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

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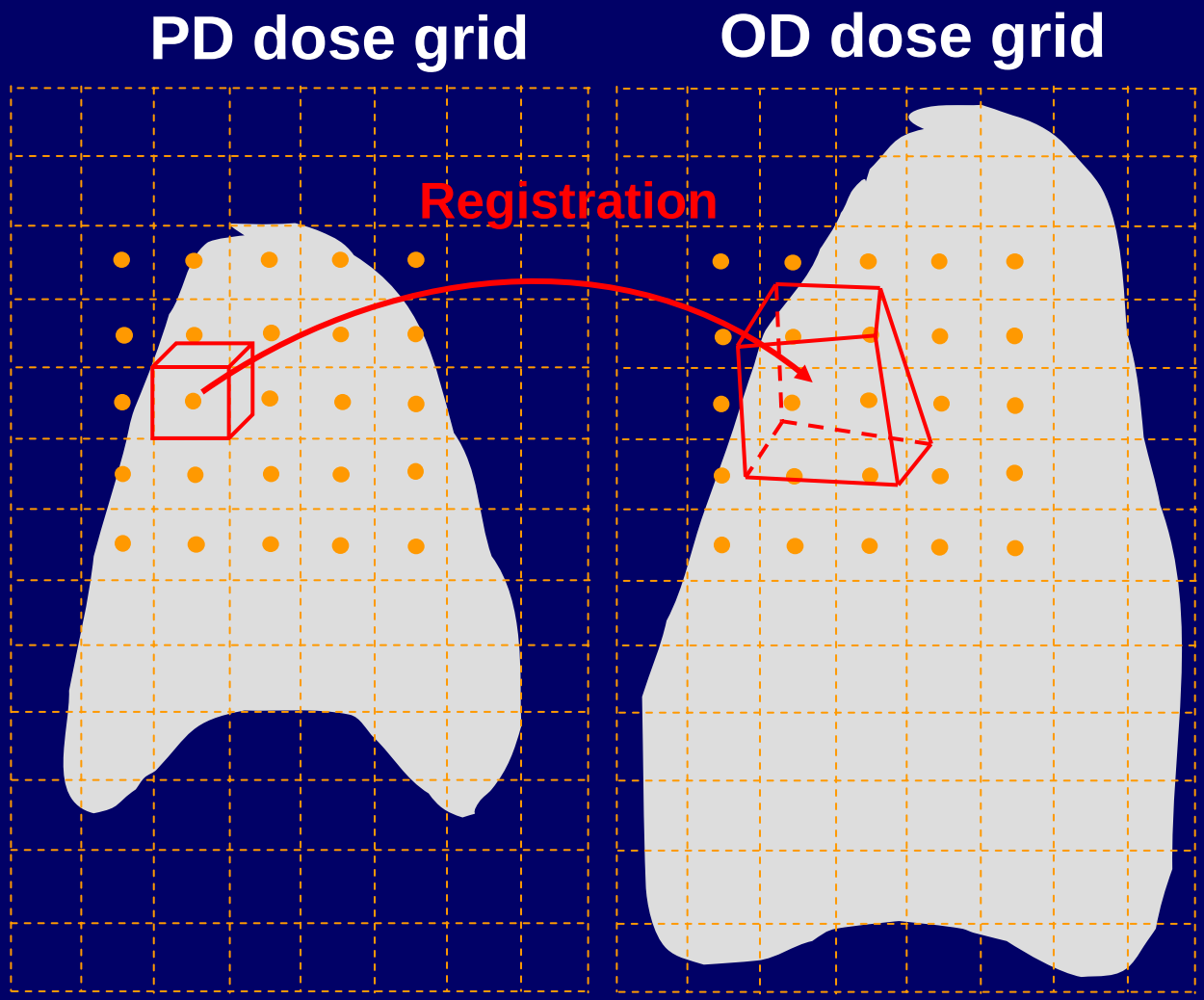
# Outline

