



Monte Carlo Non-Adaptive 4D Treatment Planning in CRT: Why, How, What To Look For?

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Outline

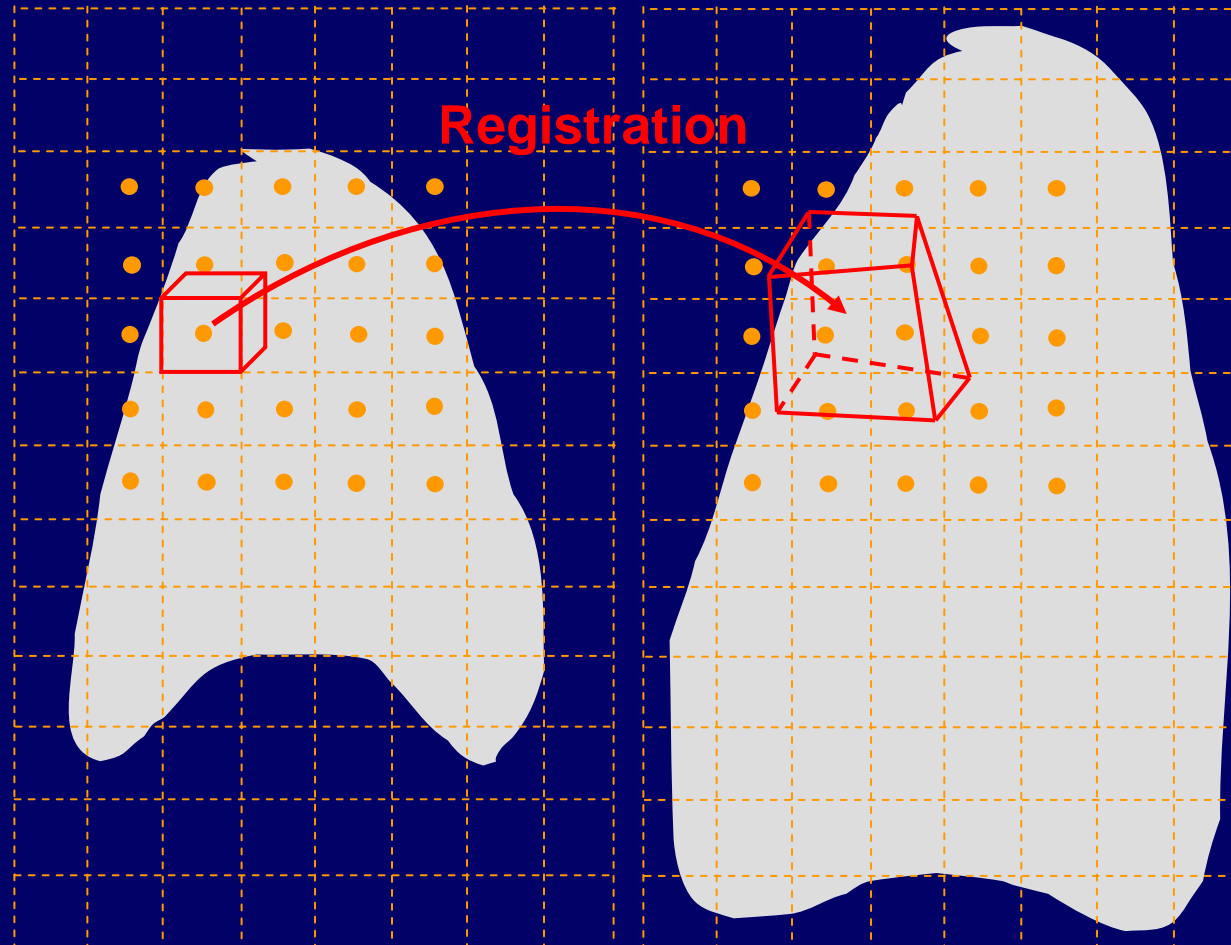
- 1 Dose accumulation
- 1 How much 4D?
- 1 Image registration
- 1 Motion vs. Heterogeneity



