Spine SRS: LINAC

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- Member of Multi-institutional international spine SRS research consortium supported by Elekta
- MGH has received research support from Raysearch
Overview

- Spine SRS: alternate treatment for mets
- Some primary lesions
  - Depends upon histology and geometry
Several treatment options exist for spinal metastases:

- Surgery: decompression, en bloc resection, stabilization, minimally invasive
- Augmentation: vertebroplasty or kyphoplasty
- Radiation therapy: conventional or stereotactic radiosurgery
Spine metastases

• About 40% of cancer patients develop vertebral metastases: serious consequences pain, paralysis, quality of life
• Palliative low-dose radiotherapy is well established evidence-based treatment
• Limited long-term efficacy of conventional palliative RT

• **Dose-intensified spine radiosurgery / SBRT**
• Practiced by 44% of US Radiation Oncologists (*Pan Cancer 2011*)
• Quicker and more durable pain relief and local tumor control
Overview

- Shift the paradigm for treating spinal metastases
- Focus on minimizing morbidity of spine care in order to:
  - Improve pain control and quality of life
  - Maximize opportunities for systemic therapy
  - Retain durable local control
- Use of intensity modulated treatment modalities to increase dose to GTV/CTV/PTV while avoiding dose to critical structures: cord, cauda, esophagus
Evolution of Radiation Techniques

2-dimensional

3-dimensional

IMRT

Oh K, et. al.
Stereotactic Body Radiation Therapy
“Spine Radiosurgery”

- SRS: Delivery of a high radiation dose (18-24 Gy) in a single fraction with high precision
- SBRT: Fractionation of ablative doses (2-5 fractions)
Case #1: Solitary and radioresistant metastasis
68 yo with metastatic RCC and solitary L4 metastasis causing back and left leg pain
Case #2: Retreatment after progression  
60 yo man with metastatic HCC and painful L1 metastasis, treated with 3 Gy x 10 in 6/2011.  
In 1/2012, progressed with new LLE numbness. 
Underwent partial corpectomy + instrumentation + fusion 

6/2011  
3 Gy x 10  

1/2012  
Clinical and radiographic progression  

6/2012  
5 months after resection  

Oh K, et. al.
Spine SRS

- Does it work?
- Several studies
- Multi-Institutional Results
Stereotactic Body Radiation Therapy: Outcomes

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>N (tumors)</th>
<th>Fractionation (median)</th>
<th>Are salvage RT</th>
<th>pain relief</th>
<th>local control</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFH Detroit</td>
<td>2005</td>
<td>61</td>
<td>10-16 Gy x 1</td>
<td>0%</td>
<td>85%</td>
<td>93%</td>
</tr>
<tr>
<td>U Pitt</td>
<td>2007</td>
<td>500</td>
<td>20 Gy x 1</td>
<td>69%</td>
<td>86%</td>
<td>88%</td>
</tr>
<tr>
<td>MDACC</td>
<td>2007</td>
<td>74</td>
<td>6 Gy x 5 or 9 Gy x 3</td>
<td>56%</td>
<td>NR</td>
<td>77%</td>
</tr>
<tr>
<td>MSKCC</td>
<td>2008</td>
<td>103</td>
<td>24 Gy x 1</td>
<td>0%</td>
<td>NR</td>
<td>90%</td>
</tr>
<tr>
<td>PMH</td>
<td>2009</td>
<td>60</td>
<td>8 Gy x 3</td>
<td>62%</td>
<td>67%</td>
<td>85%</td>
</tr>
<tr>
<td>Taiwan</td>
<td>2009</td>
<td>127</td>
<td>7.75 Gy x 2</td>
<td>22%</td>
<td>88%</td>
<td>97%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Histology</th>
<th>N (tumors)</th>
<th>dose</th>
<th>pain relief</th>
<th>local control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breast</td>
<td>83</td>
<td>20 Gy x 1</td>
<td>96%</td>
<td>100%</td>
</tr>
<tr>
<td>Lung</td>
<td>80</td>
<td>20 Gy x 1</td>
<td>93%</td>
<td>100%</td>
</tr>
<tr>
<td>Renal cell</td>
<td>93</td>
<td>20 Gy x 1</td>
<td>94%</td>
<td>87%</td>
</tr>
<tr>
<td>Melanoma</td>
<td>38</td>
<td>20 Gy x 1</td>
<td>96%</td>
<td>75%</td>
</tr>
</tbody>
</table>

Median follow-up = 21 months

Overall survival

Median FU: 12 mo

Multivariate Analysis:

