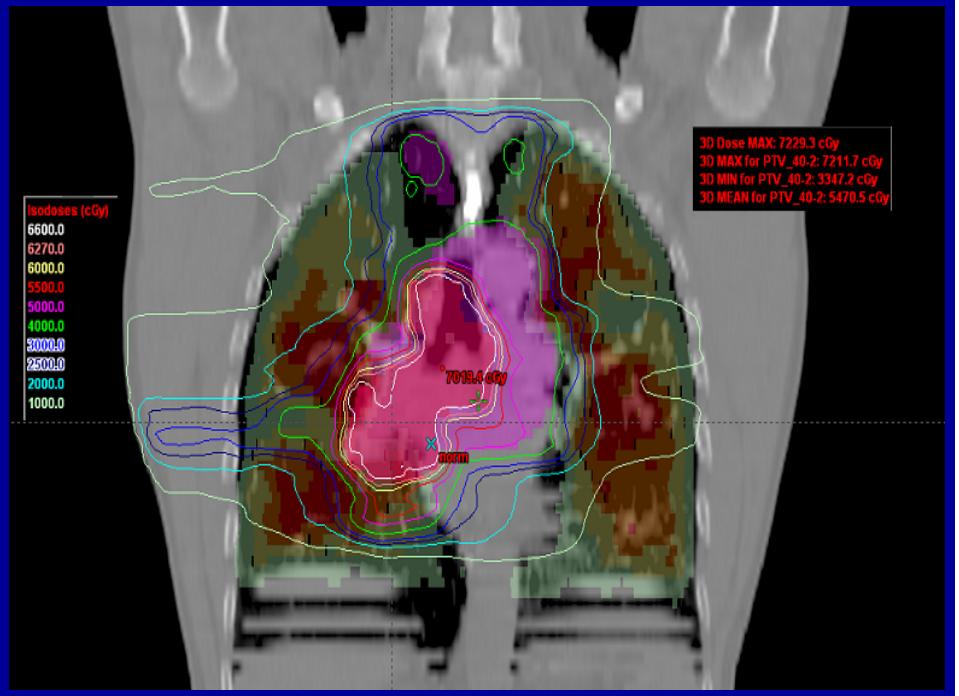
- Dose map
- Dose-Function Histogram (DFH) vs. Dose-Volume Histogram (DVH)
  - DVH measures % volume above a particular dose
  - **DFH** measures % function above a particular dose
- F_{20} and F_{30} vs. V_{20} and V_{30}
  - V_D is the % volume that receives dose above D Gy
  - $\mathbf{F_D}$ is the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

