Stereotactic Body Radiotherapy (SBRT) for Recurrent Spine Tumors

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Disclosure

- No conflicts of interest

SBRT for Spinal Metastases

- Overview
  - Spine SBRT
    - Technique
    - Brief overview of re-irradiation outcomes for spinal metastases
  - The potential for spinal cord toxicity
  - Spinal cord re-irradiation dose limits for spine SBRT

SBRT

- Defn: High dose per fraction radiation delivered conformally to a target while sparing organs at risk in a single, or up to five fractions, and >5 Gy/fraction

- Challenges in treating spine tumors SBRT:
  - Conformal dose distributions around the complex shape of a vertebral body and create steep dose gradients in all directions
  - Keep the dose just at spinal cord tolerance
    - Too conservative then underdose epidural disease
  - Precise radiation delivery
  - Ensure dose delivered is that intended
**SBRT Dose Distribution**

**Why Spine SBRT?**

- Conventional re-irradiation: 8 Gy in 1 or 20 Gy in 8
  - \( \text{BED} = n(d + \frac{d}{\alpha/\beta}) \)
  - \( n \) = number of fractions
  - \( d \) = dose per fraction
  - \( \alpha/\beta \) = tissue sensitivity and 2 for spinal cord and 10 for tumor
  - \( 8 \text{ Gy/1} = 14.4 \text{ Gy}_{10} \)
  - \( 20 \text{ Gy/8} = 25 \text{ Gy}_{10} \)

- Common re-irradiation doses used in spine SBRT:
  - 35 Gy in 5, \( \text{BED} = 60 \text{ Gy}_{10} \)
  - 24 Gy in 3, \( \text{BED} = 43 \text{ Gy}_{10} \)
  - 20 Gy in 1, \( \text{BED} = 60 \text{ Gy}_{10} \)

- Now we are delivering 3-6X the BED compared to conventional palliative re-XRT

- May have the potential for higher rates of pain and local tumor control

**Re-irradiation Outcomes SBRT**

<table>
<thead>
<tr>
<th>Author/year</th>
<th>Total No. Tumor Patient</th>
<th>Follow-up months (range)</th>
<th>Local Control/Criteria (For Post-Op cohort for mixed cohort)</th>
<th>Tumor dose/fx</th>
<th>Pain Response (Pain Assessment Tool)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Choi et al. 2010</td>
<td>51/42</td>
<td>Median 7 mo (2-47)</td>
<td>38/51 (75%) @ 0 mo Imaging</td>
<td>Median 28.3 Gy/1.5 fx</td>
<td>75% (N.S.)</td>
</tr>
<tr>
<td>Sahgal et al. 2009</td>
<td>37/25</td>
<td>Median 7 mo (1-48)</td>
<td>34/37 (92%) Imaging and/or Pain</td>
<td>Median 24 Gy/3</td>
<td>N.S.</td>
</tr>
<tr>
<td>Hamilton et al. 1999</td>
<td>5/5</td>
<td>Median 6 mo (1-12)</td>
<td>3/5 (60%) Imaging and/or clinical</td>
<td>Median 10 Gy/1</td>
<td>N.S.</td>
</tr>
</tbody>
</table>

Total: 93/72 (77.93% (83%))


UCSF Experience

**Methods**

- 39 patients / 60 spinal metastases
- 37/60 prior radiation
- 31/37 “Salvage” re-irradiated for tumor progression

**Tumor Dosimetric Characteristics**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>No Prior XRT</th>
<th>Prior XRT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median Total Dose (Gy) / Fractions</td>
<td>24 Gy (7-40) /3 (1-5)</td>
<td>24 Gy (8-30) /3 (1-5)</td>
</tr>
<tr>
<td>Median Prescription Isodose (%)</td>
<td>67 (44-84)</td>
<td>60 (38-78)</td>
</tr>
</tbody>
</table>


**Critical Neural Structure Dose**

<table>
<thead>
<tr>
<th>Dosimetric parameter</th>
<th>No Prior XRT n = 13</th>
<th>Prior XRT n = 22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median max dose (Gy)</td>
<td>16.8 (10.7-26)</td>
<td>12.8 (5.4-27)</td>
</tr>
<tr>
<td>Median max BED (Gy2)</td>
<td>56 (30-114)</td>
<td>36 (20-98)</td>
</tr>
<tr>
<td>Median dose (0.1 cc) (Gy)</td>
<td>14.7 (9-21.3)</td>
<td>9.4 (2-27.3)</td>
</tr>
<tr>
<td>Median 0.1 cc BED (Gy2)</td>
<td>50 (18-106)</td>
<td>22 (4-102)</td>
</tr>
<tr>
<td>Median dose cc (Gy)</td>
<td>8.1 (5-18)</td>
<td>6.6 (3.6-26.4)</td>
</tr>
<tr>
<td>Median 1 cc BED (Gy2)</td>
<td>19 (9-39)</td>
<td>14 (9-54)</td>
</tr>
<tr>
<td>Median dose 2 cc (Gy)</td>
<td>6.6 (2-17.4)</td>
<td>5.4 (0-19)</td>
</tr>
<tr>
<td>Median 2 cc BED (Gy2)</td>
<td>14 (2-93)</td>
<td>9 (0-54)</td>
</tr>
<tr>
<td>Median dose 5 cc (Gy)</td>
<td>4.4 (0-1.16.2)</td>
<td>2.8 (0-16.8)</td>
</tr>
<tr>
<td>Median 5 cc BED (Gy2)</td>
<td>7 (2-81)</td>
<td>4 (0-44)</td>
</tr>
</tbody>
</table>

