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Hybrid VMAT/IMRT Approach to Traditional Cranio-Spinal Irradiation (CSI): A Case Study on Planning Techniques and Delivery

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November 3, 2017

The James Cancer Hospital

- I have been a medical dosimetrist at the James Cancer Hospital since August 2015
  - Graduate of Indiana University Medical Dosimetry Program in 2015
- The James opened its new building in December of 2014
  - 2nd floor of the hospital
  - 7 Varian TrueBeams at main campus
  - 2 Varian TrueBeams at Stefanie Spielman Comprehensive Breast Center
  - PET/CT, CT and MRI in our department on campus
  - Treat 200-250 patients per day
    - 60-70% IMRT/VMAT
  - Wide Variety of disease sites
    - Pediatrics, HN, Thoracic, Blood-Based, CNS, GI, GYN, GU, Skin, Breast, Sarcomas, Stereotactic + Palliative Care

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Disclosures

- I have no conflict of interest with any of the vendors, software, or equipment used for this presentation
- This presentation is not a marketing or sales presentation regarding specific products or software
- Any software or trade names mentioned in this presentation are results of accurate reporting only

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Special Thank You to our CSI team

- Raju Raval, MD, Assistant Professor, Radiation Oncology
- Josh Palmer, MD, Assistant Professor, Radiation Oncology
- Ashlee Ewing, CMD, Medical Dosimetrist, Radiation Oncology
- Dominic DiCostanzo, MS, Medical Physicist, Radiation Oncology
- Our therapists in simulation & on the linear accelerators
- Our physics team performing QA and second checks

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Learning Objectives

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Learning Objectives

- To understand how to utilize fluence painting to create a dose gradient at field junctions
- To understand how to implement base dose planning to automatically match gradients at field junctions
- To understand the immobilization techniques and IGRT used to ensure accurate delivery

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Cranio-Spinal Irradiation (CSI) - Background

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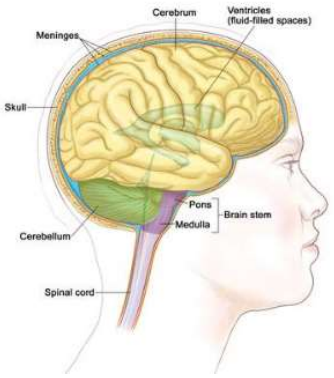
Central Nervous System tumors

- CNS tumors generally start in the brain and can spread to the spinal cord through cerebrospinal fluid (CSF)
- Leptomeningeal disease is when the tumor invades the pia and arachnoid mater, and is more common with certain types of brain tumors
- About 23,800 malignant tumors of the brain or spinal cord will be diagnosed in 2017 according to estimates from The American Cancer Society
- About 16,700 people will die from brain and spinal cord tumors



[1] American Cancer Society
[2] National Cancer Institute

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CNS tumors con't

- There are different types of brain tumors - astrocytoma, oligodendroglioma, ependymoma, medulloblastoma, and many others
- Astrocytoma
  - High grade – glioblastoma multiforme (GBM) is the fastest growing, also most common malignant brain tumor in adults
  - Intermediate grade – grow at a moderate rate
  - Low grade – tend to grow slowly but can become more aggressive over time
- Medulloblastoma – develop in cerebellum, fast growing, more common in children, part of a class of tumors called primitive neuroectodermal tumors (PNET)

[1] American Cancer Society

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Cranio-spinal Irradiation

- If the tumor has spread along the spinal cord or into the CSF, radiation can be given to the brain and spinal canal using cranio-spinal irradiation
- Previously at the James we treated lateral beams to the whole brain with matching single PA spine fields with junctions to feather the dose in the overlap regions
- Dose prescriptions vary depending on the type of disease. 36Gy is common for adults, 18Gy is common for pediatric patients. Some patients receive posterior fossa boosts as well

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CSI treatments

- Goal
  - Create homogeneous dose throughout brain and spinal canal
- Toxicities
  - Fatigue
  - Nausea
  - Emesis
  - Esophagitis
  - Increased risk for secondary malignancies

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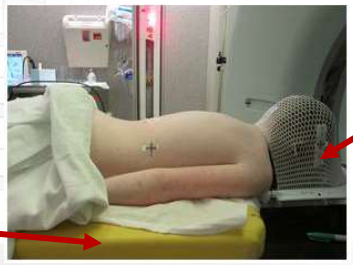
CSI at The James previously - prone

- Setup: prone, yellow pad underneath, ankle sponge, prone head holder with mask, arms at sides
- 3 point setup in brain, second set of marks halfway between shoulders and coccyx
- In treatment planning system: set origin at brain, contour spinal canal, brain, eyes, lens, optic nerves and chiasm, cochlea, brainstem



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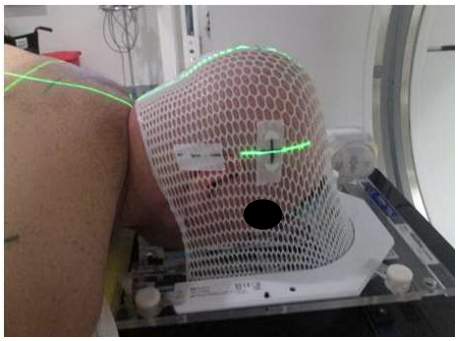
CSI – prone setup



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Brain fields – traditional CSI

- Brain fields
  - opposed laterals
  - isocenter placed at CT origin, x=0 y=0 z=0
  - inferior border placed just above shoulders
  - flash 2cm superior, anterior, and posterior
- To match divergence of spine field, calculate collimator angle for brain field using the formula:

  Arc tan [(Length Upper Spine/2) ÷ SSD]

