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
Outline

4DCT-Ventilation Imaging
- Image formation
- Validation
- Clinical applications
- Clinical trial
Calculating Ventilation Images

Calculating ventilation maps

4DCT – 10 phases

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

\[
\frac{V_{in} - V_{ex}}{V_{ex}} = \frac{HU_{in}^{\text{voi}} - HU_{ex}^{\text{voi}}}{HU_{ex}(1000 + HU_{in}^{\text{voi}})}
\]

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

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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

<table>
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<tr>
<th></th>
<th>SPECT Ventilation</th>
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<th>4DCT Ventilation</th>
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<tr>
<td></td>
<td>Right (%)</td>
<td>Left (%)</td>
<td>Right (%)</td>
</tr>
<tr>
<td>Top</td>
<td>9.5</td>
<td>2.7</td>
<td>16.8</td>
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<tr>
<td>Middle</td>
<td>30.2</td>
<td>21.1</td>
<td>21.9</td>
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<td>Lower</td>
<td>21.4</td>
<td>15.1</td>
<td>23.2</td>
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<tr>
<td>Total</td>
<td>61.1</td>
<td>38.9</td>
<td>61.8</td>
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Validation again nuclear medicine

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

4DCT-Ventilation Imaging
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Changes in lung function during RT

Week 0

Week 3

Week 5

Week 7
Functional planning concept

- Avoid functional portions of the lung in favor of irradiating through less functioning lung tissue
Functional planning concept

Clinical plan with functional imaging
Functional planning concept

Functional plan with functional imaging
Functional planning concept

Functional plan

Clinically used plan
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

MLD = 23.2 Gy
Grade 3 pneumonitis

Dose  Ventilation

DVH  DFH
Functional planning

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

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<th></th>
<th>MLD</th>
<th>fMLD</th>
<th>V20</th>
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<tr>
<td></td>
<td>0.55</td>
<td>0.62</td>
<td>0.57</td>
<td>0.66</td>
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<tr>
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<td>(p=0.29)</td>
<td>(p=0.07)</td>
<td>(p=0.23)</td>
<td>(p=0.04)</td>
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Outline

4DCT-Ventilation Imaging

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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-ventilation 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

Homogeneous 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
Acknowledgments

• NIH/NCI R01CA200817
• State of Colorado: Advanced Industries Accelerator grant

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