Single Isocenter Treatment Technique for Multiple Cranial Targets
- RapidArc and HyperArc

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LEARNING OBJECTIVES

• Summarize the published data on SRS alone for multiple brain metastases
• Review new techniques of planning and delivery system and quality assurance
• Learn about the treatment planning strategy and dose tolerance of critical structure and understand challenges of multiple metastases planning.
• Interactive clinical case planning and evaluation of the plan quality metrics.
DISCLOSURE

- Consulting agreement with Varian Medical Systems
UC SAN DIEGO RADIOSURGERY PROGRAM

- Metastases
- Resection Cavity
- Benign Tumors
- AVM
- Trigeminal Neuralgia
- Malignant Tumors
MLC BASED LINAC SRS

- Better conformity for irregular target
- Improved dose homogeneity inside the target
- Comparable dose fall-off outside the target
- Less time-consuming treatment planning
- Shorter treatment time
- Linac is not limited for cranial treatment
Multi-met Planning Strategy

**Multi-iso approach**

- Relatively easier to achieve good plan quality
- Less influenced by setup uncertainty
- Hard to control sum dose
- Contribution dose can be considered during optimization
- Worse plan quality indices as an individual plan

Need better understanding for planning tools

Requires accurate patient positioning/monitoring method
Multi-met Planning Strategy

**Single-iso approach**

- Need better understanding of planning tools
- Requires accurate patient positioning / monitoring method
**MR DISTORTION**

**TG-54**

“MRI contains distortions which impede direct correlation with CT data at the level required for SRS”

**TG-117**

Use of MRI data in Treatment Planning and Stereotactic Procedures – Spatial Accuracy and Quality Control Procedures

Gradient nonlinearity distortion, Siebert et al, PRO 2016
CCTG CE.07 PHASE III TRIAL

- STEREOTACTIC RADIOSURGERY COMPARED WITH WHOLE BRAIN RADIONUCLELY (WBRT) FOR **5-15 BRAIN METASTASES**
  - The largest target < 2.5 cm dia.
  - Total Volume ≤ 30 cm³

<table>
<thead>
<tr>
<th>Brain Metastasis volume</th>
<th>Dose Prescribed to Tumour Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lesions &lt; 4 cc</td>
<td>22 Gy</td>
</tr>
<tr>
<td>Lesions 4-10 cc</td>
<td>18-20 Gy</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Brainstem Metastasis volume</th>
<th>Dose Prescribed to Tumour Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lesions 4-10 cc</td>
<td>14-16 Gy</td>
</tr>
<tr>
<td>Lesions 1- 4 cc</td>
<td>16-18 Gy</td>
</tr>
<tr>
<td>Lesions &lt; 1 cc</td>
<td>18-20 Gy</td>
</tr>
</tbody>
</table>
• Gross Tumour Volume (GTV):
  • the contrast enhancing tumour on T1 with contrast scans.
  • Surrounding blood and edema will be excluded
  • Numbering GTV1, GTV2, GTV3 from the most cranial axial and from to back in same slice

• Clinical Target Volume (CTV): No additional margin

• Planning Target Volume (PTV):
  • 1 mm isotropic margin can be added when non-invasive immobilization is used for multiple-isocenter SRS for 6D setup, whereas 2 mm margins can be used with 3D setup correction.
CCTG CE.07 PHASE III TRIAL – TARGET DEFINITIONS (ICRU50, 62)

- **Total Brain**: the brain minus the summed volume of the GTVs
  - V12 Gy < 30 cm³ (30 cc).
  - Adjacent lesions: V12 Gy < 8.5 cc.
    If this volume is exceeded, the prescription doses to the adjacent metastases must be lowered until this constraint is met.
  - Median brain dose < 8 Gy.

- **Optic structures**: The maximum point dose < 9-10 Gy

- **Brainstem**: V12 Gy < 1 cc (the brainstem minus GTV)
VMAT OPTIMIZATION FOR MULTIPLE METASTASES

**< Island blocking problem>**

![Diagram illustrating island blocking problem]

**< Shadow>**

![Diagram illustrating shadowing effect]

**Tuning Structures**

- **Inner control max dose** = 98% of Rx
- **Middle control max dose** = 50% of Rx
- **Outer control max dose** = 40% of Rx

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BEV (FIXED JAWS VS. JAW TRACKING)

- Fixed Jaw setting
- Collimator rotation optimized manually

- Jaw tracking on
- HyperArc Collimator Angle Optimizer (CAO)
DVH (FIXED JAWS VS. JAW TRACKING)

- Total MU: 7,964, PTVs Dmax = 136.9%
- Brain-PTVs: V12 = 20.86 cm³
- Brainstem Dmax = 651.5 cGy

- Total MU: 8,737, PTVs Dmax = 142.7%
- Brain-PTVs: V12 = 10.95 cm³
- Brainstem Dmax = 374.5 cGy
Ten cases (3-11 mets), 16 combinations
- 2 versus 4 arcs
- Collimator angle 45° versus selected per beam
- Fixed jaw versus jaw tracking
- 2 Gy mean dose objective versus no low dose objective.

