Integrated Feathering for Craniospinal Irradiation

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TJU Radiation Oncology

- Center City, Philadelphia
- Bodine Center for Radiation Therapy
- 9 physicians
- 10 physicists
- 5 dosimetrists
- 23 therapists
TJU Radiation Oncology

- 2 Varian TrueBeams
- 2 Elekta Agilities
- 1 ViewRay (coming soon)
- VMAT, IMRT, 3D, TBI, TSET, ...
- CSI
  - ~4/year
Outline

Background
Classic CSI
Integrated Feathering
Other CSI methods
Outline

Background

Classic CSI

Integrated Feathering

Other CSI methods
Medulloblastoma

• Tumor of the central nervous system (CNS)
• Occurs in both children and adults
  • Most common malignant brain tumor in children
• Usually originate in the cerebellum
• Spreads to CNS through cerebrospinal fluid
Medulloblastoma

Symptoms
• Headaches
• Nausea or vomiting
• Clumsiness
• Problems with handwriting
• Visual problems

Symptoms (if spread to spine)
• Back pain
• Trouble walking
• Problems controlling bladder and bowel functions

https://www.stjude.org/disease/medulloblastoma.html
Cerebrospinal Fluid (CSF)

Cerebellum
Craniospinal Irradiation (CSI)

- Treat medulloblastoma and other tumors that may spread through CSF
- Irradiates the entire central nervous system
  - Whole brain and spine
History

CEREBELLAR MEDULLOBLASTOMA: TREATMENT BY IRRADIATION OF THE WHOLE CENTRAL NERVOUS SYSTEM

by

Edith Paterson and R. F. Farr

- First proposed in 1953 to irradiate “the entire brain and cord as one undivided volume”
- Principle from post-mortem findings of disease throughout the brain and cord
Outline

Background

Classic CSI

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Other CSI methods
Classic CSI

• Prone position
• Requires adjacent fields that must be matched
  • 2 opposed lateral whole brain fields
  • 1-2 posterior spinal fields
• Matching requires gantry, collimator, and couch rotations
• Important to avoid overdosing the spinal cord
Spinal Fields

- Two spinal fields if spinal cord > 36 cm
- Children can usually be treated with one field
- Adults need two fields
  - “Matched” by employing a gap between fields
Field Matching

- Between lateral brain fields and superior spinal field
- Requires collimator and couch rotation
Couch Rotation

\[ \alpha \]

\[ \text{SAD} \]

\[ y \]
Couch Rotation

\[ \text{SAD} \]

\[ \alpha \]

\[ y \]

SOH

CAH

TOA
Couch Rotation

TOA

\[ \tan(x) = \frac{\text{opposite}}{\text{adjacent}} \]
Couch Rotation

\[
\tan \alpha = \frac{y}{SAD}
\]
Couch Rotation Example

\[
\tan \alpha = \frac{y}{SAD}
\]
Couch Rotation Example

\[ \tan \alpha = \frac{y}{SAD} \]
\[ \tan \alpha = \frac{18 \text{ cm}}{100 \text{ cm}} \]
\[ \alpha = \tan^{-1} \frac{18 \text{ cm}}{100 \text{ cm}} \]
\[ \alpha = 10.2^{\circ} \]
Field Matching

- Beware of overdosing the cervical spine
Field Arrangements

- Avoiding divergence into the eyes/lenses is difficult
Field Matching

- Between two posterior spinal fields
- Gap calculation
Gap Calculation

[Diagram of A-shaped structures]
Gap Calculation

![Diagram of gap calculation]
Gap Calculation

\[ \text{Gap} = \frac{Y_1 d}{SSD_1} + \frac{Y_2 d}{SSD_2} \]
Gap Calculation

\[ \text{SSD}_1 \] \quad \text{Gap} \quad \text{SSD}_2 \]

\[ Y_1 \quad \text{Y}_2 \]
Gap Calculation

\[ \text{Gap} = \text{Gap}_1 + \text{Gap}_2 \]
Gap Calculation

\[ \text{SSD}_1 \]

\[ \text{Gap}_1 \]

\[ \text{d} \]

\[ \text{Y}_1 \]
Gap Calculation
Gap Calculation

\[
\frac{B_1}{B_2} = \frac{A_1}{A_2}
\]
Gap Calculation

\[
\frac{B_1}{B_2} = \frac{A_1}{A_2}
\]
Gap Calculation

\[ B_1 = \frac{A_1 B_2}{A_2} \]
Gap Calculation

\[
\text{Gap}_1 = \frac{Y_1 d}{SSD_1}
\]
Gap Calculation

\[ Gap_2 = \frac{Y_2 d}{SSD_2} \]
Gap Calculation

\[ \text{Gap} = \text{Gap}_1 + \text{Gap}_2 = \frac{Y_1 \cdot d}{\text{SSD}_1} + \frac{Y_2 \cdot d}{\text{SSD}_2} \]
Gap Calculation Example