Dose mapping

PD dose grid

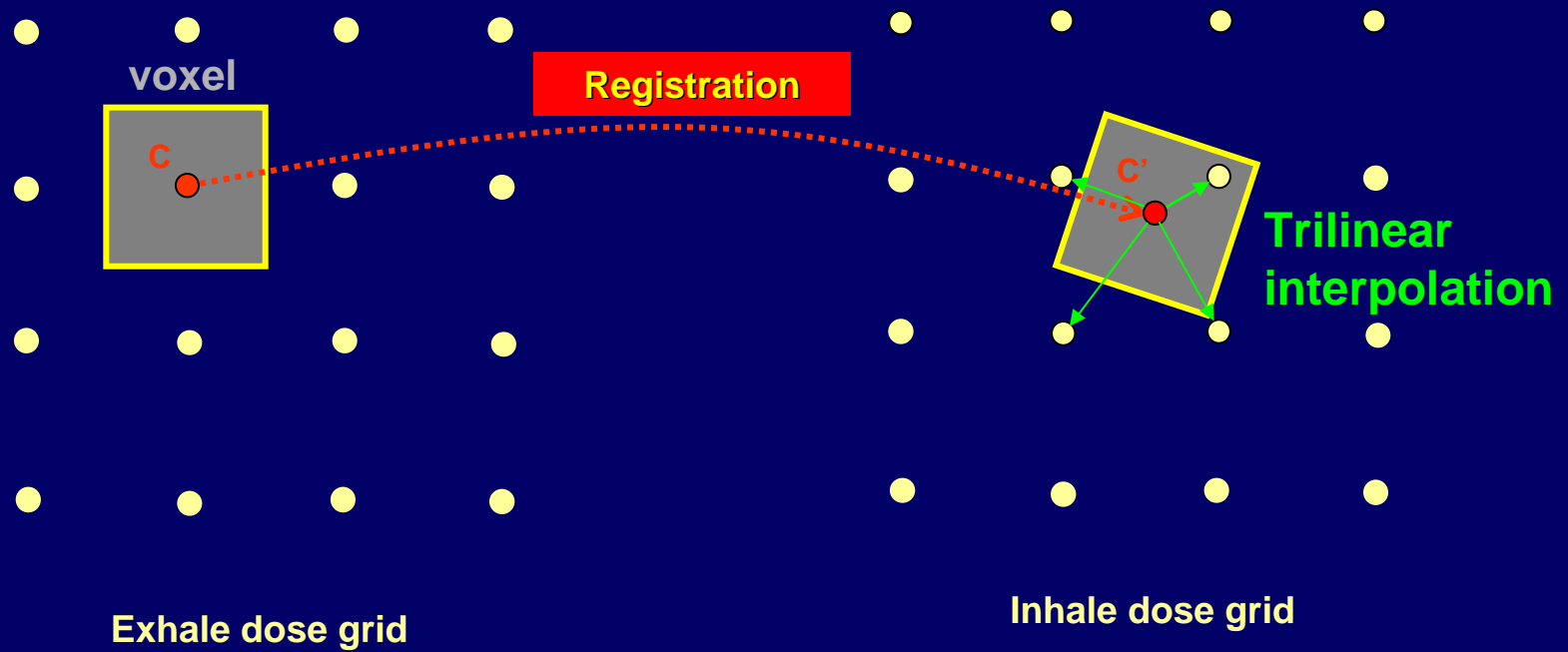
OD dose grid





Dose mapping

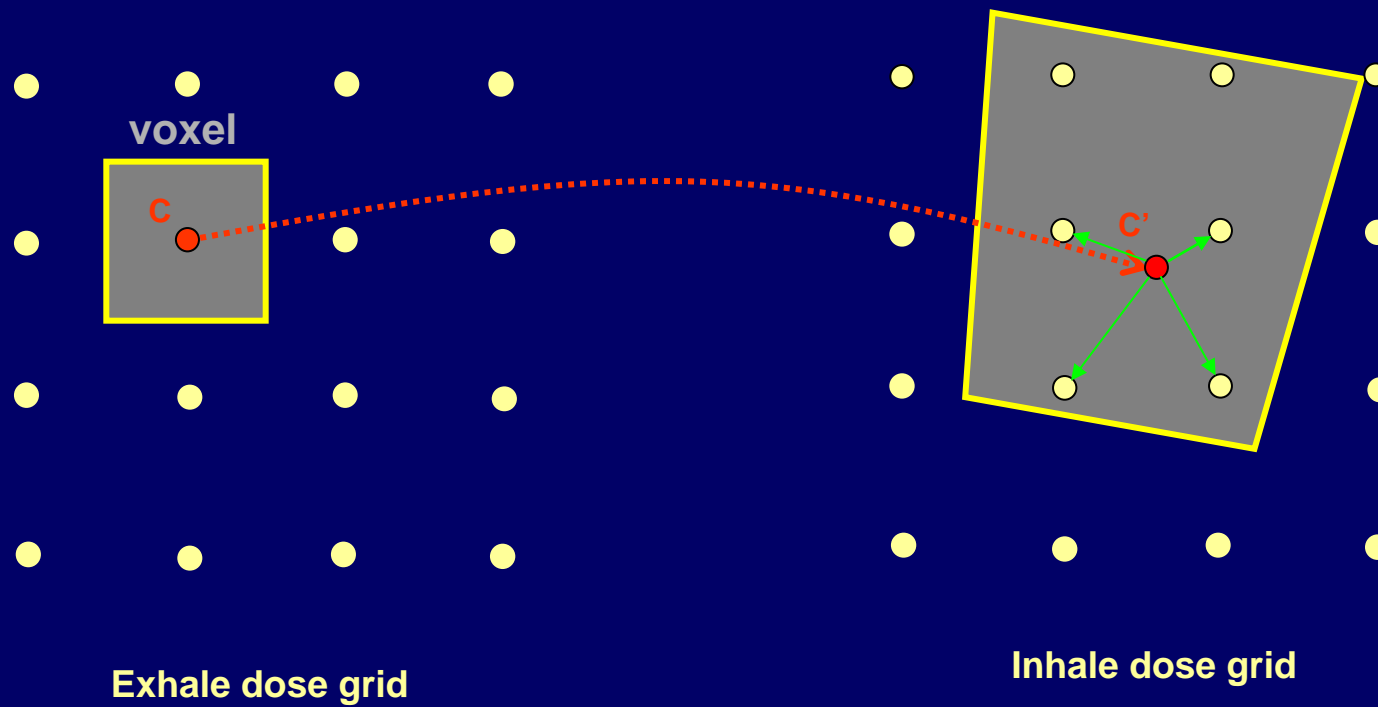
**Voxel size constant
(direct approximation)**





Dose mapping

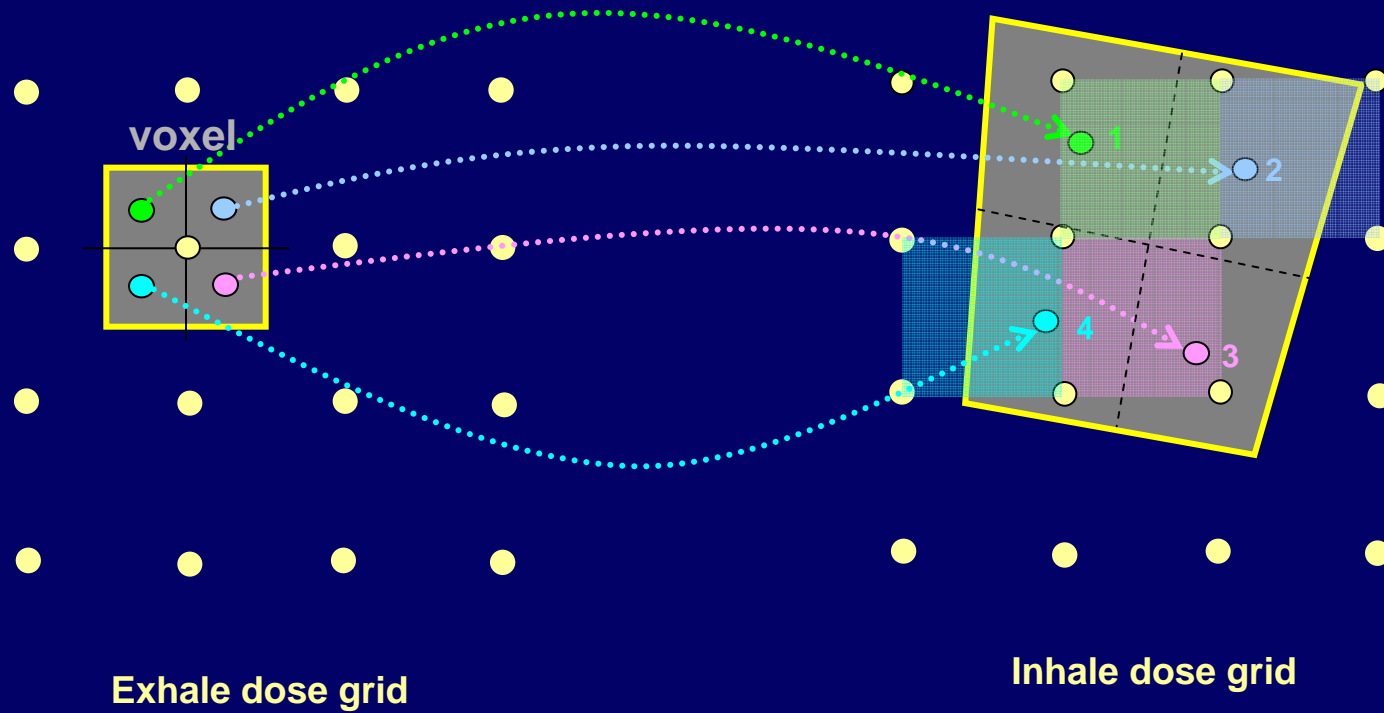
Voxel expanded





Dose mapping

**Voxel subdivision
(refined approximation)**





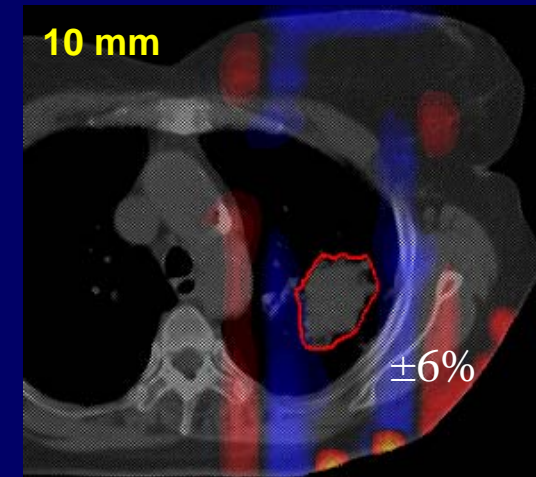
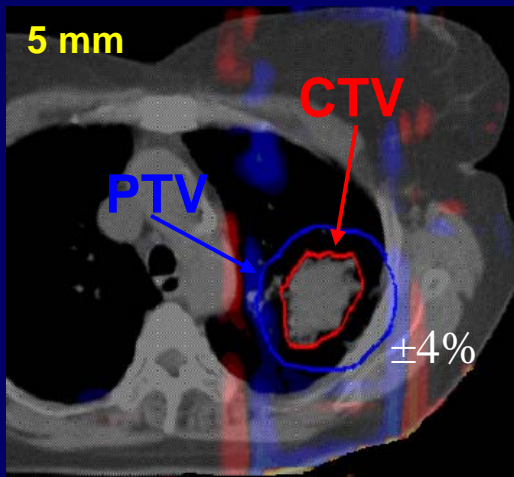
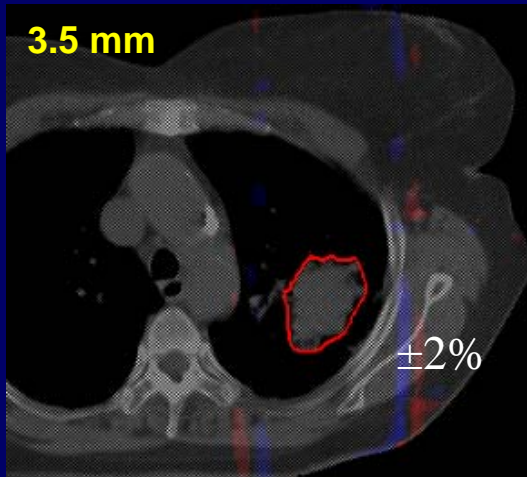
Grid size effects