Dose distribution

Function

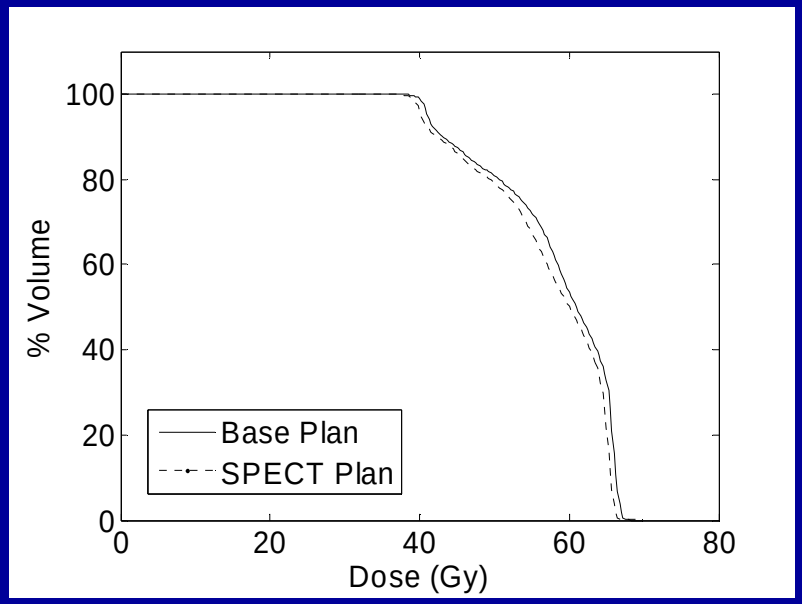


Non SPECT-guided plan

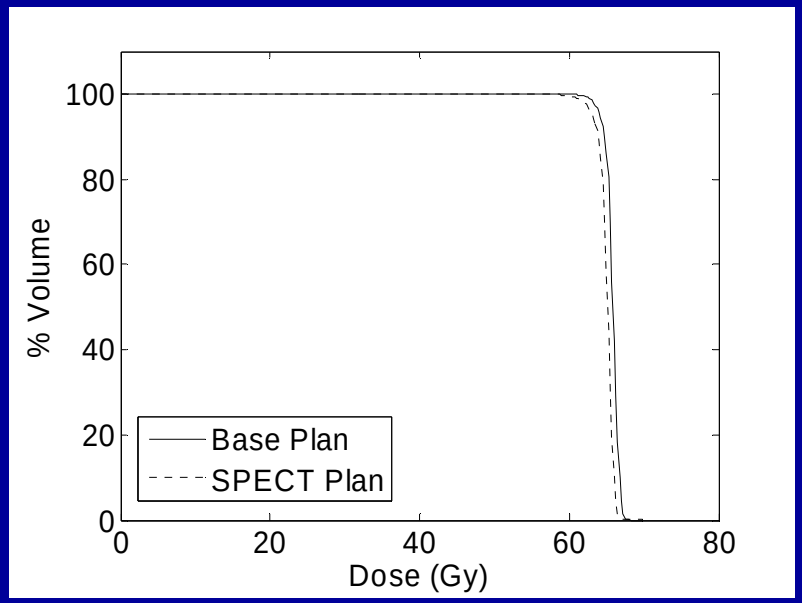


SPECT-guided plan

DVHs of targets

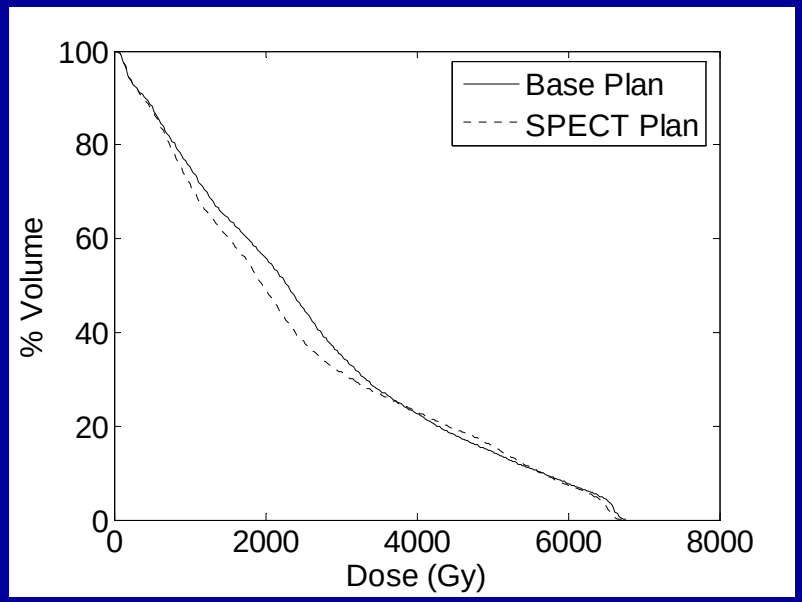


Primary



Boost

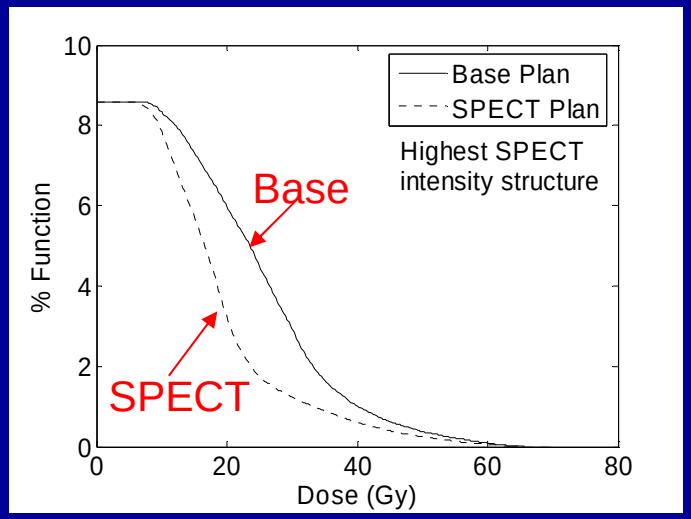
DVHs and volume sparing above 20Gy for whole lung