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

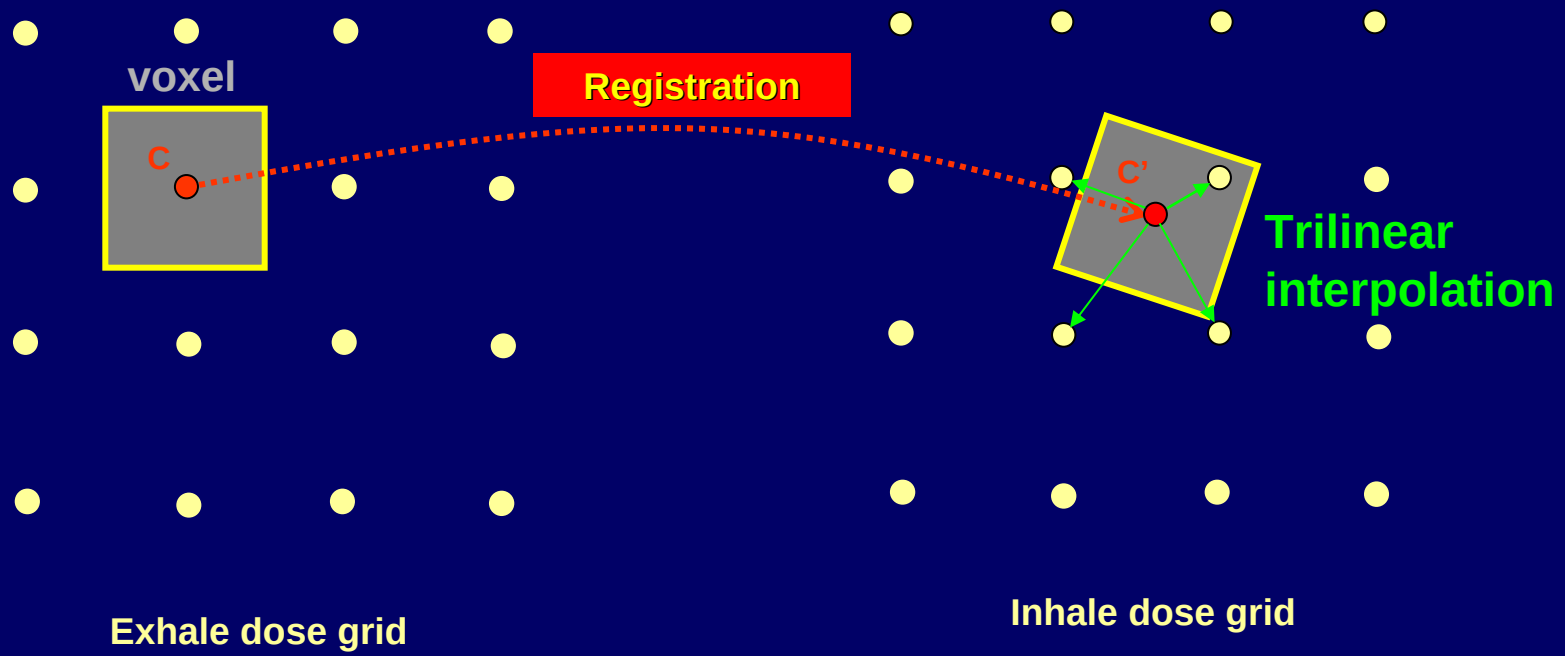
# Dose mapping



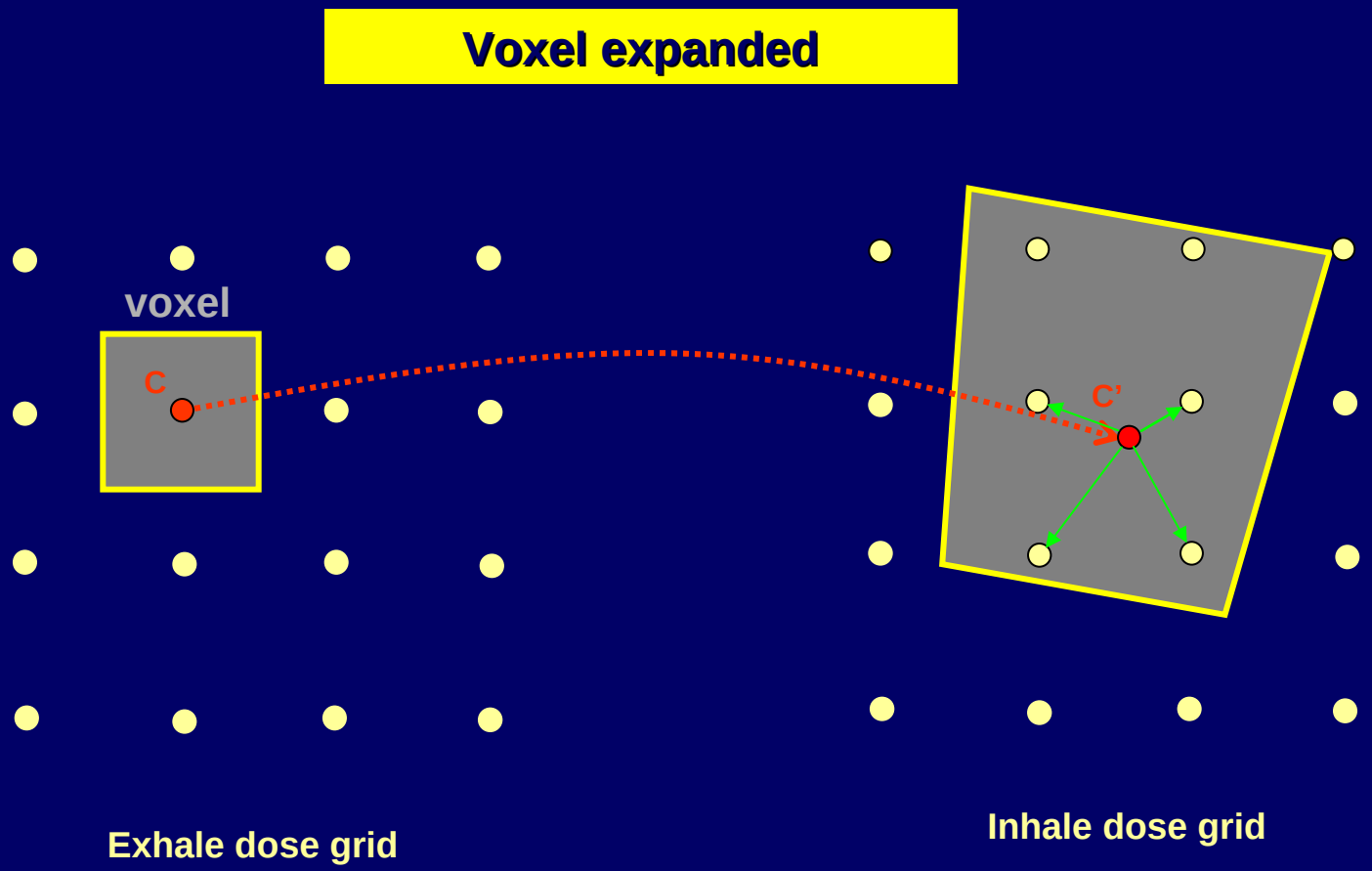
# Dose mapping

**Voxel size constant**

**(direct approximation)**



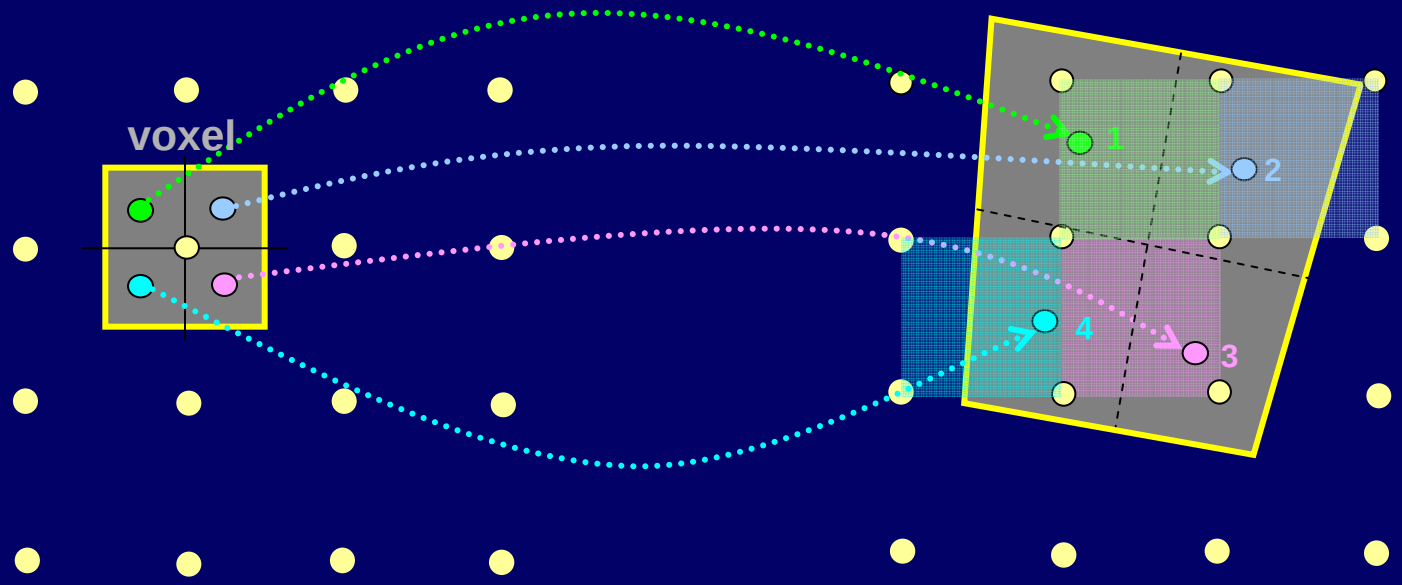
# Dose mapping



# Dose mapping

**Voxel subdivision**

**(refined approximation)**



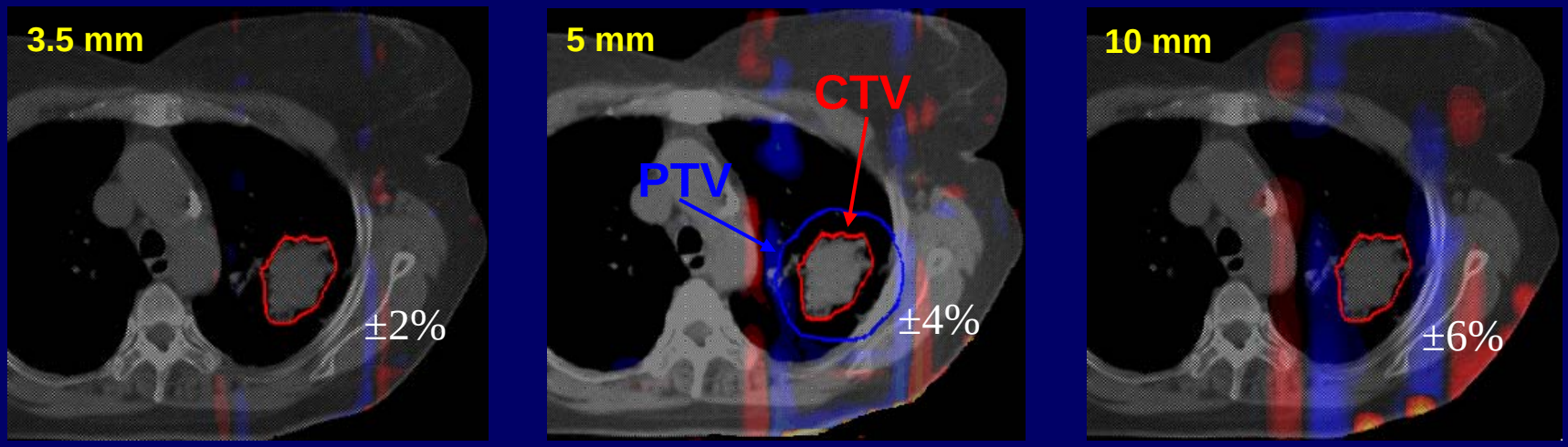

Exhale dose grid

Inhale dose grid

# Grid size effects

## Doses received by exhale voxels at inhale:

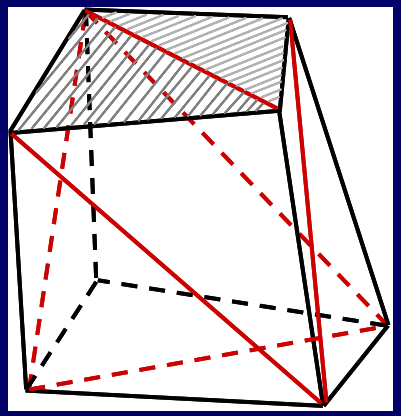
refined approximation – direct approximation




