Robotic and Gimbaled Spine SBRT
A Physicist’s Perspective

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Educational Objectives

• To grasp fundamental imaging and motion management principles of robotic and gimbaled systems for spine SBRT
• To understand operation of robotic and gimbal system in a clinical setting for spine SBRT treatment delivery
• To define unique features of robotic and gimbaled systems against standard linac-based systems for spine SBRT

Genesis of Spine SBRT Circa 1995
State-of-the Art Spine SBRT Modalities

Spine SBRT vs Conventional IMRT

<table>
<thead>
<tr>
<th>Properties</th>
<th>IMRT</th>
<th>SBRT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dose × Fractions</td>
<td>3 Gy × 10 fx</td>
<td>16-24 Gy × 1 fx</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12 Gy × 2 fx</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6-9 Gy × 3 fx</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6-10 Gy × 5 fx</td>
</tr>
<tr>
<td>Margin</td>
<td>10-20 mm</td>
<td>1-2 mm</td>
</tr>
<tr>
<td>Target Definitions</td>
<td>PTV</td>
<td>CTV/ITV/PTV</td>
</tr>
<tr>
<td>Motion Management</td>
<td>None</td>
<td>Must</td>
</tr>
<tr>
<td>Marginal Accuracy</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Radiobiology</td>
<td>Good</td>
<td>Work in Progress</td>
</tr>
</tbody>
</table>

Radiobiological Rationale

- **Single fraction:** 12-24 Gy /fx
  - No 4R: vascular damage noted

- **Hypofractionation:** 5-10 Gy /fx
  - Reoxygenation & Reassortment
**Sharp Dose Gradient**

10-15% per mm dose fall-off

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**Features of Spine SBRT Delivery**

- **Speed**: 10+ Gy/min
- **Adequate field size**: ~ 6 - 20 cm
- **Fine beam modulation**: ~ 5 mm
- **Imaging Guidance**: 2D/3D
- **Motion Management**: active/passive

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**Motion Management Techniques**

<table>
<thead>
<tr>
<th>System</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elekta</td>
<td>kV CBCT +/- 2D kV +/- BodyFrame</td>
</tr>
<tr>
<td>Artiste</td>
<td>MV CBCT</td>
</tr>
<tr>
<td>Varian/Novalis</td>
<td>kV CBCT +/- 2D kV +/- Surface markers</td>
</tr>
<tr>
<td>Cyberknife</td>
<td>2D kV +/- Feedback Beam Correction</td>
</tr>
<tr>
<td>Vero 4DRT</td>
<td>kV CBCT +/- 2D kV +/- Surface markers +/- Feedback Beam Correction</td>
</tr>
</tbody>
</table>
MV CBCT for Spine Hardware

Alignment despite presence of hardware
(E Hansen and D Larson et al. UCSF)

kV CBCT-Based Alignment

Sahgal, Bilsky, Chang et al. JNS Spine (2011)

Combining BodyFrame and IG

A Sahgal et al. 2012 (Univ of Toronto)
Online Detection/Correction Results

Mean Shifts of 1.2 mm and 0.9 deg (CI = 95%)

On-line Spine Target Motion Patterns

Δ (mm) Φ (degree)

T (sec) T (sec)

Non-rigid Setup Spine Motions

<table>
<thead>
<tr>
<th>Site</th>
<th>Required Treatment T(min)</th>
<th>Non-Random DOF</th>
<th>Required Correction T(min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T (n=20)</td>
<td>48-170</td>
<td>3.1±1.3</td>
<td>5.9 (1.1-14.3)</td>
</tr>
<tr>
<td>C (n=20)</td>
<td>30-138</td>
<td>5.5±0.7</td>
<td>5.5 (1.3-16.7)</td>
</tr>
<tr>
<td>LS (n=24)</td>
<td>44-150</td>
<td>4.1±1.3</td>
<td>7.1 (1.6-30.7)</td>
</tr>
</tbody>
</table>
Frequent Intervention Results

Periodic 1-2 min imaging-corrections

Fiducial Based Robotic Tracking

Robotic SRT/SBRT Plan Delivery

Tokyo Kamagome Cancer Hospital
Gimbaled (± 2.5°) X-ray SBRT

± 60° gantry twist
5D robotic couch → ±185° gantry rotation
ExacTRAC system

Gimbaled X-ray Spine SBRT

Tokyo Kamagome Radiation Oncology

Apparatus Dependence for Spine SBRT

Notable differences for challenging cases
Summary

- Millimeter level accuracy achievable for current Spine SBRT treatments.
- Future trend is for faster, more adaptive, and more patient-friendly spine SBRT treatments.

Acknowledgement

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