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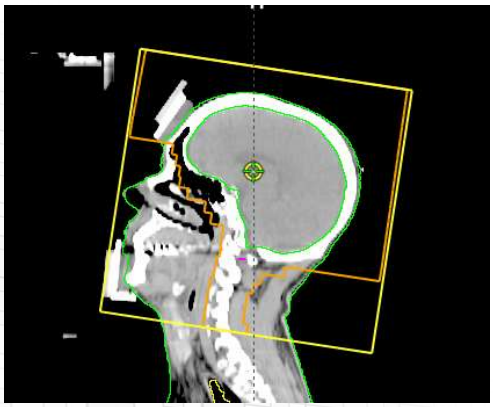
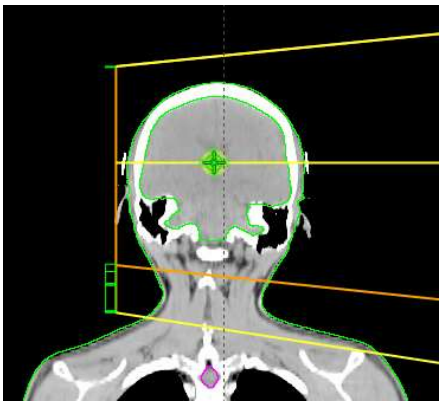
Brain fields – traditional CSI





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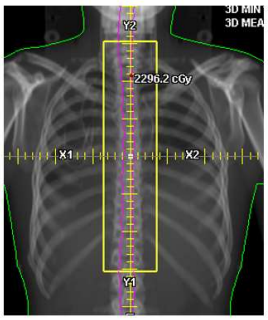
Upper Spine field – traditional CSI

- Spine fields are both single field PA beams
- Upper Spine field has superior border placed to match brain field inferior border on skin posteriorly, inferior border is approximately at marks from CT halfway between shoulders and coccyx.



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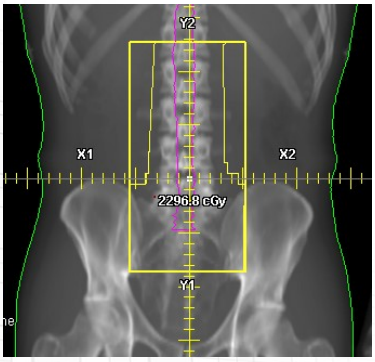
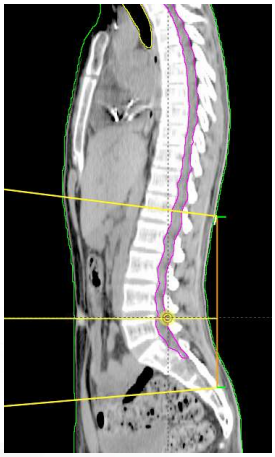
Lower Spine field – traditional CSI

- Lower spine field has its superior border matched with the inferior border of upper spine field on skin surface, lower border is about S2





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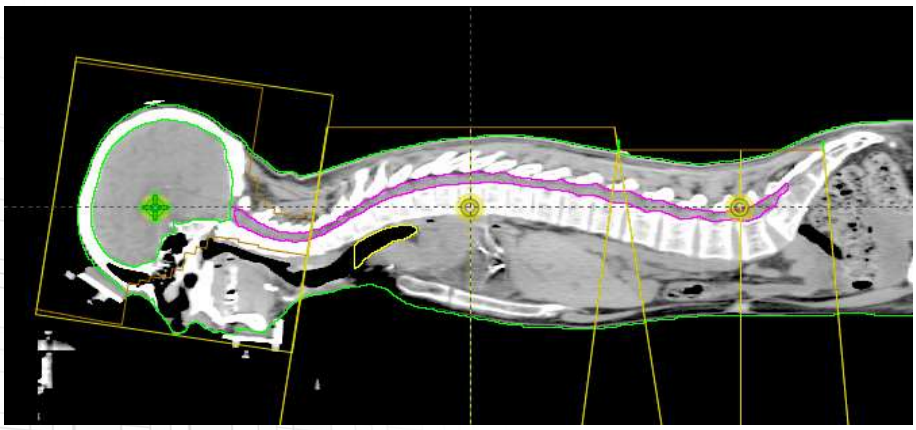
CSI Field Placement



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CSI Junctions

- Physician draws MLCs
- 3 junctions total for each plan
- No need to shift every 5 treatments, we treated all 3 junctions each day

- For Brain: each junction moves Y1 jaw superior then uses field in field to create homogeneous dose distribution
- For Upper spine: superior junction moves superior 1 cm, inferior junction moves 1 cm superior, utilizes field in field
- For lower spine: superior junction border moves 1cm superior, inferior border remains at S2 for all fields

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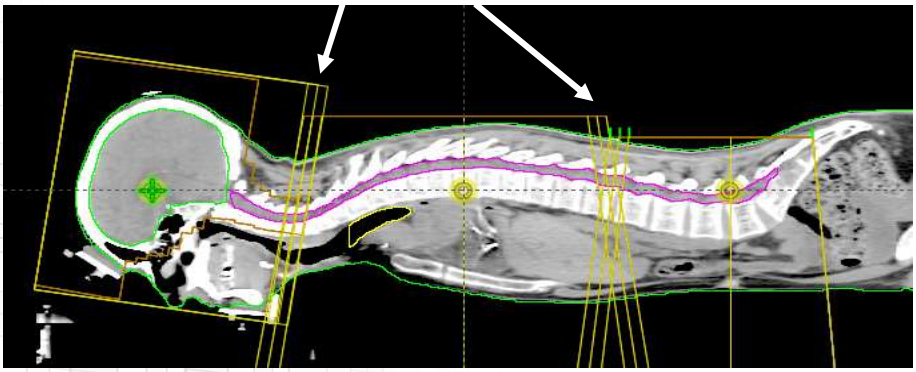
CSI Field Placement

