Stereotactic Body Radiotherapy for Lung Lesions using the CyberKnife
State-of-the-art and New Innovations

Chad Lee, PhD
CK Solutions, Inc. and
CyberKnife Centers of San Diego
Outline

- Basic overview of CyberKnife
- Synchrony with fiducials: How does it work?
- Imaging, contouring & dose prescriptions
- Monte Carlo dose calculation
- Xsight Lung: How does it work?
CyberKnife system approach to SBRT

- Robot with 6 degrees of freedom coupled to an X-band linac
- Integrated with an orthogonal pair of X-ray images acquired repeatedly throughout treatment
- DRRs from planning CT compared with live orthogonal images to determine translational and rotational offsets
CyberKnife system approach to SBRT (cont.)
CyberKnife system approach to SBRT (cont.)

- CyberKnife’s robotic arm makes treatment non-isocentric
- Radiation beams re-targeted as needed throughout treatment based on DRR/live image comparison
  - Submillimeter targeting accuracy maintained with limited immobilization (thermoplastic mask for skull, vacuum bags for extracranial locations)
CyberKnife system approach to SBRT (cont.)

- Radiation is 6 MV
  - $D_{\text{max}} = 1.5\text{cm}$
  - No flattening filter
- Output 600-800 MU/min
- 12 fixed collimators (5mm to 60mm)
- Newest addition: IRIS variable aperture collimator
CyberKnife system approach to SBRT (cont.)

Full Body Radiosurgery

- Intracranial
- Spine
- Lung
- Soft Tissues
- Prostate

- Skull Tracking
- Xsight Spine Tracking
- Synchrony Respiratory Tracking
- Xsight Lung Tracking
- Fiducial Tracking
Question 1: Which aspect of the CyberKnife system allows continuous adjustment of the radiation beam during treatment?

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**Correct answer: 2.**
Synchrony with fiducials: How does it work?
Synchrony with fiducials: How does it work? (continued)

**Synchronization** of two trackable signals:

- **Implanted fiducials**
- **Light-emitting diodes (LEDs) on the chest**
Synchrony with fiducials: How does it work? (continued)

Static diagnostic images are acquired at discrete time points identified on the real-time 3-D chest movement cycle
Synchrony with fiducials: How does it work? (continued)
Synchrony with fiducials: How does it work? (continued)

- Top row: Real-time LED traces
- Middle row: LED position (x axis) vs. fiducial position (y axis)
- Bottom row: Last 15 correlation errors (3-D difference between new fiducial position and prediction of the model)
Synchrony with fiducials: How does it work? (continued)

- Top row:
  Real-time LED traces
Synchrony with fiducials: How does it work? (continued)

- Middle row:
  LED position (x axis) vs. fiducial position (y axis)
- Model types: linear, arc, double-arcs (hysteresis)
Synchrony with fiducials: How does it work? (continued)

- Bottom row:
  Last 15 correlation errors (3-D difference between new fiducial position and prediction of the model)
Synchrony with fiducials: How does it work? (continued)

- Models are not always clean
- System interrupts treatment for correlation errors > 5mm
- Automatic interruption in real time for sneezes, coughs, apnia, etc.
Synchrony with fiducials: How does it work? (continued)

- Synchrony does not replace careful observation and decisions based on experience!
- PTV margins should reflect correlation model limits (and vice versa)
Synchrony with fiducials: How does it work? (continued)
**Question 2:**

Synchrony software is used by CyberKnife to correlate which two measured quantities?

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Question 2: Synchrony software is used by CyberKnife to correlate which two measured quantities?

1. Fiducial ant/post translations and fiducials sup/inf translations
2. **Fiducial 3-D translations and light-emitting diode (LED) 3-D translations**
3. Fiducial 3-D translations and LED rotations
4. Fiducial rotations and LED 3-D translations
5. Fiducial rotations and fiducial 3-D translations

Correct answer: 2.
Imaging, contouring & dose prescriptions

- CT always required (for DRR creation)
- CT with breath-hold is used (generally at full exhalation) without contrast
- Fusion of PET scans is common for lung and pancreatic lesions
- Fusion of breath-hold MR images often used for liver, pancreatic lesions
Common dose schema:

- Peripheral lesions:
  - 20 Gy x 3 (Timmerman RTOG0236, homogeneous calculations)
  - 18 Gy x 3 (Timmerman RTOG0618, heterogeneous calculations)

- Central lesions:
  - 12 Gy x 4 (Nagata et al 2005)
  - 12 Gy x 5 (Lagerwaard et al 2008)
Imaging, contouring & dose prescriptions (continued)

Peripheral
Central

Defines zone of the proximal bronchial tree
Imaging, contouring & dose prescriptions (continued)

- New trial (CyberKnife only): STARS
  - MD Anderson; central AND peripheral
- STARS trial definitions (Stage I NSCLC):
  - GTV
  - PTV1 (GTV + margin)
  - CTV (PTV1 + margin)
  - PTV2 (CTV + margin)
- PTV1 and PTV2 both have minimum dose and coverage requirements
Question 3: Which of the following dose fractionation schemes is not typical for SBRT of early stage lung cancer?

