Stereotactic Body Radiation Therapy: Planning and Delivery

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I have no conflicts of interest to disclose.

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Challenges for SBRT
How to accurately define target?
--- 4D imaging
How to accurately localize target?
--- SBRT
How to obtain conformal dose and steep dose gradients?
--- 3DCRT, Inverse Planning, IMRT, VMAT
How to reduce irradiated volume of critical organs for a moving target?
--- Gating, Tracking...
SBRT Planning

- Inhomogeneous dose inside PTV
- Sharp dose falloff outside PTV
- High fractional dose → High BED

Target definition
- Motion management
- SBRT or IMRT/VMAT
- Interplay effect
- Dose calculation
- Prescription and Dose constraints

AAPM Task Group No. 101

Target Definition

Static Target: PTV = CTV + setup margin
Moving Target: PTV = ∑ cTVi or CTV_MIP (for Lung) / ∑ mTVi + setup margin

- Target margin for regular breathing
- AAPM101 only for target definition

Lung example

Pancreas example

PTV, ITV (±2-3mm margin)

Motion Management (Delivery)

- Gating Technique
- Breath holding Technique
- Tracking Technique

Respiratory Gating (screw/cover)
Breath-holding technique
Tracking technique
Advantages:

- Better dose conformity
- Easy to control/constrain dose to OARs
- Higher MU, longer treatment time
- Interplay effect between target and MLC motion

Disadvantages:

- Higher MU, longer treatment time
- Interplay effect between target and MLC motion

3DCRT vs. IMRT/VMAT

- Spine/Prostate/Pancreas/HN — IMRT/VMAT
- Some Lung/Liver — 3DCRT

Interplay Effect: Trigle SRS 1000MU/Min, 12GYX4F
VMAT/SBRT:
- TrueBeam 6FFF 1400MU/Min, 18GyX3F

Li, Yang et al, JACMP, 2013
Riley, Yang et al, Med. Phys, 2014

Isodose Dose Profile 3%/3mm γ map 1% failed 29% failed 5mm residual motion 10mm residual motion 3cm 1D motion, 4.0s period 7mm total motion, 30% – 75% gating window with 5mm residual motion 10mm total motion, 25% – 75% gating window with 5mm residual motion

Quasar phantom with real patient data
Case 1
Case 2

Interplay Effect: Gated RapidArc
Inhomogeneity Correction

- Dose difference for targets from PBC and Acuros XB could be more than 10%
- PBC should not be used for lung SBRT

RPC Thorax Phantom
Eclipse PBC
Eclipse AAA
TomoTherapy CSA

Inhomogeneity Correction

For a small isolated target, even AAA is not accurate enough!

- Beam energy
- Target size
- Lung density
- Target location

AAA
Acuros XB

6 MV 4.0 cm x 4.0 cm photon beam

Prescriptions and Dose Constraints

- AAPM TG 101 Table III
- ROTG Protocols
  - Lung: 0236, 0618, 0813 and 0915
  - Spine: 0631
  - Liver: 0438, 1112

These protocols specify detailed requirements for treatment planning:

Dose Prescription
Target Coverage
Dose Constraints
### Table 1

<table>
<thead>
<tr>
<th>Dose Constraints</th>
<th>0236</th>
<th>0618</th>
<th>0813</th>
<th>0915</th>
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</thead>
<tbody>
<tr>
<td>Prescribed Dose</td>
<td>60Gy/3f</td>
<td>60Gy/3f</td>
<td>50Gy/5f</td>
<td>34Gy/1f vs. 12Gy/4f</td>
</tr>
<tr>
<td>Location</td>
<td>Peripheral</td>
<td>Peripheral</td>
<td>Central</td>
<td>Peripheral</td>
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<tr>
<td>Allow IMRT</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Allow Inhomogeneity Correction</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

### Timmerman's Definition of Centrality

- Global dose maximum = 150% of GTV mean dose
- 100% of GTV receives 95% of prescription dose
- MLI optimization
- Reduce dose amount through the contralateral lung when possible.

### RTOG 1112: Liver

- 27.5 – 50 Gy in 5 fr
- Prescription dose based on mean liver dose
- Cover 95% of GTV

**Stanford**

- 220Gy-460Gy in 1-5F
- Mean liver dose <140Gy
- 500cc liver <120Gy
- 700cc liver <120Gy

### RTOG 1112: Lung

- Global dose maximum = 150% of GTV mean dose
- 100% of GTV receives 95% of prescription dose
- MLI optimization
- Reduce dose amount through the contralateral lung when possible.