Doses received by exhale voxels at **inhale**:

refined approximation

–

direct approximation

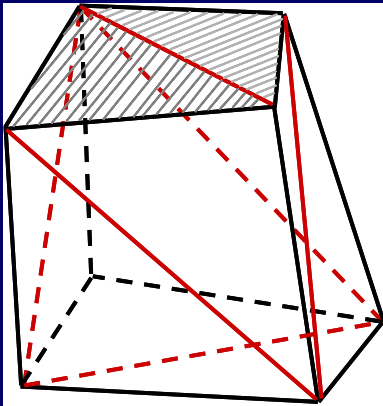


Differences between the interpolation schemes:

- Primarily in steep dose gradient regions
- Voxel size dependent
- Magnitude is less than the alterations in dose due to positional and shape changes from breathing in the first place
- 3-4 mm dose grid size is good (also appropriate for a good balance accuracy vs speed in MC calcs)

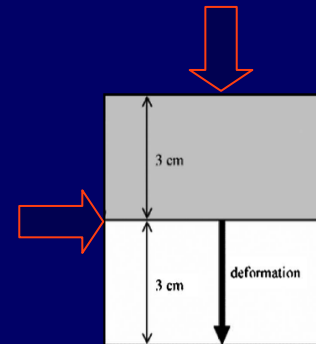


Direct voxel tracking *(E. Heath, McGill University)*

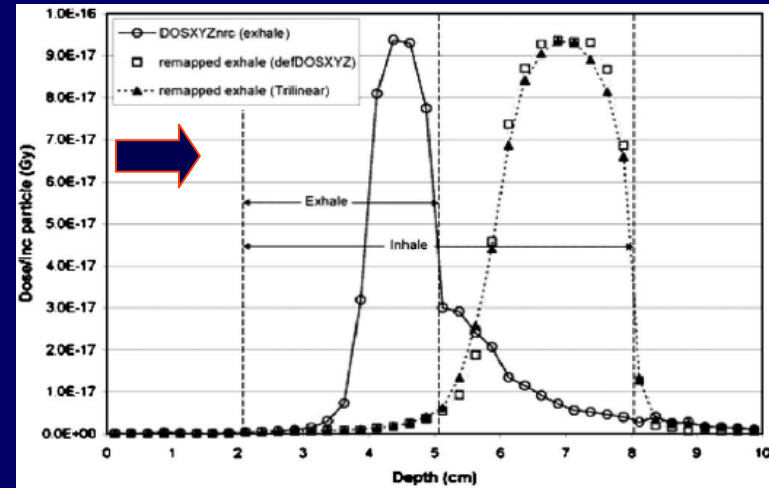
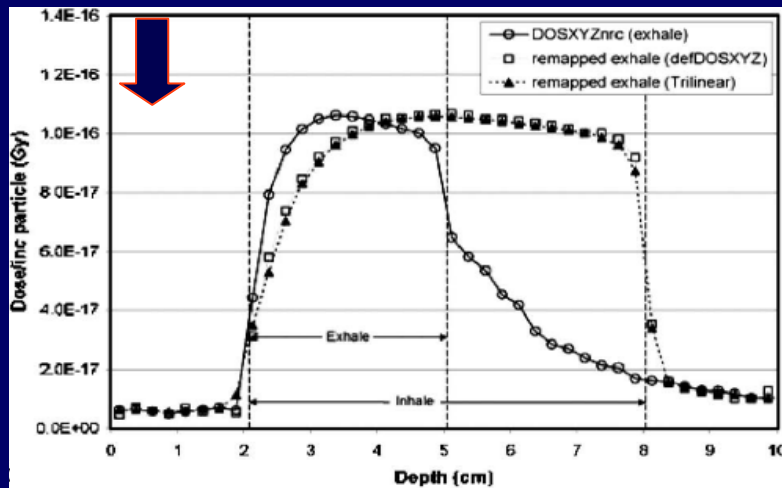


- Dose deposition in deformed voxels
- Deformed voxel surface approximated with 12 planes

