Functional lung radiation therapy with 4DCT-Ventilation: from theory to clinical implementation

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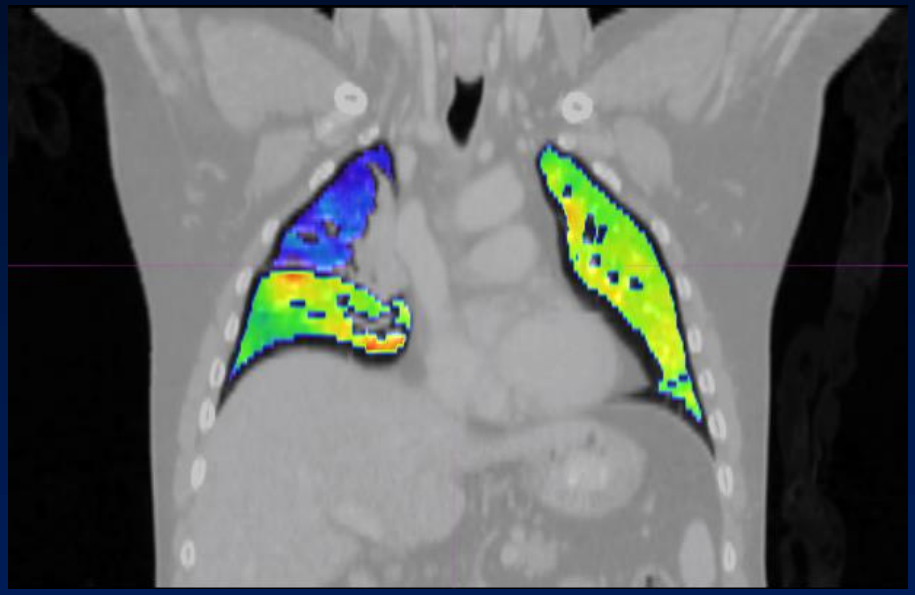
Background

4DCT-Ventilation Imaging

4DCT

4DCT-Ventilation



Background

4DCT-Ventilation Imaging

- Reduced cost
- Reduced dose
- Better spatial resolution
- Anatomical + Functional information
- Better quantification

Outline

4DCT-Ventilation Imaging

- Image formation
- Validation
- Clinical applications
- Clinical trial

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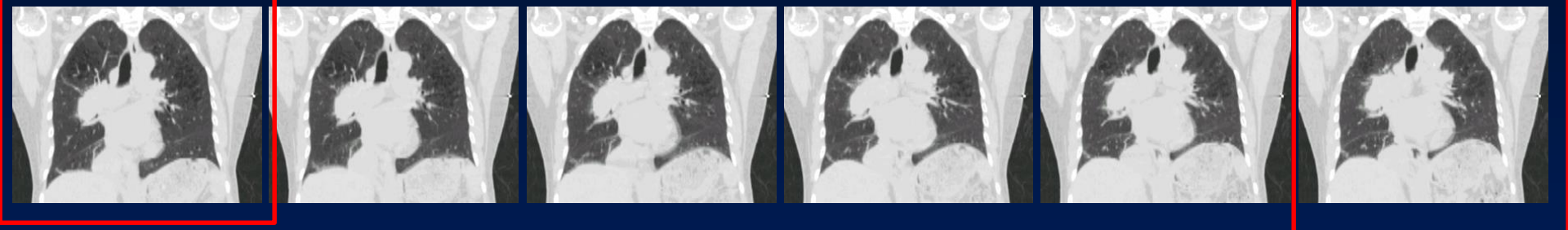
Calculating Ventilation Images

Calculating ventilation maps

4DCT – 10 phases

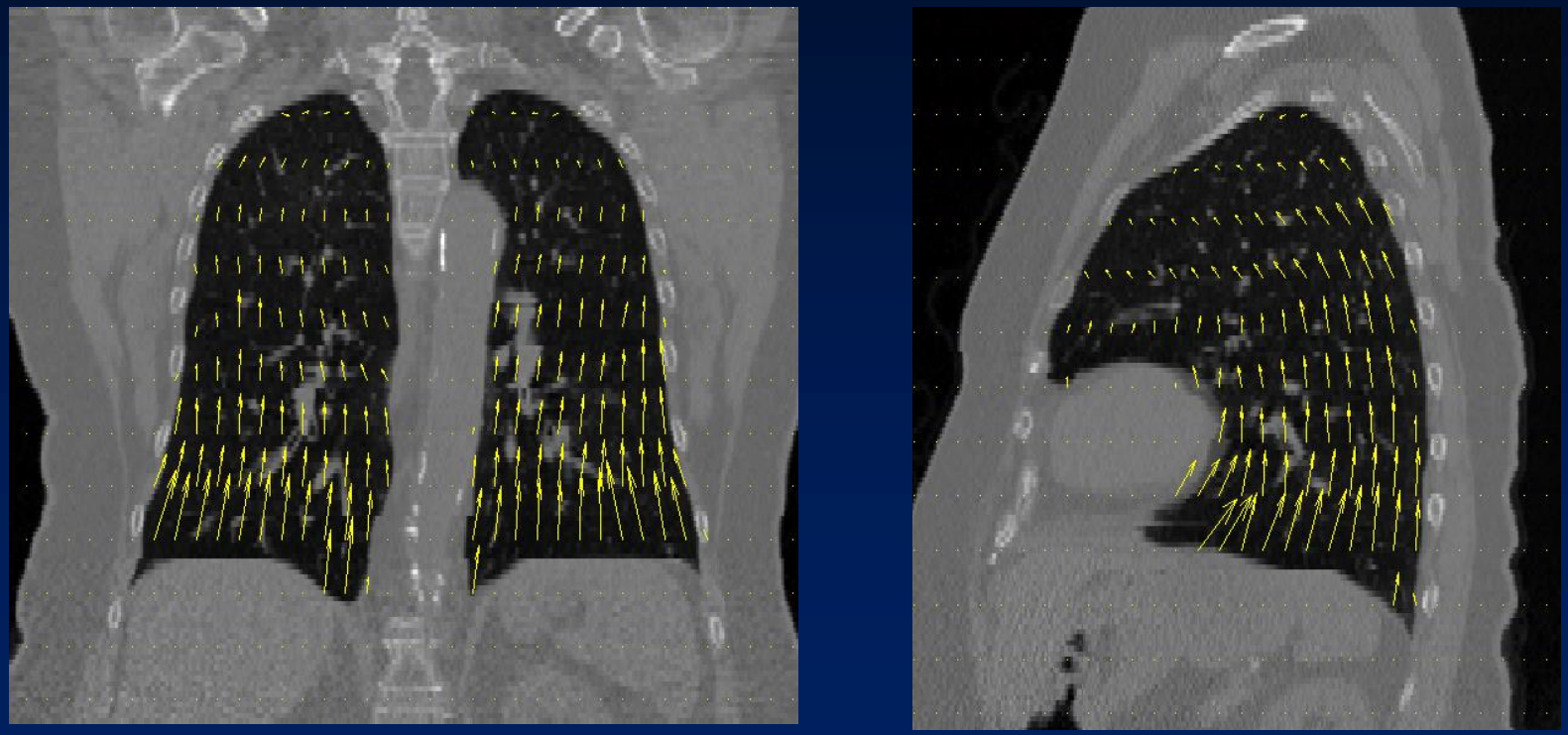


0% 10% 20% 30% 40% 50%

Calculating Ventilation Images

Link lung voxels from inhale phase to exhale phase
using deformable image registration