Differences between the interpolation schemes:

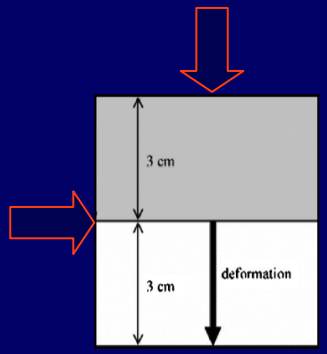
- Primarily in steep dose gradient regions
- Voxel size dependent
- Magnitude is less than the alterations in dose due to positional and shape changes from breathing in the first place
- 3-4 mm dose grid size is good (also appropriate for a good balance accuracy vs speed in MC calcs)

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

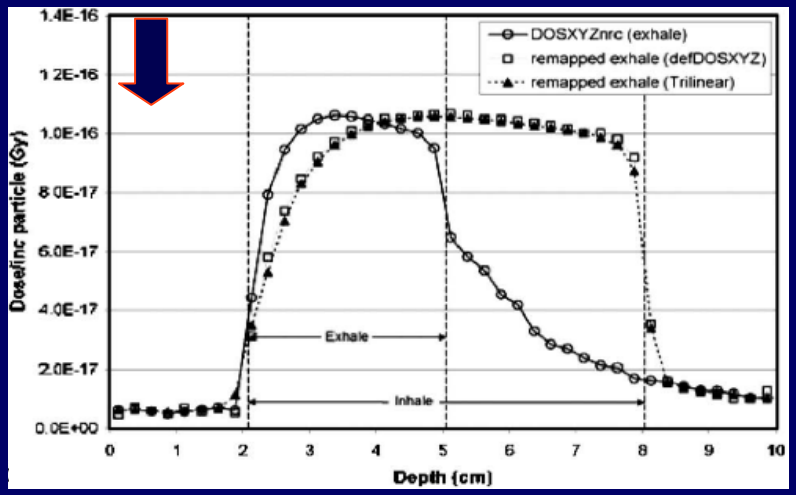


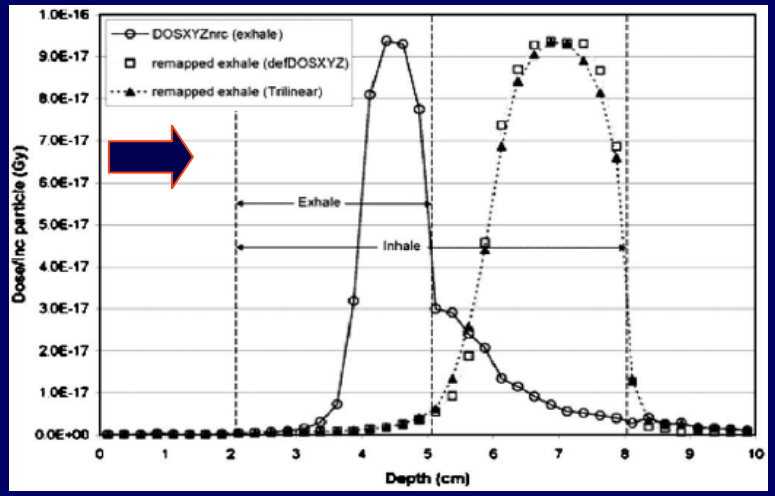
- **Dose deposition in deformed voxels**
- **Deformed voxel surface approximated with 12 planes**