**Figure 4.** Mean difference between dose volume histograms for normal brain for each parameter. Negative numbers indicate that collimator angle optimization, jaw tracking, or a low dose objective reduces the volume of normal brain at the given dose. The bands indicate the 95% confidence intervals.
<table>
<thead>
<tr>
<th>PLAN OPTIMIZATION - SRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Constraints (GTV, CTV, PTV, OARs)</td>
</tr>
<tr>
<td>• NTO or Tuning Structures</td>
</tr>
<tr>
<td>• MU constraint</td>
</tr>
<tr>
<td>• Optimization resolution</td>
</tr>
<tr>
<td>• Calc. grid size</td>
</tr>
</tbody>
</table>
## CONSTRAINTS

- **TG-101**

<table>
<thead>
<tr>
<th>Serial Tissue</th>
<th>Max vol. (cc)</th>
<th>One fraction</th>
<th>Three fraction</th>
<th>Five fraction</th>
<th>End point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optic pathway</td>
<td>&lt;0.2</td>
<td>8</td>
<td>10</td>
<td>15.3</td>
<td>17.4</td>
</tr>
<tr>
<td>Cochlea</td>
<td></td>
<td>9</td>
<td>10</td>
<td>17.1</td>
<td>25</td>
</tr>
<tr>
<td>Brainstem (not medulla)</td>
<td>&lt;0.5</td>
<td>10</td>
<td>15</td>
<td>18</td>
<td>23.1</td>
</tr>
<tr>
<td>Spinal cord and medulla</td>
<td>&lt;0.35 &lt;1.2</td>
<td>10</td>
<td>14</td>
<td>18</td>
<td>21.9</td>
</tr>
</tbody>
</table>

- Normal Brain V10 < 12 cc or V12 < 10 cc (One fraction SRS)
- Cranial Nerves (fifth, seventh and eighth CN) 12.5-15 Gy
  (Flicker et al., IJROBP 2004)
Table 6  Published dose constraints for SRS, with NTCP estimates\(^a\)

<table>
<thead>
<tr>
<th>Tissues</th>
<th>Dose (Gy)</th>
<th>Volume</th>
<th>Fraction</th>
<th>Endpoint</th>
<th>NTCP</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brain</td>
<td>14</td>
<td>5-10 cc</td>
<td>1</td>
<td>Necrosis</td>
<td>1–20%</td>
<td>This study</td>
</tr>
<tr>
<td>Brainstem</td>
<td>12.5</td>
<td>max</td>
<td>1</td>
<td>Neuropathy</td>
<td>&lt; 5%</td>
<td>QUANTEC</td>
</tr>
<tr>
<td>Brainstem</td>
<td>10.0</td>
<td>0.5 cc</td>
<td>1</td>
<td>Neuropathy</td>
<td>Unknown</td>
<td>TG 101</td>
</tr>
<tr>
<td>Optic nerves</td>
<td>12.0</td>
<td>max</td>
<td>1</td>
<td>Neuropathy</td>
<td>0.7%</td>
<td>QUANTEC</td>
</tr>
<tr>
<td>Optic nerves</td>
<td>8.0</td>
<td>0.2 cc</td>
<td>1</td>
<td>Neuropathy</td>
<td>1.1%</td>
<td>TG 101</td>
</tr>
<tr>
<td>Cochlea</td>
<td>12.0</td>
<td>max</td>
<td>1</td>
<td>Hearing loss</td>
<td>11.8%</td>
<td>Timm. 2008</td>
</tr>
<tr>
<td>Spinal cord</td>
<td>14.0</td>
<td>max</td>
<td>1</td>
<td>Myelitis</td>
<td>1.6%</td>
<td>RTOG 0915</td>
</tr>
</tbody>
</table>

\(^a\)Notes: (1) Dose constraints from the listed references [3, 61, 63, 65]. (2) Volume effect limits and more details are available [5–7]. (3) NTCP results from Seminars in Radiation Oncology, April 2016 [4–7] or QUANTEC [3]. (4) NTCP depends on the exact circumstances of each dataset [4–7]