Deformable registration maps



4D deformable registration using trajectory modeling (Castillo et al., 2010)

Calculating Ventilation Images

$$\frac{V_{in} - V_{ex}}{V_{ex}} = 1000 \frac{\overline{HU}_{in}^{voi} - HU_{ex}}{HU_{ex}(1000 + \overline{HU}_{in}^{voi})}$$

Specific ventilation

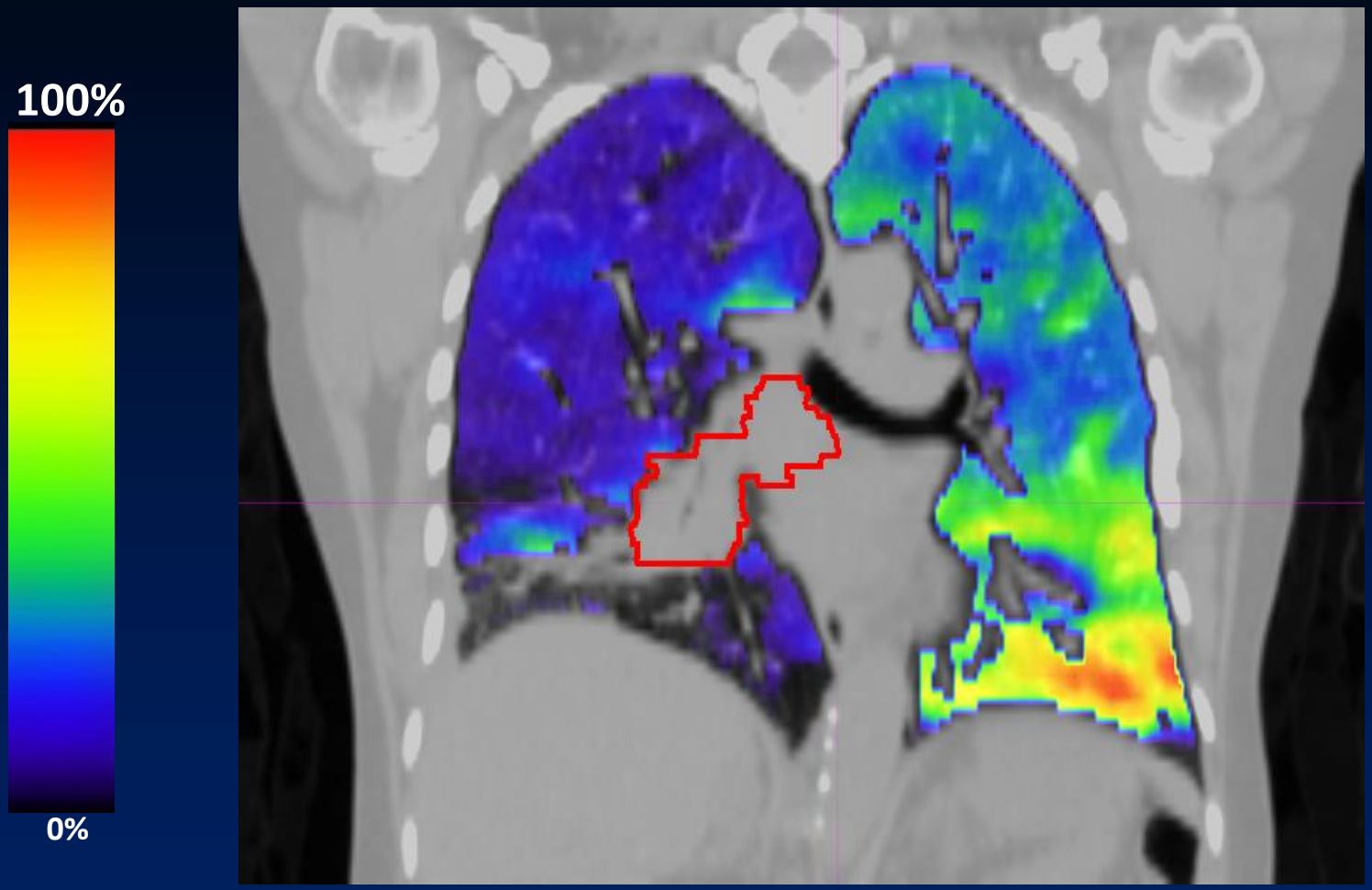
Local fractional change in air content

Specific ventilation of 0 = no volume change

Specific ventilation of 1 = volume of air doubled

Simon et al., 2000, Guerrero et al., 2006, Fuld et al., 2008

Calculating Ventilation Images



Outline

4DCT-Ventilation Imaging

- Image formation
- Validation
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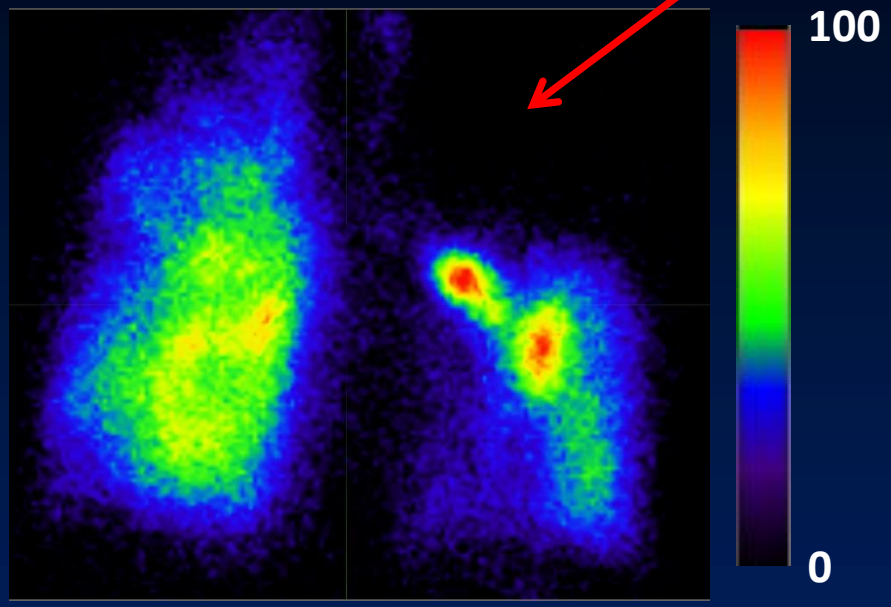
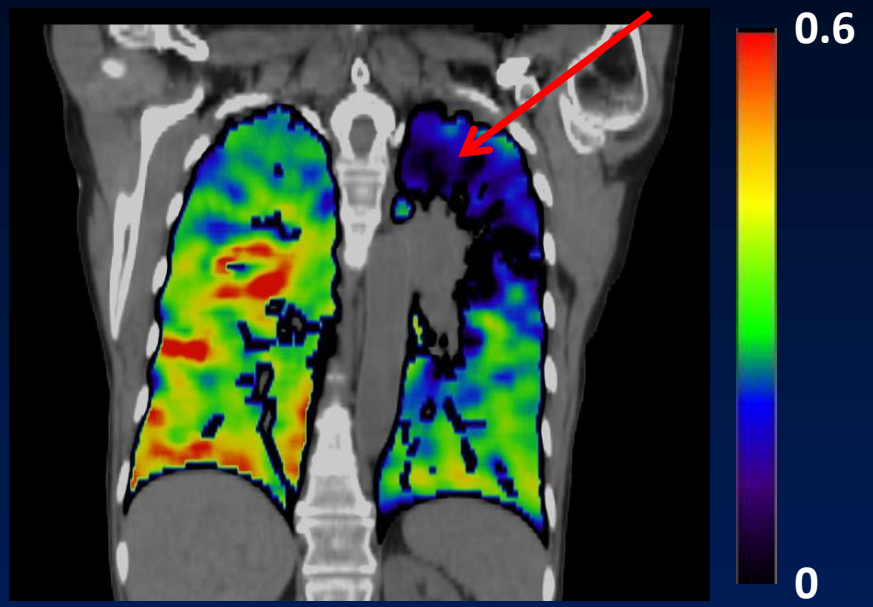
- Clinical trial