2X2 $cm^2$ 6 MV




0.25 $cm^3$ voxels

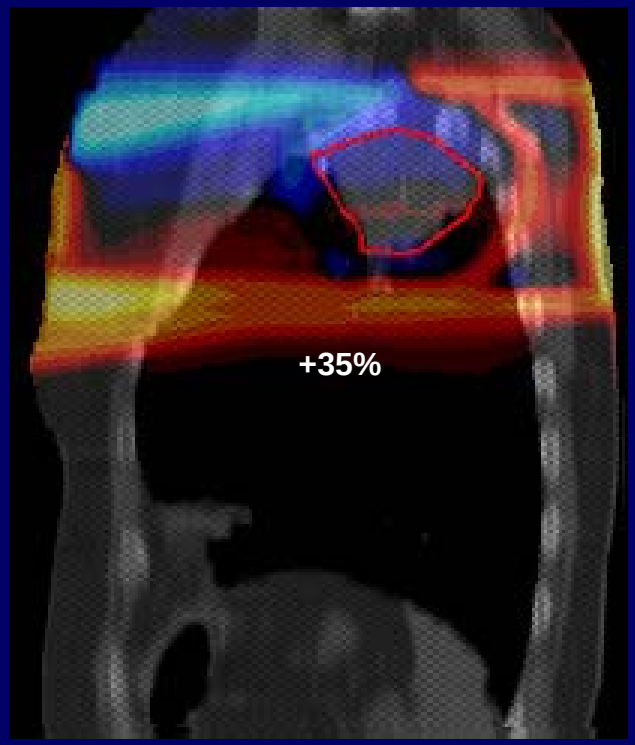


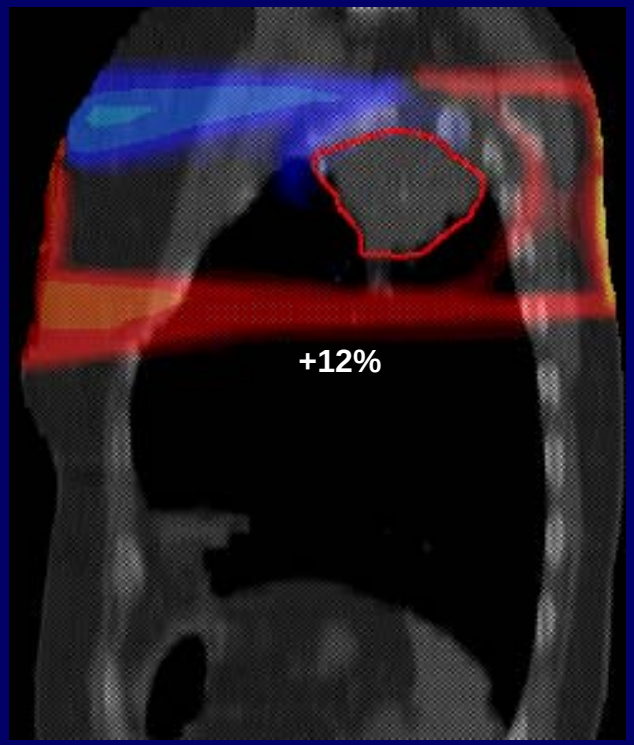

*Med. Phys. 33, 2006, Heath and Seuntjens*

# Dose to deforming anatomy

**INHALE**
minus
**STATIC**




**CUMMULATIVE**
minus
**STATIC**

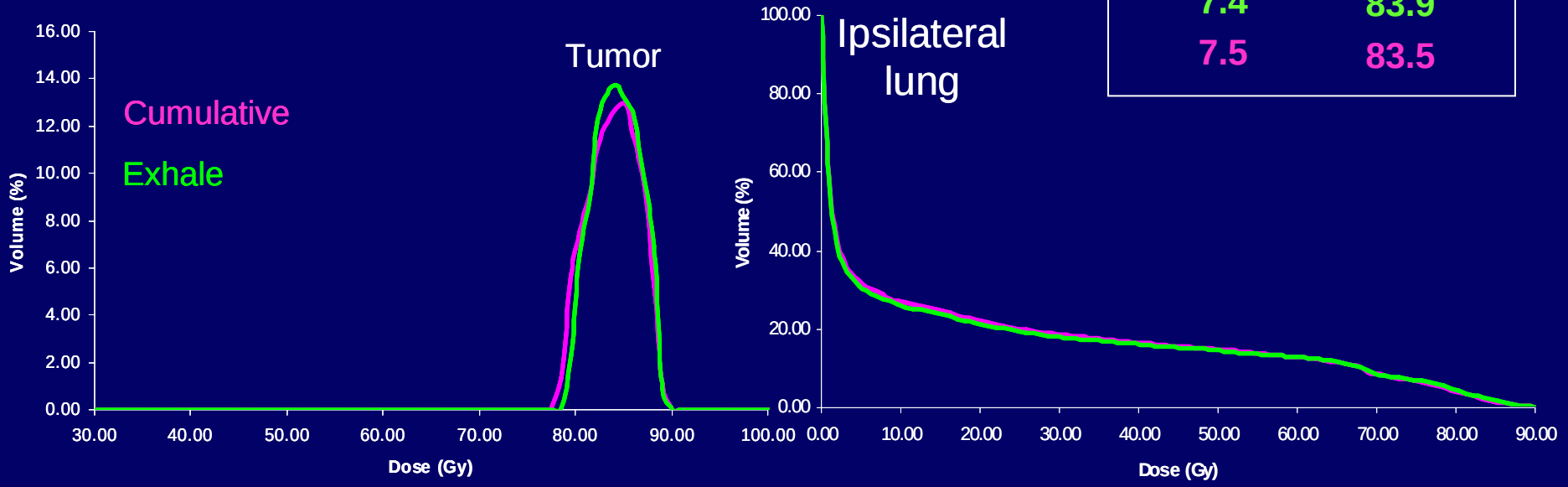



70% Exhale

30% Inhale

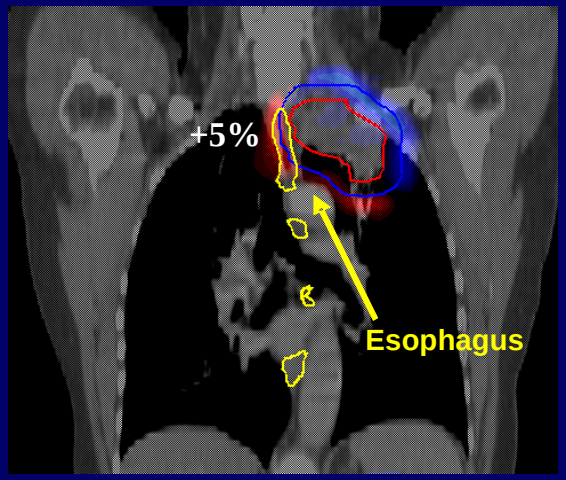
# Dose to deforming anatomy

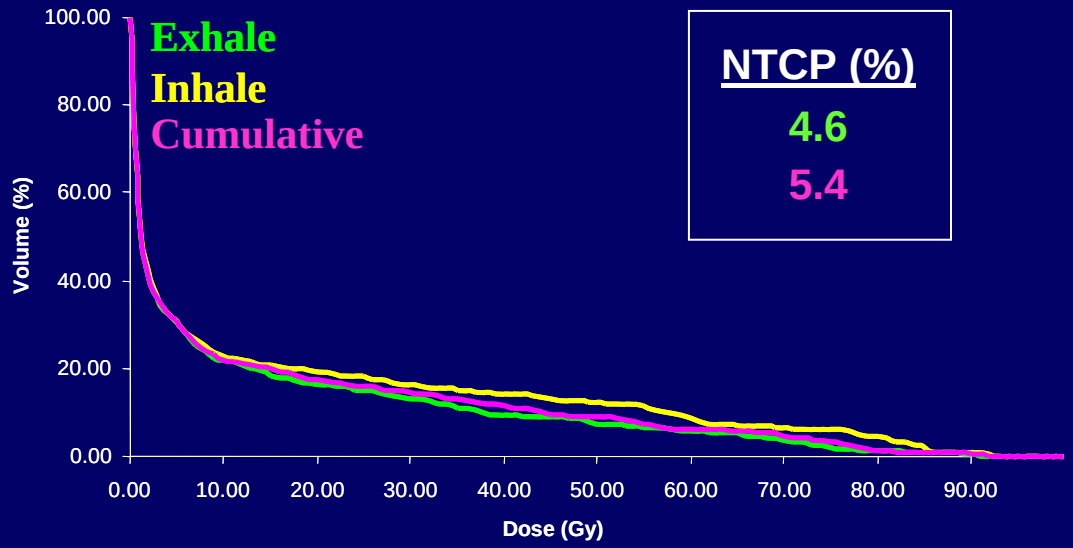
| MLD (Gy) | EUD (Gy) |
|---|---|
| 7.4 | 83.9 |
| 7.5 | 83.5 |




- 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

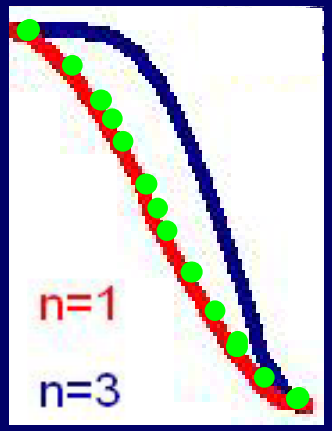
# Summary (I)