Junctions used to feather



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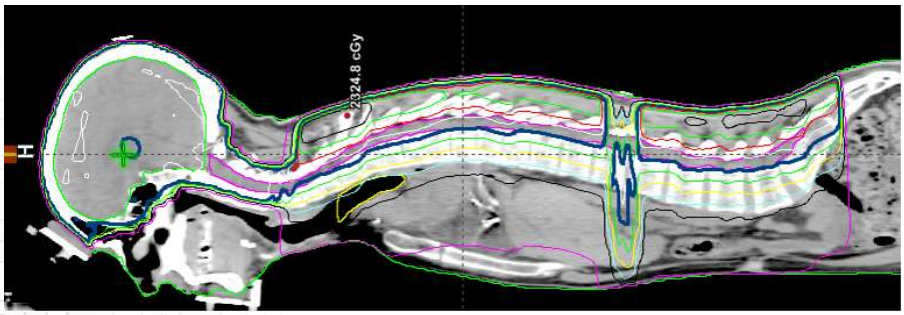
CSI Dose Distribution



Blue – 100% isodose line = prescription dose

Black – 129% hot

Pink – 60% of prescription dose

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Our technique

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Our CSI technique

- We wanted to develop a technique for treating our CSI patients supine for their comfort and anesthesia purposes that is faster so their time spent on the table is decreased
- Our physicians requested any new technique we implement result in a similar dose distribution as before
- Our pediatric physicians did not want to use full VMAT arcs in spine due to the low dose spread throughout the body, especially in the lungs and bowel

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Our CSI technique

- Full VMAT arcs in the brain matched to two static IMRT PA fields for the upper and lower spine
- New technique requires no physical junctions or gap calculations for each plan
- Manually adjust the fluence on each spine field to feather the dose, the planning is more robust

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CT Simulation

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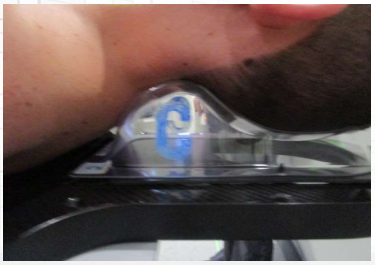
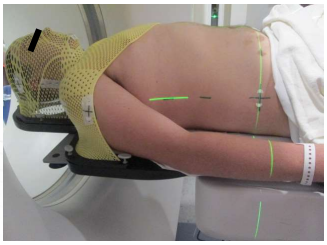
CT Sim

- Supine
- B or C head rest, no custom HR, ensure patient's chin is comfortably tilted up as much as possible
- Long aquaplast mask
- Hands reaching down to grasp hand pegs (keep shoulders down)
- Knee sponge and foot sponge indexed





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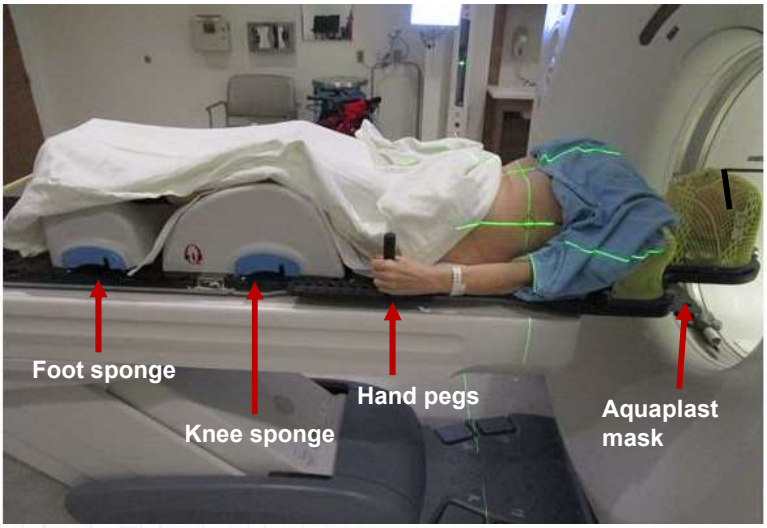
CT Sim - overview



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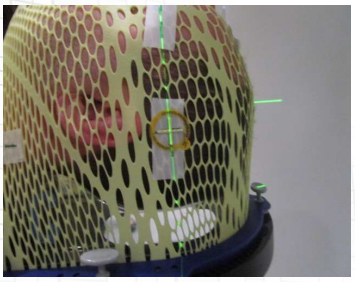
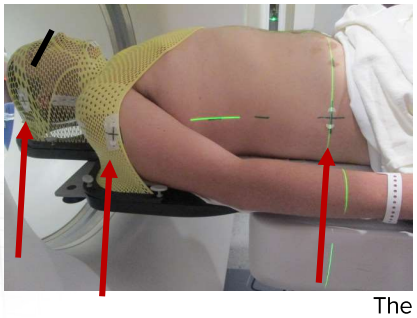
CT Sim

- 3 point setup in brain is CT origin: superior and slightly posterior to EAM
- Move inferior, usually 20-30cm, and mark second set of 3 point marks with levelers, works best to have marks on mask for stability
- Move table inferior again, about 55-60cm from brain, mark third set of 3 point marks on lower abdomen





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CT Sim – scan parameters

- Scan superiorly from above the conformal board through the pelvis to mid-femurs
- Use the topogram to ensure the patient is straight
- Scan at eFoV to ensure we get all of the shoulders in the scan
- Free Breathing CT scan acquired with 2.5mm slice thickness
- Ensure fiducials are visible at CT origin in brain

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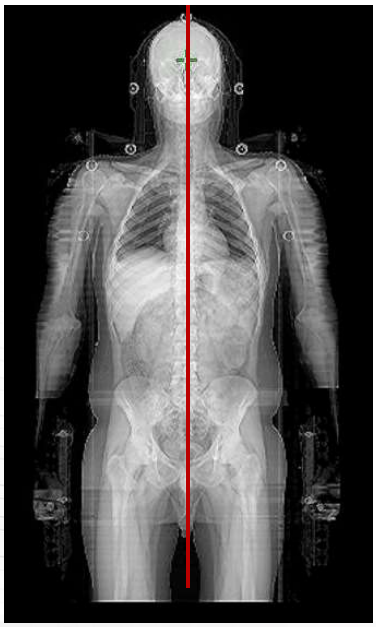
CT Sim



