Reirradiation of Brain Tumor in Pediatric Patient using VMAT
A Case Study

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Disclosures

I have no disclosures to report.
The Case Study

- 4 year old male
- Diagnosed with recurrent anaplastic ependymoma (WHO Grade III)
- Previously treated with passive scatter proton therapy 2 years prior
  - Prescribed: 54 Gy in 30 fractions

Ependymoma

- Form from glial cells that line the ventricles in brain and spinal canal
  - Most common location in children is the posterior fossa
- Third most common type of pediatric brain tumor (6-10%)
  - Median age of diagnosis is 3.6 years old
  - Unknown cause
- Symptoms depend on location, however headache and vomiting are the most common
- Diagnosed with imaging and biopsy
  - Lumbar puncture to look for spread
- Treatment: surgery, radiation, chemotherapy
- 5 year survival: 67% (overall), 39% (progression-free)
- 10 year survival: 50% (overall), 29% (progression-free)
- Recurrence: usually occurs at primary tumor site (74%)
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**Prescription – VMAT**

Rt base of skull 3960 cGy in 22 fractions

**GTV**: 3960 cGy  
V100% ≥ 95%, V95% ≥ 99%,  
V105% ≤ 10%, Dmax ≤ 110%  

**CTV**: 3960 cGy  
V100% ≥ 95%, V95% ≥ 99%,  
V105% ≤ 10%, Dmax ≤ 110%  

**PTV**: 3960 cGy  
V100% ≥ 95%, V95% ≥ 99%,  
V105% ≤ 10%, Dmax ≤ 110%

**Composite Constraints (Protocol)**

**Brain – PTV:**  
Max dose 0.03cc ≤ 95 Gy  
Max dose 1cc ≤ 90 Gy  

**Optic Chiasm:**  
Max dose 0.3cc ≤ 60 Gy  

**Optic Nerves:**  
Max dose 0.3cc ≤ 60 Gy  

**Brainstem:**  
Max dose 1cc ≤ 70 Gy  

If constraints cannot be met:  
**GTV** to 39.6 Gy, **CTV** and **PTV** to 36 Gy
Protocol: Dose-Volume Constraints for Reirradiation of Recurrent Brain Tumors

- Currently, no dose-volume recommendations for guiding brain reirradiation treatment planning

- Pilot study:
  - Dose-volume constraints are determined by:
    - Dx, age, concurrent chemo, and interval since previous radiation treatment
  - Follow-ups for 25 months after completion of reirradiation
  - The adult arm is closed: 21 adults; 1 case of grade 4 radionecrosis
  - The pediatric arm of the protocol is still open

- Previous study (2016)²
  - 12 children with recurrent brain tumors treated at MDACC
  - 2 year overall survival of 58% after reirradiation
  - No radiation-related high-grade hearing loss, visual pathway deficit, or IQ loss

Deformable Image Registration

FIRST COURSE CT
RT1

BLENDED CT
CTs Overlaid

SECOND COURSE CT
RT2
DEFORMATION PROCESS

- Physics performs and validates deformation
  - Match bony anatomy → algorithms deform soft tissue of moving CT to better match target CT using Hounsfield units assigned to voxels → dose is “attached” to each voxel and deforms with the image
- Physician validates deformed contours of targets and normal tissue structures
  - Aids physicians to determine changes in volumes and creates a more accurate plan sum.³
**RT2 Plan Set-up**

**Beams**
- 2 full arcs, CW and CCW

**Prescriptions**
- 39.6 Gy in 22 fractions
- Load RT1 deformed dose for composite plan

**Contours by Physician**
- Targets, Brainstem, Optic Chiasm, Pituitary, Hippocampus, Hypothalamus, Spinal Cord, Optic Nerves

**Contours by Dosimetrist**
- Eyes, Lens, Cochleas, Brain, Planning Structures

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**Review RT1**
Review RT1

**Composite Constraints**
- **Brain – PTV:** Max dose 0.03cc ≤ 95 Gy, Max dose 1cc ≤ 90 Gy
- **Optic Chiasm:** Max dose 0.3cc ≤ 60 Gy
- **Optic Nerves:** Max dose 0.3cc ≤ 60 Gy
- **Brainstem:** Max dose 1cc ≤ 70 Gy

