The role of radiology in advanced stereotactic radiosurgery

Gaurav Singal
Dr. Gillian Lieberman
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Ms. C: Brief History

<table>
<thead>
<tr>
<th>ID</th>
<th>83yo F with 40 pack-year smoking hx</th>
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<tbody>
<tr>
<td>HPI</td>
<td>Worsening cough</td>
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<td>CAD, Skin Cancer, No COPD</td>
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Medical evaluation inconclusive, so imaging obtained…
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<td>CT</td>
<td>3.9 cm RLL peripheral lesion</td>
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<tr>
<td>Bx</td>
<td>NSCLC, poorly differentiated, likely primary</td>
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Imaging: Staging (PET/CT)

Stage 1b NSCLC (T2 N0 M0)

RLL lesion is FDG avid (max SUV 9)

Spherical RLL soft-tissue density c/w known NSCLC. Measures 3.5x2.7cm

PET/CT Fusion

Axial CT

BIDMC, Nuclear Medicine
Ms. C: Treatment Options

- **Surgery?**
  - 83 years old!
  - Co-morbidities: CAD
  - Significantly increased morbidity, decreased survival time with surgery in elderly
    - (Mery et al., *Chest* 2005)

- **Other options?**
Ms. C: Alternative Treatments

- Chemotherapy
  - Systemic toxicity

- Conventional Radiation
  - Significant parenchymal damage

- RF/Thermal Ablation
  - Limited by lesion size

- Palliative Care
Ms. C: Alternative Treatments

- Stereotactic Radiosurgery!
  - Traditionally restricted to intracranial lesions
  - Frame-requiring systems

- Limitations of traditional therapy
  - Unable to target extracranial lesions
    - Anatomical landmarks less defined
    - Movement, respiratory variation

http://www2.uhb.nhs.uk/
CyberKnife

• Stereotactic Radiosurgical Robot
• Computer-driven robotic arm can fire from 101 positions
CyberKnife: Overview

- **Frameless**
  - Guided by real-time in-procedure imaging

- **Fiducial markers**
  - Proxies for anatomical reference

[x-ray emitters]

[Digital detector]

www.accuray.com
CyberKnife: Role of Radiology

Radiology critical in every step of CyberKnife procedure…
CyberKnife: Imaging Steps

- Fiducial Seeds
- Assess for Complications
- Pre-treatment Planning Imaging
- Treatment with Real-time Imaging
- Follow-up Imaging

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CyberKnife: Imaging Steps

1. Fiducial Seeds
2. Assess for Complications
3. Pre-treatment Planning Imaging
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BIDMC, PACS
CyberKnife: Imaging Steps

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Courtesy of Dr. Hines-Peralta
CyberKnife: Imaging Steps

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CyberKnife: Imaging Steps

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BIDMC, Nuclear Medicine
Step 1: Fiducial Seed Placement

1. Fiducial Seeds
2. Assess for Complications
3. Pre-treatment Planning Imaging
4. Treatment with Real-time Imaging
5. Follow-up Imaging
Fiducial Seeds: Reference Targets

- 3-6 markers
- Implanted by IR
  - CT
  - US
  - Fluoroscopy
- 30% risk of pneumothorax
  - Only 10% require intervention
- Multiple seeds per puncture
  - Minimize number of pleural punctures

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2x5mm Fiducial seeds
Fiducial Seeds: Reference Targets

- Requirements:
  1. Within 6cm of lesion (one within)
Fiducial Seeds: Reference Targets

- **Requirements:**
  1. Within 6cm of lesion (one within)
  2. 2-12cm apart
Fiducial Seeds: Reference Targets

Requirements:
1. Within 6cm of lesion (one within)
2. 2-12cm apart
3. Non-collinear relative to x-ray
Step 2: Assess for Complications

- Fiducial Seeds
- Assess for Complications
- Pre-treatment Planning Imaging
- Treatment with Real-time Imaging
- Follow-up Imaging
Ms. C Fiducial Seeds on Axial CT
Ms. C Pneumothorax on Axial CT
Ms. C developed small R apical pneumothorax as complication of CT-guided fiducial seed placement, visible on CT and plain film.

Pneumothorax shows interval resolution from morning to afternoon on day of procedure.

Complete resolution of pneumothorax seen by third plain film taken two months later.
Ms. C: Simple R Pneumothorax on upright CXR

R apical pneumothorax
- Pleural line 1.5cm from chest wall
- Absence of lung markings
- No mediastinal shift
Ms. C: Simple R Pneumothorax on upright CXR

Interval improvement

BIDMC, PACS
Ms. C: Resolved Pneumothorax on upright CXR

Two months later
Step 3: Pre-treatment Imaging

1. Fiducial Seeds
2. Assess for Complications
3. Pre-treatment Planning Imaging
4. Treatment with Real-time Imaging
5. Follow-up Imaging
Pretreatment Imaging: Companion Patient #1

- 2-7 days after markers
  - Allow incisions to heal, markers to settle
- CT, MRI, or US
- Define tumor boundaries
- Define “protected” regions
- CyberKnife software plans trajectories of radiation beams
- 4D-CT

Courtesy of Dr. Hines-Peralta
Step 4: Real-time Imaging

1. Fiducial Seeds
2. Assess for Complications
3. Pre-treatment Planning Imaging
4. Treatment with Real-time Imaging
5. Follow-up Imaging
Real-time Imaging

- Pre-treatment imaging (CT) loaded into robotic control system
  - Trajectories planned by CyberKnife system
- Respiratory model computed by 4D-CT
- Two oblique x-rays taken every 20-40 seconds to verify location of tumor and adjust radiation trajectories and respiratory model
Monitor changes in patient and tumor position using real time x-rays.

However, all pre-treatment planning done using CT need to generate “simulated” x-rays to compare against real-time x-rays.

Digitally reconstructed radiographs (DRR) created from CT by projecting at expected in-procedure angles.

http://www.varian.com/shared/orad/prd131-2l.jpg
Respiratory Variation

- **Pre-procedure**
  - Respiratory model derived
  - 4D respiratory-gated CT

- **In-procedure**
  - Patient wears vest with optical markers
  - Model updated and refined with real-time imaging, predictions adjusted
  - LINAC arm moves in synchrony with respiration

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Step 5: Follow-up Imaging

- Fiducial Seeds
- Assess for Complications
- Pre-treatment Planning Imaging
- Treatment with Real-time Imaging
- Follow-up Imaging
**Imaging: Follow-up (PET/CT)**

PET/CT Fusion

- **PET/CT Fusion**
  - Only small sphere of increased FDG uptake. Max SUV 2.7 (down from 9 pre-treatment). No focal uptake in areas of fibrotic changes.

Axial CT

- **Axial CT**
  - Numerous soft tissue densities in RLL. Difficult to differentiate atelectasis from tumor recurrence or post-radiation fibrotic changes.
Summary

- Ms. C’s NSCLC
  - Continues to be stable 18 months after procedure
- CyberKnife offers potential for minimally invasive radiosurgical treatment of until now inaccessible extracranial tumors
- Radiology allows previous obstacles such as respiratory variation and patient mobility to be overcome
- Multidisciplinary even within radiology, combining nuclear medicine, interventional radiology, and diagnostic radiology
Many thanks to:

- Andrew Hines-Peralta, MD
- Gillian Lieberman, MD
- Nuclear Medicine Staff
- Maria Levantakis
- BIDMC Staff
References