Achieving Low-Gradient Field Matching with VMAT
Craniospinal and Beyond

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Mayo Clinic Arizona

AAMD Region I Meeting
Las Vegas Nevada
October 7-8, 2016
Mayo Clinic Arizona Department of Radiation Oncology

- Two Campus Locations – Scottsdale and Phoenix
- 5 linear accelerators
- 2 CT Simulators
- IORT
- Brachytherapy HDR
- 6 photon dosimetrists
- 9 medical physicists
Pediatric Radiation Oncology Program at Mayo Clinic Arizona

Joint collaboration to provide radiation oncology services for Phoenix Children's Hospital
History of Pediatric Radiation Oncology Treatments

• Radiation Oncology Department in Arizona opened in 1988
• No pediatric department at Mayo Arizona
• First patient January of 2014
• First patient CSI with Posterior Fossa and Spine Boost
• Three staff pediatric radiation oncologists
• Currently treat approximately 4-6 pediatric patients per day
Objective

Demonstrate a versatile and adaptable method for planning craniospinal treatments utilizing Volumetric Modulated Arc Therapy (VMAT) therefore eliminating the need for match line shifts.
Outline

• Describe the planning process of low gradient field matching with VMAT for CSI

• Apply the VMAT low dose gradient method to other cases requiring matching fields

• Case Descriptions
  
  CSI
  Hodgkin’s Lymphoma
  Head and Neck
  Metastatic Lumbar Spine
  Whole Thorax and Abdomen
Dangerous Gradients

• What is a low gradient field junction?

• Why is a low-gradient field junction better than conventionally matched fields?
High Gradient Profile

Figure 1: Dose profiles showing the contribution from two overlapping spine fields, and their sum dose. Profiles from TPS planned junction using conventional jaw collimation (solid lines) and with 4-mm setup error (dashed line)
Low Gradient Profiles

**Figure 2:** Dose profiles showing the contribution from two overlapping spine fields, and their sum dose.

**Upper** Profiles from TPS inversely planned junction with a 10-cm field overlap (solid lines) and 4-mm setup error (dashed line)

**Lower** Profiles manually generated from junctions with a 10-cm field overlap (solid lines) and 4-mm setup error (dashed line) using combined forward and inverse planning technique
Junction Gradients

<table>
<thead>
<tr>
<th>Junction Overlap (cm)</th>
<th>Static Collimation</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>18.9</td>
</tr>
<tr>
<td>6</td>
<td>14.6</td>
</tr>
<tr>
<td>8</td>
<td>13.6</td>
</tr>
<tr>
<td>10</td>
<td>12.6</td>
</tr>
<tr>
<td>TPS</td>
<td>25.6</td>
</tr>
<tr>
<td>Manual</td>
<td>14.8</td>
</tr>
<tr>
<td></td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td>9.4</td>
</tr>
<tr>
<td></td>
<td>8.6</td>
</tr>
</tbody>
</table>

Table 1. Max difference, in % of prescription dose, between dose profiles of planned delivery compared to dose profiles from field junctions with 4-mm shift applied to simulate error, for various field overlap distances. Manual junctions used forward and inverse planning; TPS junctions were inversely planned.
CSI Treatment : Goals

- Streamlined, reproducible setup
- Efficient method of imaging
- Straightforward and timely delivery to reduce time under anesthesia
- Class solution method of treatment planning for dosimetry
- No match line shifts
Comparison of Methods for planning CSI

- Hybrid Forward and Inverse Planned IMRT
  - 3 field method and Single Posterior Field
  - VMAT – Forward Planning for Brain
    VMAT Planning for Spine
Lateral Brain
Posterior Spine Only
3 Field Spine  
VMAT
CSI Technique Comparison

Single spine field

Post LPO-RPO

VMAT
## CSI Technique Comparison

<table>
<thead>
<tr>
<th>Plan</th>
<th>Heart Mean &lt; 1100 cGy</th>
<th>Lung Total Mean &lt; 1000 cGy</th>
<th>R Kidney Mean &lt;1000 cGy</th>
<th>L Kidney Mean &lt;1000 cGy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single spine</td>
<td>1793 cGy</td>
<td>702 cGy</td>
<td>603 cGy</td>
<td>764 cGy</td>
</tr>
<tr>
<td>3 Field IMRT</td>
<td>896 cGy</td>
<td>1108 cGy</td>
<td>987 cGy</td>
<td>993 cGy</td>
</tr>
<tr>
<td>VMAT</td>
<td>844 cGy</td>
<td>1062 cGy</td>
<td>811 cGy</td>
<td>832 cGy</td>
</tr>
</tbody>
</table>
CSI - Workflow