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Contouring

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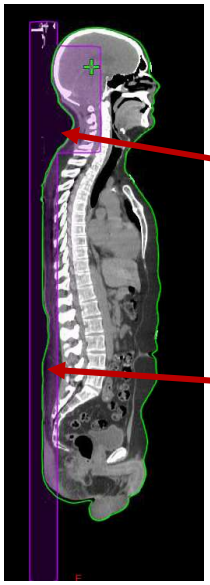
Contouring – overview

- Patient is scanned on a conformal board so no table or rails are inserted, but table and immobilization are contoured on each slice
- Both the table and head rest immobilization are included inside the body contour so the TPS takes into account their attenuation



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Contouring - Targets

- Physician will draw
  - Spinal cord
  - Spinal canal
  - PTV CSI
    - Expansion from Spinal Canal: 1.5cm left and right, 0.3cm anterior and posterior
    - Expansion from Brain: started with 0.3cm but increased to 0.4cm
  - GTV, CTV, and PTV Posterior Fossa Boost (if applicable)

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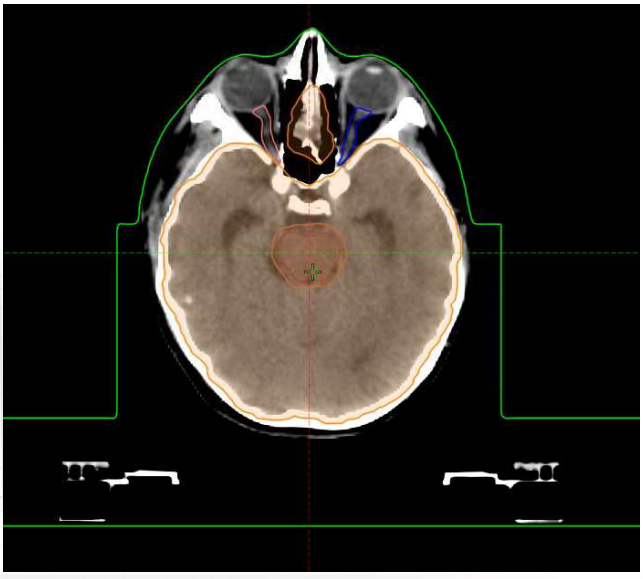
Axial slice in brain



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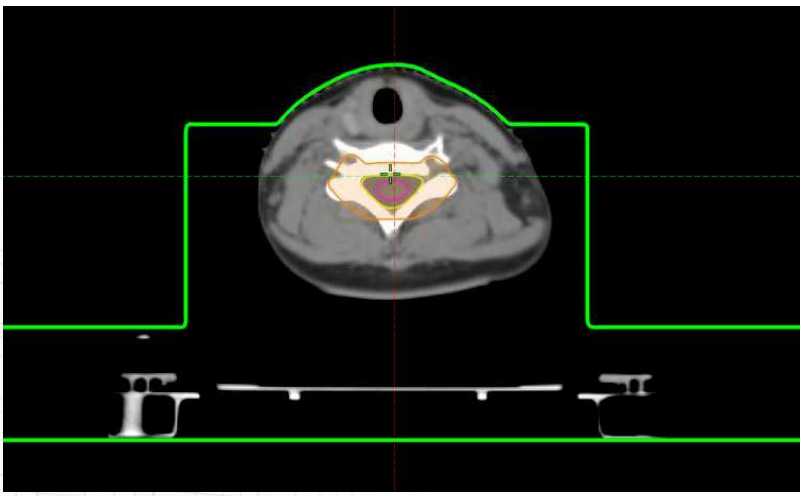
Axial slice through neck



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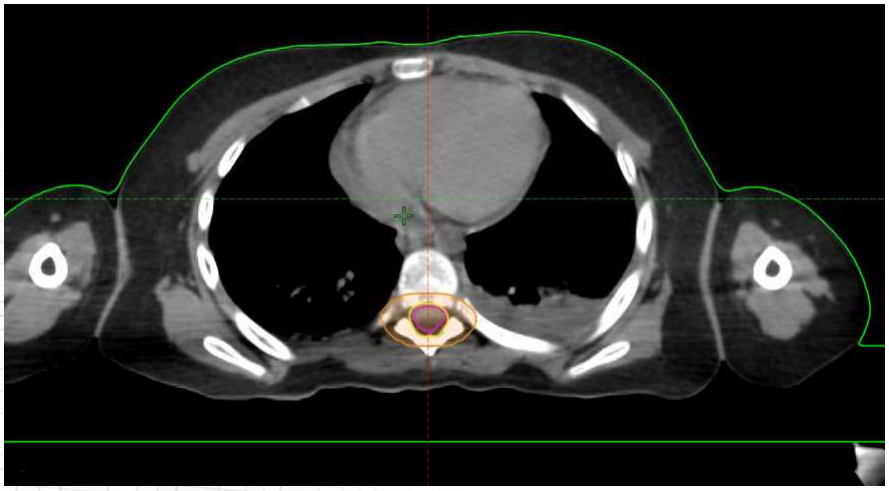
Axial slice through chest



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Axial slice through low pelvis

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Contouring – Normal structures

- To be contoured by dosimetrist or physician:
  - Bones can be contoured for pediatric patients if needed

Bowel	Eye Lt	Larynx	Lung Lt	Optic Nerve Rt
Brain	Eye Rt	Kidney Lt	Lung Rt	Retina Lt
Brainstem	Esophagus	Kidney Rt	Oral Cavity	Retina Rt
Cochlea Lt	Genitalia	Lens Lt	Optic Chiasm	Bones
Cochlea Rt	Heart	Lens Rt	Optic Nerve Lt	