**Stanford: Volume-Adapted SABR**

- Global dose maximum = 150% of GTV mean dose
- 100% of GTV receives 95% of prescription dose
- MLI optimization
- Reduce dose amount through the contralateral lung when possible.

### RTOGs: Lung

**Dose Constraints**

- 0813 and 0915 Table 1

### Conformity

- Dose Volume vs. PTV Volume

- Global dose maximum > 120% and centered in GTV
- 100% of GTV receives 100% of prescription dose
- MU optimization
- Avoid beam entrance through the contralateral lung when possible.

**Intermediate Dose Spillage:**

- R < 50% and D < 2 cm

**Conformity:**

- Dose Volume vs. PTV Volume

- Global dose maximum > 120% and centered in GTV
- 100% of GTV receives 100% of prescription dose
- MU optimization
- Avoid beam entrance through the contralateral lung when possible.

**27.5 – 50 Gy in 5 fr**

- Prescription dose based on mean liver dose
- Cover 95% of PTV

**Stanford**

- 220Gy-460Gy in 1-5F
- Mean liver dose <140Gy
- 500cc liver <120Gy
- 700cc liver <120Gy

**Prescription Dose**

- 500cc liver <7Gy
- 700cc liver <12Gy

**RTOGs: Lung**

- 22Gy-60Gy in 1-5F
- Mean liver dose <10Gy
- 500cc liver <7Gy
- 700cc liver <12Gy

**500cc liver <7Gy**

**700cc liver <12Gy**
RTOG 0631: Spine

Prescription: 16 or 18 Gy in 1 fx
Dose constraints:
- Spine Cord: Dmax (0.03cc) < 14 Gy
  V10 < 3.5 cc
- Esophagus: Dmax < 16 Gy
  D5 cc < 11.5 Gy

Stanford

Prescription: 16 or 20 Gy in 1 fx
24 or 27 Gy in 3 fx
Dose constraints:
- Spine Cord:
  1fx: Dmax < 14 Gy, V10 < 0.35 cc
  3fx: Dmax < 20 Gy, V15 < 1 cc
- Esophagus:
  1fx: Dmax < 10 Gy, V5 < 1 cc
  3fx: Dmax < 20 Gy, V12 < 1 cc

Target Localization & Plan Delivery

Pre-Treatment Setup
(AV/MV, CT/CBCT)

Fluoroscopic Verification

Plan Delivery & Beam-Level Imaging
(AV, Fluoro, Close MV, AV/MV CBCT)

Post-Treatment Image & Data Analysis

Accuracy
- Spine: 1-2 mm
- Lung: < 2 mm
- Abdomen: < 5 mm
Target Positioning: Spine

Positional setup accuracy with CT-guided correction assessed by an immediate post-treatment CT.

15 cases with 40 patient setup


<table>
<thead>
<tr>
<th>Mode/Level</th>
<th>3D</th>
<th>2D</th>
<th>1D</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>6.4 ± 1.7</td>
<td>6.2 ± 1.7</td>
<td>6.1 ± 1.7</td>
</tr>
<tr>
<td>Y</td>
<td>6.2 ± 1.8</td>
<td>6.2 ± 1.8</td>
<td>6.2 ± 1.8</td>
</tr>
<tr>
<td>Z</td>
<td>6.4 ± 1.7</td>
<td>6.2 ± 1.7</td>
<td>6.2 ± 1.7</td>
</tr>
</tbody>
</table>

Target Positioning: Lung

Table 1: Correction, measurement, correction education, and target motion by navigation device

A total of 409 patients with 427 tumors underwent 1593 fractions of lung SBRT.


Intrafraction variation (mm): AP 0.0 ± 1.7, ML 0.6 ± 2.2, SI 1.0 ± 2.0, 3D 3.1 ± 2.0.

Fluoroscopy Verification

Fluoroscopic imaging to verify target motion and gating window.

Yellow: in gating window, Beam-Off

Green: out gating window, Beam-Off.

Gating window should be adjusted so that fiducials fall within tracking structures when beam is on.

Pre-Treatment images for a pancreas SBRT case.
Advantage:
- No dose, 'free' information
- Beam eye view

Disadvantage:
- MLC blocks image
- Image quality

3D tracking if combined with kV imaging

Verification of intra-fraction geometric accuracy of SABR
- 20 SABR patients (lung/liver/pancreas)
- RPM-based gating treatment
- Geometric error: 0.8 mm on average; 2.1 mm at 95th percentile
• Continuous fluoroscopy during dose delivery
• In-house program for CBCT reconstruction
• 20 lung SABR patients
• Treatment verification
• Routine clinical use
Thank You!