Table 7  Published dose constraints for SBRT, with NTCP estimates\(^a\)

<table>
<thead>
<tr>
<th>Tissues</th>
<th>Dose (Gy)</th>
<th>Volume</th>
<th>Fraction</th>
<th>Endpoint</th>
<th>NTCP</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brain</td>
<td>28.8</td>
<td>5–10 cc</td>
<td>5</td>
<td>Necrosis</td>
<td>1–20%</td>
<td>This study</td>
</tr>
<tr>
<td>Brainstem</td>
<td>31.0</td>
<td>max</td>
<td>5</td>
<td>Neuropathy</td>
<td>Unknown</td>
<td>TG 101</td>
</tr>
<tr>
<td>Brainstem</td>
<td>23.0</td>
<td>0.5 cc</td>
<td>5</td>
<td>Neuropathy</td>
<td>Unknown</td>
<td>TG 101</td>
</tr>
<tr>
<td>Optic nerves</td>
<td>25.0</td>
<td>max</td>
<td>5</td>
<td>Neuropathy</td>
<td>0.8%</td>
<td>TG 101</td>
</tr>
<tr>
<td>Optic nerves</td>
<td>20.0</td>
<td>0.2 cc</td>
<td>5</td>
<td>Neuropathy</td>
<td>1.7%</td>
<td>Timm. 2008</td>
</tr>
<tr>
<td>Cochlea</td>
<td>25.0</td>
<td>max</td>
<td>5</td>
<td>Hearing loss</td>
<td>13.8%</td>
<td>TG 101</td>
</tr>
<tr>
<td>Spinal cord</td>
<td>30.0</td>
<td>max</td>
<td>5</td>
<td>Myelitis</td>
<td>2.6%</td>
<td>RTOG 0813</td>
</tr>
</tbody>
</table>

\(^a\)Notes: (1) Dose constraints from the listed references [61, 63, 64]. (2) Volume effect limits and more details are available [5–7]. (3) NTCP results from Seminars in Radiation Oncology, April 2016 [4–7]. (4) NTCP depends on the exact circumstances of each dataset [4–7]
### PLAN OPTIMIZATION – MU

<table>
<thead>
<tr>
<th>Field</th>
<th>Arc 1</th>
<th>Arc 2</th>
<th>Arc 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Plan A</strong></td>
<td>4116</td>
<td>2105</td>
<td>2105</td>
</tr>
<tr>
<td><strong>Plan B</strong></td>
<td>3488 (18% ↓)</td>
<td>1794 (17% ↓)</td>
<td>1794 (17% ↓)</td>
</tr>
</tbody>
</table>
CALCULATION GRID SIZE

- Expected effects for SRS case

- Calculation accuracy
- Max dose
- Conformity Index
- Gradient
- DVH
MECHANICAL ACCURACY

Re-examining TG-142 recommendations in light of modern techniques for linear accelerator based radiosurgery

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(Received 8 June 2016; revised 14 July 2016; accepted for publication 24 August 2016; published 13 September 2016)
# 4D VS. 6D COUCH

## Table 2

<table>
<thead>
<tr>
<th>$P$</th>
<th>$d$ (cm)</th>
<th>Pitch</th>
<th>Roll</th>
<th>Yaw</th>
<th>Pitch</th>
<th>Roll</th>
<th>Yaw</th>
</tr>
</thead>
<tbody>
<tr>
<td>.90</td>
<td>5.00</td>
<td>0.11</td>
<td>0.14</td>
<td>0.15</td>
<td>0.03</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>.95</td>
<td>5.00</td>
<td>0.13</td>
<td>0.17</td>
<td>0.17</td>
<td>0.03</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>.98</td>
<td>5.00</td>
<td>0.15</td>
<td>0.19</td>
<td>0.20</td>
<td>0.04</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>.99</td>
<td>10.00</td>
<td>0.21</td>
<td>0.28</td>
<td>0.20</td>
<td>0.06</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td>.95</td>
<td>10.00</td>
<td>0.26</td>
<td>0.34</td>
<td>0.35</td>
<td>0.07</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>.98</td>
<td>10.00</td>
<td>0.29</td>
<td>0.39</td>
<td>0.40</td>
<td>0.08</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>.90</td>
<td>15.00</td>
<td>0.32</td>
<td>0.42</td>
<td>0.44</td>
<td>0.08</td>
<td>0.13</td>
<td>0.13</td>
</tr>
<tr>
<td>.95</td>
<td>15.00</td>
<td>0.38</td>
<td>0.51</td>
<td>0.52</td>
<td>0.10</td>
<td>0.16</td>
<td>0.15</td>
</tr>
<tr>
<td>.98</td>
<td>15.00</td>
<td>0.44</td>
<td>0.58</td>
<td>0.59</td>
<td>0.11</td>
<td>0.18</td>
<td>0.18</td>
</tr>
</tbody>
</table>

6D, 6 degrees of freedom. A 1-mm margin accounts for 95% of intraoperative uncertainties at 10 cm (values shown in bold).