2X2 cm² 6 MV



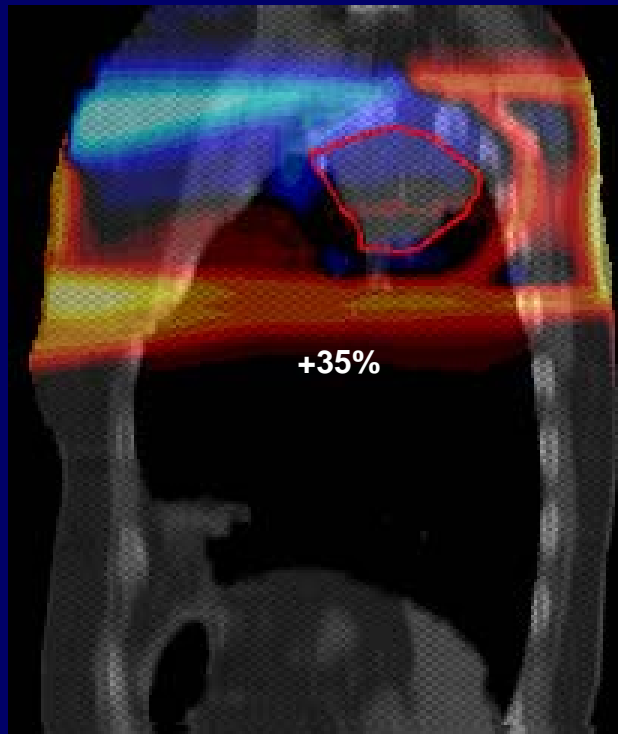
0.25 cm³ voxels



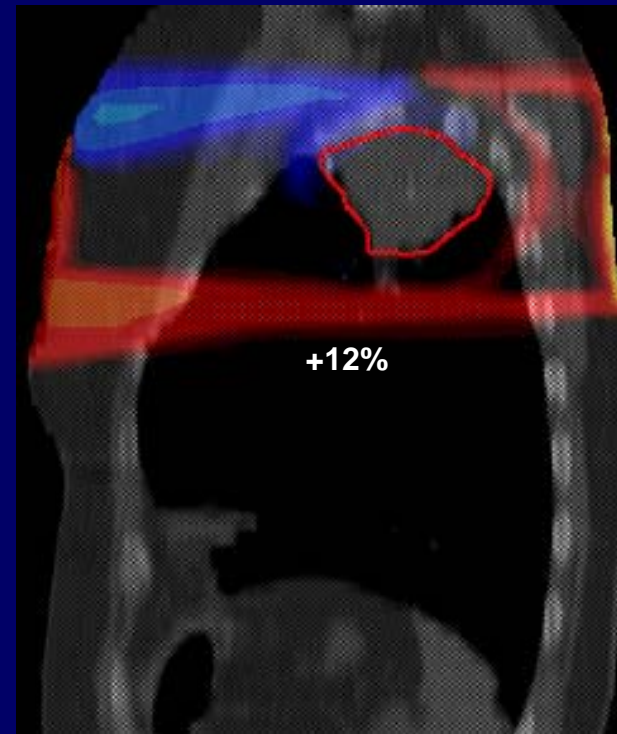


Dose to deforming anatomy

INHALE
minus
STATIC



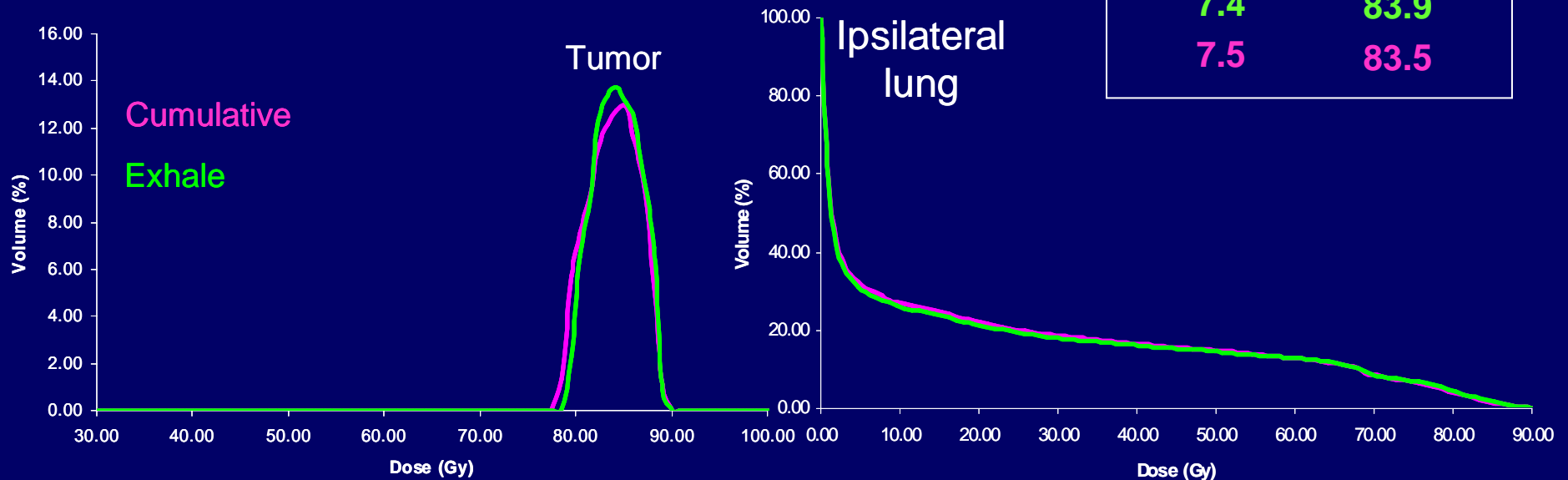
CUMMULATIVE
minus
STATIC



70% Exhale
30% Inhale



Dose to deforming anatomy



<u>MLD (Gy)</u>	<u>EUD (Gy)</u>
7.4	83.9
7.5	83.5

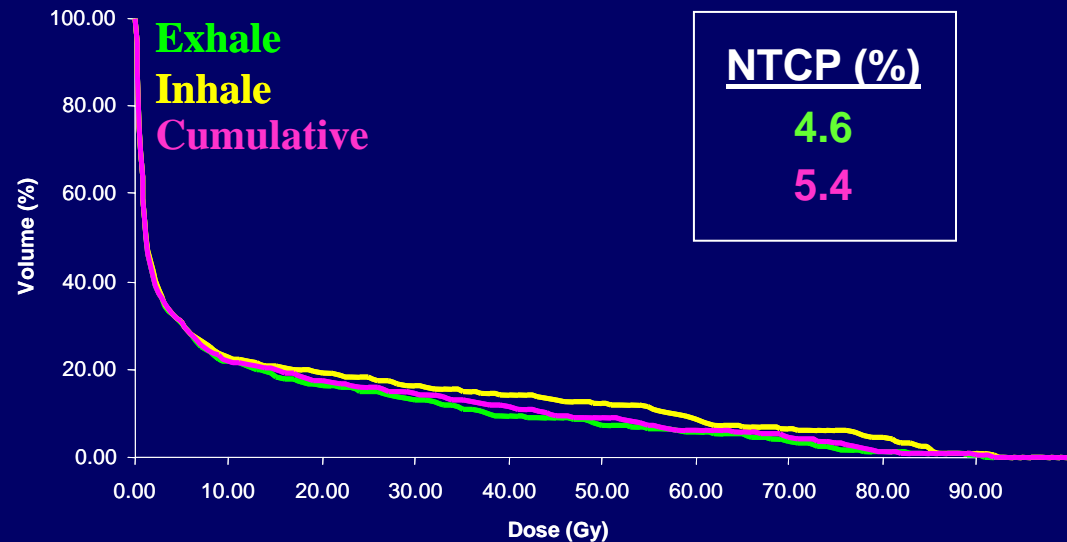
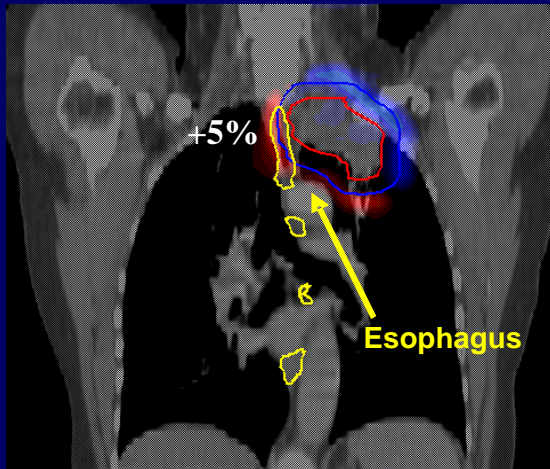
■ Motion and deformation do redistribute doses, changes are not clinically significant

➤ Tumors - consequence of a proper PTV design

➤ Normal lung - due to the parallel nature of a large volume organ



Dose to deforming anatomy



- Serial organs – hot spots may be clinically important in certain cases
 - maximum prescription dose allowed by an upper 5% limit in the esophagus NTCP for late toxicity
 - cumulative dose indicates increased probability for esophagitis above the upper bound as a result of motion/deformation



Summary (I)

Changes due to deformation in thorax:

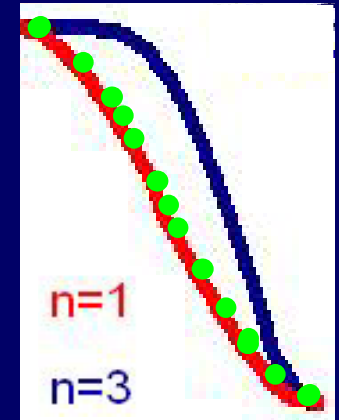
- Overall changes in the cumulative dose exhibit the behavior determined by the displacement with respect to the beam
- The overall effects have large variability among patients, being dependent on tumor location, field size, tissue heterogeneity and direction of tumor displacement with respect to the beam
- Large parallel organs such as lung are likely to be less sensitive to changes in doses emerging from motion and deformation
- In certain cases these changes may have an impact on serial organs such as esophagus.



How much 4D data is needed?

