**Overview**

- SBRT planning and delivery considerations
  - Beam margins – lung
  - Beam geometry
  - Image-guidance and system accuracy, QA
- Institutional experience
  - U of Chicago Multiple Mets Trial
  - Treatment process
    - Planning
    - Delivery
    - Verification and QA
- Summary

**Beam Geometry: most dominant factor for SRS dose**

Increased conformity and dose gradients require many well-separated beams in 3D!

**Limited non-coplanar Beam Geometry for SBRT**

Lung: geometrically optimized beams

<table>
<thead>
<tr>
<th>Beam Configuration</th>
<th>DT</th>
<th>Dose/patient (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two coplanar 5 beams</td>
<td>51</td>
<td>1.92</td>
</tr>
<tr>
<td>Three coplanar 3 beams</td>
<td>3</td>
<td>1.50</td>
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</tbody>
</table>

Liver: geometrically optimized beams

<table>
<thead>
<tr>
<th>Beam Configuration</th>
<th>DT</th>
<th>Dose/patient (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two coplanar 1 beam</td>
<td>1</td>
<td>1.53</td>
</tr>
<tr>
<td>Three coplanar 3 beams</td>
<td>3</td>
<td>1.39</td>
</tr>
</tbody>
</table>

Limited non-coplanar beam space for SBRT (Lu et al, PMB, 2004)
Beam “penumbra” margin

For the same prescription dose at the tumor:
- smaller beam margin ⇒ higher MU and higher dose to lung in the beam path
- larger beam margin ⇒ less MU and more normal lung outside tumor

What is the optimal beam/block margin that minimizes normal tissue toxicity?

Study 1. Cardinale et al (UROBP, 1999) – DVH parameters (PTV, V100%, V50%, D50) and NTCP for lung and liver for 6MV photon beam margins of 0-18 mm

<table>
<thead>
<tr>
<th>Beam Margin (mm)</th>
<th>V100% (cc)</th>
<th>V50% (cc)</th>
<th>D50 (Gy)</th>
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<tbody>
<tr>
<td>0</td>
<td>14</td>
<td>22</td>
<td>32</td>
</tr>
<tr>
<td>2</td>
<td>1.1</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>4</td>
<td>1.1</td>
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<td>1.2</td>
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<tr>
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<td>1.1</td>
<td>1.2</td>
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<tr>
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<td>1.1</td>
<td>1.2</td>
<td>1.2</td>
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<td>1.2</td>
<td>1.2</td>
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<tr>
<td>16</td>
<td>1.1</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>18</td>
<td>1.1</td>
<td>1.2</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Beam margins of 0-4mm yield optimal normal lung sparing based on V10 Gy
Zero beam margins result in best V10Gy lung sparing

Test of Overall Accuracy

- CT scan phantom with “hidden” targets
- Localize target on segmented images (coordinates, etc)
- Position target/phantom in treatment beam isocenter
- Image phantom and determine deviation of target position
  - Image registration accuracy
  - Evaluate concordance of treatment and imaging isocenters

QA procedure must test all steps including verification of image guidance vs. treatment beam

University of Chicago Oligomets Trial

Five or less metastatic lesions
- Lung
- Liver
- Abdomen
- Extremity
  - Life expectancy > 3 months
  - No prior RT to currently involved sites
  - Each site ≤10 cm or ≤500cc
  - Normal organ and marrow function

Dose Limiting Toxicities (DLT)
- Grade 3-5 non-hematological toxicities
- Grade 4-5 hematological toxicities
- Grade 3 mucositis or esophagitis lasting ≤7 days will not be considered a DLT

Dose escalation tiers:
- 8 Gy/fx x 3 = 24 Gy
- 10 Gy/fx x 3 = 30 Gy
- 12 Gy/fx x 3 = 36 Gy
- 14 Gy/fx x 3 = 42 Gy
- 16 Gy/fx x 3 = 48 Gy
- 18 Gy/fx x 3 = 52 Gy
- 20 Gy/fx x 3 = 60 Gy

Current: Lung and abdomen
**UC SBRT Simulation Procedure**

- Near full-body immobilization: upper and lower alpha cradles, knee cushion, indexing to CT and treatment tables
- Gated CT and 4DCT for all abdominal and lung sites, free-breathing for others
- Treatment planning CT scans
  - Gated non-contrast → dose calculations
  - Gated contrast → tumor volume delineation (augmented by PET-CT/MR)
  - Retrospective (4DCT) → customized ITV's