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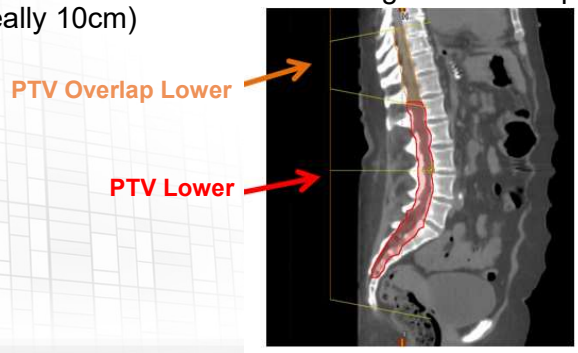
Contouring

- PTV Lower
  - 1.5cm lateral margin, 0.3cm ant/post margin from spinal canal with the field including 1cm inferior for flash
- PTV Overlap Lower
  - Extends from superior border of lower spine plan to a minimum of 5cm inferior – the larger the overlap, the better (ideally 10cm)



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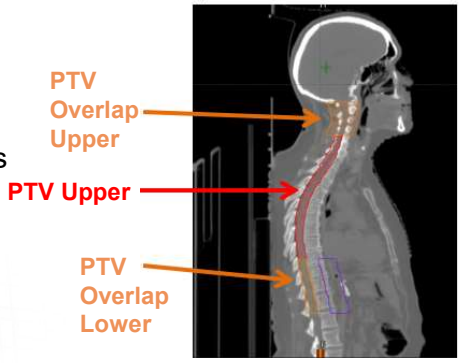
Contouring

- PTV Overlap Upper
  - Depends on shoulder placement, superiorly begins at first slice of spinal canal, last slice is at level of shoulders
  - Should be at least 5cm sup-inf and extends 1.5cm in all radial directions for planning
- PTV Upper
  - Same margins as PTV Lower, begins superiorly at PTV Overlap Upper, extends inferiorly to PTV Overlap Lower
- PTV Overlap Upper, PTV Upper and PTV Overlap Lower should all be within 37cm max field size of the upper spine plan



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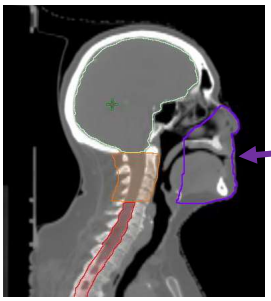
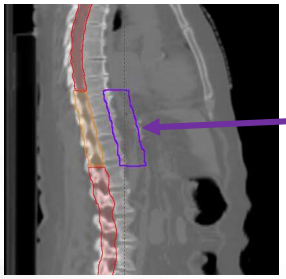
Contouring – Optimization structures

- Anterior Face Avoid
  - Anterior margin from PTV CSI then cropped away from PTV to limit dose to anterior face
- Anterior Spine Avoid
  - Anterior margin from PTV Overlap Lower, cropped away from PTV Overlap Lower to control dose in overlap region





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Treatment Planning

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Treatment Planning

- Machine capabilities:
  - Linac with 6MV and 10MV energies is preferable
    - 6MV is best for brain while 10MV is better for spine fields
  - Linac with 40x40cm field size is necessary to cover PTV using 3 isocenters for an adult patient
  - Linac with CBCT capability is best for setup
    - Orthogonal films are adequate for spine positioning but using CBCT for verifying the brain setup is preferable

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Treatment Planning

- Start with Lower Spine plan
  - Each plan is based off the plan inferior to it, so we start with the most inferior plan
  - IMRT field using single PA beam, energy is 10MV
  - Once calculated, we edit the fluence in the overlap region from the hottest reading to about 10%
  - Calculate using sliding window
  - Goal is to have 100% isodose line following the shape of the spinal canal

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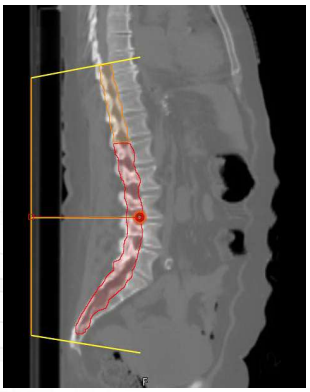
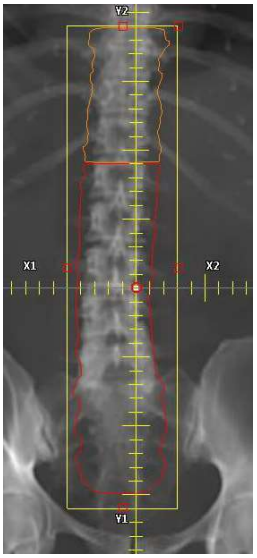
Treatment Planning – Lower Spine

- Place field to cover PTV Lower Spine and PTV Overlap Lower with 1cm flash inferior

- Gantry – 180
- Collimator – 0
- Energy – 10MV





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Treatment Planning – Lower Spine

- Optimization objectives

	ID/Type	Vol[cm³]	Vol [%]	Dose [cGy]	Actual Dose [cGy]	Priority	gEUD a	
☑	PTV LOWER	291.8						
	Upper		0.0	4100		125		x
	Lower		100.0	3600		125		x
☑	PTV OVERLAP LOW	56.4						
	Upper		0.0	4100		125		x
	Lower		100.0	3600		125		x
☑	Ant Spine Avoid	102.0						
	Upper		0.0	3240		75		x
☑	BODY	124609.9						

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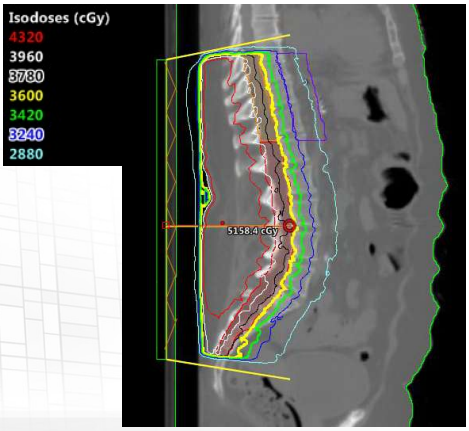
Treatment Planning – Lower Spine