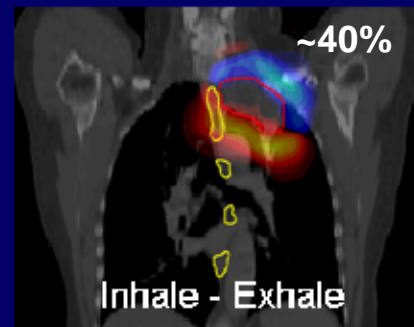
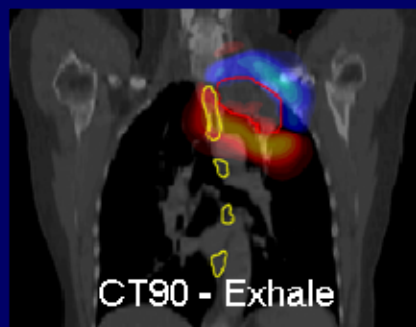
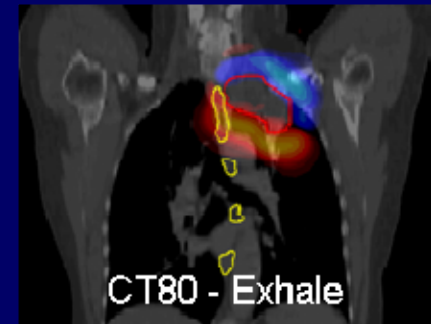
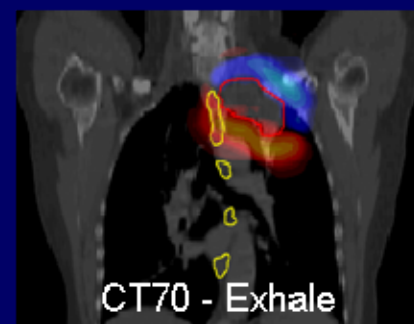
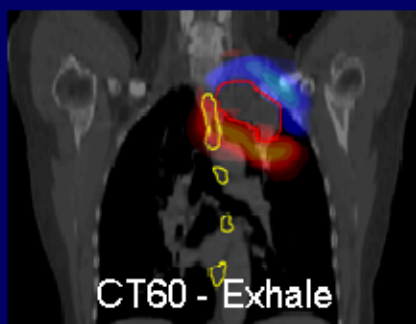
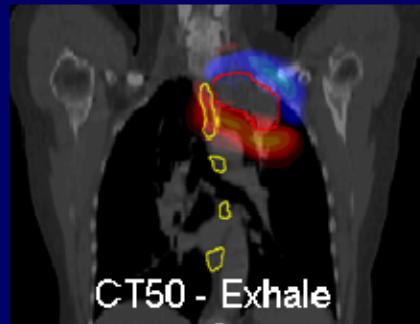
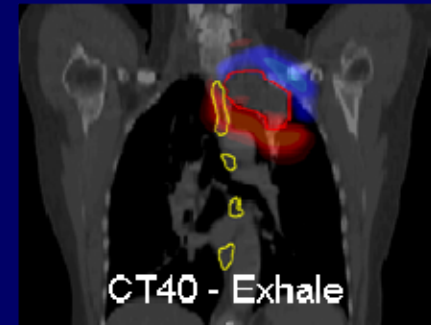
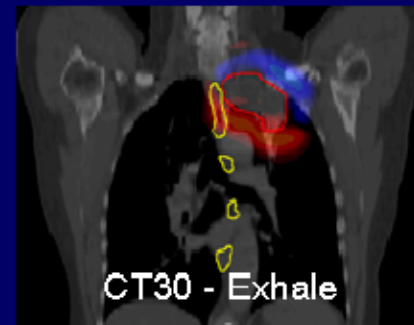
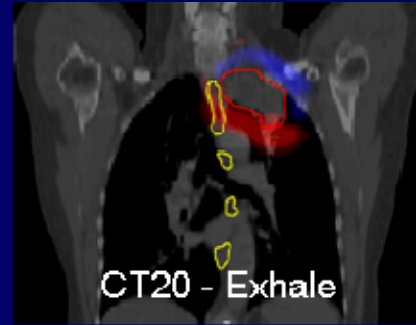
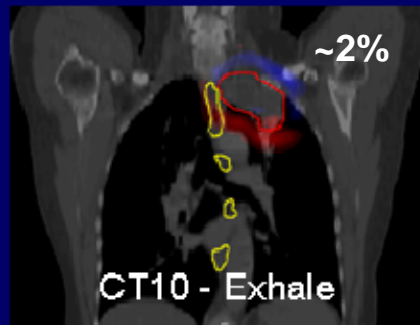
The cumulative doses (reported on the exhale planning CT) were estimated in five scenarios:

- Exhale, Inhale, 10÷90% geometries (“11-state dose”)
- Exhale, Inhale, 20÷80% geometries (“6-state dose”)
- Average breathing phases from the first and the second half of the breathing cycle (“2-ave state dose”)
~10% and ~80% for n=3 and ~20% and ~80% for n=1
- Exhale and inhale geometries (“2-state dose”)
- Average state over breathing cycle (“ave dose”)
~30% for n=3 and 50% for n=1



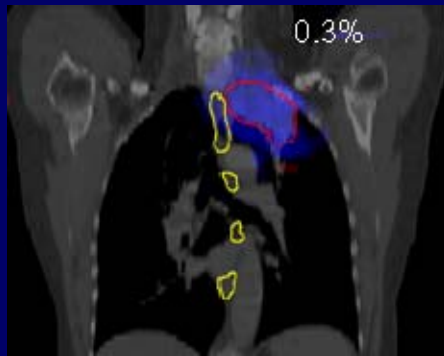


Changes from exhale

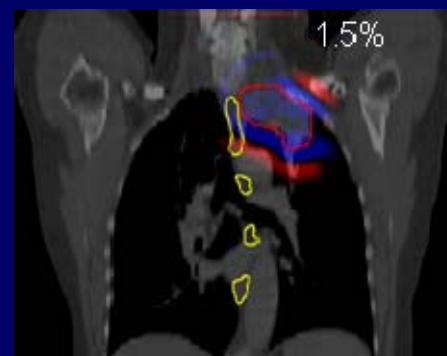




Comparisons between various scenarios



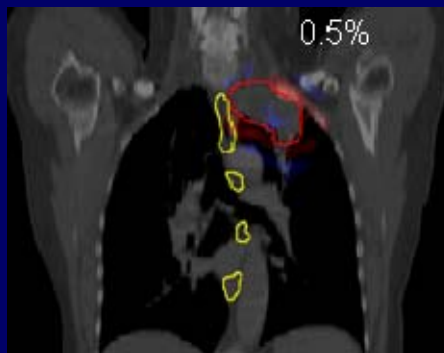
"11 state" – "6 state"



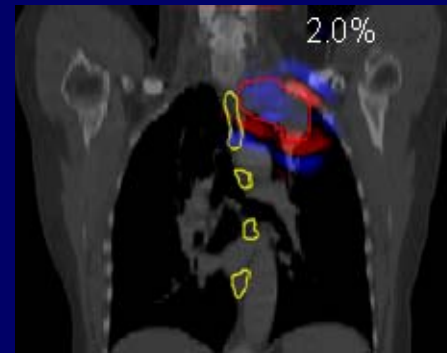
"11 state" – "2 state"



"11 state" – Exhale



"11 state" – "2-ave state"



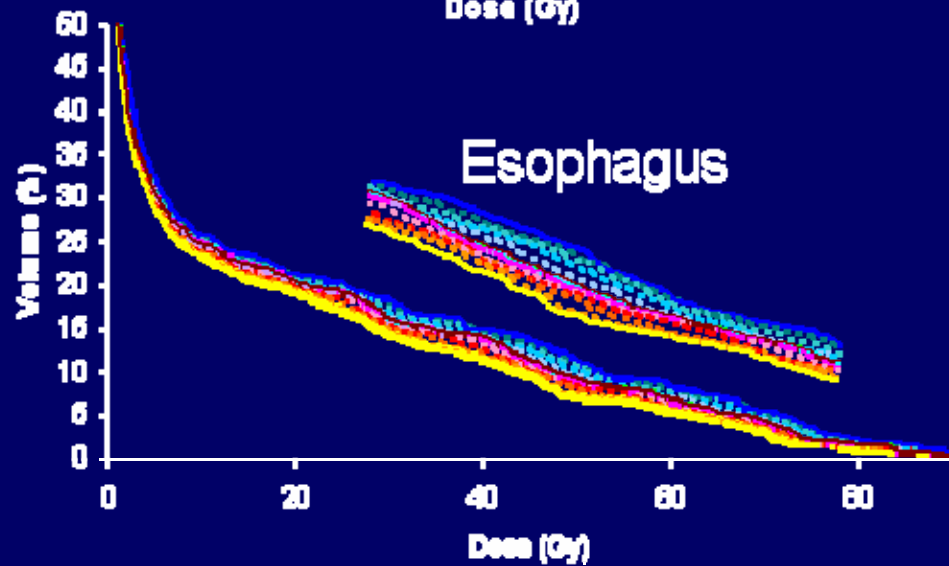
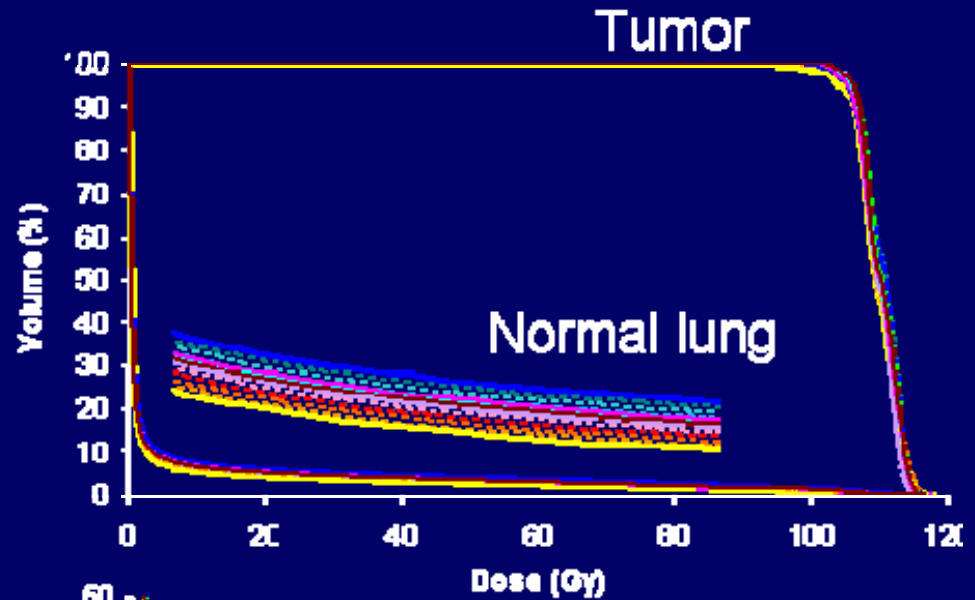
"11 state" – "50% state"