Validation again nuclear medicine

VQ Ventilation Scan

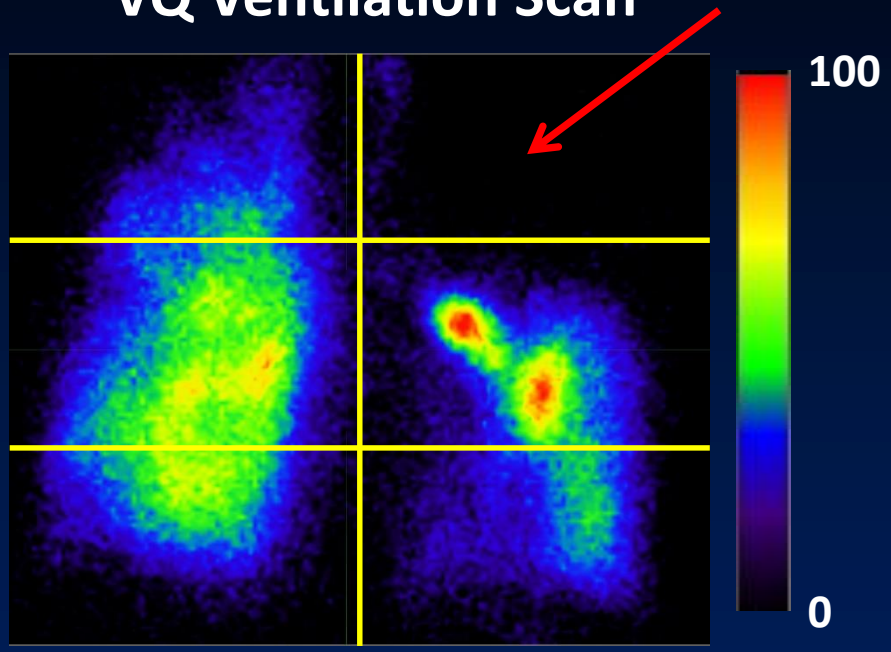


4DCT Ventilation Map

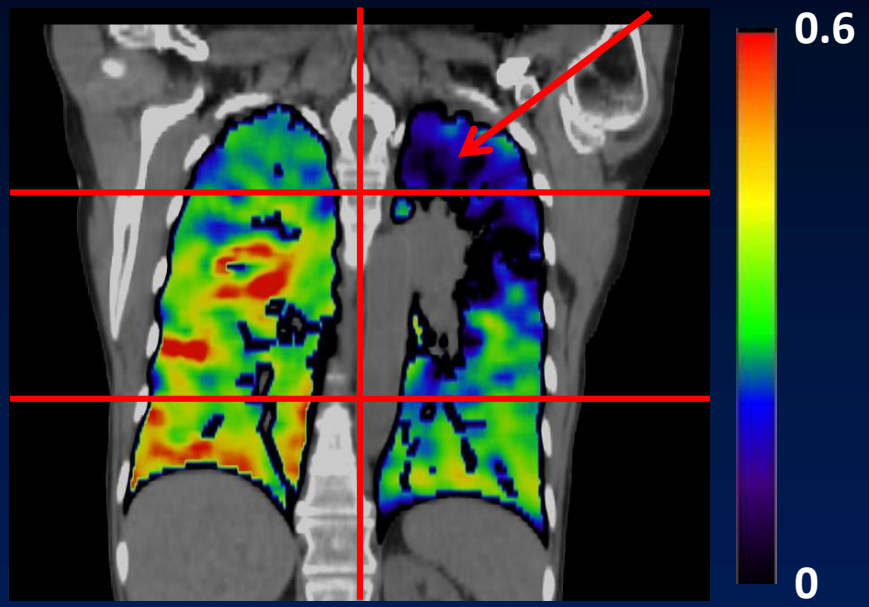


Validation again nuclear medicine

VQ Ventilation Scan



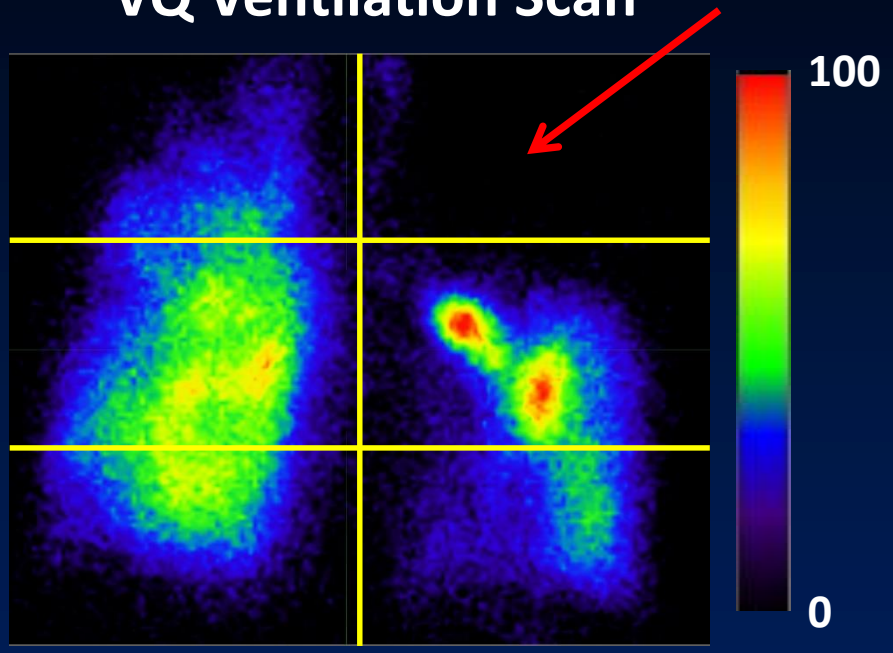
4DCT Ventilation Map



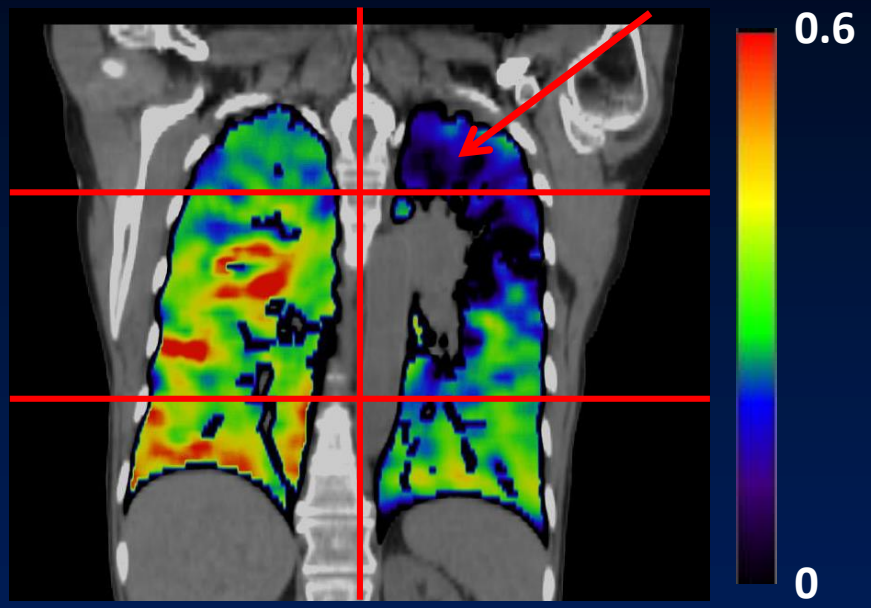
	SPECT Ventilation		4DCT Ventilation	
	Right (%)	Left (%)	Right (%)	Left (%)
Top	9.5	2.7	16.8	8.1
Middle	30.2	21.1	21.9	12.4
Lower	21.4	15.1	23.2	17.7
Total	61.1	38.9	61.8	38.2

Validation again nuclear medicine

VQ Ventilation Scan



4DCT Ventilation Map



- Correlation coefficient = 0.65
- Radiologist observations: Sensitivity = 90%, Specificity = 64%, Accuracy = 81%

Outline