- Dose distribution after optimization
- Need to add fluence inferior and step down the fluence superior within PTV Overlap Lower



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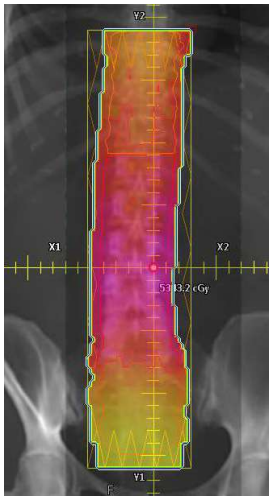
Treatment Planning – Lower Spine

- This is the fluence before we manually step down the dose in the overlap region
- To step down the dose, measure transmission factor in the superior portion of the PTV Lower contour
- Decrease the transmission factor by a defined value
  - If the transmission measures 0.730, we divide that by the number of cm in the overlap region so .730/10cm for this pt
- Want to decrease fluence every 1cm in the overlap region until we get to 10%



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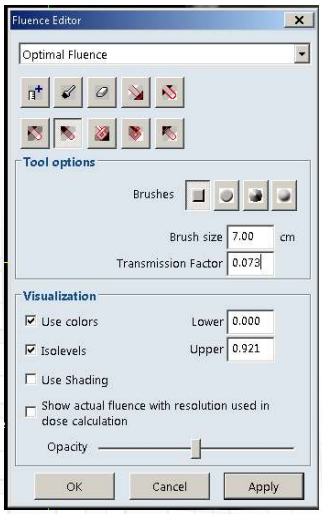
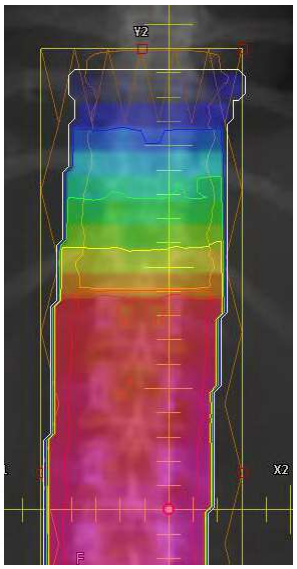
Editing Fluence





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Dose distribution

Now the dose decreases as we move superior along the spine

When planning the upper spine, use the lower spine as a base dose plan to create the step down region for the inferior portion of the upper spine plan

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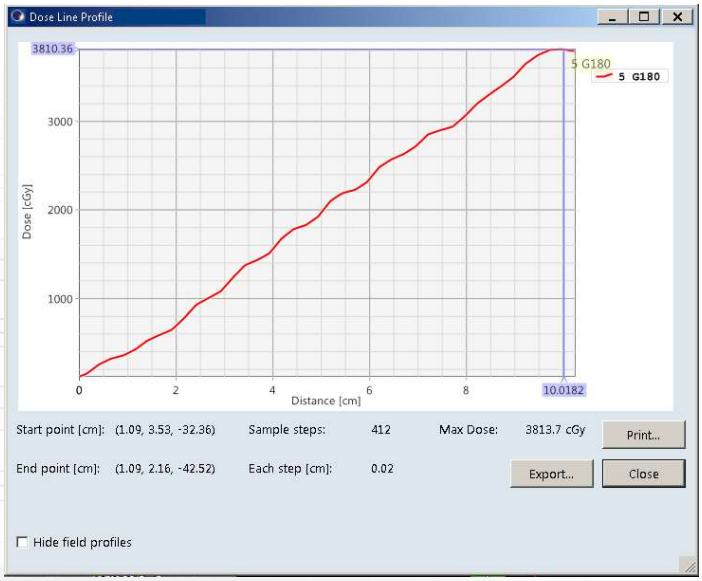
Dose profile – Lower Spine plan overlap



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Treatment Planning – Upper Spine

- Move to Upper Spine plan
  - Use Lower Spine plan as base dose plan when optimizing
  - IMRT plan using single PA field, energy is 10MV
  - Once calculated, we edit the fluence in the upper overlap region the same way we did the lower spine overlap
  - Calculate using sliding window
  - Goal is to have 100% isodose line following the shape of the spinal canal

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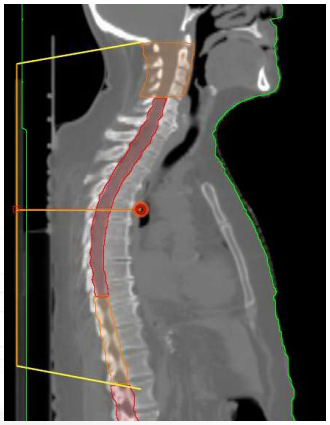
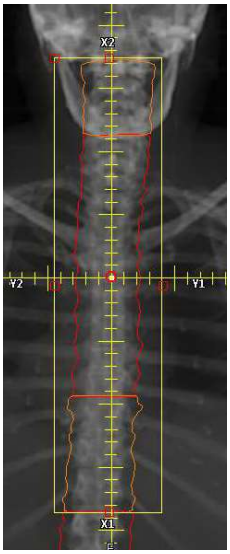
Treatment Planning – Upper Spine

- Field should cover PTV Overlap Lower, PTV Upper, and PTV Upper Overlap with at least 5cm coverage of PTV Upper Overlap
- Gantry – 180
- Collimator – 90
- Energy – 10MV





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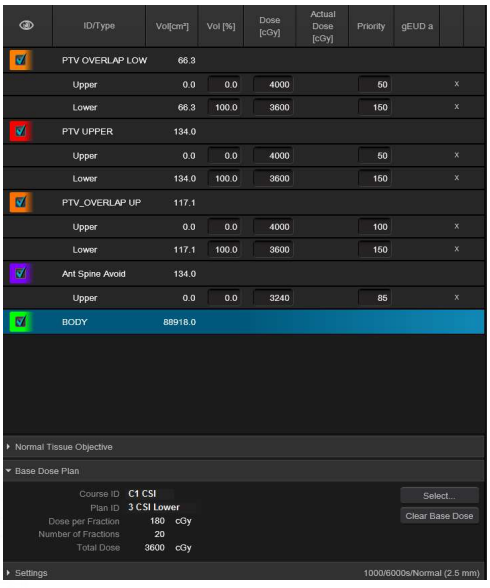
Optimization