**Treatment Planning**

- Nine to thirteen coplanar and non-coplanar non-opposing static conformal beams
- Beams eye-view blocking with MLC at the isocenter with a margin of 0-2 mm
- PTV (Rx Dose) ≥ 95%
- Normal tissue dose limits: hard constraints

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**Normal Tissue Tolerances**

<table>
<thead>
<tr>
<th>Organ</th>
<th>RTOG</th>
<th>Karolinska</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spinal Cord</td>
<td>≥ 1.8 Gy</td>
<td>No published recommendation</td>
</tr>
<tr>
<td>Heart</td>
<td>≤ 8 Gy</td>
<td>≤ 8 Gy per fraction</td>
</tr>
<tr>
<td>Tracheal Pleura</td>
<td>≤ 7.5 Gy</td>
<td>≤ 7.5 Gy per 3-5 fractions</td>
</tr>
<tr>
<td>Tracheal/Bronchial</td>
<td>≤ 5 Gy</td>
<td>≤ 5 Gy per 3-5 fractions</td>
</tr>
<tr>
<td>Esophagus</td>
<td>≤ 7.0 Gy</td>
<td>≤ 7.0 Gy per 3-5 fractions</td>
</tr>
<tr>
<td>Lung</td>
<td>≤ 1.5 ≤ 100% radiation, 7.0 Gy</td>
<td>≤ 7.0 Gy per 4-5 fractions</td>
</tr>
<tr>
<td>Liver</td>
<td>≤ 70% of normal liver ≤ 6 Gy</td>
<td>≤ 7.0 Gy per 4-5 fractions</td>
</tr>
<tr>
<td>Stomach-Small Bowel</td>
<td>≤ 6 Gy</td>
<td>≤ 7.0 Gy per 4-5 fractions</td>
</tr>
<tr>
<td>Kidney</td>
<td>≤ 6 Gy 30% kidney</td>
<td>Primary ≤ 10 Gy ≤ 5 fractions</td>
</tr>
</tbody>
</table>

**Lung Mets: The “Good”..**

ITV derived from 4DCT, free-breathing 1x delivery
11 non-coplanar beams
Rx = 3 x 1400 cGy
PTV: V4200cGy = 96%
Lung (ITV2000cGy) < 8%
Lung Mets: The Bad..
(Metastatic Melanoma: 4 lesions in lung)

All lesions: 3x1200 cGy
Static conformal plan
38 total beams
V20 (W:Lung-GTV)=14%

Lung Mets: The Ugly..
(Four lung metastases + two new)

New lesion

Beam Placement and Dose Shaping
(restrict the beam overlap with already treated volume)

How much more lung is damaged?

Composite dose cloud of 1300 cGy from both courses of SBRT
How much more lung is damaged?

Dose cloud of 1300Gy from course 1 and course 2

Image-Guidance: Treatment Verification

- Pre-treatment verification: 3D
  - Non-contrast gated CT (big-bore, 16-slice scanner)
  - CBCT
- On-board kV/MV imaging: 2D
  - Image registration to reference DRR’s
  - Orthogonal and portal verification gated images
- Mid and post procedure imaging
  - Evaluation of intrafraction patient/target motion

Lung DVH Characteristics versus RTOG0236

<table>
<thead>
<tr>
<th>Patient</th>
<th>Toxicity</th>
<th>Location</th>
<th>PTV max dimension (cm)</th>
<th>PTV (cc)</th>
<th>Prescripti on</th>
<th>Max dose at 2cm from PTV (Gy)</th>
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<tbody>
<tr>
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<td></td>
<td>RTOG 0236</td>
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<tr>
<td>1</td>
<td>1</td>
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<td>9.8</td>
<td>76.65</td>
<td>14Gy x3</td>
<td>41.46</td>
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<td>0</td>
<td>LLung</td>
<td>8.1</td>
<td>76.65</td>
<td>14Gy x3</td>
<td>41.46</td>
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<td>3</td>
<td>0</td>
<td>RUL</td>
<td>8.1</td>
<td>76.65</td>
<td>14Gy x3</td>
<td>41.46</td>
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<tr>
<td>4</td>
<td>0</td>
<td>LLung</td>
<td>8.1</td>
<td>76.65</td>
<td>14Gy x3</td>
<td>41.46</td>
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<td>LUL</td>
<td>8.1</td>
<td>76.65</td>
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<td>41.46</td>
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<td>6</td>
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<td>MCLL</td>
<td>9.8</td>
<td>76.65</td>
<td>14Gy x3</td>
<td>41.46</td>
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<td>MCLL</td>
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<td>41.46</td>
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<td>0</td>
<td>LLung</td>
<td>8.1</td>
<td>76.65</td>
<td>14Gy x3</td>
<td>41.46</td>
</tr>
</tbody>
</table>