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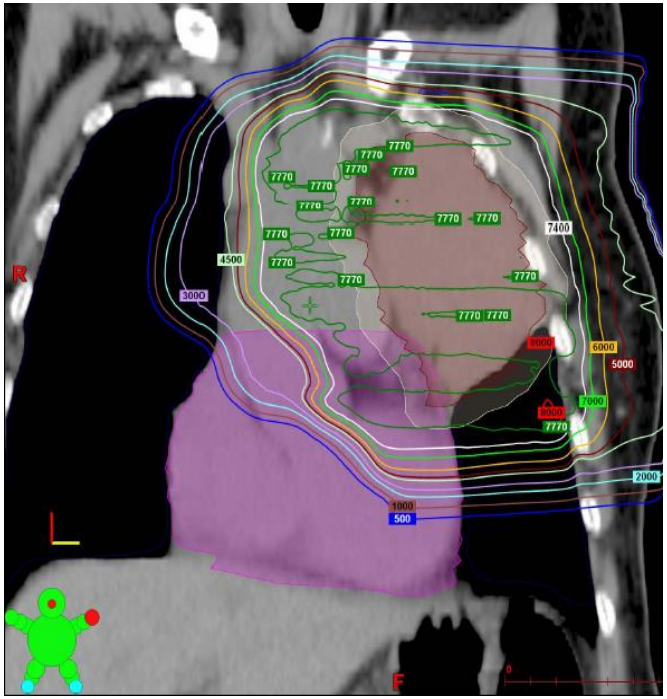
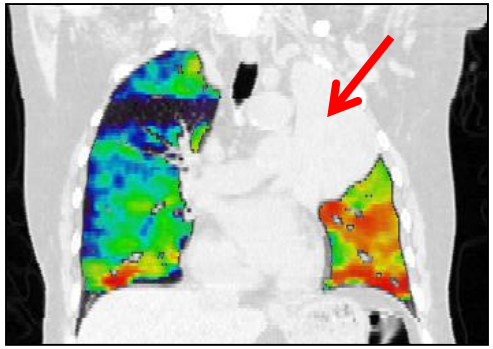
Changes in lung function during RT



Week 0



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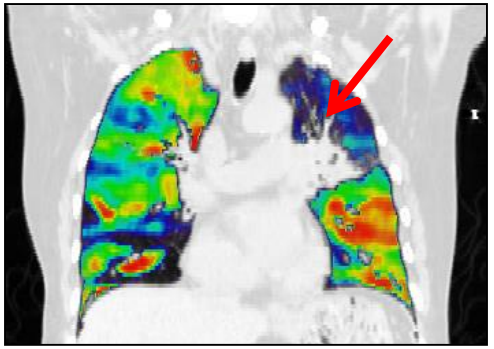

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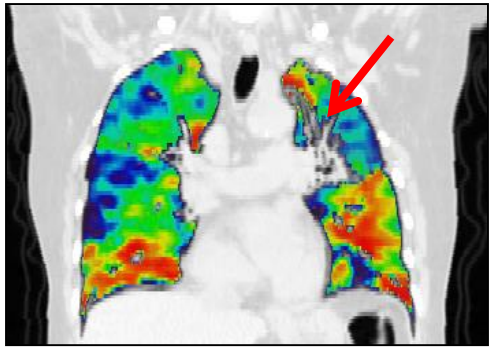
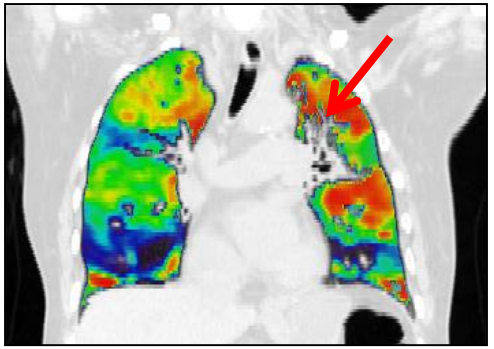
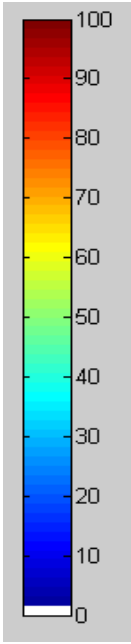


Week 7





Functional planning concept

- **Avoid functional portions of the lung in favor of irradiating through less functioning lung tissue**

Incorporation of functional imaging data in the evaluation of dose distributions using the generalized concept of equivalent uniform dose

