Dosimetric comparison of SBRT for lung cancer: Cyberknife vs. Linac

Chuxiong Ding, Ph.D., Cheng-Hui Chang, Ph.D., Joshua Haslam, Ph.D., Robert Timmerman, M.D., Timothy Solberg, Ph.D.

Department of Radiation Oncology, University of Texas Southwestern Medical Center, Dallas, TX
History of Stereotactical Radiosurgery

Single large radiation dose.

Multiple non-coplanar beams.

Accurate targeting.

Evolution of Technological Innovation

Lung, Liver, Pancreas, Prostate, Spine
Stereotactic Body Radiation Therapy (SBRT)

- Radiation delivery to a demarcated tumor target using:
  - optimal immobilization
  - motion accounting
  - many small fields
  - accurate targeting
  - heterogeneous target dose
  - steep dose gradients outside targets
  - ablative intent

few large dose treatments
Conformal high dose

Prescription Dose: 60Gy in 3 fractions

Target 60Gy 60Gy 30Gy 30Gy 7.5Gy 7.5Gy
Challenges for lung tumor SBRT treatment

- Localization
- Respiratory Motion

Inhalation Exhalation

Tumor excursion Diaphragm excursion
Purpose of Study

IGRT technique
Immobilization
Linac used
Collimator
Respiration Compensation
Treatment planning system
etc.

Dosimetric Difference
Linac Based Lung Cancer SBRT - Tumor Localization

• SBRT Frame: immobilization, localization.

• Cone Beam CT
Linac Based Lung Cancer SBRT - Respiratory Motion Control

- Large margin to GTV, Gating, ABC, Abdominal Compression, etc.
Cyberknife Lung Cancer SBRT - Tumor Localization

• Sophisticated image guidance tumor Localization
Cyberknife Lung Cancer SBRT - Respiratory Motion Motion Control

Internal Fiducial Markers

External Optical Markers

DEPT OF RADIATION ONCOLOGY

SOUTHWESTERN
DEPT OF RADIATION ONCOLOGY
Clinical SBRT Procedure in UTSW

4DCT → MIP for contour → Tx Planning → QA

Dose Delivery → CBCT Alignment → Patient Setup
SBRT Dose prescription in UTSW

**RTOG 0236**
A Phase II Trial of Stereotactic Body Radiation Therapy (SBRT) in the Treatment of Patients with Medically Inoperable Stage I/II Non-Small Cell Lung Cancer

**Prescription:** 60Gy in 3 fractions.

60-90% isodose line cover at least 95% of PTV.

99% of PTV should receive a minimum of 90% of prescript dose.

<table>
<thead>
<tr>
<th>Parallel Tissue</th>
<th>Critical Volume (cc)</th>
<th>Critical Volume Dose Max (Gy)</th>
<th>Endpoint (≥ Grade 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lung (Right &amp; Left)</td>
<td>1000 cc</td>
<td>13.5 Gy</td>
<td>Pneumonitis</td>
</tr>
</tbody>
</table>
Target Definition

Inhalation Exhalation MIP

____________ Tumor excursion _____________ Diaphragm excursion

PTV\textsubscript{3D} GTV

ITV

PTV\textsubscript{4D}
Study Protocol

Radiation Start Timing

Respiratory Cycle

4D CT Study

ITV, PTV_{3D}, MIP, and AVG images

4D calculation

GTV, PTV_{4D}, 50% phase CT

Deformable Registration

Synchrony

GTV

PTV_{4D}

PTV_{3D}

ITV

0% 50% 90%

GTV, PTV_{4D}, 50% phase CT

0% 50% 90%

0% 50% 90%

GTV

PTV_{4D}
Result (1): Dose to Tumor

- Tumor coverage
- Tumor dose homogeneous
- Maximum Dose
Result (1): Dose to Tumor

<table>
<thead>
<tr>
<th>DHI for GTV ( (D_{20} - D_{80}) / D_{prescription} )</th>
<th>Maximum point dose to GTV (Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cyberknife</strong></td>
<td><strong>Linac</strong></td>
</tr>
<tr>
<td>10.09</td>
<td>78.2</td>
</tr>
<tr>
<td>9.01</td>
<td>72.4</td>
</tr>
<tr>
<td>5.93</td>
<td>74.3</td>
</tr>
<tr>
<td>11.28</td>
<td>75.2</td>
</tr>
<tr>
<td>6.24</td>
<td>73.3</td>
</tr>
<tr>
<td>8.36</td>
<td>77.1</td>
</tr>
<tr>
<td>8.62</td>
<td>73.3</td>
</tr>
<tr>
<td>10.13</td>
<td>76.2</td>
</tr>
<tr>
<td>8.71±1.87</td>
<td>75.0±2.0</td>
</tr>
<tr>
<td>3.35±1.47</td>
<td>70.7±2.3</td>
</tr>
</tbody>
</table>

