Uncertainties and Quality Assurance of Localization and Treatment in Lung SBRT

Jing Cai, PhD
Duke University Medical Center

2013 AAPM 55th Annual Meeting, Educational Course, Therapy Track, MOC SAM Program

The Process: Image Guidance

X-Ray
(X-ray/CBCT)

CBCT

Fluoroscopy

(RPM)

Free-breath 3D CBCT Match

Pre-treatment 3D reconstruction

Post-treatment 3D reconstruction

Wang et al Ref J 2007

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
**Which CT for CBCT Matching?**

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-sim, Re-planned

---

**CBCT ITV Uncertainty**


---

**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


MVCT for Lung SBRT IGRT

Siker et al, Red J, 2006

Rotational Shifts in Lung SBRT

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

Dosimetric Effects of Rotations

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

Dosimetric Effects of Rotations

Cine MV: tumor motion during TX

Zhang et al, RPO 2013

- Image Registration Uncertainty: Inter-observer Variation

- MVCT for Lung SBRT IGRT
  - Siker et al, Red J, 2006

- Rotational Shifts in Lung SBRT
  - Shang et al, 5th NC IMRT/IGRT Symposium, 2012

- Dosimetric Effects of Rotations
  - Catalano et al, 5th NC IMRT/IGRT Symposium, 2012

- Dosimetric Effects of Rotations
  - Cine MV: tumor motion during TX
    - Zhang et al, RPO 2013

- Rotational Shifts in Lung SBRT
  - Absolute Corrections of Pitch/Roll
    - Shang et al, 5th NC IMRT/IGRT Symposium, 2012

- Dosimetric Effects of 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.
Intra-fractional Mean Tumor Position Shift

- 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

409 Patients
427 Tumors
1593 Fractions


Change of Tumor Size 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

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

ExacTrac 6D vs. CBCT 6D

ML: 1.06 mm  Pitch: 1.22°
AP: 1.43 mm  Row: 0.64°
SI: 1.43 mm  Yaw: 1.66°

Chang et al, Radiother Oncol, 2010

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

Onboard DTS Imaging

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

Better Match

Courtesy from Dr. Ren of Duke University

MRI for Image Guidance

Synchrony Respiratory Tracking System (RTS)

ExacTrac 6D   v.s.  CBCT 6D

ML:  1.06 mm  Pitch:  1.22°
AP:  1.43 mm  Row:  0.64°
SI:  1.43 mm  Yaw:  1.66°

Chang et al, Radiother Oncol, 2010

40 lung SBRT patients

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

Synchrony Respiratory Tracking System (RTS)

ExacTrac 6D   v.s.  CBCT 6D

ML:  1.06 mm  Pitch:  1.22°
AP:  1.43 mm  Row:  0.64°
SI:  1.43 mm  Yaw:  1.66°

Chang et al, Radiother Oncol, 2010

40 lung SBRT patients
On-Board SPECT

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

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