**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.

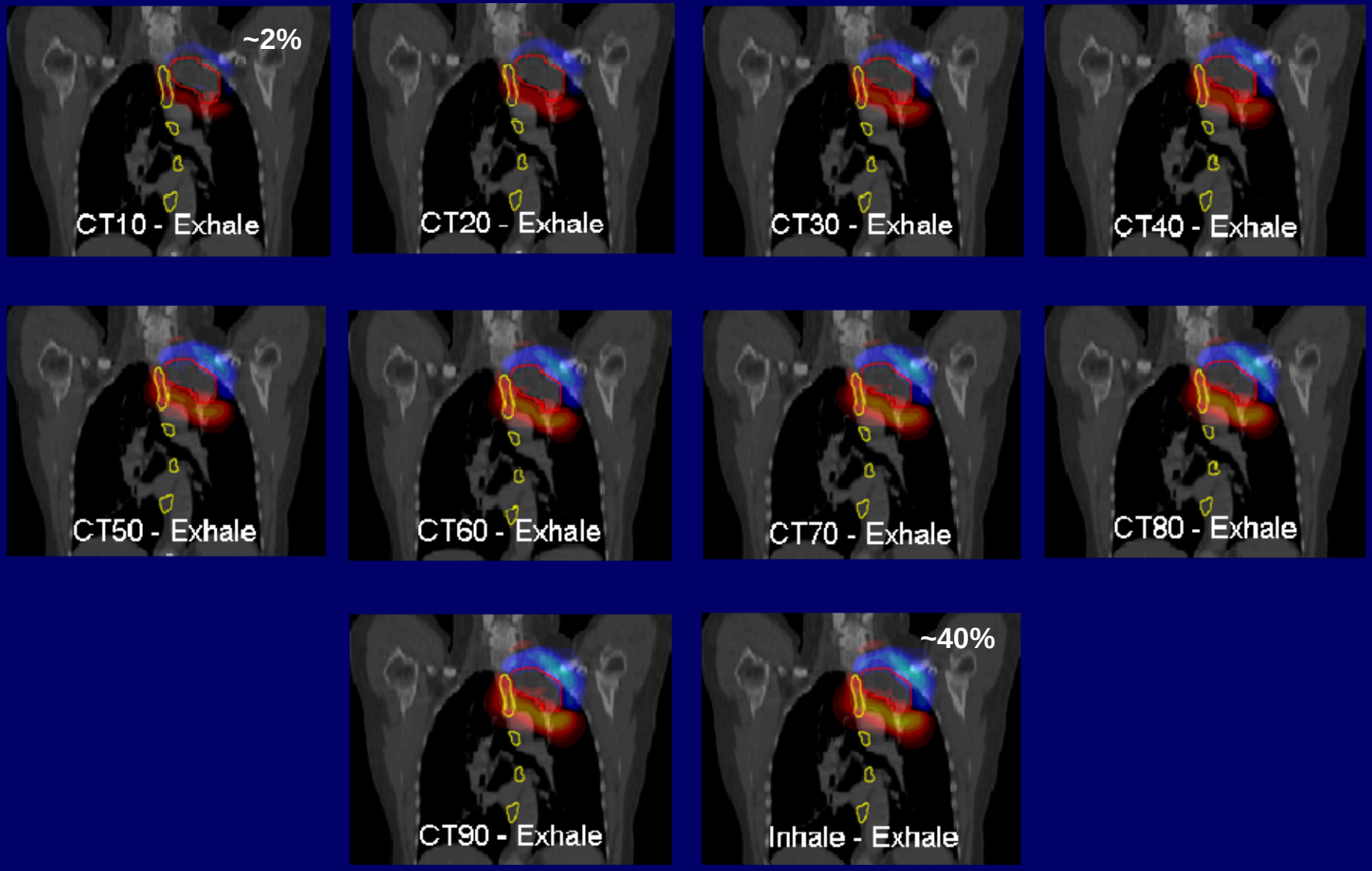
# How much 4D data is needed?

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

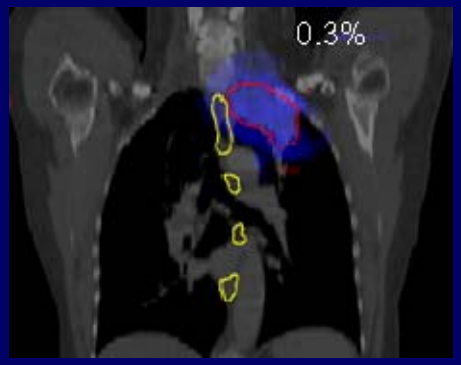



- Exhale, Inhale, 10÷90% geometries (“11-state dose”)
- Exhale, Inhale, 20÷80% geometries (“6-state dose”)
- Average breathing phases from the first and the second half of the breathing cycle (“2-ave state dose”)
  *~10% and ~80% for n=3 and ~20% and ~80% for n=1*
- Exhale and inhale geometries (“2-state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

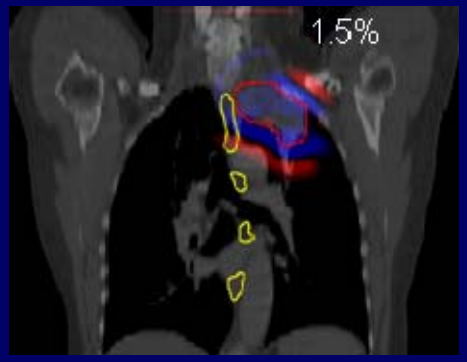
# Changes from exhale



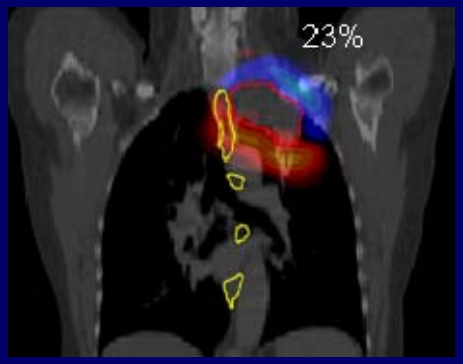
# Comparisons between various scenarios



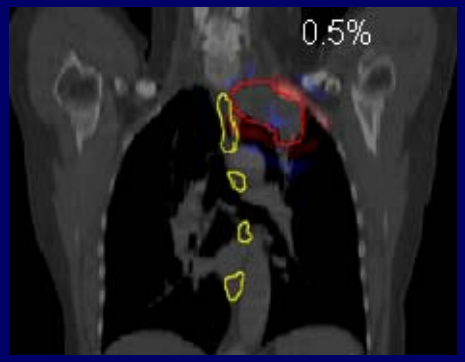

"11 state" – "6 state"



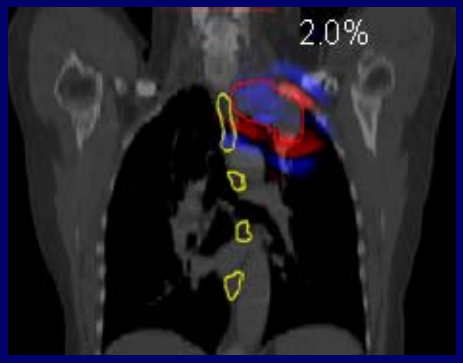

"11 state" – "2 state"




