**SBRT I: Overview of Simulation, Planning, and Delivery**

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**Imaging in Lung SBRT**

- CT MRI PET
- Fluoroscopy Optical X-ray DTV CBCT SPECT
- Cine MV

**The Process: Image Guidance**

- X-ray
- (ExacTrac)
- CBCT
- Fluoroscopy
- (X-ray/CBCT)
- Cine-MV X-ray
- X-ray/CBCT

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**Free-breath 3D CBCT Match**

Wang et al Ref J 2007

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**Uncertainties in Lung SBRT IGRT**

- Tumor volume in CBCT
- Soft-tissue contrast
- Inter-observer variations
- Reproducibility of tumor location at breath-hold
- Internal-external motion correlation
- Changes of tumor size and motion
- Changes of anatomy
- Shifts and rotations in matching
- ……
Which CT for CBCT Matching?

4DCT-AIP v.s. CBCT

3D FB-CT v.s. CBCT

CBCT Matching: Tiny Tumor

Tumor Size ~ 5 mm; Tumor Motion ~ 20 mm

CBCT Matching: Large Anatomical Change

Pleural effusion at Sim
Largely disappeared at 1 fx
Re-simed, Re-planned

CBCT ITV Uncertainty


<table>
<thead>
<tr>
<th>Tumor</th>
<th>Free-Breathing ITV (cm³)</th>
<th>4D ITV (cm³)</th>
<th>Volume Underestimation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.78</td>
<td>2.97</td>
<td>40.1</td>
</tr>
<tr>
<td>B</td>
<td>35.62</td>
<td>46.98</td>
<td>24.2</td>
</tr>
</tbody>
</table>

Vergalasova et al, Med Phys 2011
Target Matching Uncertainty

Turner et al. 2013 AAPM

Image Registration Uncertainty: Inter-observer Variation

Cui et al, 2011; 81:305-312.

MVCT for Lung SBRT IGRT

Siker et al, Red J, 2006

Question: Which one of the following answers represents the best estimate of the inter-observer variation in image registration in lung SBRT?

1. 1 mm
2. 2 mm
3. 3 mm
4. 5 mm
5. >5 mm

Correct Answer: 2. 2 mm


Discussion

Correct Answer: 2. 2 mm


Image Registration Uncertainty: Inter-observer Variation

Table 2

<table>
<thead>
<tr>
<th>Protocol no.</th>
<th>Imager modality</th>
<th>No. of datasets</th>
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<th>Left-right</th>
<th>Superior-inferior</th>
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<tr>
<td>0815 (Lung)</td>
<td>MVCT</td>
<td>71</td>
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Histogram of registration differences


Rotational Shifts in Lung SBRT

Shang et al, 5th NC IMRT/IGRT Symposium, 2012

<table>
<thead>
<tr>
<th>Degree of Corrections</th>
<th>104 Lung SBRT Cases</th>
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<tbody>
<tr>
<td>Absolute Mean Pitch</td>
<td>0.87</td>
</tr>
<tr>
<td>Absolute Mean Roll</td>
<td>0.60</td>
</tr>
<tr>
<td>Variance Pitch</td>
<td>0.03</td>
</tr>
<tr>
<td>Variance Roll</td>
<td>0.30</td>
</tr>
<tr>
<td>Average Pitch &gt;0.5</td>
<td>69.2%</td>
</tr>
<tr>
<td>Average Roll &gt;0.5</td>
<td>50.0%</td>
</tr>
<tr>
<td>Average Pitch &gt;1.0</td>
<td>89.4%</td>
</tr>
<tr>
<td>Average Roll &gt;1.0</td>
<td>51.0%</td>
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Table 3

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Histogram of registration differences

**Dosimetric Effects of Rotations**

- 95.6% of all differences were <1% or <1 Gy.
- Overall small dosimetric effects of uncorrected rotations.

- Large inter-subject variations at large rotation angles.
- Up to 4% reduction in PTV coverage, 6 Gy increase in cord D0.35cc, and 4 Gy in Esophagus D0.35cc observed.

**Cine MV: tumor motion during TX**

Cine MV, 4D-CT

Tumor motion during 5-fx lung SBRT

Zhang et al, RPO 2013

- Intra-fractional variation:
  - AP: 0.0 ± 1.7 mm
  - ML: 0.6 ± 2.2 mm
  - SI: −1.0 ± 2.0 mm
  - 3D: 3.1 ± 2.0 mm

- 3D vector variation:
  - > 2 mm in 67.8%
  - > 5 mm in 14.3%

- Depending on immobilization (Range: 2.3 – 3.3 mm)
- Body Frame < Alpha Cradle < Body Fix < Wing Board

**Change of Tumor During Lung SBRT**

Initial tumor size: 0.7-7.3 cm

Change of tumor diameter:
- Range: -34.2% to 33.0%
- Mean: -7.9 ± 11.45%

Qin et al, Red J, 2013

**ExacTrac**

ExacTrac 6D v.s. CBCT 6D

- Small but maybe clinically significant discrepancies between ExacTrac X-ray 6D and CBCT 6D match
**Cyberknife**

- Targeting error: 0.1 – 0.3 mm
- Correlation error: 0.3 – 2.5 mm
- Prediction error: 1.5 ± 0.8 mm
- Total error: 0.7 – 5.0 mm

Pepin et al, Med Phys. 2011

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**Question:** Which one of the following answers represents the best estimate of the mean intra-fractional 3D tumor position shift in lung SBRT?

| 20% |  1. 1 mm |
| 20% |  2. 2 mm |
| 20% |  3. 3 mm |
| 20% |  4. 5 mm |
| 20% |  5. >5 mm |

**Correct Answer:** 3. 3 mm


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**Discussion**

**Correct Answer:** 3. 3 mm


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**Onboard DTS Imaging**

- Free-breathing Reference DTS
- Phase-matched Reference DTS
- On-board Acquired DTS

409 Patients
427 Tumors
1593 Fractions

3D: 3.1 ± 2.0 mm

**On-Board SPECT**

- SPECT on robotic arm
- Molecular targeting
- Multi-Pinhole collimation

Courtesy from Dr. Bowsher of Duke University

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**MRI for Image Guidance**

409 Patients
427 Tumors
1593 Fractions

3D: 3.1 ± 2.0 mm

"Better Match"
Summary

- Uncertainties exist in each step of image guidance of lung SBRT
- Understanding root causes and characteristics of these uncertainties is important for successful implementation of lung SBRT
- Next generation of on board imaging techniques has the potential to minimize uncertainties of image guidance of lung SBRT

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