- Optimization for Upper Spine plan with Lower Spine plan as base dose, will automatically create the feathered fluence on the inferior portion of the Upper Spine plan
- After calculating, need to edit the fluence on the superior portion of the field in the PTV Upper Overlap region



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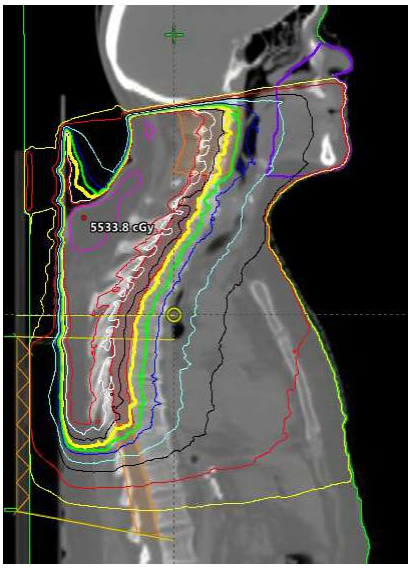
Dose distribution

- Example of the dose distribution after optimization, using the base dose plan
- Now we need to step down fluence superiorly within PTV Overlap Upper



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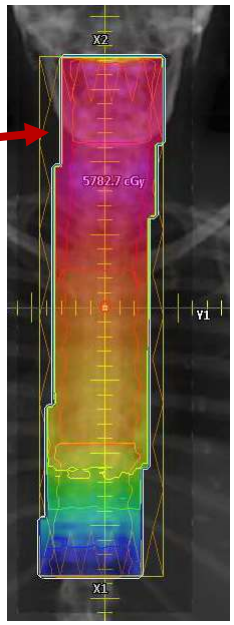
Fluence – Upper Spine

- Need to step down the dose here in the overlap region of the PTV Upper Spine
- The dose steps down automatically inferior because the optimization created the fluence based off the Lower Spine plan



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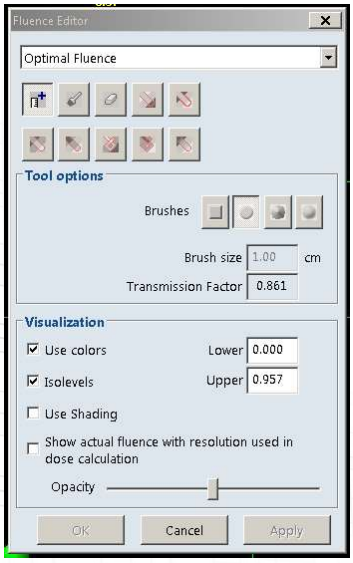
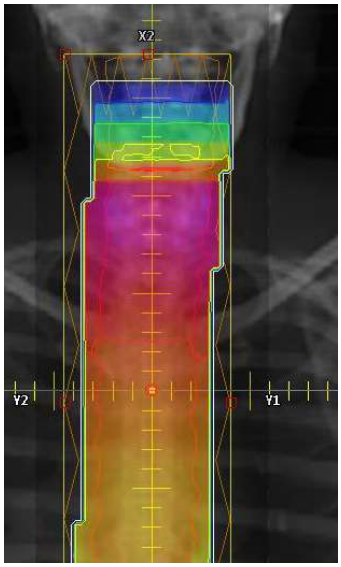
Editing fluence



$\frac{0.861}{6\text{cm}}$ = 0.143 is transmission factor



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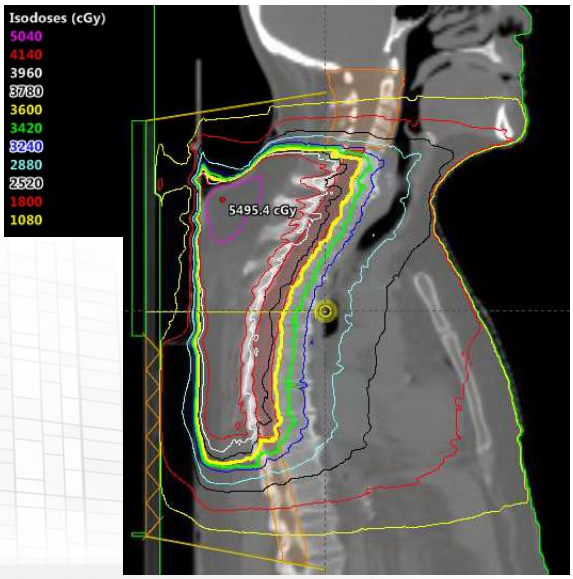
Dose Distribution



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Dose Profile in overlap

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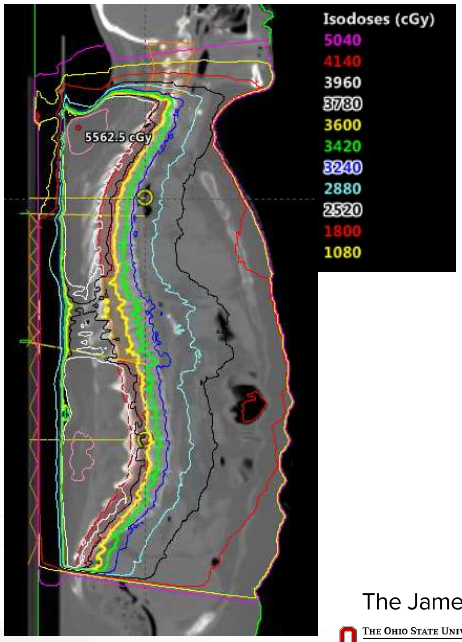
Spine plan sum