Summary of Key Results:

- Median overall survival: 18 months (9-22)
- Freedom from progression:
  - 1 year: 85%
  - 2 year: 69%
- In total 8/60 tumors had failed at last follow-up:
  - Prior radiation did not predict for failure
- No case of radiation myelopathy or any grade >2 toxicity

How much can we give the previously irradiated spinal cord?

Scope of the Problem

- Current knowledge of human cord tolerance is limited
- Does not apply to spine SBRT as based on:
  1. Homogeneous dose distributions associated with wide fields
  2. Conventional radiation fractionation

Scope of the Problem

- With steep dose gradients adjacent to the spinal cord minor deviations can affect spinal cord dose delivered
Line Plot of Residual Target Motion

Rotational Variation  Translational Variation

Effects of residual target motion for image-tracked spine radiosurgery
Cynthia Chuang, Arjun Sahgal, Leitah Lee, David Larson, Kim Huang, Pauo Petti, Anna Verner, and John Hn
Medical Physics

Contouring of the CNS:
Thecal sac or cord +1.5-2 mm PRV

Residual Target Motion Error: n=6 patients

<table>
<thead>
<tr>
<th>No.</th>
<th>Target volume (cc)</th>
<th>$\Delta D_{\text{Target50%}}$ (Gy)</th>
<th>$\Delta D_{\text{Target50%}}$ (Gy)</th>
<th>$\Delta D_{\text{Conf1%r}}$ (Gy)</th>
<th>$\Delta D_{\text{Conf1%c}}$ (Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15.6</td>
<td>0.8(2.1%)</td>
<td>0.6(1.5%)</td>
<td>1.6(3.9%)</td>
<td>1.6(4.1%)</td>
</tr>
<tr>
<td>2</td>
<td>12.5</td>
<td>0.3(0.7%)</td>
<td>0.2(0.6%)</td>
<td>0.4(1.0%)</td>
<td>0.7(1.7%)</td>
</tr>
<tr>
<td>3</td>
<td>32.5</td>
<td>0.4(1.1%)</td>
<td>0.2(0.4%)</td>
<td>0.6(1.5%)</td>
<td>0.5(1.4%)</td>
</tr>
<tr>
<td>4</td>
<td>17.5</td>
<td>0.8(2.2%)</td>
<td>0.02(0.05%)</td>
<td>0.6(1.7%)</td>
<td>0.4(1.1%)</td>
</tr>
<tr>
<td>5</td>
<td>18.1</td>
<td>0.9(2.0%)</td>
<td>0.5(1.05%)</td>
<td>1.3(2.8%)</td>
<td>1.0(2.1%)</td>
</tr>
<tr>
<td>6</td>
<td>31.9</td>
<td>0.7(1.8%)</td>
<td>0.3(0.8%)</td>
<td>1.7(4.5%)</td>
<td>1.5(4.0%)</td>
</tr>
</tbody>
</table>


Human Spinal Cord SBRT Dose Limits

**CLINICAL INVESTIGATION**

**SPINAL CORD TOLERANCE FOR STEREOTACTIC BODY RADIOTHERAPY**

Arjun Sahgal, M.D.,† Liun Ma, Ph.D.,‡ Iris Grigs, M.D.,§ Peter C. Gerstken, M.D.,∗
Sam Ryu, M.D.,∥ Scott Soltsys, M.D.,∥ Vivian Winchero, Ph.D.,∥ Shun Wong, M.D.,∥
Eric Chang, M.D.,∥ Jack Fowler, D.Sc., Ph.D.,∥ and David A. Larson, M.D., Ph.D.∥

Int J Rad Onc Biol Phys. Epub
Re-Irradiation Spinal Cord SBRT Dose Limits

**Methods**

- 5 cases of re-irradiation myelopathy post-SBRT
- 14 patients, 14 tumors re-treated with SBRT from UCSF with no myelopathy
  - Spinal cords contoured per the thecal sac

**Analysis**

- SBRT Dose to Point maximum, 0.1 cc, 1 cc, 2 cc
- Cumulative 2Gy equivalent BED = nBED
  - nBED = BED/(1+d/\(\alpha/\beta\))
  - nBED = BED/2