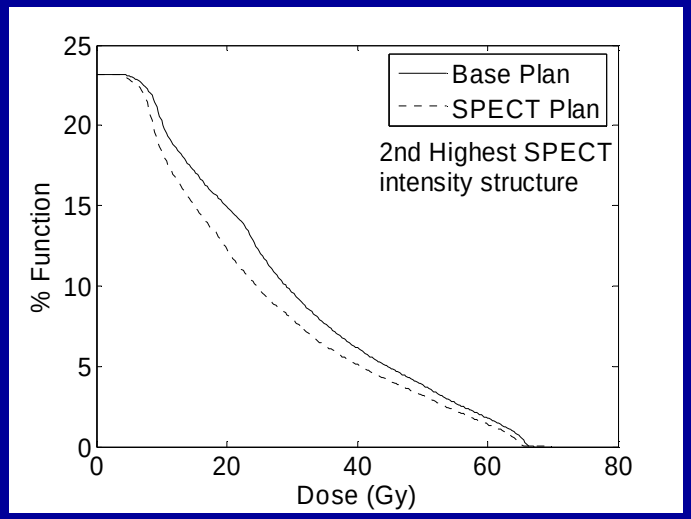
Patient A

Patient	V_{20}		
	Base (%)	SPECT (%)	% Reduction
A	55.9	49.3	11.8
B	49.7	47.9	3.7
C	48.2	42.6	11.5
D	32.0	30.5	4.7
E	43.1	41.2	4.5
	Average		7.2 ± 4.0

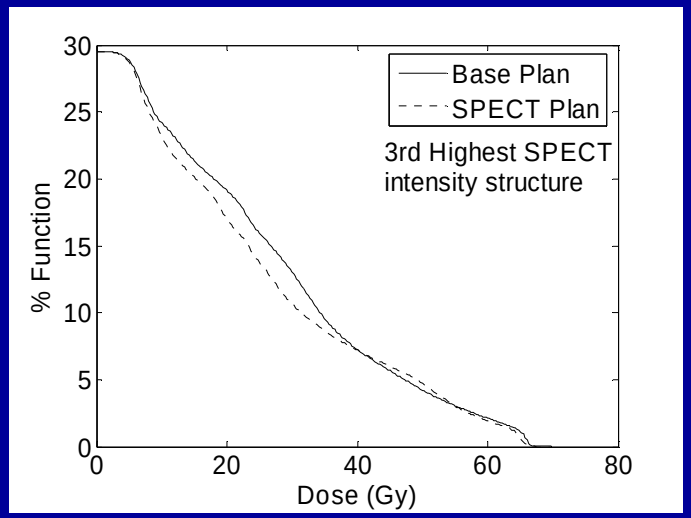
Dose Function Histograms: SPECT Structures (one patient)