<table>
<thead>
<tr>
<th>Influence parameter</th>
<th>p-value</th>
<th>HR (CI)</th>
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</thead>
<tbody>
<tr>
<td>Sex (male)</td>
<td>0.010</td>
<td>0.60</td>
</tr>
<tr>
<td>Performance Status (&lt; 90)</td>
<td>0.001</td>
<td>0.52</td>
</tr>
<tr>
<td>Visceral Metastases (no)</td>
<td>0.013</td>
<td>1.79</td>
</tr>
<tr>
<td>Controlled systemic disease (no)</td>
<td>0.026</td>
<td>0.53</td>
</tr>
</tbody>
</table>

Performance status and metastatic disease for selection of patients with long OS expectancy
Imaging verified local tumor control

Median FU: 9.5 mo

Multivariate Analysis:

<table>
<thead>
<tr>
<th>Influence parameter</th>
<th>p-value</th>
<th>HR (CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interval PD to SBRT:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 29.9 months</td>
<td>0.017</td>
<td>0.40</td>
</tr>
<tr>
<td>Histology:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other, NSCLS, Kidney, Melanoma</td>
<td>0.005</td>
<td>0.21</td>
</tr>
</tbody>
</table>

Number of Tx fractions, prescribed dose, EQD2/10 and Bilsky Score not correlated local tumor control
Pain control assessed at last clinical follow-up

- Long term pain control
- High rates of complete pain response

Median FU: 11.0 months
Toxicity

Acute toxicity

<table>
<thead>
<tr>
<th></th>
<th>Dermatitis</th>
<th>Dysphagia</th>
<th>Pain</th>
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</thead>
<tbody>
<tr>
<td>Tox assessment</td>
<td>322</td>
<td>324</td>
<td>348</td>
</tr>
<tr>
<td>G0</td>
<td>307</td>
<td>290</td>
<td>290</td>
</tr>
<tr>
<td>G1</td>
<td>15</td>
<td>31</td>
<td>35</td>
</tr>
<tr>
<td>G2</td>
<td>0</td>
<td>3</td>
<td>20</td>
</tr>
<tr>
<td>G3</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
</tbody>
</table>

Fracture

<table>
<thead>
<tr>
<th></th>
<th>New fracture</th>
<th>Progressive fracture</th>
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<tbody>
<tr>
<td>Tox assessment</td>
<td>403</td>
<td>400</td>
</tr>
<tr>
<td>Positive</td>
<td>17 (4.2%)</td>
<td>21 (5.3%)</td>
</tr>
</tbody>
</table>

- Low rates and low grade acute toxicity
- 10% fracture rate, but 50% progressive fracture
- No case of radiation induced myelopathy
What are the primary aims of spine SRS/SBRT for vertebral metastases?

1. Pain Reduction
2. Local Control
3. Curative
4. 1 and 2
5. 2 and 3
Answer

- 1 and 2
- “maximize pain control and local control for the long term”
Spine Radiosurgery

Benefits

- Single session
- Higher dose to tumor ("radioresistant")
- Retreatment after failed conventional RT ("salvage")
- Multimodality therapy to minimize extent of resection ("separation surgery")

Potential drawbacks

- Vertebral body fractures which are dose-dependent
- Reoccurrence local to the cord
Case #1 revisited: Solitary and radioresistant metastasis

Oh K, et. al.
Case #2 revisited: Retreatment after progression

6/2011

1/2012

6/2012

5 months after resection

Spine radiosurgery alone
limited surgery + spine radiosurgery

Oh K, et. al.
Stereotactic Body Radiation Therapy: How does it work?

- Exploit dose and fractionation
Influence of dose per treatment

Biologically:
\[(18 \text{ Gy} \times 1) > (2 \text{ Gy} \times 9)\]
Stereotactic Body Radiation Therapy: How does it work?

- Exploit dose and fractionation
- Rigid immobilization
- Precise patient positioning
- Sophisticated radiation planning
- Reduce toxicity to the cord by dose avoidance instead of fractionation
Immobilization and Visualization

- Rigid immobilization using custom body mold and vacuum bag (BodyFix) or QFix (Mask) for upper T-spine and C-Spine
- Real-time CT in treatment position with integrated hexapod couch
6 DOF Robotic Couch
CBCT System

- Automatic 6 DOF Registration
- Bone, Gray-Scale
- Clip Box
- 200 deg, Fast Scan
- 1 mm³ Voxels
Patient Setup Uncertainty

- Residual Error (mm/deg)

- Vector (mm)

- X (mm)

- Y (mm)

- Z (mm)

- Rx (deg)

- Ry (deg)

- Rz (deg)
What is the expected accuracy of patient positioning for CBCT guided linac Spine SRS?