• Standard simulation procedure

• Planning method must have good dosimetric quality and be practical to deliver with the possibility for quick turn around

• Clearly define for the therapists anatomic landmarks and tolerances for setup
  • At what point is the spine straight enough?
  • Imaging – Use of “bounding box”
It all begins with the immobilization ......
CSI : Simulation

• Managing multiple-isocenter delivery
  • Head tilt reproducibility
  • Stretching of neck
  • Spine straightness
  • Smooth workflow to reduce anesthesia time
CSI: Treatment Tolerances
(Lateral FinF Brain)

- Impact of head tilt (5°); 3mm PTV
CSI: Treatment Tolerances
When is the spine “straight enough”

2 mm L/R setup error

4 mm L/R setup error
(1% reduction of CTV D95%)
Bounding Box for KV Imaging
Planning Targets

- CTV spine – Spinal cord and nerve roots
- CTV brain - brain
- PTV brain – 3 mm expansion of CTV brain
- PTV spine – 5 mm expansion of CTV spine
OAR Structures

- Cribiform plate
- Lenses
- Eyes
- Cochlea
- Lungs
- Heart
- Kidneys
CSI: Set Field Isocenters
Brain and Lower Spine

Brain iso
10.0 cm Superior to shoulder

Lower spine iso
40 cm length field
2.0 cm inferior to PTV
CSI: All Field Isocenters
Create PTV Segments
Whole Brain FiF to Create Low Gradient Junction
Whole Brain FiF to Create Low Gradient Junction
Whole Brain FiF to Create Low Gradient Junction
Dose profile of Forward Planned Brain
Field in Field Gradient with MLC

Incorrect Taper

![Incorrect Taper Graph](image)

Correct Taper

![Correct Taper Graph](image)
## Lower Spine - Optimization

### Table: Dose Parameters

<table>
<thead>
<tr>
<th>ID/Type</th>
<th>Vol [cm³]</th>
<th>Vol [%]</th>
<th>Dose [cGy]</th>
<th>Actual Dose [cGy]</th>
<th>Priority</th>
<th>gEUD a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower</td>
<td>1.5m06</td>
<td>6.7</td>
<td>1820</td>
<td>1215</td>
<td>50</td>
<td>x</td>
</tr>
<tr>
<td>Lower</td>
<td>1.5m07</td>
<td>9.4</td>
<td>2160</td>
<td>2294</td>
<td>50</td>
<td>x</td>
</tr>
<tr>
<td>Lower</td>
<td>1.5m08</td>
<td>9.1</td>
<td>2382</td>
<td>3008</td>
<td>50</td>
<td>x</td>
</tr>
<tr>
<td>Lower</td>
<td>1.5m09</td>
<td>7.5</td>
<td>2520</td>
<td>2704</td>
<td>50</td>
<td>x</td>
</tr>
<tr>
<td>Lower</td>
<td>1.5m10</td>
<td>9.9</td>
<td>2882</td>
<td>3056</td>
<td>50</td>
<td>x</td>
</tr>
<tr>
<td>Lower</td>
<td>2.1m0p03Op1</td>
<td>247.7</td>
<td>3240</td>
<td>4013</td>
<td>80</td>
<td>x</td>
</tr>
<tr>
<td>Lower</td>
<td>2.1m0p04Op1</td>
<td>220.0</td>
<td>3600</td>
<td>3710</td>
<td>50</td>
<td>x</td>
</tr>
<tr>
<td>Lower</td>
<td>2.1m0p05Op1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Diagram: Dose Distribution
- Isodose lines indicate the distribution of dose across different areas.
- The highest dose is concentrated in the lower spine region.