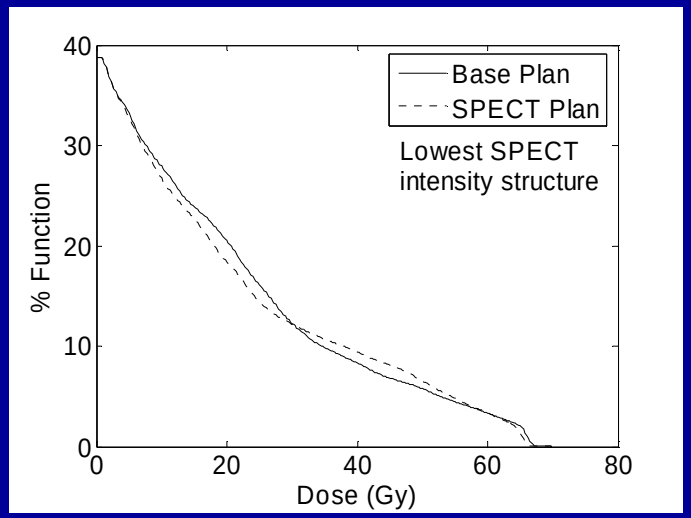
Highest intensity SPECT region DFH



2nd Highest intensity SPECT region DFH

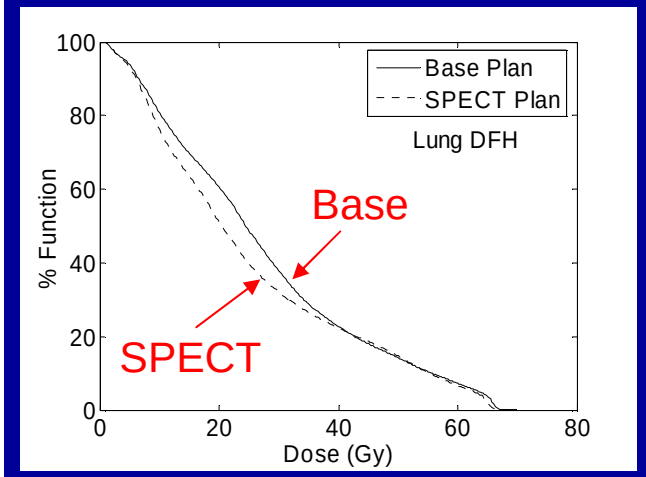


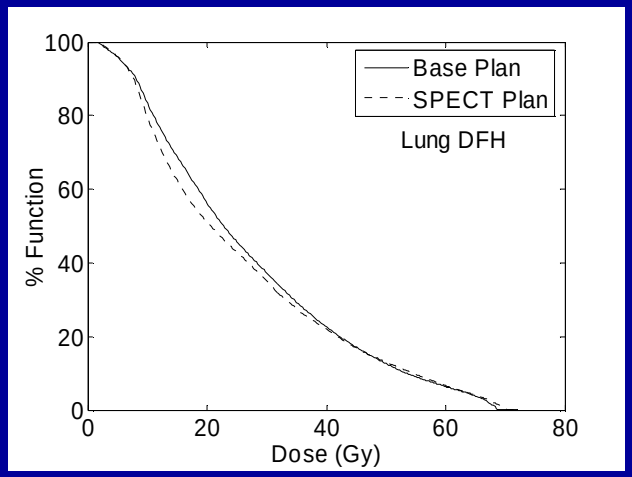
3rd Highest intensity SPECT region DFH

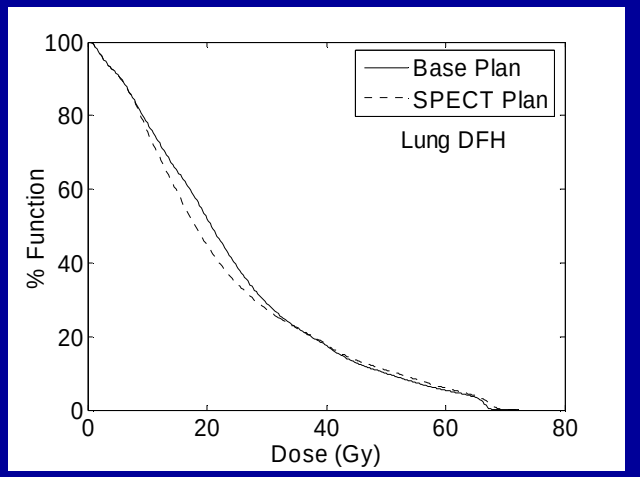


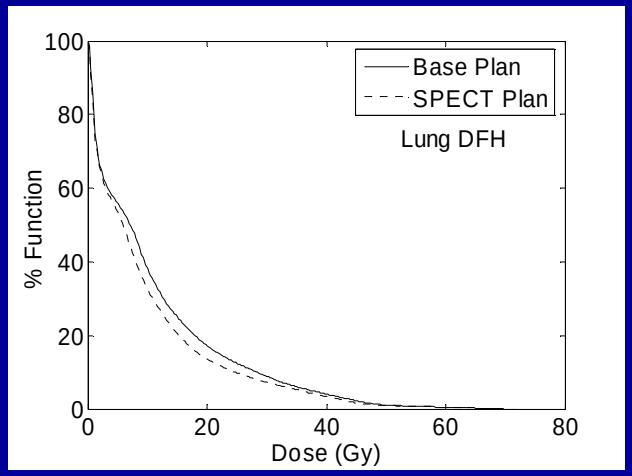
Lowest intensity SPECT region DFH

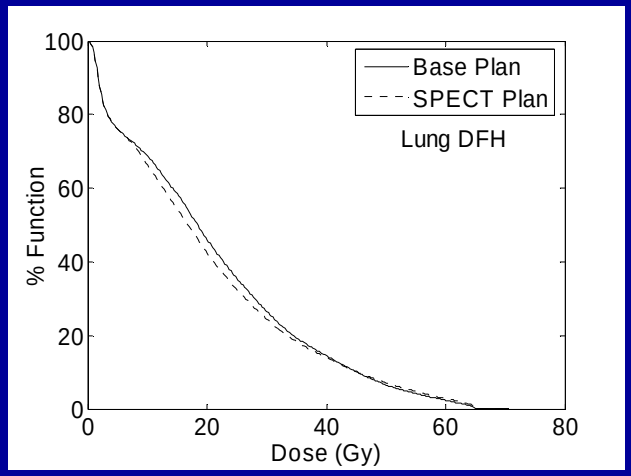
Lung Dose-Function Histograms (5 patients)