Unlikely that these differences will lead to any clinically important changes when any of these scenarios is used to estimate the cumulative dose



Comparisons between various scenarios

- EXH
- - - CT10
- - - CT20
- - - CT30
- - - CT40
- - - CT60
- - - CT80
- - - CT70
- - - CT80
- - - CT90
- BH
- 11 State
- 8 State
- 2 State (Exh/Inf)
- 2 State (20% 80%)





Summary (II)

For 4D planning (thorax):

- The use of the *exhale and inhale* scans appears to be a feasible and adequate choice to accurately estimate cumulative doses for thorax
 - The *average state* over the breathing cycle would suffice, but has lower degree of reproducibility.
- Is breathing pattern reproducible? Not necessarily, but this doesn't change the validity of our observations.

Update dose (to ave state or weighting coefs for exhale and inhale).



Image registration – where does it matter?

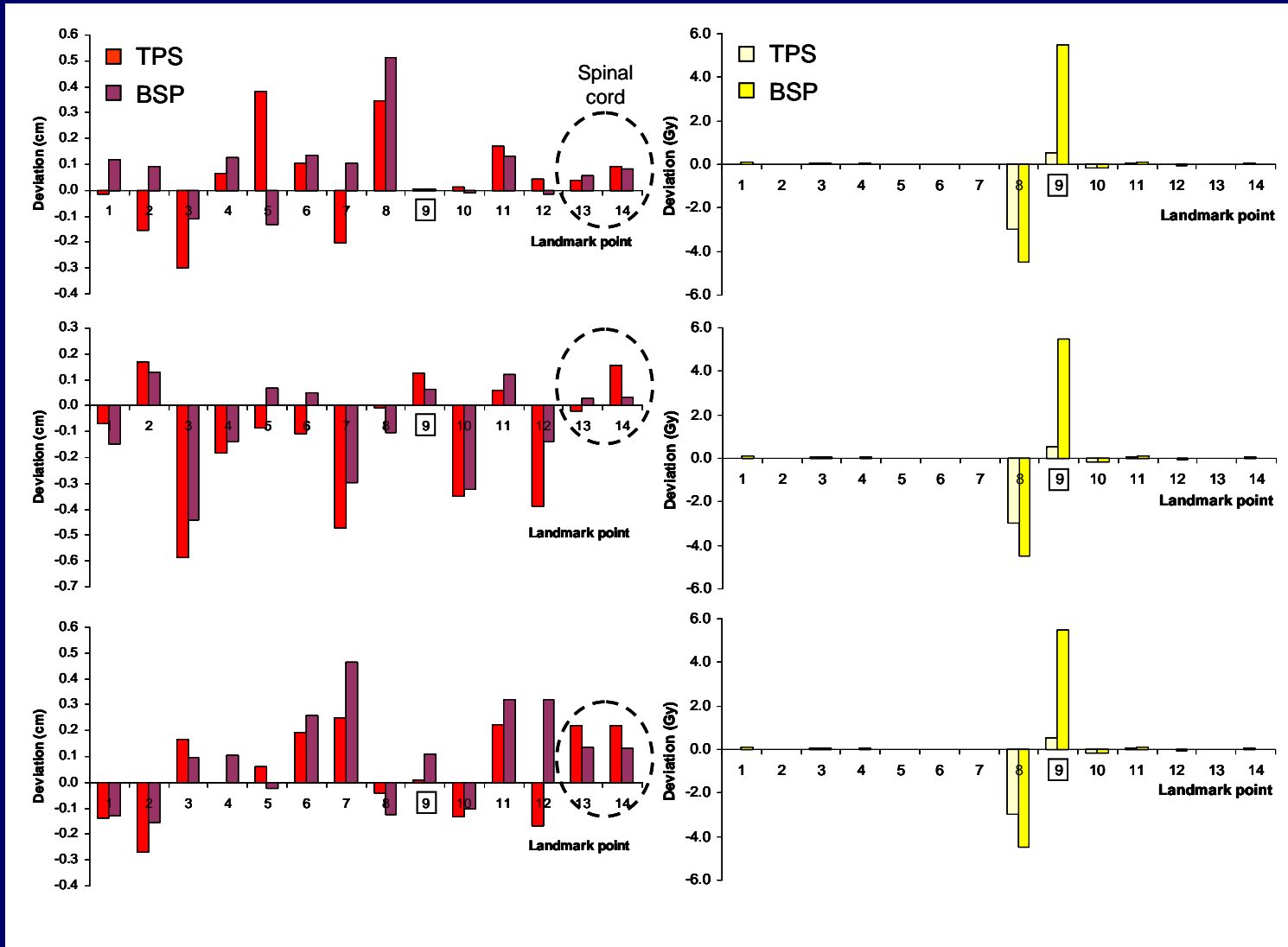
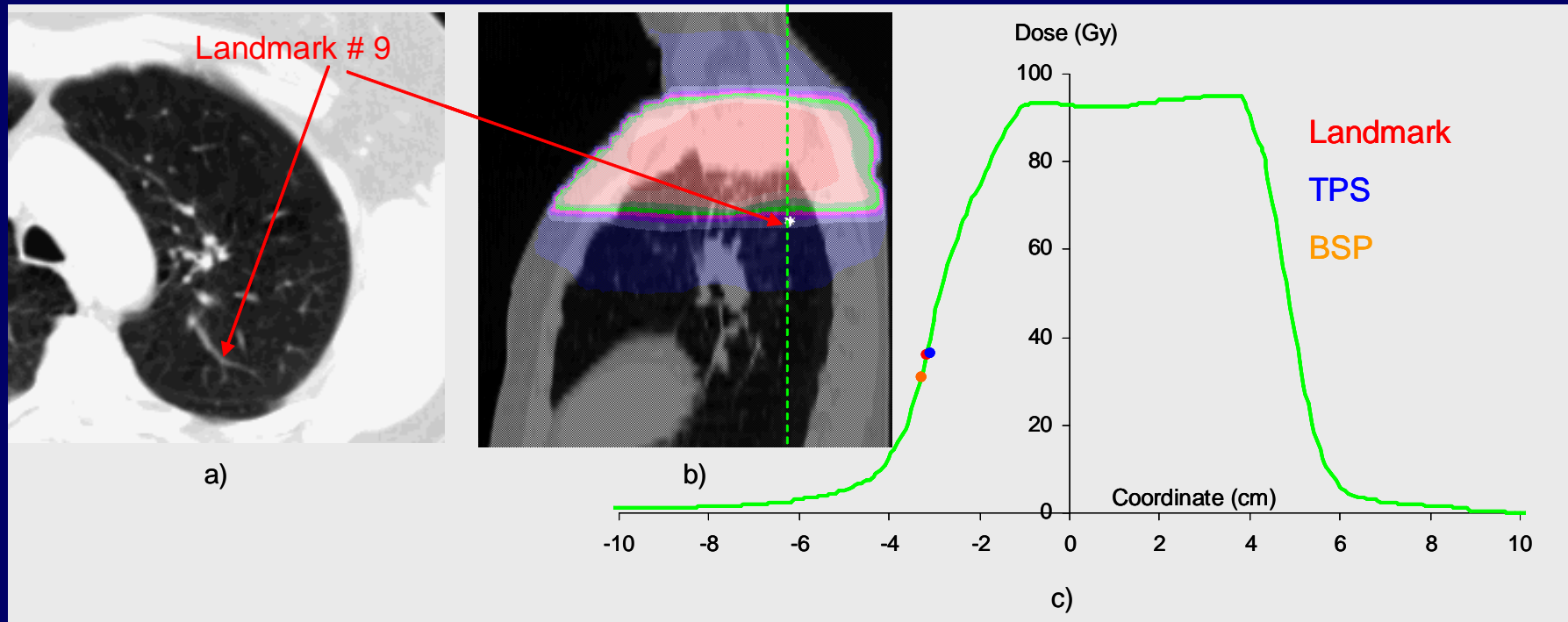




Image registration – where does it matter?