"11 state" – Exhale



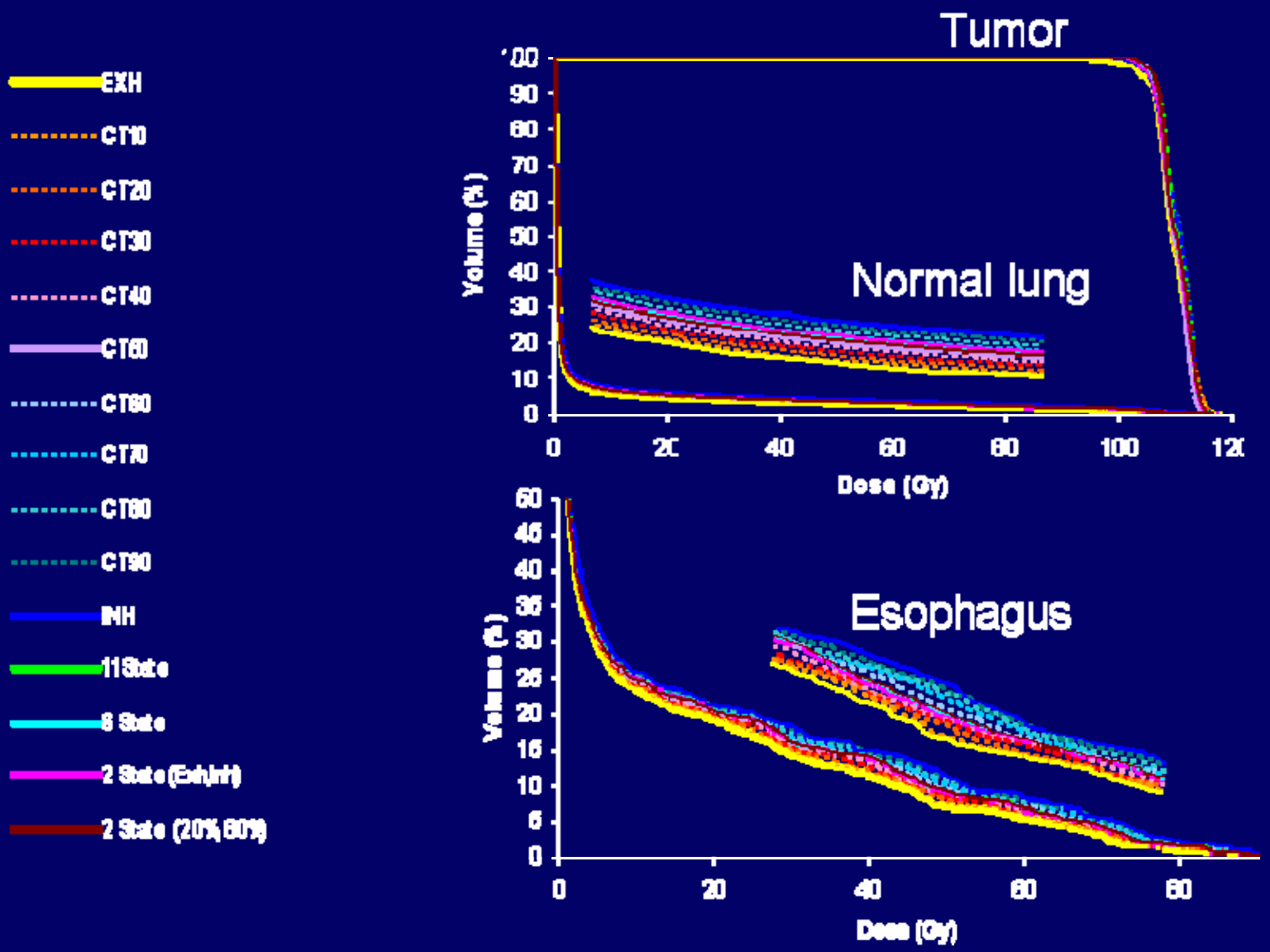

"11 state" – "2-ave state"




"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



# Summary (II)

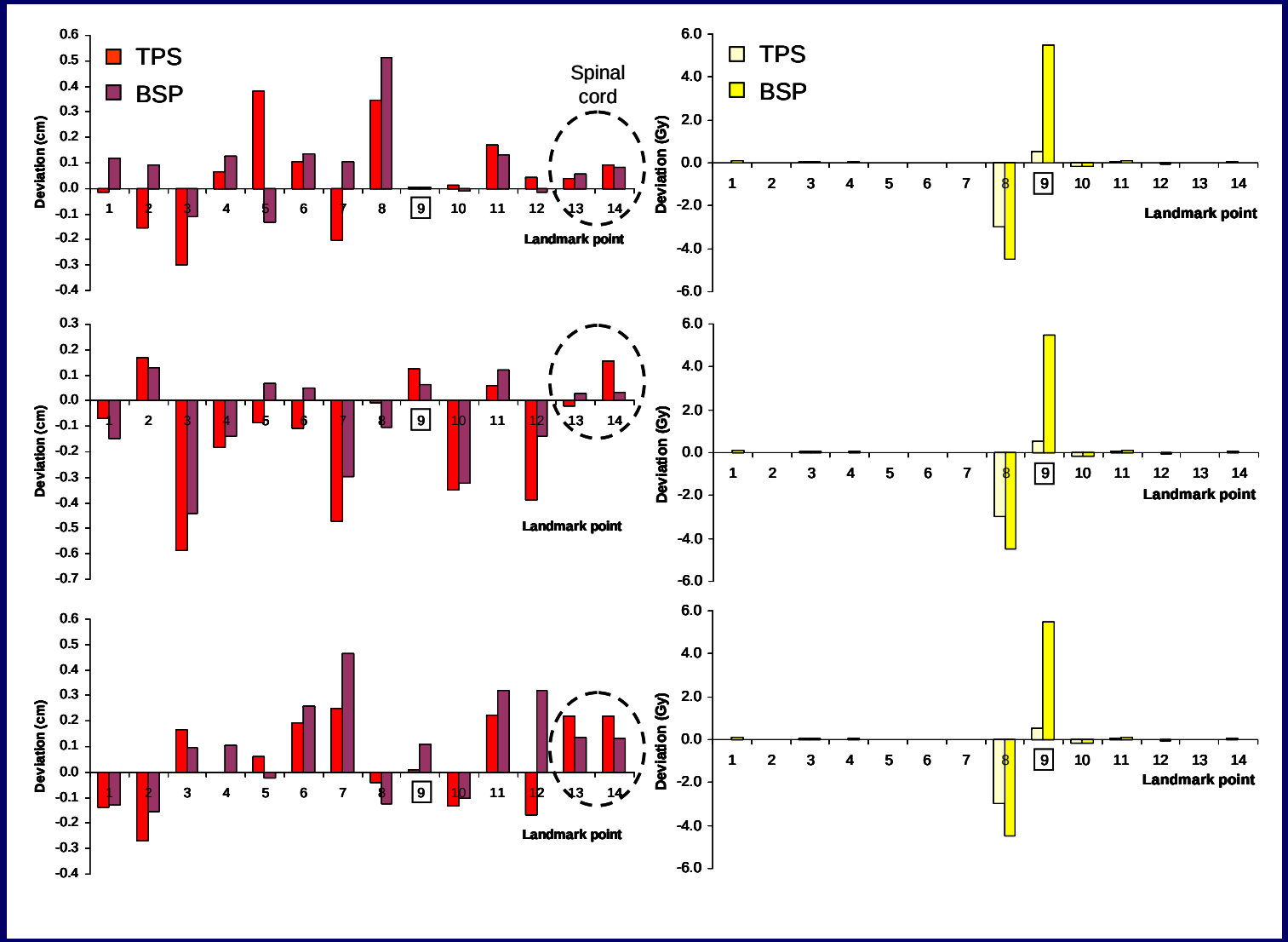
**For 4D planning (thorax):**

- 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.

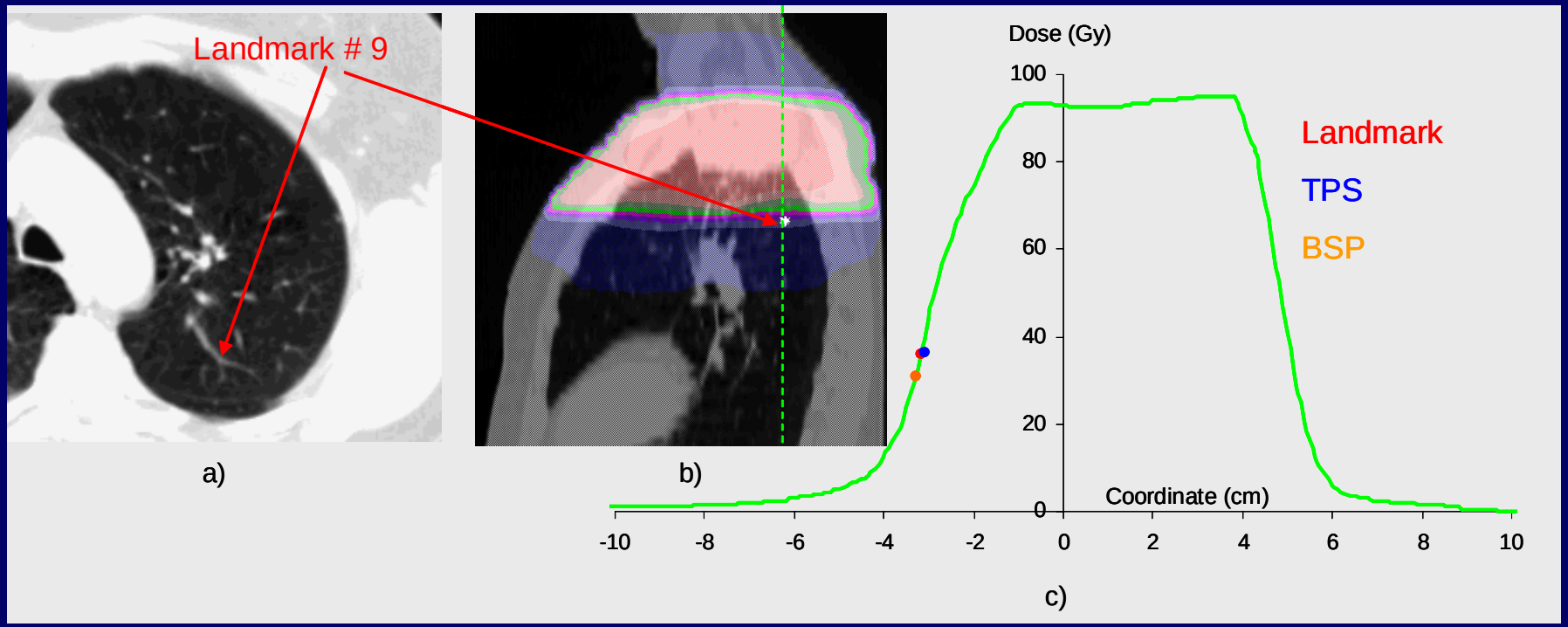
➢ Is breathing pattern reproducible? Not necessarily, but this doesn't change the validity of our observations.