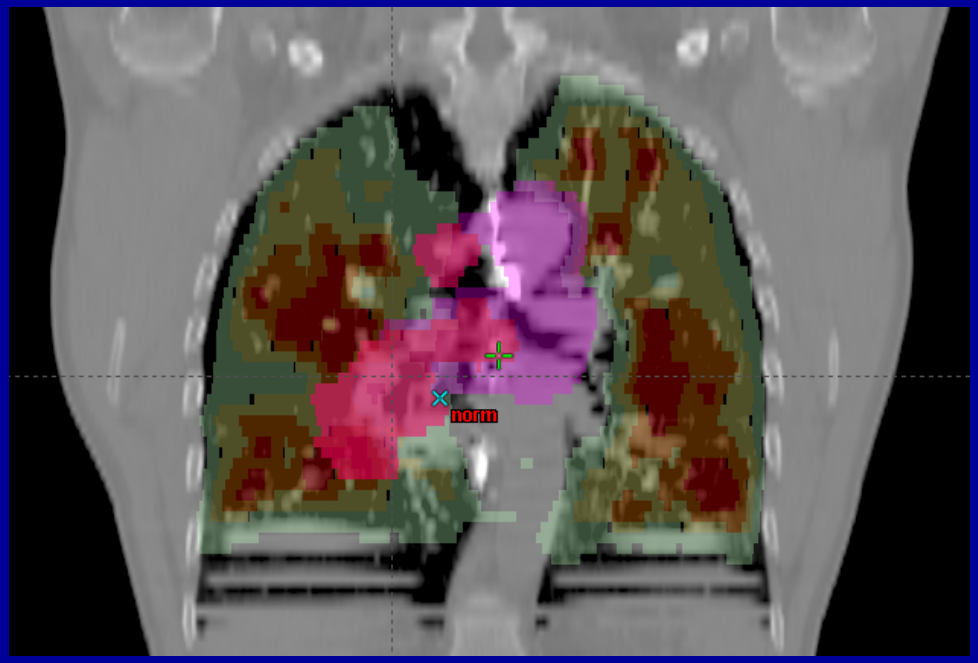


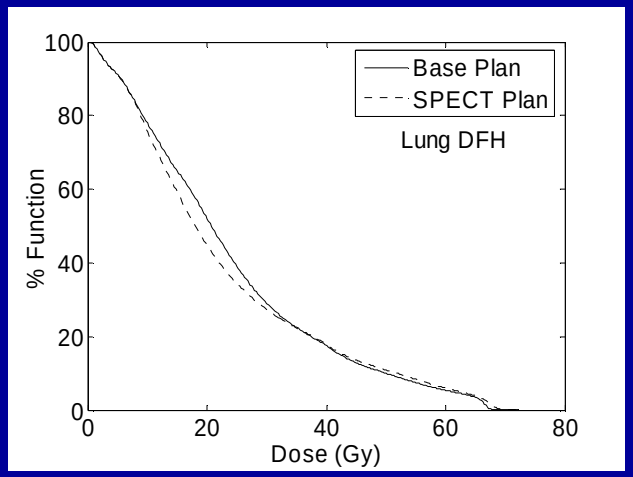




Lung function sparing above 20 Gy, 30 Gy

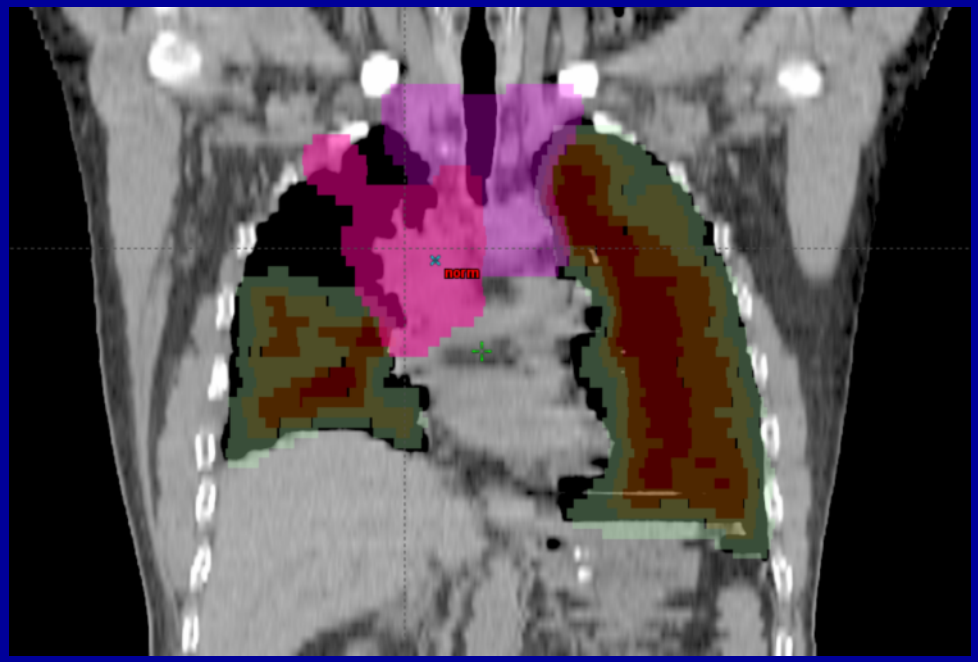
Patient	F_{20}			F_{30}		
	Base (%)	SPECT (%)	% Reduction	Base (%)	SPECT (%)	% Reduction
A	60.6	51.0	15.8	37.9	32.0	15.6
B	56.3	51.1	9.2	37.2	35.1	5.6
C	52.0	44.6	14.2	29.0	27.3	5.9