Summary (III)

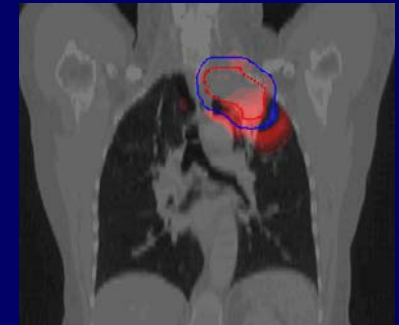
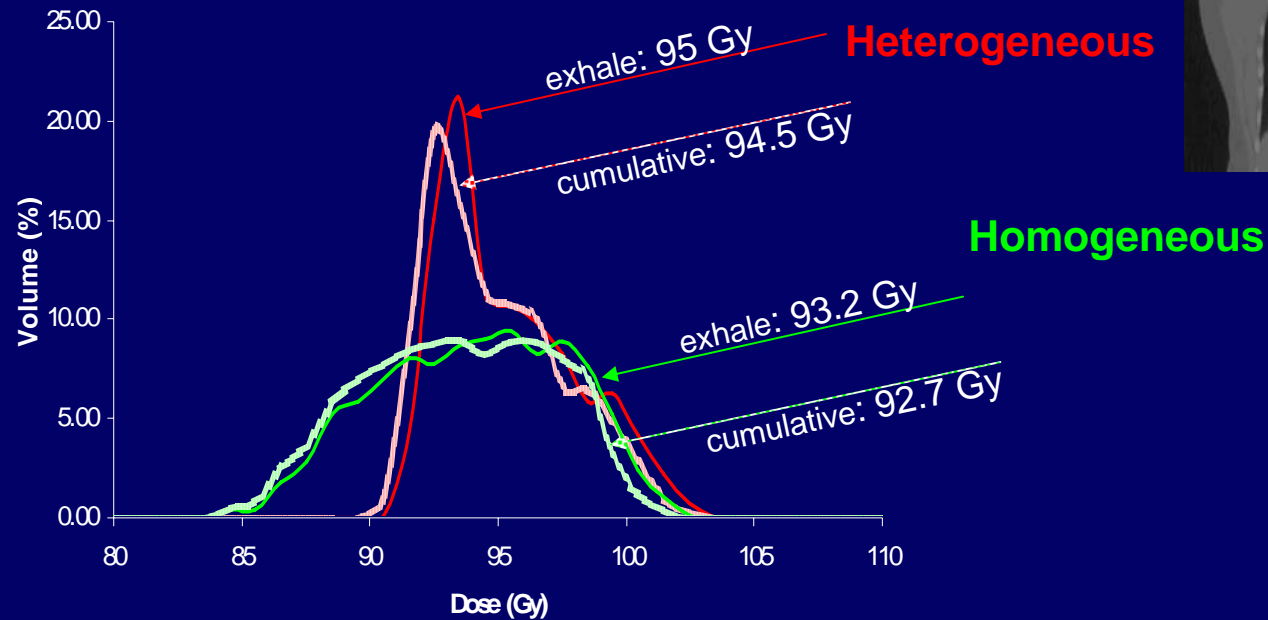
- Registration errors important in regions of steep dose gradient



Inhomogeneity vs. motion

Tumor

EUD:

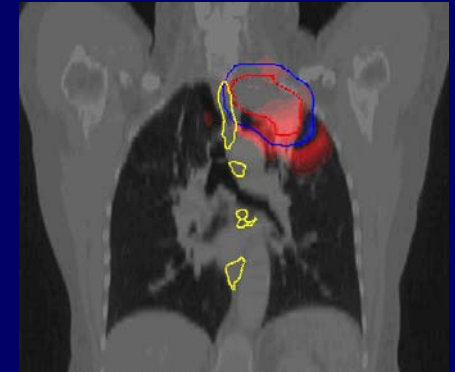
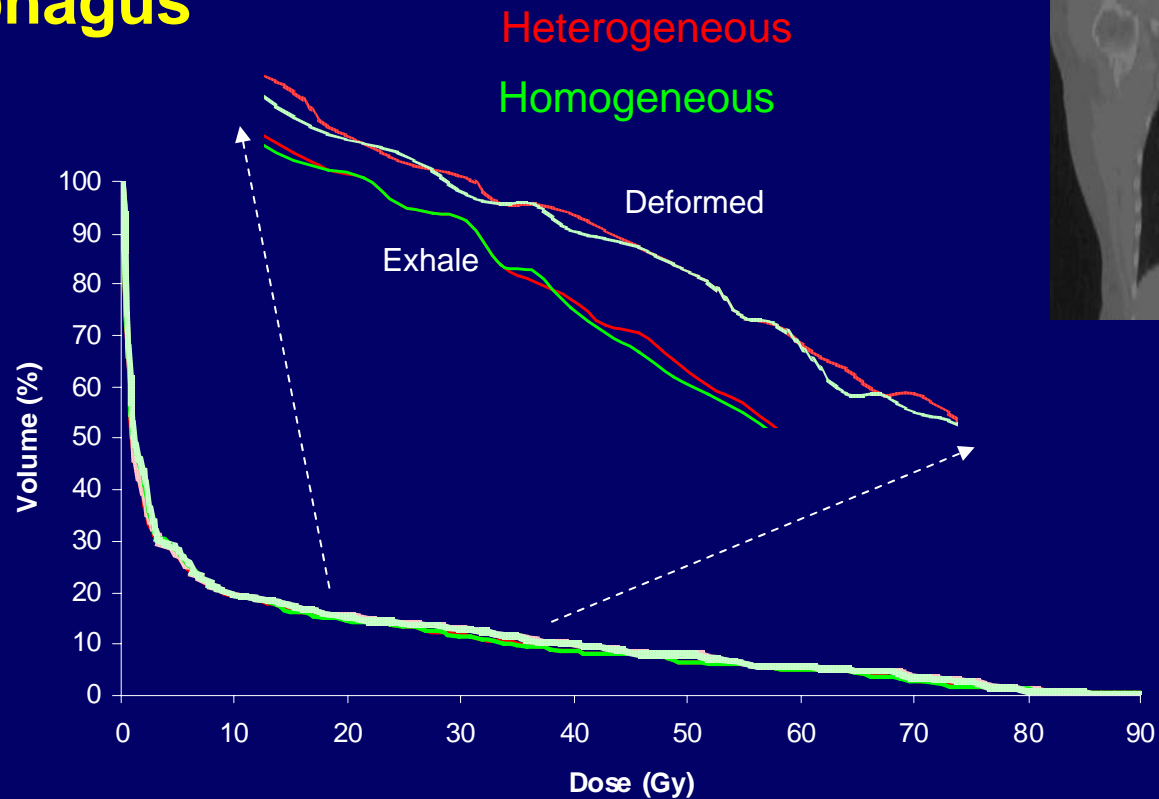


- More dose to tumor from lung scatter and reduced attenuation
- Motion slightly shifts doses to lower values
- Inhomogeneity effect is larger