1. Within 0.5 mm
2. 0.5 mm
3. 1.0 mm
4. 2.0 mm
5. 3.0 mm
1.0 mm

Other studies have demonstrated the same level of accuracy: Gerszten, et. al. JNS 2010 “Setup accuracy of spine radiosurgery using cone beam computed tomography image guidance in patients with spinal implants”
Sophisticated Radiation Planning

- Dose constraints:
  - Spinal cord < 12-14 Gy x 1
  - Cauda equina < 16 Gy x 1
  - Sacral plexus < 18 Gy x 1

Oh K, et. al.
Clinical Summary

- Provide fast and multidisciplinary care for patients with spinal metastases
- Goal of minimizing morbidity and while preserving local control and QOL
LINAC SRS Workflow
Diagnosis
Immobilization
Initial Contouring

- PTV, OARs - physician
- Planning Structures
- Hardware, artifacts
- Add Couch to CT (T5 and lower)
- T5 and above, typically use QFix or mask
Planning

- IMRT or VMAT
- Coplanar 7-9 beams/2 arcs
- Posterior (Anterior used for Cervical Vertebral locations)
- ~20 deg separation
- 600-1000 MU/beam
- Collimator Rotation Can Reduce MUs
# Planning

![Planning Image]

<table>
<thead>
<tr>
<th></th>
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<tbody>
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<td>0</td>
<td>180</td>
<td>1.65 -0.03 -2.27</td>
<td>MGH Synergy_S [6.0 MV]</td>
<td>180.0</td>
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<tr>
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<td>3</td>
<td>120</td>
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<td>MGH Synergy_S [6.0 MV]</td>
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<td>4</td>
<td>220</td>
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<td>MGH Synergy_S [6.0 MV]</td>
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<td>-10.50 10.50 -8.00 8.00</td>
<td>Fixed</td>
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<tr>
<td>5</td>
<td>200</td>
<td>1.65 -0.03 -2.27</td>
<td>MGH Synergy_S [6.0 MV]</td>
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<tr>
<td>6</td>
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<td>1.65 -0.03 -2.27</td>
<td>MGH Synergy_S [6.0 MV]</td>
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<td>-10.50 10.50 -8.00 8.00</td>
<td>Fixed</td>
<td>6</td>
<td>826.26</td>
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</table>
Planning

[Image of user interface with ROI and constraints]

[Graph showing DVH curves]

[Interface elements for tradeoffs, constraints, and navigation]
Final Dose
Delivery

- Pre Treatment kV/MV coincidence tests
- CBCT 1 to calculate transformation
- CBCT 2 to confirm shifts
- CBCT 3 if CBCT 2 has residuals >0.5mm
- Treat First Half
- CBCT3(4) account for intrafraction motion
- Treat Second Half
- CBCT4(5) measure residuals
- Tx Time: ~25 min (Depends on Dose rate)
IMRT versus VMAT

- Highly dependent on Maximum Dose Rate
- Both IMRT and VMAT will use maximum dose rate for many segments due to high dose/fraction
- Great potential for FFF treatments
IMRT versus VMAT

Chen et al. PRO 2015 “Efficiency Gains for Spine SRS using MCO IMRT guided VMAT Planning”
What is the most important technique for reducing the treatment delivery time for Spine SRS?

1. Use VMAT instead of IMRT
2. Use fewer IMRT fields
3. Use more IMRT fields
4. Use higher dose rates
5. Rotate the collimator
Answer:

- User higher dose rate
- VMAT may be faster but not always significant
- Collimator rotation can reduce MU
- Dose rate is the primary limiting factor for delivery time

<table>
<thead>
<tr>
<th>Variable</th>
<th>Colli: 0</th>
<th></th>
<th>Colli: Rot</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MCO-IMRT</td>
<td>VMAT</td>
<td>MCO-IMRT</td>
<td>VMAT</td>
</tr>
<tr>
<td>MU</td>
<td>6216 ± 756&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5861 ± 896&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4681 ± 726&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4360 ± 722&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Delivery time (min)</td>
<td>–</td>
<td>–</td>
<td>18.3 ± 2.5&lt;sup&gt;c&lt;/sup&gt;</td>
<td>14.2 ± 2.0&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Chen et al PRO 2015 “Efficiency Gains for Spine SRS using MCO IMRT guided VMAT Planning”
Quality Assurance

- TG-142
- Commissioning
- Isocentricity tests: Imaging, MV, Robotic positioner
- Dosimetric QA
Commissioning

- Small fields (1x1 cm$^2$ and larger)
Commissioning

- Small fields (1x1 cm² and larger)
- Patient positioning and imaging systems (< 1 mm uncertainty)
Commissioning

- Small fields (1x1 cm$^2$ and larger)
- Patient positioning and imaging systems (< 1 mm uncertainty)
- Dosimetric tests
Daily Isocentricity

- Daily
- Plastic Densities
- Tungsten Ball
Patient QA

- Multiple solutions
- Rotational independence and resolution
LINAC SRS Conclusions

- SRS is a valuable treatment option for vertebral metastases
- Linacs equipped with CBCT and 6 DOF robotic positioners can accurately and safely treat spine SRS
- FFF can significantly reduce the treatment times and reduce the risk of patient motion