D	17.2	13.6	20.9	8.9	7.3	18.0
E	46.1	42.4	8.0	26.5	24.5	7.5
	Average		13.6 ± 5.2	Average		10.5 ± 5.8

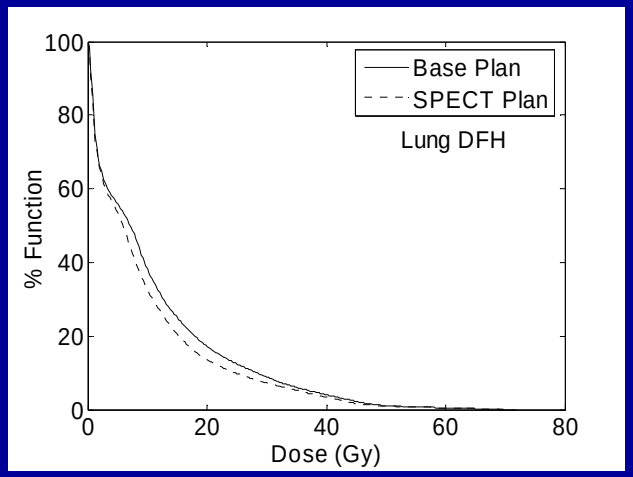




F_{20} = -14.3 % F_{30} = -5.9 %

SPECT distribution can be very spatially heterogeneous





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

- Varian Medical Systems
- NIH Grant No. CA69579