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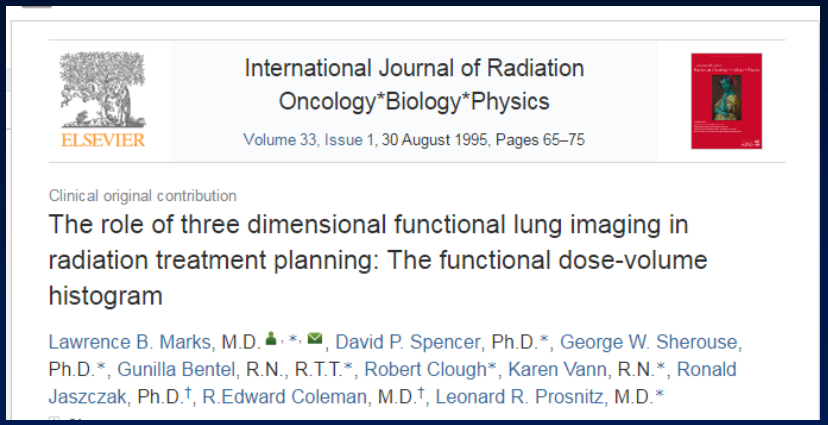

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Clinical original contribution

The role of three dimensional functional lung imaging in radiation treatment planning: The functional dose-volume histogram

Lawrence B. Marks, M.D.*, David P. Spencer, Ph.D.*, George W. Sherouse, Ph.D.*, Gunilla Bentel, R.N., R.T.T.*, Robert Clough*, Karen Vann, R.N.*, Ronald Jaszczak, Ph.D.†, R.Edward Coleman, M.D.†, Leonard R. Prosnitz, M.D.*

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Radiotherapy and Oncology

Volume 77, Issue 3, December 2005, Pages 271–277

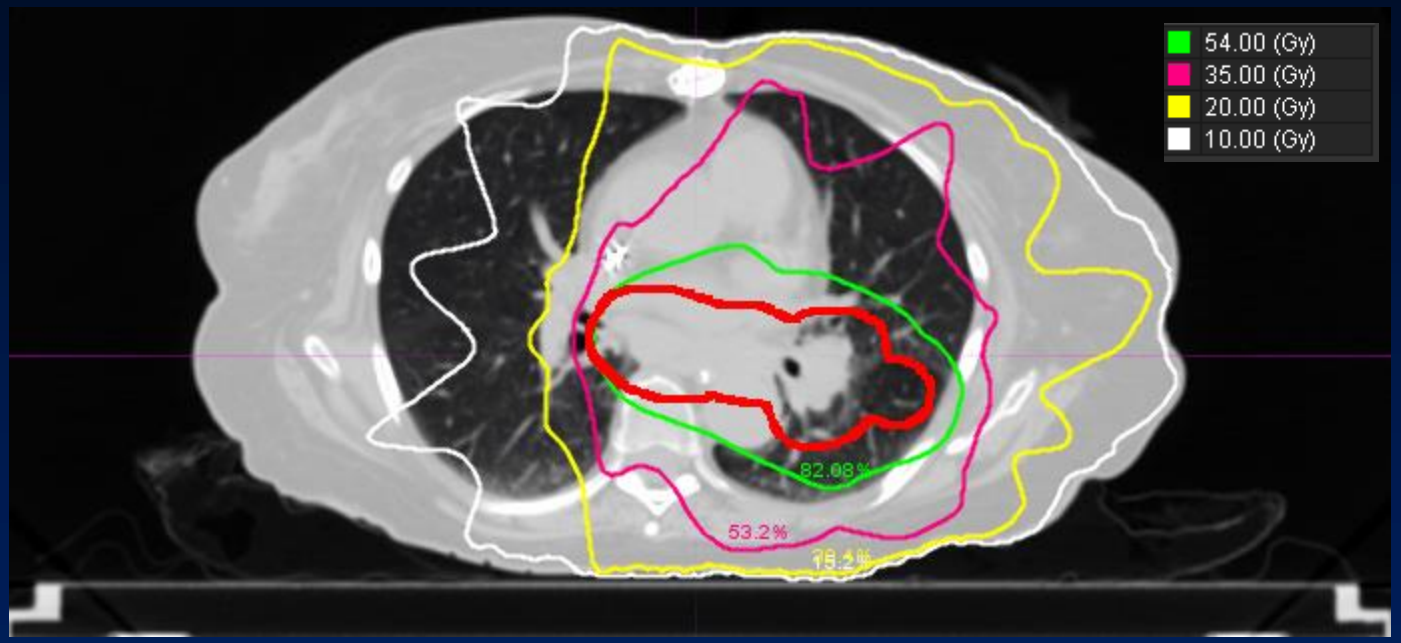
SPECT in treatment planning

The incorporation of SPECT functional lung imaging into inverse radiotherapy planning for non-small cell lung cancer

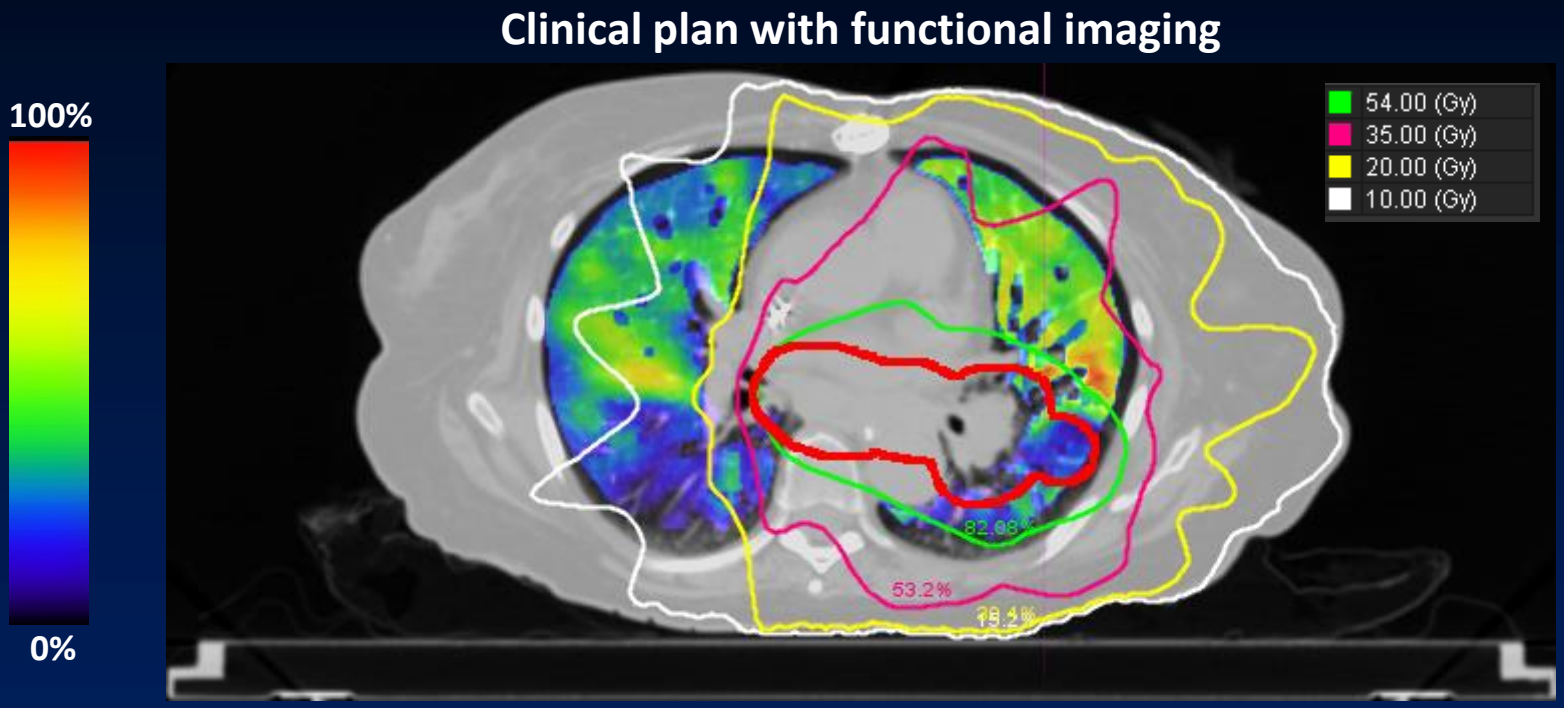
Judith A. Christian[a], Mike Partridge[a], Elena Nioutsikou[a], Gary Cook[a], Helen A. McNair[a], Bernadette Cronin[a], Frederic Courbon[b], James L. Bedford[a], Michael Brada[a]