**Graph:**

- **Patient 1**
  - **Linac**
  - **Cyber**

- **Graph Parameters**
  - Dose (Gy) range: 0 to 80
  - Volume range: 0 to 1

- **Graph Lines:**
  - GTV_Cyber
  - PTV4D_Cyber
  - GTV SBRT
  - PTV4D SBRT
Result (1): Dose to Tumor

Beam Profile

- Cyberknife
- Synergy

7~10 beams
More Than 100 Beams

Patient 1

- GTV_Cyber
- PTV40_Cyber
- GTV SBRT
- PTV40 SBRT
Result (2): Dose to Lung

Institutional Dose Limit for Lung
SBRT: 1000cc lung get less than 13.5Gy
Result (2): Dose to Lung

Minimum Dose to 1000cc Lung

<table>
<thead>
<tr>
<th>Patients</th>
<th>Anterior</th>
<th>Middle</th>
<th>Posterior</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.00</td>
<td>6.00</td>
<td>3.00</td>
</tr>
<tr>
<td>2</td>
<td>8.00</td>
<td>7.00</td>
<td>4.00</td>
</tr>
<tr>
<td>3</td>
<td>9.00</td>
<td>8.00</td>
<td>5.00</td>
</tr>
</tbody>
</table>

Cyberknife vs. Linac SBRT
Result (2): Dose to Lung

<table>
<thead>
<tr>
<th>Patient</th>
<th>$V_{PTV4D}$</th>
<th>$V_{20}$ Cyberknife</th>
<th>$V_{20}$ Linac</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.34%</td>
<td>1.34%</td>
<td>3.27%</td>
</tr>
<tr>
<td>2</td>
<td>1.19%</td>
<td>3.67%</td>
<td>3.11%</td>
</tr>
<tr>
<td>3</td>
<td>0.91%</td>
<td>4.31%</td>
<td>4.90%</td>
</tr>
<tr>
<td>4</td>
<td>4.75%</td>
<td>16.32%</td>
<td>13.37%</td>
</tr>
<tr>
<td>5</td>
<td>1.49%</td>
<td>2.16%</td>
<td>2.59%</td>
</tr>
<tr>
<td>6</td>
<td>1.74%</td>
<td>9.11%</td>
<td>6.95%</td>
</tr>
<tr>
<td>7</td>
<td>0.53%</td>
<td>2.21%</td>
<td>2.74%</td>
</tr>
<tr>
<td>8</td>
<td>1.02%</td>
<td>4.83%</td>
<td>5.67%</td>
</tr>
<tr>
<td>mean±std</td>
<td>1.5%±1%</td>
<td>5.5%±5%</td>
<td>5.3%±3.6%</td>
</tr>
</tbody>
</table>

$V_{20} = m \times V_{PTV4D} + b$

$r^2 = 0.88$

$r^2 = 0.84$
Result (3): Whole body dose

- Cyberknife: Total MU 25,000 ~ 50,000
- Linac: Total MU 10,000 ~ 15,000

Cover PTV

Cover 60~80% PTV dimension
Result (3): Whole body dose

- The absolute risk of both modalities are minimal.
- CyberKnife risk was higher due to the greater number of MU’s.

## Some Practical Consideration

<table>
<thead>
<tr>
<th></th>
<th>Cyberknife</th>
<th>Linac</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Treatment Planning</strong></td>
<td>• Inverse Planning.</td>
<td>• Beam can come through posterior of patient</td>
</tr>
<tr>
<td></td>
<td>• No beam come through posterior of patient</td>
<td>• Beam angle limited by table and gantry collision</td>
</tr>
<tr>
<td><strong>Tumor Localization</strong></td>
<td>• Few X-Ray images</td>
<td>• CBCT Required</td>
</tr>
<tr>
<td><strong>Respiratory Control</strong></td>
<td>• Need Fiducial (Synchrony)</td>
<td>• Larger target area</td>
</tr>
<tr>
<td></td>
<td>• Non Fiducial tracking (X-sight Lung tracking).</td>
<td>• Abdominal compression</td>
</tr>
<tr>
<td><strong>Dose Delivery</strong></td>
<td>• Robert moving time</td>
<td>• Less MU</td>
</tr>
<tr>
<td></td>
<td>• More MU</td>
<td>• Adjust treatment couch angle</td>
</tr>
</tbody>
</table>
Conclusion

- No difference in dose coverage.
- Cyberknife is heterogeneous dose to GTV.
- All lung dose within constrains.
- No difference to lung in high dose region.
- Lung dose depends on tumor location in low dose region.
Thank you!