88 cm SSD

5 cm depth

90 cm SSD
Gap Calculation Example

88 cm SSD

18 cm

90 cm SSD

5 cm depth

6 cm
Gap Calculation Example

\[ \text{Gap} = \frac{Y_1 d}{SSD_1} + \frac{Y_2 d}{SSD_2} \]

\begin{align*}
  d &= 5 \text{ cm} \\
  Y_1 &= 18 \text{ cm} \\
  SSD_1 &= 88 \text{ cm} \\
  Y_2 &= 6 \text{ cm} \\
  SSD_2 &= 90 \text{ cm}
\end{align*}
Gap Calculation Example

\[
\text{Gap} = \frac{Y_1 d}{SSD_1} + \frac{Y_2 d}{SSD_2}
\]

\[
\text{Gap} = \frac{(18 \text{ cm})(5 \text{ cm})}{(88 \text{ cm})} + \frac{(6 \text{ cm})(5 \text{ cm})}{(90 \text{ cm})}
\]

\[
\text{Gap} = 1.02 \text{ cm} + 0.33 \text{ cm}
\]

\[
\text{Gap} = 1.35 \text{ cm}
\]

d = 5 \text{ cm}
Y_1 = 18 \text{ cm}
SSD_1 = 88 \text{ cm}
Y_2 = 6 \text{ cm}
SSD_2 = 90 \text{ cm}
Field Borders

• Brain fields
  • Standard whole brain field with flash superiorly and posteriorly

• Upper spinal field
  • Junction with lower spinal field at around T12/L1

• Lower spinal field
  • Standard spade-shaped field
Feathering

- Shift the field junction match lines throughout treatment
- Needs to be accounted for during planning
- Typically 1 cm shift
- Every 5-6 fractions
No feathering

With feathering
Patient Setup

• Prone
  • Visualize field junctions on patient surface with light fields

• Supine
  • More comfortable
  • More reproducible

• Head extended to allow for chin clearance for each feather
Field Setup

- Brain fields
  - Rotate gantry to avoid lenses
  - Set inferior border to ensure chin clearance after shifts
  - Rotate couch to match inferior borders
- Upper spinal field
  - Rotate collimator for brain fields to match spinal field
- Lower spinal field
  - Overlap with upper spinal field anterior of cord (avoid hotspot)
Outline

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Example

- Adult CSI patient
  - 4 fields
- 36 Gy in 18 fractions
- Feather every 6 fractions
  - 3 plans
Workload

Dosimetrist
Doctor
Physicist
Therapist
Dosimetrists have to:
- Create an additional plan for each feather
- Prepare/export multiple plans
Workload

Doctors have to:

- Approve 3 plans + composite
- Review 3 sets of port films
Workload

Physicists have to:
- Check 3 different plans
- Confirm match/shift in each plan
Workload

Therapists have to:
- Port film/set up patient 3 times
  - Takes up more machine time
Workload

Dosimetrists

Doctors

Physicists

Therapists
Workload

Dosimetrist  Doctor  Physicist  Therapist
Integrated Feathering

- Field-in-field beams
  - Feather across the match line region in **one plan**
  - 3 equally-weighted segments
  - 1 cm shift between segments
- Same plan throughout entire treatment
New Workload

Dosimetrists have to:
- Create one field-in-field plan
  - Field matching is the longest part
  - Takes the same time as 3 plans (1 hr)
- Prepare/export one plan (30 min)
  - 1/3 less work
Physicists have to:
- Check one plan
  - Learning curve
  - Should reduce plan review time
Workload

Therapists have to:

• Port film/set up patient once
  • Same setup for each fraction
  • Less risk/room for error (safer for patient)
Treatment Schedule

Fx 1 +40 min of port film
Fx 7 +40 min of port film
Fx 13 +40 min of port film
Treatment Schedule

Fx 1 +39 min of port film
Fx 2
Fx 3
Fx 4
Fx 5
Fx 6
Fx 7
Fx 8
Fx 9
Fx 10
Fx 11
Fx 12
Fx 13
Fx 14
Fx 15
Fx 16
Fx 17
Fx 18

80 min saved
Setup Error

- Simulated isocenter setup errors of upper spinal field
  - 2 mm shifts up to 10 mm
- Classic CSI plans
  - Shifted one of the three upper spinal fields (1/3 affected)
- Integrated CSI plans
  - Shifted 1/3 fractions of upper spinal field-in-field
Setup Error