1. 3 x 18 Gy
2. 3 x 20 Gy
3. 4 x 12 Gy
4. 4 x 20 Gy
5. 5 x 12 Gy
Question 3: Which of the following dose fractionation schemes is not typical for SBRT of early stage lung cancer?

1. 3 x 18 Gy (RTOG 0618)
2. 3 x 20 Gy (RTOG 0236)
3. 4 x 12 Gy (Nagata 2005)
4. 4 x 20 Gy
5. 5 x 12 Gy (Lagerwaard 2008)

Correct answer: 4.
Monte Carlo dose calculations

- The MultiPlan dose calculation algorithm is inaccurate near interfaces between different types of materials (tissue-air) and different densities (lung tissue-tumor tissue).
- Accurate calculation of doses to the edge of the planning target volume (PTV) requires another physical model.
- The Monte Carlo method is the gold standard – it models individual photons.
Monte Carlo dose calculations (continued)

- Monte Carlo is stochastic, so smaller uncertainty requires more photon histories (calculations can be lengthy)
- Clever techniques reduce uncertainty without too much time increase
  - Pre-computed phase space calculation
  - Single source model
  - Sampling of electron tracks already computed
  - Russian roulette
  - More!
Monte Carlo dose calculations (continued)

- Additional beam data used to construct source model
Monte Carlo dose calculations (continued)

- Patient model based on CT image set
- Both electron and mass densities employed
- Divides patient into material types
  - Air
  - Soft tissue
  - Bone
Monte Carlo dose calculations (continued)
Monte Carlo dose calculations (continued)
Monte Carlo dose calculations (continued)
Question 4:
Which of the following is **not** included in the Monte Carlo calculation software for CyberKnife?

1. Pre-computed phase space calculation
2. Single source model
3. Dose enhancement effects in metal
4. Angle- and energy-dependent photon source distributions
5. Pre-computed electron tracks
Question 4: Which of the following is not included in the Monte Carlo calculation software for CyberKnife?

1. Pre-computed phase space calculation
2. Single source model
3. **Dose enhancement effects in metal (air, soft tissue, bone)**
4. Angle- and energy-dependent photon source distributions
5. Pre-computed electron tracks

Correct answer: 3.
Xsight Lung: How does it work?

- In certain cases, the density difference between lung and solid tumor can be used for tracking without need for fiducials.
- No pneumothorax risk.
- No delay for fiducial implant and 7-day recovery period before imaging.
Xsight Lung: How does it work? (continued)

- Centroids of target on DRR and live diagnostic images are compared to determine 3-D translation
- Rotation determined using spine tracking, then shifting from spine- to tumor-center
- Synchrony still used to track breathing motions
- XST has been available for about one year (still fairly new)
Xsight Lung: How does it work? (continued)

- First, use spine grid to fix body rotations... then shift to tumor centroid to create Synchrony model
Xsight Lung: How does it work? (continued)

- Tracking requirements:

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<th>Target Dimensions:</th>
<th>Tumor must measure greater than 15 mm on all axis</th>
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<td>Target Location:</td>
<td>Peripheral region of the lung</td>
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<td>Target Visualization:</td>
<td>Tumor not completely obstructed by spine structures in the live X-ray projection and DRR images</td>
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In my limited experience (about 25 cases since June 2007), Accuray’s acceptance criteria are correct.

A local search algorithm is employed to determine a confidence level.

100% confidence has been observed without perfect overlay of contour with dense “blob” on Live Image.

About 30-50% of lung cases are XLT candidates.
Question 5:
Which of the following criteria would not preclude a patient from receiving CyberKnife treatment using Xsight Lung tracking?

1. Tumor dimension greater than 15mm
2. Tumor at 45° to spine
3. Tumor at 45° to heart
4. Tumor at 45° to greater vessels
5. Tumor located within dense lung parenchyma
Question 5:
Which of the following criteria would **not** preclude a patient from receiving CyberKnife treatment using Xsight Lung tracking?

1. **Tumor dimension greater than 15mm (less than 15mm precludes)**
2. Tumor at 45° to spine
3. Tumor at 45° to heart
4. Tumor at 45° to greater vessels
5. Tumor located within dense lung parenchyma

**Correct answer: 1.**
References

Thank You