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### RM Cases

<table>
<thead>
<tr>
<th>Patient &amp; Tumor</th>
<th>Tumor Type</th>
<th>Spine Tumor Location and Target Volume (cc)</th>
<th>Prior Radiation Spinal Cord Total Dose (Gy)/fx</th>
<th>Time Interval to SBRT (months)</th>
<th>SBRT Thecal Sac Pmax (Gy)/fx</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Breast</td>
<td>T5, 10.7</td>
<td>40/22</td>
<td>81</td>
<td>20.3/2</td>
</tr>
<tr>
<td>B</td>
<td>Breast</td>
<td>T1, 18.8</td>
<td>25.2/28</td>
<td>70</td>
<td>20.9/2</td>
</tr>
<tr>
<td>C</td>
<td>Renal Cell</td>
<td>T11-112, 119</td>
<td>21.2/5</td>
<td>11*</td>
<td>12.3/1</td>
</tr>
<tr>
<td>D</td>
<td>Chordoma</td>
<td>C1/C2, 31.5</td>
<td>51.9/28</td>
<td>18</td>
<td>32.6/3</td>
</tr>
<tr>
<td>E</td>
<td>Renal cell</td>
<td>T10, 46.4</td>
<td>43.2/15</td>
<td>12</td>
<td>14.7/1</td>
</tr>
</tbody>
</table>

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### Total nBED Analysis

Under review, not published other than abstract ASTRO 2010, subject to change
Spine SBRT nBED Analysis

Recommendations for safe re-irradiation practice

1. The total $P_{\text{max}}$ nBED should be approximately $\leq 70 \text{ Gy}_{2\alpha}$

2. The SBRT $P_{\text{max}}$ nBED re-treatment should be approximately $\leq 25 \text{ Gy}_{2\alpha}$

- These apply given certain caveats

SBRT vs Initial EBRT nBED

Pmax SBRT/Total NBED vs. Initial EBRT

Under review, not published other than abstract ASTRO 2010, subject to change
Recommendations for safe re-irradiation practice within a prior conventional nBED ranging from 30-50 Gy2/2.

1. The total $P_{max}$ nBED should be approximately $\leq 70 \text{ Gy}_{2/2}$
2. The SBRT $P_{max}$ nBED re-treatment should be approximately $\leq 25 \text{ Gy}_{2/2}$
3. The percent SBRT $P_{max}$ nBED/total nBED should be approximately $\leq 50$
4. There should be a time interval between courses of at least 5 months

Re-Irradiation Spinal Cord Dose Limits

<table>
<thead>
<tr>
<th>Conventional Radiotherapy (nBED)</th>
<th>1 Fraction SBRT $P_{max}$ Thocal Sac</th>
<th>2 fractions SBRT $P_{max}$ Thocal Sac</th>
<th>3 fractions SBRT $P_{max}$ Thocal Sac</th>
<th>4 fractions SBRT $P_{max}$ Thocal Sac</th>
<th>5 fractions SBRT $P_{max}$ Thocal Sac</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 Gy in 5 fractions (30 Gy2/2)</td>
<td>9 Gy</td>
<td>12.2 Gy</td>
<td>14.2 Gy</td>
<td>16.5 Gy</td>
<td>18 Gy</td>
</tr>
<tr>
<td>30 Gy in 10 fractions (37.5 Gy2/2)</td>
<td>9 Gy</td>
<td>12.2 Gy</td>
<td>14.5 Gy</td>
<td>16.2 Gy</td>
<td>18 Gy</td>
</tr>
<tr>
<td>37.5 Gy in 15 fractions (42 Gy2/2)</td>
<td>9 Gy</td>
<td>12.2 Gy</td>
<td>14.5 Gy</td>
<td>16.2 Gy</td>
<td>18 Gy</td>
</tr>
<tr>
<td>40 Gy in 20 fractions (40 Gy2/2)</td>
<td>NA</td>
<td>12.2 Gy</td>
<td>14.5 Gy</td>
<td>16.2 Gy</td>
<td>18 Gy</td>
</tr>
<tr>
<td>45 Gy in 25 fractions (43 Gy2/2)</td>
<td>NA</td>
<td>12.2 Gy</td>
<td>14.5 Gy</td>
<td>16.2 Gy</td>
<td>18 Gy</td>
</tr>
<tr>
<td>50 Gy in 25 fractions (50 Gy2/2)</td>
<td>NA</td>
<td>11 Gy</td>
<td>12.5 Gy</td>
<td>14 Gy</td>
<td>15.5 Gy</td>
</tr>
</tbody>
</table>

What we aim for…


What we aim to avoid
Thanks to:

Dr. David Larson
Dr. Lijun Ma
Dr. Mack Roach III

PMH and Sunnybrook Health Sciences Centre
University of Toronto