Functional planning concept

Clinical plan

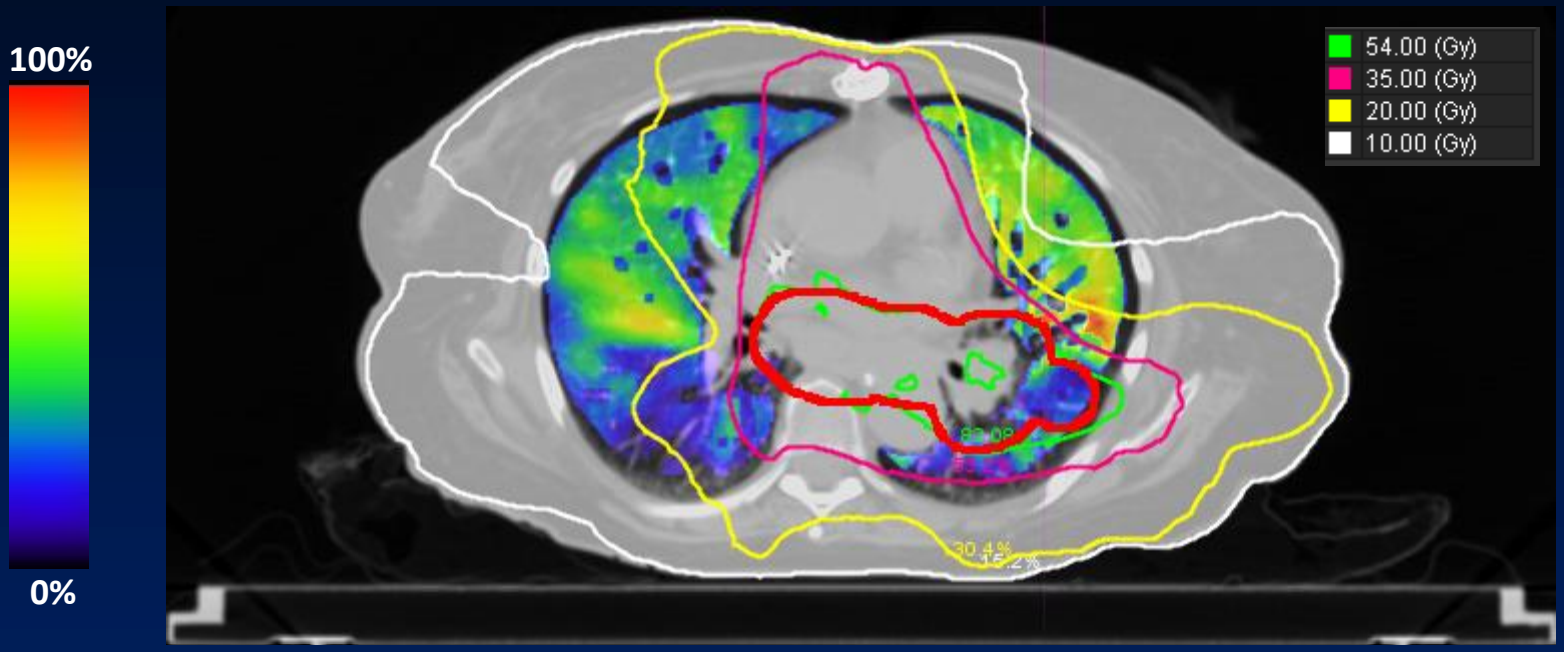


Functional planning concept

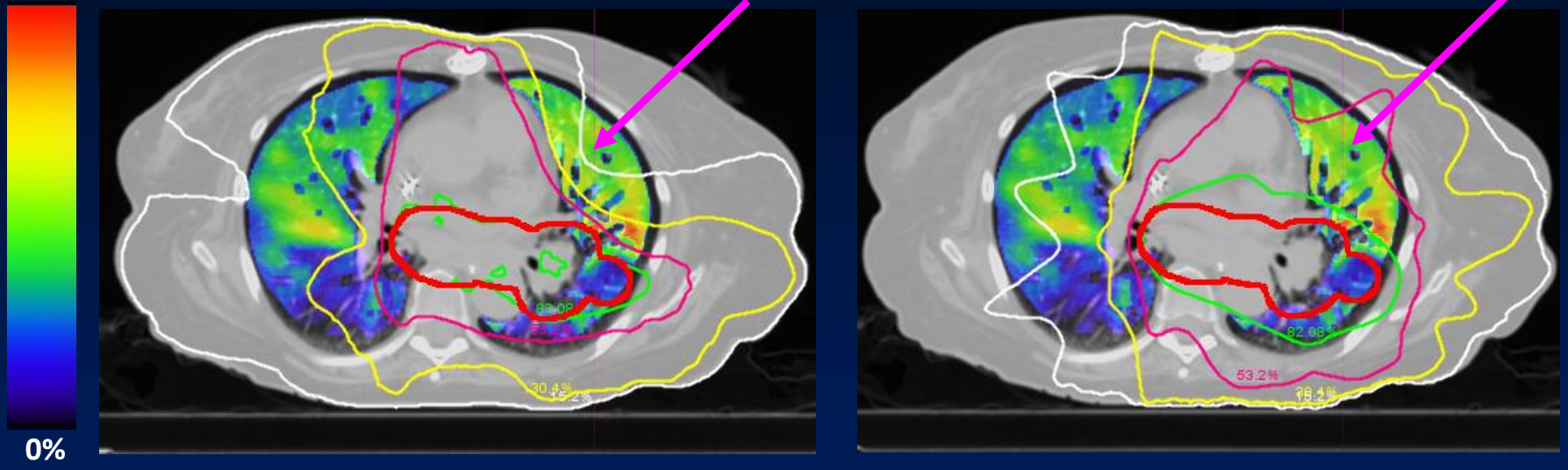


Functional planning concept

Functional plan with functional imaging



Functional planning concept



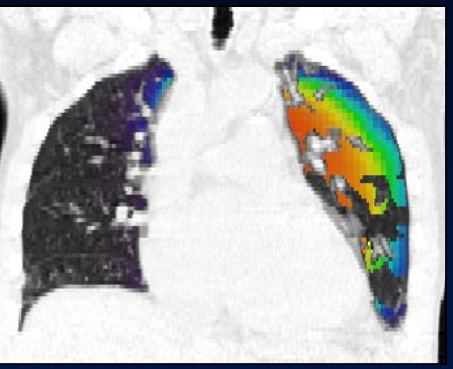
Functional planning – Will it work?