Cord max % Difference

Upper Spinal Field Isocenter Shift (mm)

-10  -8  -6  -4  -2  0  2  4  6  8  10

Inf  Sup

Classic  Integrated
Integrated Feathering

- Decreases staff workload
- Decreases patient time on table
- Reduces effects of potential setup errors
Outline

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Intensity-modulated radiation therapy and volumetric-modulated arc therapy for adult craniospinal irradiation—A comparison with traditional techniques

Matthew T. Studenski, Ph.D.,* Xinglei Shen, M.D.,* Yan Yu, Ph.D.,* Ying Xiao, Ph.D.,* Wenyin Shi, M.D.,* Tithi Biswas, M.D.,† Maria Werner-Wasik, M.D.,* and Amy S. Harrison, M.S.*

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**CSI: 3D vs. IMRT/VMAT**

- 10 patients
- 36 Gy

### 3D
- 100 cm SSD
- Prone

### IMRT
- 5-field cranial
- 5-field spinal

### VMAT
- 2 full arcs cranial
- 1 200° arc spinal

CSI: 3D vs. IMRT/VMAT

## CSI: 3D vs. IMRT/VMAT

<table>
<thead>
<tr>
<th>Pros</th>
<th>3D</th>
<th>IMRT</th>
<th>VMAT</th>
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<tbody>
<tr>
<td>• Most efficient</td>
<td>• OAR sparing</td>
<td>• OAR sparing</td>
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</tr>
<tr>
<td>• Negligible OAR dose increase for cranial</td>
<td>• Target coverage</td>
<td>• Target coverage</td>
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</table>

<table>
<thead>
<tr>
<th>Cons</th>
<th>3D</th>
<th>IMRT</th>
<th>VMAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Higher dose to OARs for spinal fields</td>
<td>• Difficult to QA junctions</td>
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<td></td>
<td>• Hard to control hotspots outside of PTV</td>
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<td></td>
<td>• Longest treatment times</td>
<td>• Longest treatment times</td>
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<tr>
<td></td>
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<td>• Low dose spread</td>
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CRANIOSPINAL IRRADIATION TECHNIQUES: A DOSIMETRIC COMPARISON OF PROTON BEAMS WITH STANDARD AND ADVANCED PHOTON RADIOTHERAPY

Myonggeun Yoon, Ph.D.,* Dong Ho Shin, Ph.D.,* Jinsung Kim, Ph.D.,† Jong Won Kim,* Dae Woong Kim,* Sung Yong Park, Ph.D.,* Se Byeong Lee, Ph.D.,* Joo Young Kim, M.D.,* Hyeon-Jin Park, M.D.,‡ Byung_Kiu Park, M.D.,‡ and Sang Hoon Shin, M.D.§

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CSI: Proton vs. Photon

- 10 patients
- 1.8 Gy x 20 fractions = 36 Gy
- Three plans:
  1. 3D
  2. Tomotherapy
  3. Proton

Proton Beam Craniospinal Irradiation Reduces Acute Toxicity for Adults With Medulloblastoma

Aaron P. Brown, MD,* Christian L. Barney, BS,‖ David R. Grosshans, MD, PhD,* Mary Frances McAleer, MD, PhD,* John F. de Groot, MD, † Vinay K. Puvvulli, MD, † Susan L. Tucker, PhD, ‡ Cody N. Crawford, CMD,* Meena Khan, CMD,* Soumen Khatua, MD,§ Mark R. Gilbert, MD, † Paul D. Brown, MD,* and Anita Mahajan, MD*

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CSI: Proton vs. Photon

- 21 treated with photon
  - Classic CSI
- 19 treated with proton
  - Supine
  - Similar beam arrangements
  - Vertebral body-sparing with proton range
CSI: Proton vs. Photon

CSI: Proton vs. Photon

CSI: Proton vs. Photon

Proton CSI

• Dosimetry (Yoon et al)
  • Lower OAR organ equivalent doses
  • Significantly lower dose to the chest/abdomen
  • Similar dose to head & neck area
• Clinical outcomes (Brown et al)
  • Less acute gastrointestinal toxicities (nausea/vomiting)
  • Less hematologic toxicities
• Limited availability
Varian Auto-Feathering

- Eclipse v15.5
- Only for inverse optimized plans
- Controls hot and cold spots at junction
Take-Home Points

• Review math/geometry for CSI calculations
• Gantry, collimator, and couch rotations to match brain fields
• Integrated feathering 😊
• IMRT/VMAT CSI
• Protons CSI
Thanks!

Sidney Kimmel Cancer Center
Jefferson Health® | NCI – designated

Until every cancer is cured