### Additional Information:
- **Normal Tissue Objective**: 50/Manual
- **MU Objective**: 0/2000/0
- **Base Dose Plan**: Normal (2.5 mm)

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Dose profile  Lower Spine
Dose profile Lower Spine – Adjust
Reoptimize
Sum Plan
Brain and Lower Spine

Use as base plan for Upper Spine Optimization
Final optimization – Mid Spine
**Final CSI Plan**

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<thead>
<tr>
<th>Heart Mean &lt; 1100 cGy</th>
<th>Lung Total Mean &lt; 1000 cGy</th>
<th>R Kidney Mean &lt;1000 cGy</th>
<th>L Kidney Mean &lt;1000 Gy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1076 cGy</td>
<td>631 cGy</td>
<td>826 cGy</td>
<td>626 cGy</td>
</tr>
</tbody>
</table>

PTV Coverage = 97.7%

Sum Plan of Brain, Upper and Lower Spine
And Beyond .......
Case 2

- 15 year old male
- Hodgkin’s Lymphoma Stage IIB
- Neck, and intra-thoracic nodal involvement
- Chemotherapy prior to radiation
Target DVH Objectives

- PTV – 21 Gy
- Heart – Mean dose < 11Gy
- Total Lung – Mean dose < 8 Gy
  - V13Gy <20%
  - V18Gy <15%
- Larynx - < 10 Gy
- Cord – Max < 22 Gy
- Left Ventricle - < 8 Gy
Treatment Planning: VMAT Only
Issues with VMAT Only Treatment Plan

- PTV Coverage Low
- Decrease larynx, esophagus lung and thyroid dose
Create a Low Dose Gradient Plan

• Split PTV Volume into Upper and Lower
• Create 5.0 cm or more gradient between upper and lower fields with FiF segments
• Create a VMAT plan for the inferior portion of the PTV volume using the Upper plan as a base dose plan
Create a dose taper at the inferior edge of field with Forward planning Field in Field
Dose Taper
Approved vs. Rejected Plan: Spot the difference
Approved vs. Rejected Plan:
Spot the difference
Approved vs. Rejected Plan: Spot the difference
Case 3

- 72 year old male
- Newly diagnosed Merkel Cell of Left Eyebrow
- S/P wide excision and sentinel node biopsy
- Treated with adjuvant radiation therapy
Left Eyebrow and Scalp
Neck Nodes
Initial Plan – No Change in Electron Cutout
Dose Profile
No Electron Cutout Change

Start point [cm]: (6.99, 14.27, 7.38)  Sample steps: 1337  Max Dose: 102.3 %
End point [cm]: (6.99, 3.12, -2.58)  Each step [cm]: 0.01
Left Eyebrow and Scalp
Combined Dose Profile

![Dose Line Profile: NewFinal](image)

- Start point [cm]: (6.93, 13.64, 7.79)
- End point [cm]: (6.93, 8.02, 2.65)
- Sample steps: 304
- Each step [cm]: 0.03
- Max Dose: 127.1 %
Case 4

- 76 year old male with Stage T3N1 Esophagus Ca
- Underwent neo adjuvant Chemo / RT
- 4500 cGy / 5000 cGy / 25 fractions
- Surgical Resection with IORT 1000 cGy / 1 Fraction
- Subsequently presents with metastatic disease in the region of L1 and surrounding soft tissue
Target DVH Objectives

• PTV – 28 Gy / 3.5 Gy per Fraction
• Cord dose –
  • Prior dose to cord in adjacent region ranging from 26 Gy to 40 Gy
• Duodenum, colon, kidneys skin and cauda equina
Previous Dose from Esophagus Treatment

PTV 28 - New volume
Approved vs. Rejected Plan
Case 5

• 31 yo male with Anaplastic Ependymoma
• CSI to 3600 cGy in 2011
• Areas of disease to 4500 cGy
• Recurrent disease in 2015
• Re-treat symptomatic lumbar area in 2015
CSI Treatment 2011

(Can be supine or prone)

Lateral Opposed Whole Brain Fields
(Collimator and couch rotation)

Immobilization Device

PA Spine Field

Isodoses (cGy)
4000
3600
3500
3000
2000
Low Gradient Plan  T11-L2
Mayo Clinic Proton Beam Therapy
Proton Plan - Retreat CSI
Low Gradient Junction in Boost Area
Proton Plan - Retreat CSI
Low Gradient Junction in Boost Area
Conclusion

• TPS generated junctions may not provide as much control over the gradient as manual methods.

• Manually creating low gradient junctions and maintaining a sufficient overlap distance allows more control within the region of the field junction while maintaining uniform dose distributions.
Thank you

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Questions ?