Inhomogeneity vs. motion

Esophagus



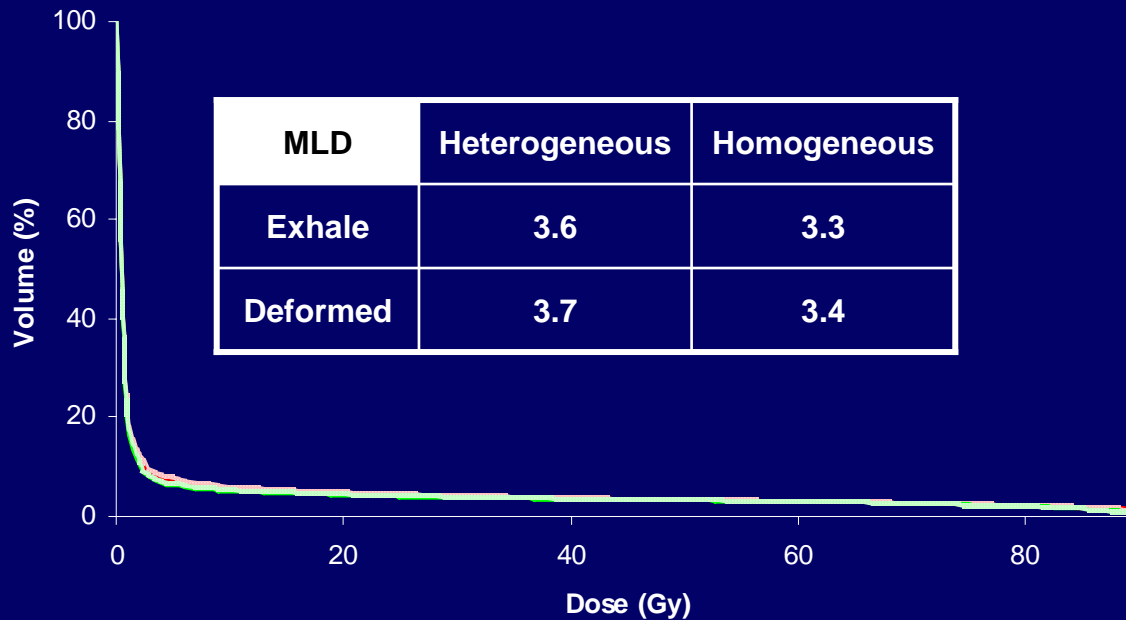
NTCP	Heterogeneous	Homogeneous
Exhale	4.6	4.2
Deformed	5.4	5.2

- Motion/deformation more important



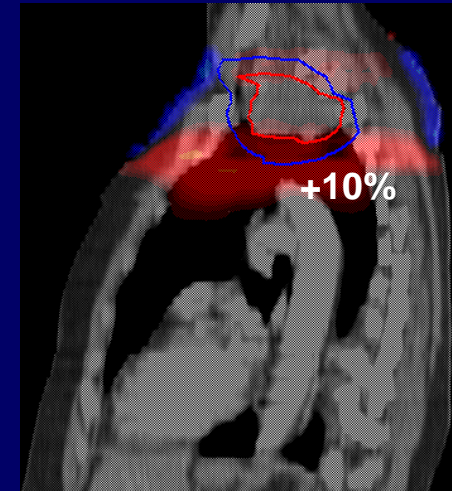
Inhomogeneity vs. motion

Lung

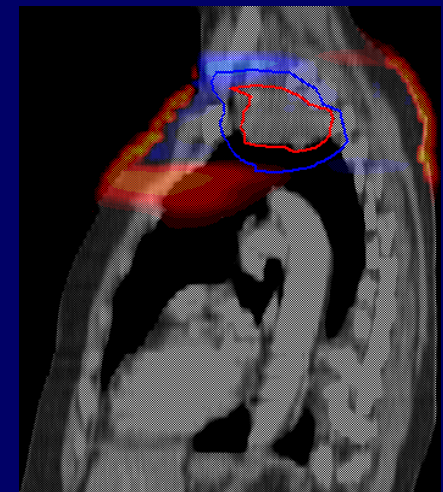


- Motion/deformation and heterogeneities have comparable magnitudes, but the V_{eff} changes are too small to have a clinical impact *for this patient*

Hetero - Homo



Cumulative - Exhale

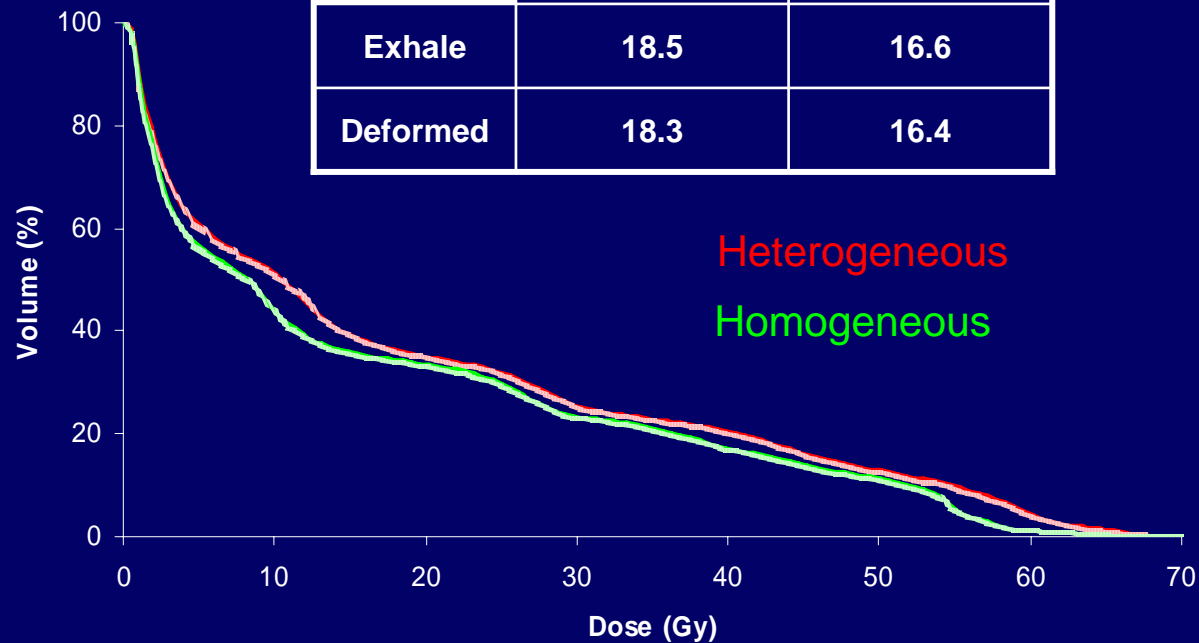




Inhomogeneity vs. motion

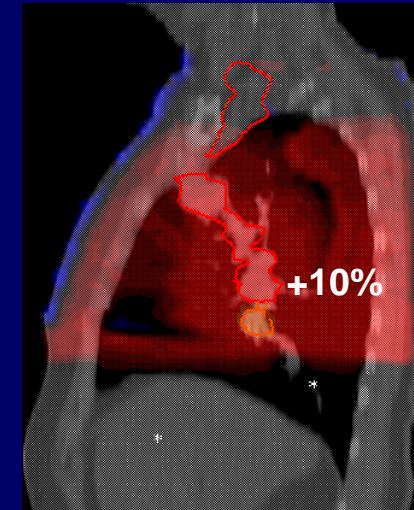
Lung

MLD	Heterogeneous	Homogeneous
Exhale	18.5	16.6
Deformed	18.3	16.4

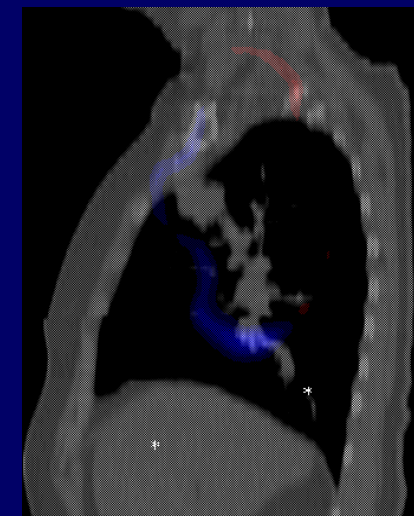


- Heterogeneities have larger effect for this patient, deformation and motion are second order effects

Hetero - Homo



Deformed - Exhale





Summary (IV)

- Large point dose changes are induced by accounting for either tissue heterogeneities or motion/deformation.
- Although both effects are noticeable, properly accounting for tissue heterogeneities will likely have greater importance in terms of predicted clinical response parameters.