## Figure 1

Box plot of initial rotational uncertainty for the U-frame thermoplastic mask system at setup when no rotational corrections are made; measured from 20-kV cone beam computed tomography scans. The central line indicates the median, the edges of the box are the 25th and 75th percentiles, and whiskers are the most extreme points that are not outliers. Uncertainty (σ) in the rotational correction before treatment is noted.
Assessing the feasibility of single target radiosurgery quality assurance with portal dosimetry

Elizabeth L. Covington | Jesse D. Snyder | Xingen Wu | Rex A. Cardan | Richard A. Popple

**Fig. 4.** The percent difference between the delivered and predicted portal image output at central axis for open fields at dose rates of 400, 1200, and 2400 MU/min.

**Fig. 3.** (a) The measured to treatment planning system (TPS) dose in the >90% maximum dose region as a function of target size. While the film remains relatively flat across all target size, the portal dosimetry results are target size dependent. (b) The ratio of film to portal dosimetry measurements as a function of target size.
HYPERARC™

- Fixed geometry: up to 4 arcs (1 coplanar and 3 non-coplanar)
- Achieve the optimal dose coverage, highest conformity, sparing of normal tissue with non-coplanar arcs
- Collision prevention, avoidance and detection
- Enable automatic tx. delivery: shorten the overall tx. time
HYPERARC TRAJECTORY

- Isocenter is automatically defined
- Optimization of collimator rotation
- Optimization of Jaw setting
COLLIMATOR ANGLE OPTIMIZER

- Max length of field opening: 17 cm
- Max leaf travel: 15 cm
- Max width of field opening: 40 cm if it’s at most 40 cm
- Optimized the angle to avoid island blocking
- Optimized at the end of the fields generation (HyperArc Trajectory)

Pre and post CAO
HYPERARC OPTIMIZATION

• Automatic Lower Dose Objective (ALDO)
• VMAT optimization: PO15.5 or above
• Warning if the target is not converted as a hi-resolution structure
• Use SRS NTO
• Use hi-resolution optimization by default
• Aperture shaper off
• Use cal. grid to 1.25 mm by default
PLAN EVALUATION - HYPERARC

• Target coverage
• DVH evaluation
  • Location of hot and cold spots
• Dose to Organ at Risk (OAR)
  • DVH evaluation
• Conformity, Gradient, Homogeneity
• Normal tissue irradiated
• Delivery efficiency
• Number of MU
• Collision
Example RA SRS case: Rx = 22 Gy, Total MU = 6922 MU

- Total delivery time 4 arcs: 14 min 31 sec
- Total beam beam-on time: 5 min 22 sec
- G/C Motion + in/out time: 9 min 09 sec
## TREATMENT DELIVERY - COMPARISON

<table>
<thead>
<tr>
<th>Method</th>
<th>Time</th>
<th>Dose</th>
<th>MU</th>
</tr>
</thead>
<tbody>
<tr>
<td>HyperArc</td>
<td>8:40</td>
<td>22 Gy</td>
<td>7555</td>
</tr>
<tr>
<td>RapidArc</td>
<td>14:31</td>
<td>22 Gy</td>
<td>6922</td>
</tr>
</tbody>
</table>

![Graphs showing treatment delivery times and doses for HyperArc and RapidArc methods.](image-url)
• **Collimation rotation Offset**: the max. dev. of the nominal versus the actual collimator rotation (5 coll. rotation angles)

• **Gantry rotation**
  Use eight representative gantry angles (0, 45, 90, 135, 180, 225, 270, 315°)

• **Enhanced Couch**
  The rotation-induced couch shift is the offset of this center of rotation from the treatment isocenter.
SUMMARY

- Single isocenter for multiple brain metastases treatment is rapidly changing the practice of radiosurgery.
- QA needs to be carefully developed and performed to ensure the quality of treatment.
- HyperArc can enable improved plan quality as well as save significant planning time.
- Automatic delivery saves treatment time in the meantime, enforced safety features prevent potential adverse incident ahead of time.