If constraints cannot be met: GTV to 39.6 Gy, CTV and PTV to 36 Gy

Planning Structures

**pPTV**
- Account for dose fall off for OARs with max dose constraints
  - Formula: $2.916 \times \ln(\text{difference in Gy}) + 0.044 = mm$
  - Ex: $2.916 \times \ln(26) + 0.044 = 9.5 \text{ mm expansion from brainstem}$
  - $39.6 \text{ Gy } Rx - (70 \text{ Gy } RT2 \text{ composite max dose constraint } - 56 \text{ Gy } -RT1 \text{ max dose}) \approx 26 \text{ Gy}$
- Create expansions to take out of PTV
Things to keep in mind while you plan

- Make small edits, otherwise it may be hard to tell what breaks your plan
- Review composite plan after each run
- Set isodose lines that will help to visualize (ex. 70 Gy for brainstem)

  *Ex:*

  15 Gy in RT2 ≈ 70 Gy in RT1+RT2 composite plan in the brainstem

RT1 deformed onto RT2 CT

Dose (cGy)

- 6000
- 5400
- 4150
- 3960
- 3600
- 2500
- 2000
- 1000

- 6000
- 5400
- 4150
- 3960
- 3600
- 2500
- 2000
- 1000
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**RT2 – Early Optimization Run**

“Dose painting”
Create planning structures as needed that will fill in missing Rx, cool hot spots, and avoid that will push dose off of OARs and normal tissue

<table>
<thead>
<tr>
<th>Dose (cGy)</th>
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<tr>
<td>3960</td>
</tr>
<tr>
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<tr>
<td>2500</td>
</tr>
<tr>
<td>2000</td>
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<tr>
<td>1000</td>
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**RT2 – Later Optimization Run**

“Dose painting”
Typically start with target coverage, then slowly tighten plan to see how low you can push the normal tissue and make the plan more conformal and homogeneous

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Difficulty meeting both target coverage objective and brainstem constraint

Discuss priorities with physician

Physician approves higher brainstem constraint to 80 Gy

Approved Plan

Tip: Brainstem composite max dose 1cc ≤ 80 Gy

RT1: 56 Gy

80 Gy – 56 Gy = 24 Gy

Only 1cc of the area that overlapped with the RT1 56 Gy can receive 24 Gy, and the rest can receive more

VMAT allows dose to “wrap” around brainstem
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Composite Plan

Composite Constraints

- **Brain – PTV**: Max dose 0.03cc ≤ 95 Gy ✓
- Max dose 1cc ≤ 90 Gy ✓✓
- **Optic Chiasm**: Max dose 0.3cc ≤ 60 Gy ✓
- **Optic Nerves**: Max dose 0.3cc ≤ 60 Gy ✓
- **Brainstem**: Max dose 1cc ≤ 70 Gy ✗ → 80 Gy ✓

Dose (cGy)

- 9500
- 9360
- 8000
- 7000
- 6000
- 5400
- 4150
- 3960
- 3600
- 2500
- 2000
- 1000

Weekly QA: higher dose is more appropriate

Adaptive plan for remaining treatments
Adaptive Plan (RT2a)

o New prescription:
  • 50.4 Gy to the GTV
  • 45 Gy to PTV
  • 28 fractions

o What does this mean for dose constraints?
  • Discuss with physician: protocol, target coverage vs OAR constraints

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Adaptive Plan (RT2a)

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  • 28 fractions

o What does this mean for dose constraints?
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<td>Brain – PTV: Max dose 0.03cc ≤ 105 Gy, Max dose 1cc ≤ 100 Gy</td>
</tr>
<tr>
<td>Optic Chiasm: Max dose 0.3cc ≤ 75 Gy</td>
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<td>Optic Nerves: Max dose 0.3cc ≤ 75 Gy</td>
</tr>
<tr>
<td>Brainstem: Max dose 1cc ≤ 80 Gy</td>
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Adaptive Planning\textsuperscript{3,4}