Patient 1: CBCT Verification

(Excellent match for upper lung lesions- free-breathing)
**Patient 2: CBCT Verification**
*(Good match in bone and lung)*

Registered CBCT overlaid on planning CT: Patient setup adjusted 5 mm post

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**Patient 2: MV Portal Verification**

Tumor is captured in portal images

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**Patient Immobilization Issues with Spine**

Early Memory: Immobilization in room CT - guidance from IJROBP (2003)

Current Memory: Current immersion CT- guidance from IJROBP (2005)

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**L4 Spinal Met: 3 x 1200 cGy**

11-coplanar beams and IMRT Planning
L4 Spinal Met: 3 x 1200 cGy

UC Trial Clinical Outcome Analysis
(Clinical Cancer Research 2008- in press)

An Initial Report of a Radiation Dose Escalation Trial in Patients with One to Five Sites of Metastatic Disease

Author: [Insert author name]

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Metastatic Lung/Mediastinal Lesions

<table>
<thead>
<tr>
<th>Dose (Gy)</th>
<th>CR (100%)</th>
<th>PR (50%)</th>
<th>SD (10%)</th>
<th>PD (0%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 Gy</td>
<td>CR (1/1)</td>
<td>PR (2/3)</td>
<td>SD (0/2)</td>
<td>PD (0/1)</td>
</tr>
<tr>
<td>30 Gy</td>
<td>CR (0/1)</td>
<td>PR (0/3)</td>
<td>SD (0/2)</td>
<td>PD (0/1)</td>
</tr>
<tr>
<td>36 Gy</td>
<td>CR (1/1)</td>
<td>PR (2/2)*</td>
<td>SD (0/1)</td>
<td>PD (0/1)</td>
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</table>

Primary Pathology

<table>
<thead>
<tr>
<th>Lesion</th>
<th># Lesions</th>
<th>24 Gy</th>
<th>30 Gy</th>
<th>36 Gy</th>
</tr>
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<tbody>
<tr>
<td>NSCLC</td>
<td>(NE)</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>RCC</td>
<td>(NE)</td>
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<td>Thyroid</td>
<td>(NE)</td>
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<td>Melanoma</td>
<td>4</td>
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</table>

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100% of Prescription (3600 cGy) = 90% of PTV
Cauda: $D_{max} = 1400$ cGy
Metastatic Abdominal Lesions

<table>
<thead>
<tr>
<th># Lesions</th>
<th>24 Gy</th>
<th>36 Gy</th>
<th>48 Gy</th>
<th>60 Gy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Resp</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Local Control</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Q1. The optimal beam margin for SBRT planning with 6 MV photon beams in the lung that minimizes the normal tissue complication probability is typically

0% 1. - 2 mm
0% 2. 0 to 4 mm
0% 3. 5 to 9 mm
0% 4. 10 mm
0% 5. 18 mm

Q2. Unlike conventional radiotherapy, SBRT uses a greater number of beams to achieve

0% 1. larger dose heterogeneities
0% 2. smaller hot spots
0% 3. better target dose conformity and rapid dose fall-off away from the target
0% 4. a shallower dose gradient
Q2. Unlike conventional radiotherapy, SBRT uses a greater number of beams to achieve
1. larger dose heterogeneities
2. smaller hot spots
3. better target dose conformity and rapid dose fall-off away from the target
4. a shallower dose gradient

Q3. The most important aspect of a rigorous QA program for an image guided SBRT approach is
0% 1. Room lasers are accurately calibrated
0% 2. Stereotactic Frame is indexed to the treatment table
0% 3. Patient skin marks are consistently documented
0% 4. An end to end test confirms the link between imaging and dose delivery steps in the overall treatment process

Q3. The most important aspect of a rigorous QA program for an image guided SBRT approach is
1. Room lasers are accurately calibrated
2. Stereotactic Frame is indexed to the treatment table
3. Patient skin marks are consistently documented
4. An end to end test confirms the link between imaging and dose delivery steps in the overall treatment process

Summary
• SBRT requires multi-disciplinary team approach
• Clinical experience with conventional radiotherapy does not extrapolate to SBRT
• Verification of each step in the SBRT treatment process is a must
“We are like blind men peeping through a fence”

Japanese Proverb

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References