- 96 NSCLC patients
- Radiation pneumonitis toxicity information using CTCAE grading
- Calculated dose metrics
- Calculated dose + function metrics
- Is dose + function a better predictor of toxicity than dose alone

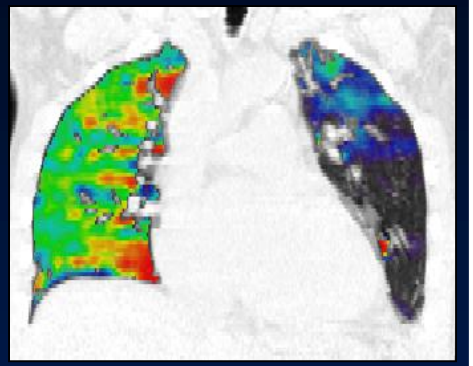
Functional planning

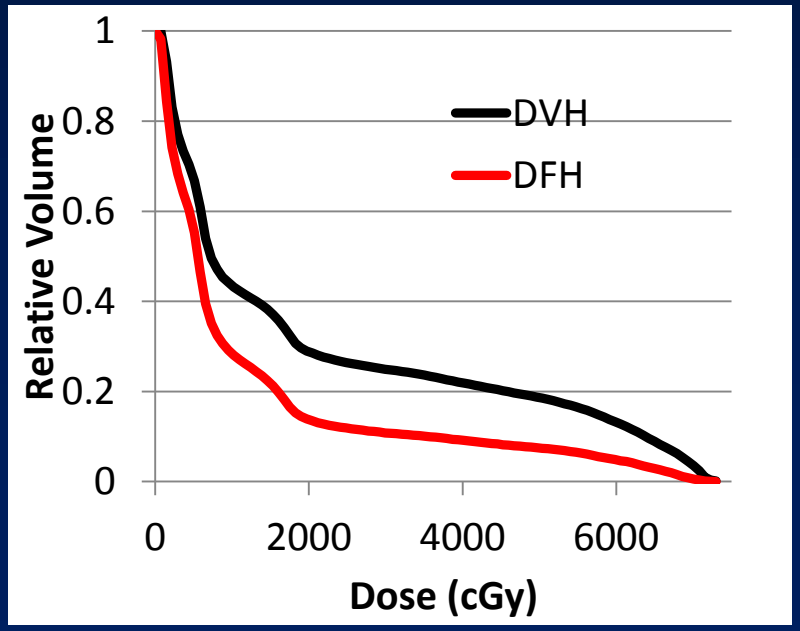
MLD = 22.9 Gy
No pneumonitis

Dose



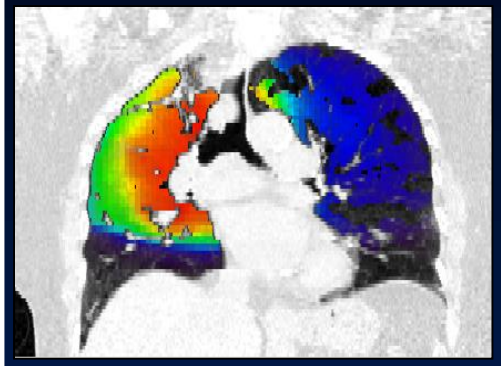
Ventilation



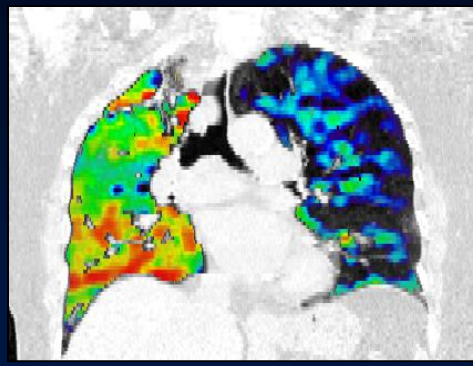


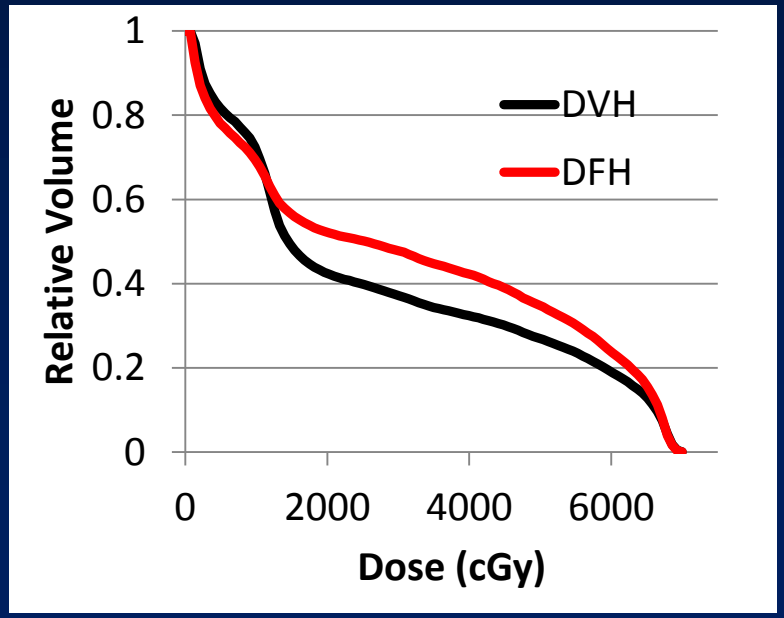
MLD = 23.2 Gy
Grade 3 pneumonitis

Dose



Ventilation





Functional planning

- Area under the curve (AUC) and logistic regression p value

MLD	fMLD	V20	fV20
0.55 (p=0.29)	0.62 (p=0.07)	0.57 (p=0.23)	0.66 (p=0.04)