- Adaptive planning is the re-planning of a radiation therapy treatment plan during the course of treatment.
- Possible reasons for an adaptive plan: changes in patient set-up, tumor volume, or patient anatomy, or any other situation that physician/physics deems necessary to alter the current plan of treatment
  - It is necessary when sufficient target volume coverage and/or organ at risk sparing is not achieved by the original plan
- Typically a new CT data set is acquired and registered with the original CT
  - A “verification plan” can be done to validate if an adaptive plan is necessary
- Turn around time for the adaptive plan is relatively quick
  - To avoid unnecessary delays, the patient will most often continue with the original plan until the adaptive plan is completed and approved

**NOTE**
This “adaptive” plan was not done a new CT, therefore it did not have a verification plan. The new plan was planned on the same CT; this is also commonly called a rework.
RT2a – Faux “Verification Plan”

**Scale RT2 to 28 fx**

Evaluate composite

<table>
<thead>
<tr>
<th>Dose (cGy)</th>
<th>5300</th>
<th>5040</th>
<th>4500</th>
<th>4140</th>
<th>3701</th>
<th>3600</th>
<th>2400</th>
<th>1900</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Dose (cGy)</th>
<th>5000</th>
<th>4600</th>
<th>4150</th>
<th>4110</th>
<th>3701</th>
<th>3600</th>
<th>2800</th>
<th>2500</th>
</tr>
</thead>
</table>

**RT2a Composite Constraints**

- **Brain – PTV**: Max dose 0.03cc ≤ 105 Gy, Max dose 1cc ≤ 100 Gy
- **Optic Chiasm**: Max dose 0.3cc ≤ 75 Gy
- **Optic Nerves**: Max dose 0.3cc ≤ 75 Gy
- **Brainstem**: Max dose 1cc ≤ 80 Gy
RT2a Plan Set-up

Beams
- 2 full arcs, CW and CCW

Prescriptions
- 39.6 Gy in 22 fractions → 50.4 Gy in 28 fractions
- Load deformed dose for composite plan
- Load RT2, set to 5 fractions

Contours
- None (use same contours because adaptive plan was done on same CT)

*Patient was treated for 4 days + 1 day was given to complete plan = 5 days on RT2
RT2a Plan Set-up

Beams
- 2 full arcs, CW and CCW

Prescriptions
- 39.6 Gy in 22 fractions → 50.4 Gy in 28 fractions
  *Set this to 180 cGy/fraction for 23 fractions (28-5)
- Load deformed dose for composite plan
- Load RT2, set to 5 fractions
  *Patient was treated for 4 days + 1 day was given to complete plan = 5 days on RT2

Contours
- None (use same contours because adaptive plan was done on same CT)

Preliminary Planning

1. Review DVHs
2. Scroll through OARs
3. Calculations:
   - The patient received 180 cGy x 5 days = 900 cGy
   - Plan RT2a to 23 fx:
     - GTV: 5040 cGy/28 fx = 180 cGy → 180 cGy x 23 fx = 4140 cGy
     - PTV: 4500 cGy/28 fx = 161 cGy → 161 cGy x 23 fx = 3701 cGy
4. Create expansions for OARs
5. Create pPTV(s)
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Review What Has Been Given

RT2 scaled down to 5 fx

RT1 + RT2 (5 fx) Composite

Review What Has Been Given – RT1 + RT2 (5 fx)
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1. Planning structures take into account RT1+RT2(5fx)

- 49 Gy isodose cloud
Planning structures take into account RT1 + RT2 (5fx)
1. 49 Gy isodose cloud
2. 58 Gy isodose cloud
RT2a Planning Structures: pPTVs

- Planning structures take into account RT1+RT2 (5fx)
  1. 49 Gy isodose cloud
  2. 58 Gy isodose cloud
  3. PTV in brainstem that received 58 Gy
     - pPTV22 (80 Gy – 58 Gy)
  4. PTV in brainstem that received 49 Gy – (pPTV22 + 2 mm)
     - pPTV31 (80 Gy – 49 Gy)