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

# Image registration – where does it matter?



# Image registration – where does it matter?



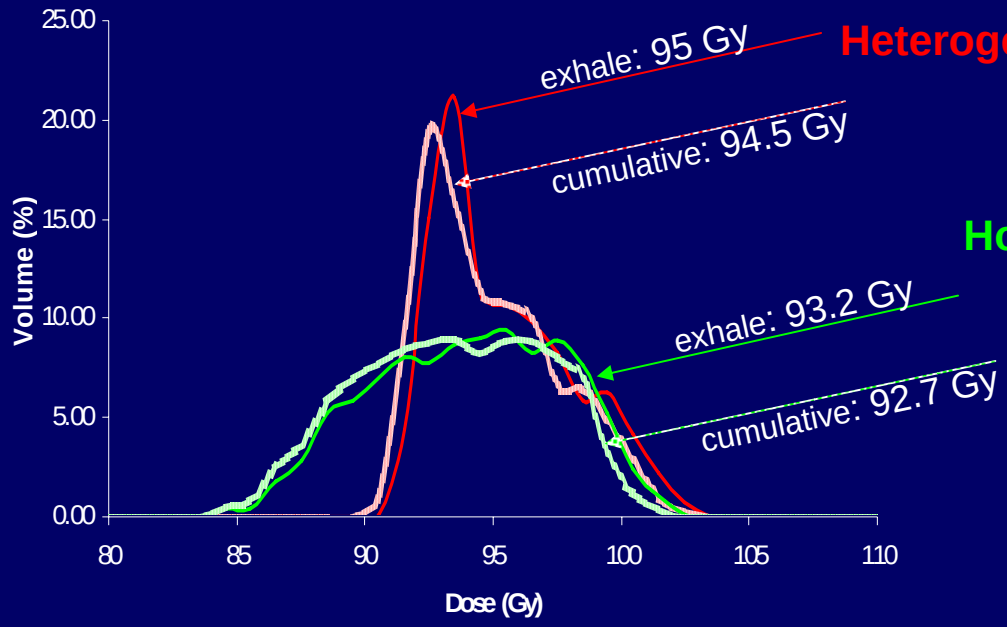
# Summary (III)

- Registration errors important in regions of steep dose gradient

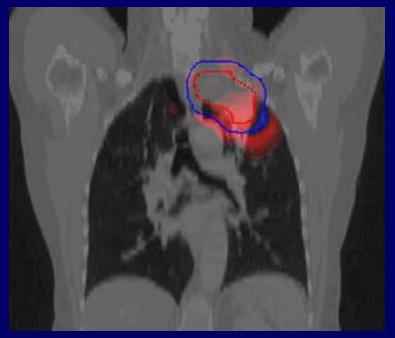
# Inhomogeneity vs. motion

**Tumor**

EUD:




**Heterogeneous**

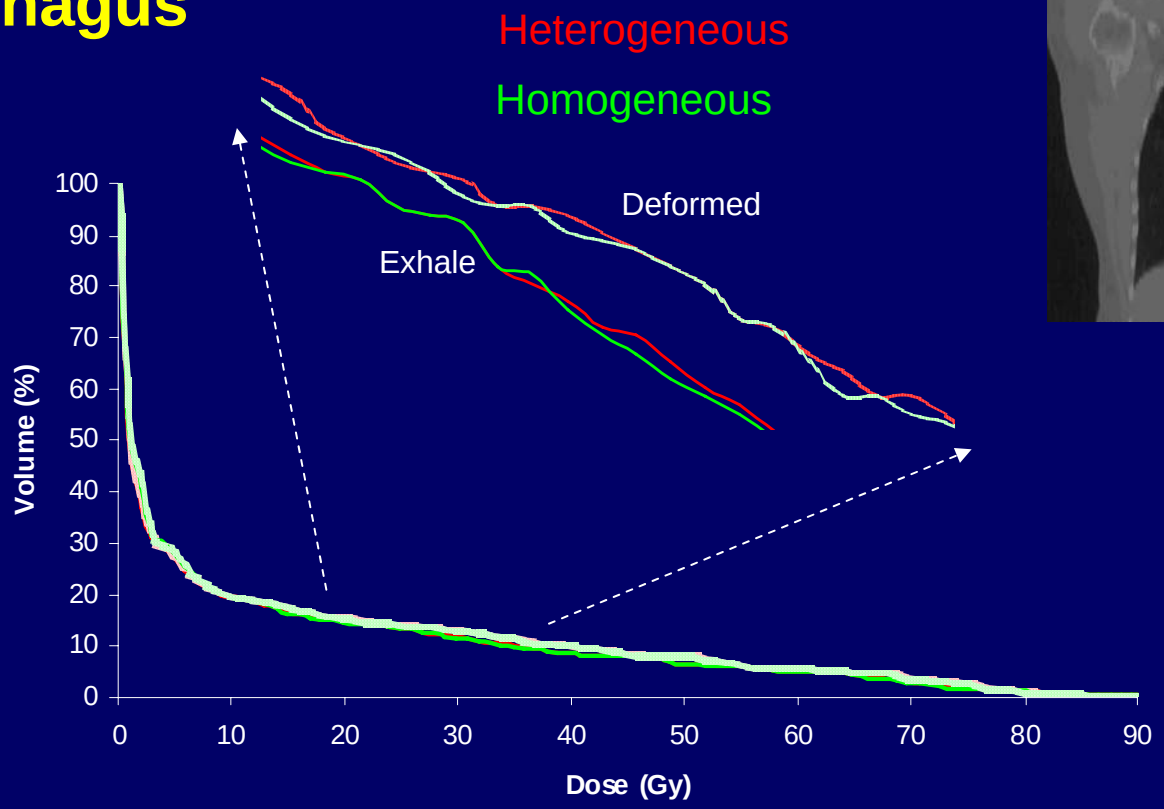


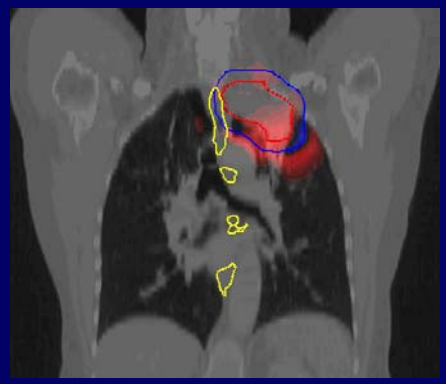
**Homogeneous**

- 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



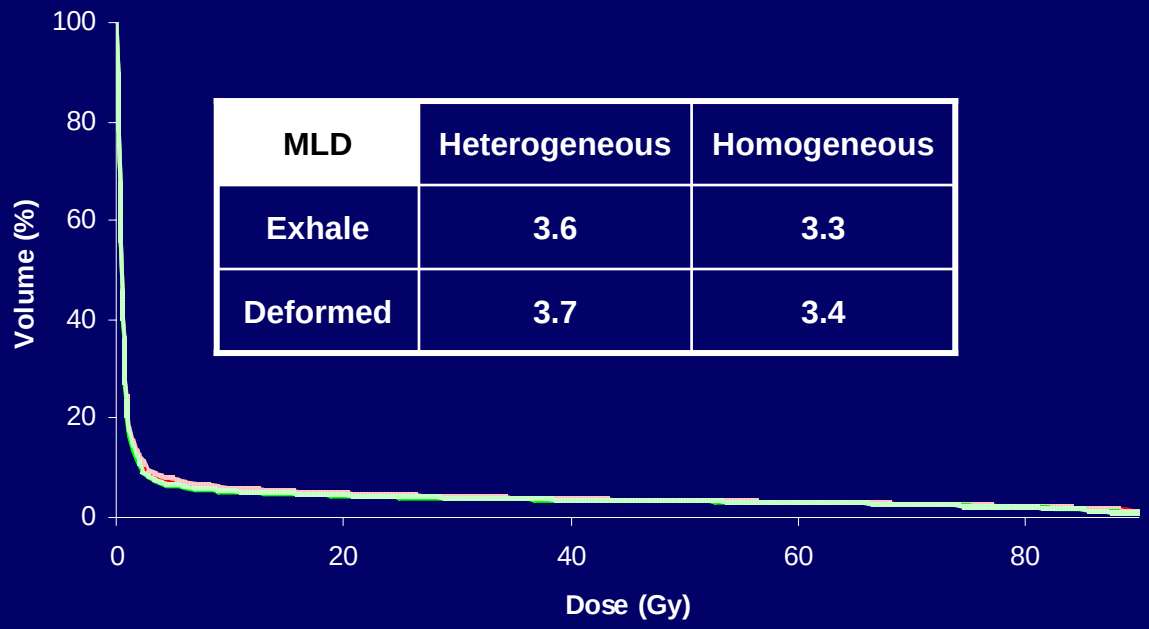



| NTCP | Heterogeneous | Homogeneous |
|---|---|---|
| Exhale | 4.6 | 4.2 |
| Deformed | 5.4 | 5.2 |

- Motion/deformation more important

# Inhomogeneity vs. motion

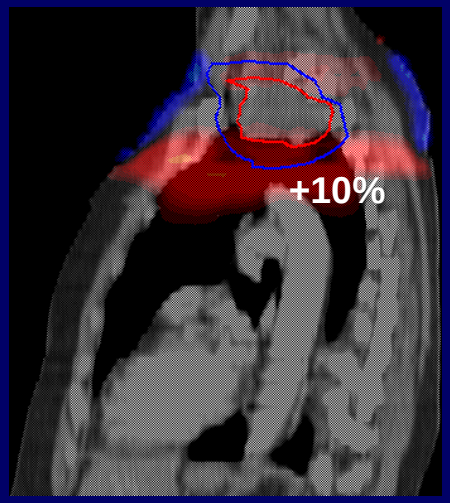
## Lung



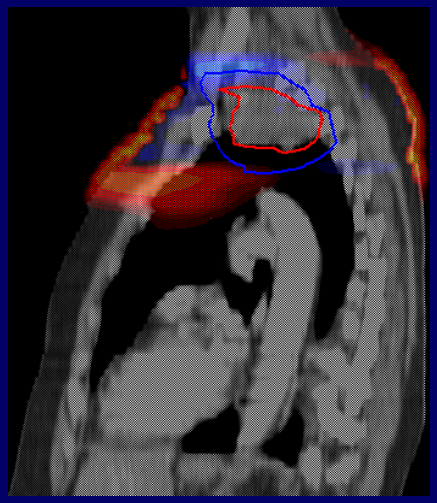

| MLD | Heterogeneous | Homogeneous |
|---|---|---|
| Exhale | 3.6 | 3.3 |
| Deformed | 3.7 | 3.4 |

- 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**



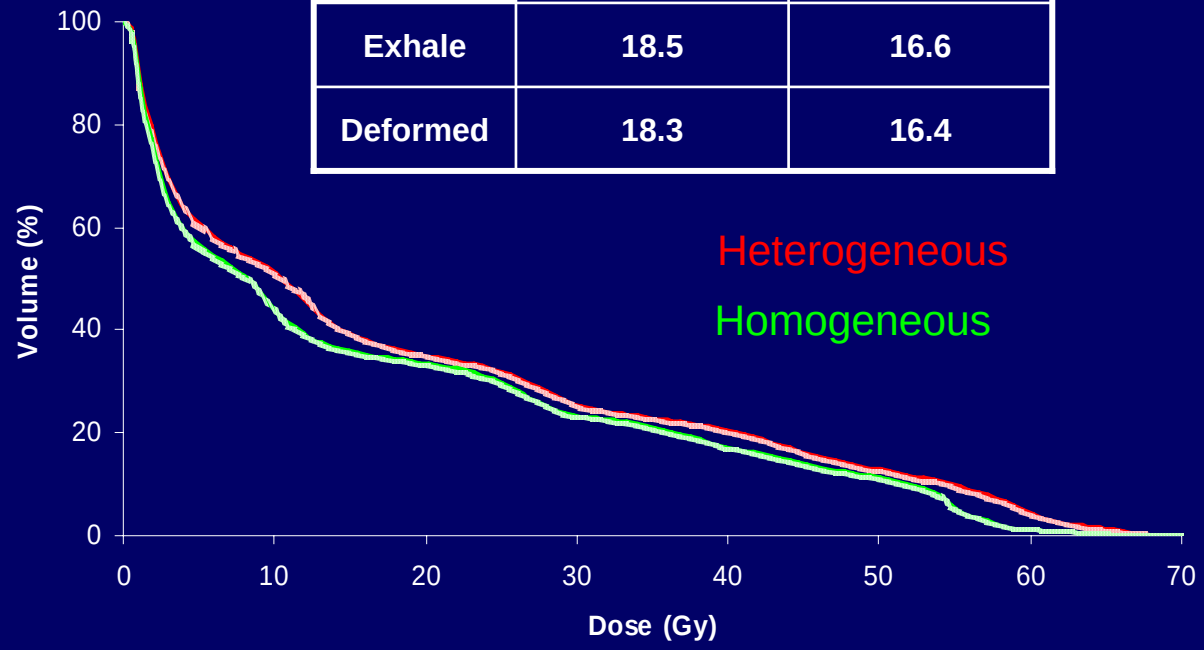

**Cumulative - Exhale**



# Inhomogeneity vs. motion

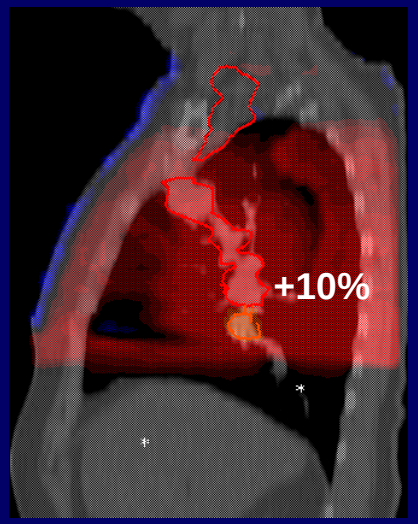
## Lung

| MLD | Heterogeneous | Homogeneous |
|---|---|---|
| Exhale | 18.5 | 16.6 |
| Deformed | 18.3 | 16.4 |

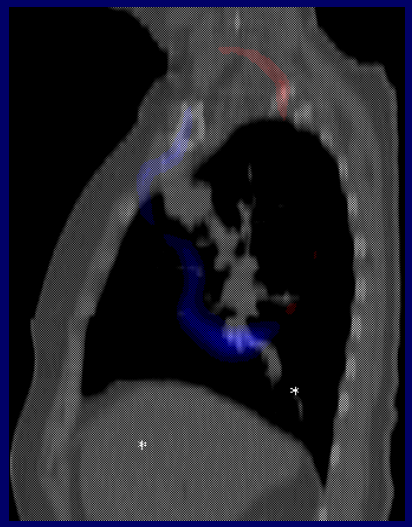



- Heterogeneities have larger effect for this patient, deformation and motion are second order effects

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.