Outline

4DCT-Ventilation Imaging

- Image formation
- Validation
- Clinical applications
- Clinical trial

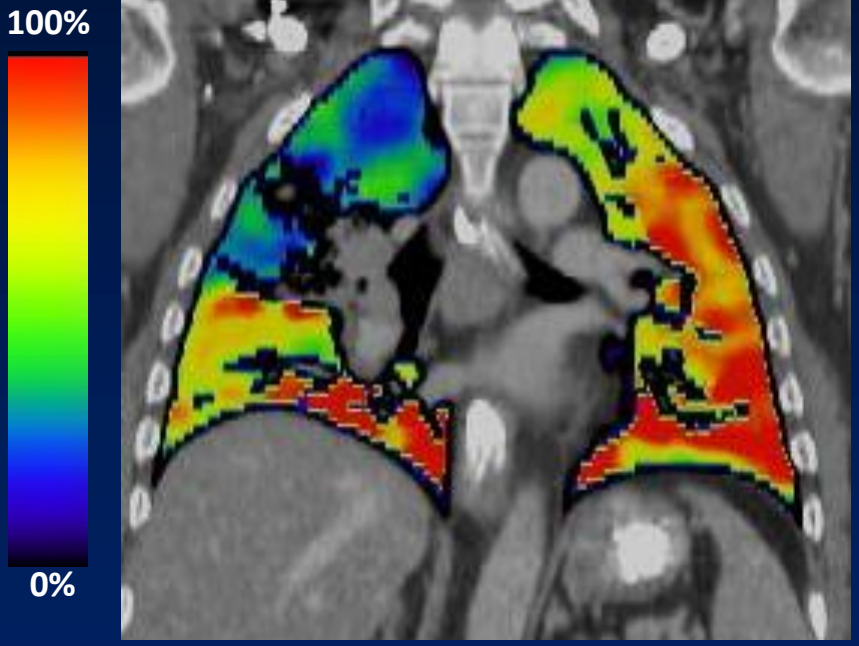
4DCT-Ventilation Clinical Trial

- 70 lung cancer patients between 2 institutions
- Use 4DCT to calculate ventilation imaging
- Use 4DCT-ventilation to design functional radiation plans
- Hypothesis: 4DCT-venitlation functional planning results in less pulmonary toxicity than toxicity with current standard of care techniques
- Assess lung function in a variety of ways
  - CTCAE Toxicity (Pneumonitis, esophagitis)
  - QOL Questionnaires
  - PFTs
  - CT/4DCT-Ventilation imaging
  - Nuclear Medicine VQ Imaging
  - PET Imaging

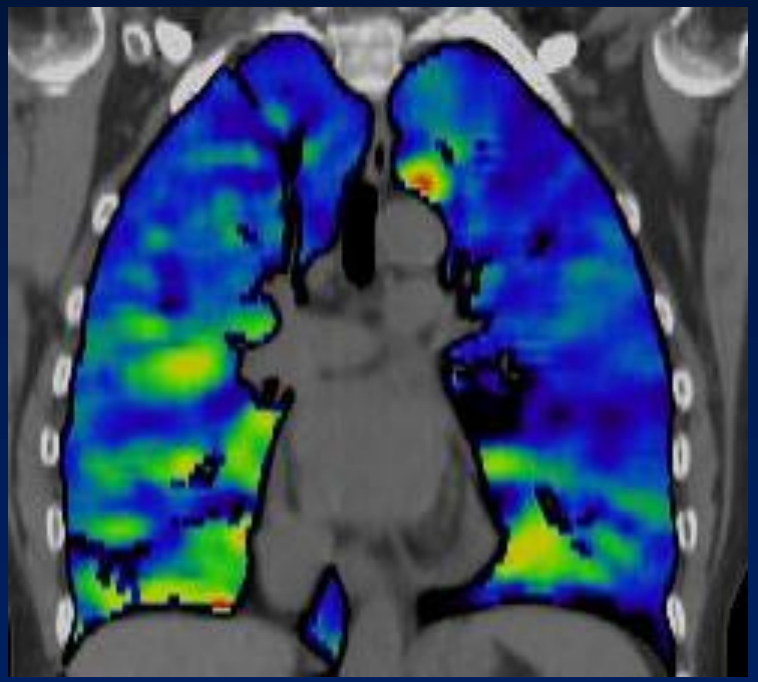
Should all patients be eligible?

Patient spatial lung function

Heterogeneous ventilation
Suitable for functional sparing



Homogenous ventilation
Not-suitable for functional sparing

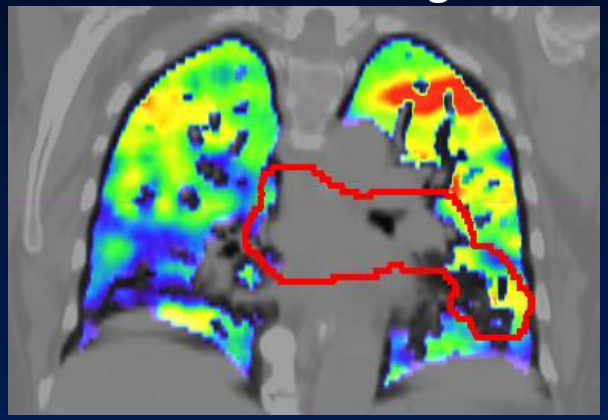


Protocol Basics

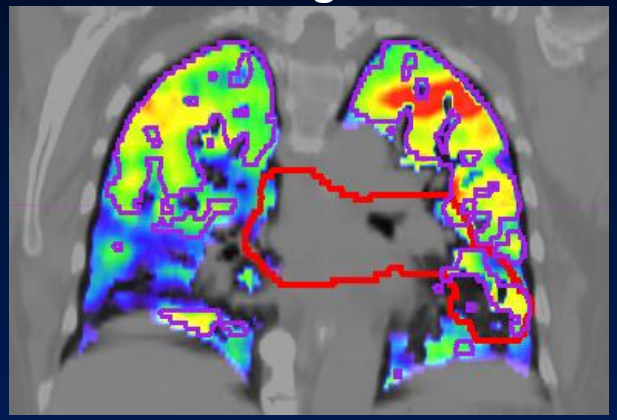
- Functional planning
  - Structure based functional approach

Planning techniques

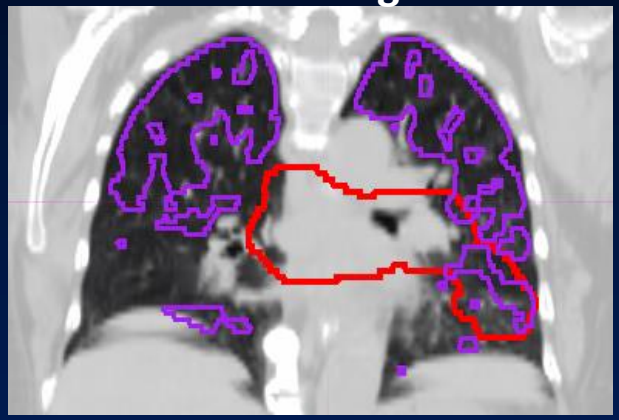
Functional Image



Functional Image + Structure



Functional Planning Structure



Protocol Basics

- Functional planning
  - Structure based functional approach
  - Start with standard (non-functional plan)
  - Planning priorities 1) Target coverage 2) OAR constraints 3) Reducing dose to functional lung

Conclusions

- 4DCT-Ventilation calculates lung ventilation maps from 4DCT data
- 4DCT-Ventilation has been validated against established methods of measuring lung function
- Retrospective work suggests toxicity can be reduced with functional planning
- Clinical trials are underway to evaluate 4DCT-Ventilation based functional planning

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