1. Dose fall off from 50.4 Gy CTV+GTV to pPTV22 and pPTV31
RT2a Planning Structures: pPTVs

1. Dose fall off from 50.4 Gy $\text{CTV} + \text{GTV}$ to $\text{pPTV22}$ and $\text{pPTV31}$
   - Expand the $\text{pPTV22}$ by 8 mm
     \[ \approx 2.916 \times \ln(50.4 - 22) + .044 \]
   - Expand the $\text{pPTV31}$ by 7 mm
     \[ \approx 2.916 \times \ln(50.4 - 31) + .044 \]
1. Dose fall off from 50.4 Gy CTV + GTV to pPTV22 and pPTV31
   • Expand the pPTV22 by 8 mm
     \( \approx 2.916 \times \ln(50.4-22) + .044 \)
   • Expand the pPTV31 by 7 mm
     \( \approx 2.916 \times \ln(50.4-31) + .044 \)

2. CTV + GTV – Expansions
   ➢ pPTV50.4 in CTV + GTV

3. PTV – (CTV + GTV + 1 mm) – Expansions
   ➢ pPTV45 in PTV
**RT2a Planning Structures: pPTVs**

1. Dose fall off from 50.4 Gy CTV+GTV to pPTV22 and pPTV31
   - Expand the pPTV22 by 8 mm
     \(\approx 2.916 \times \ln(50.4-22) + .044\)
   - Expand the pPTV31 by 7 mm
     \(\approx 2.916 \times \ln(50.4-31) + .044\)

2. CTV+GTV – Expansions
   - pPTV50.4 in CTV+GTV

3. PTV – (CTV+GTV+1 mm) – Expansions
   - pPTV45 in PTV

**RT2a – Early Optimization Run**

- Start with more loose constraints
- Adjust the “pPTV31” and “pPTV22” as you need to meet brainstem constraints
  - Changed to manage 24 Gy and 19 Gy, respectively
RT2a – Later Optimization Run

- Focus on coverage first

Dose (cGy)
- 5300
- 5040
- 4500
- 4140
- 3701
- 2400
- 1900

RT2a – Later Optimization Run

- Tighten up the dose as you optimize
- Adjust the “pPTV31” and “pPTV22” as you need to meet brainstem constraints
  - Initially changed to manage 24 Gy and 19 Gy, respectively
  - Towards the end of optimization, changed again to manage 22 Gy and 18.5 Gy, respectively
Approved Plan

RT2a to 23 fx

CTV + GTV to 4140 cGy
PTV to 3701 cGy

RT2a to 23 fx
RT2 to 5 fx

CTV + GTV to 6000 cGy
PTV to 4500 cGy

RT2a to 23 fx
RT2 to 5 fx
RT1 deformed dose

Composite: RT1 + RT2 (5fx) + RT2a

Composite Constraints
- Brain – PTV: Max dose 0.03cc ≤ 105 Gy
- Max dose 1cc ≤ 100 Gy
- Optic Chiasm: Max dose 0.3cc ≤ 75 Gy
- Optic Nerves: Max dose 0.3cc ≤ 75 Gy
- Brainstem: Max dose 1cc ≤ 80 Gy
CONCLUSION

Final Thoughts

What we’ve learned:
- Treatment planning has a lot of moving parts
- Communication is key
  - Need upfront dose constraints from physician
- Adaptive plans can be time consuming
  - Preliminary planning and many iterations
- Adaptive plans require quick turn around time
  - The sooner an adaptive plan is implemented, the more effective it is

Other thoughts:
- Adaptive plans tend to look different and sometimes physicians want the same plan
- Tumors don’t always shrink: sometimes targets get bigger or completely disappear, and the tissue landscape changes drastically
- Protocol constraints

Patient Update
- Despite being more aggressive with the dose, patient recently has had progressive disease
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REFERENCES


Questions?

Thank You!

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