- Plan sum of upper and lower spine plans



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Treatment Planning – Brain

- Plan brain fields last, use Upper Spine plan as base dose when optimizing
- 3 full VMAT arcs
- Gantry: 181-179 CW, 178-182 CCW, 181-179 CW
- Collimator: 10, 350, 90 respectively
- The fluence in the PTV Upper Overlap region will feather automatically from optimizing with the Upper Spine plan as a base dose plan so no manual fluence editing necessary

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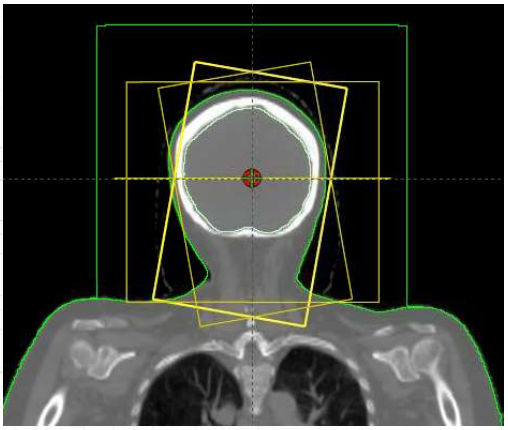
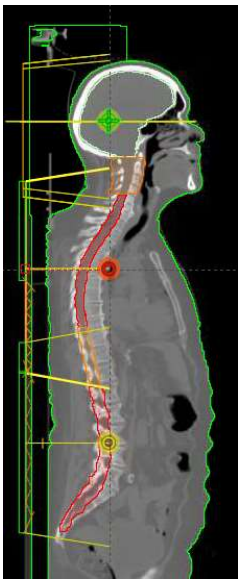
Brain plan fields

- Fields should cover the brain and the PTV Overlap Upper just above the shoulders





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Optimization objectives

	ID/Type	Vol[cm³]	Vol [%]	Dose [cGy]	Actual Dose [cGy]	Priority	gEUD a	
	3_PPTV_Brain	1483.6						
	Upper		0.0	3700		125		x
	Lower		100.0	3600		125		x
	PTV_OVERLAP UP	117.1						
	Upper		0.0	3850		125		x
	Lower		100.0	3600		125		x
	Ant Face Avoid	546.8						
	Mean			800		70		x
	Cochlea L	0.2						
	Upper		0.0	2500		60		x
	Mean			1500		60		x
	Cochlea R	0.2						
	Upper		0.0	2500		60		x
	Mean			1500		60		x

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Optimization objectives con't

	Eye Left	9.0				
	Upper		0.0	2000	60	x
	Eye Right	8.9				
	Upper		0.0	2000	60	x
	Lens Left	0.2				
	Upper		0.0	1000	50	x
	Lens Right	0.2				
	Upper		0.0	1000	50	x
	Retina_L	3.6				
	Upper		0.0	2000	50	x
	Retina_R	3.7				
	Upper		0.0	2000	50	x
	BODY	88918.0				

Normal Tissue Objective

MU Objective

Base Dose Plan

Course ID C1 CSI
Plan ID 2 CSI Upper
Dose per Fraction 180 cGy
Number of Fractions 20
Total Dose 3600 cGy

Select...
Clear Base Dose

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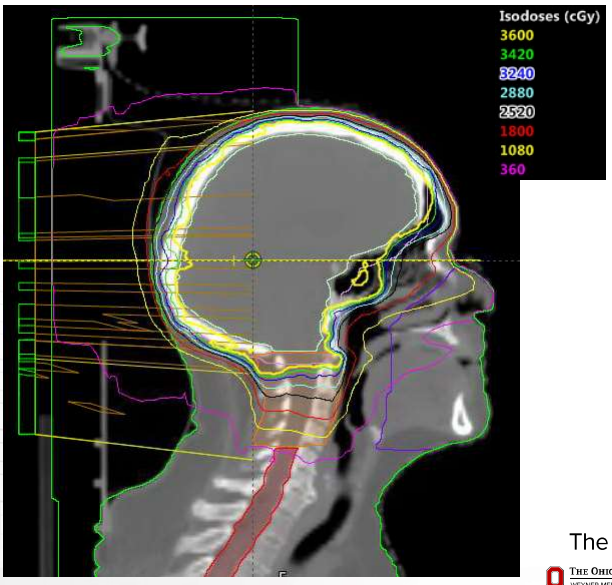
Dose distribution – brain plan



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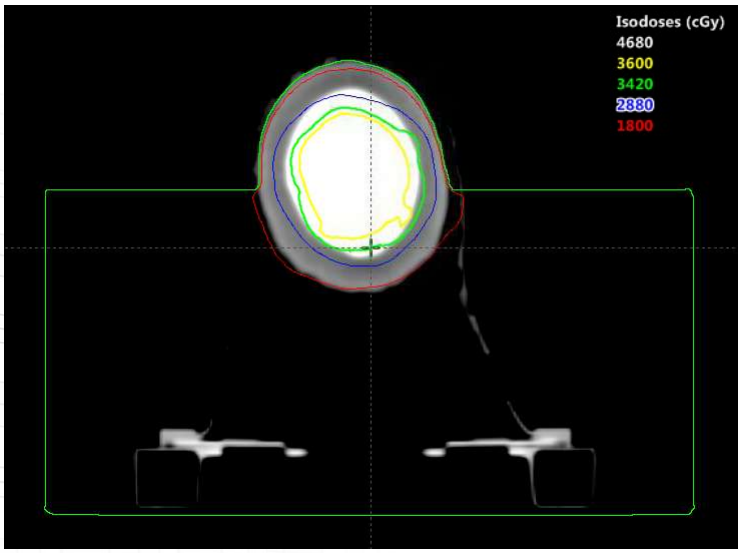
Axial slice - brain



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Axial slice - brain

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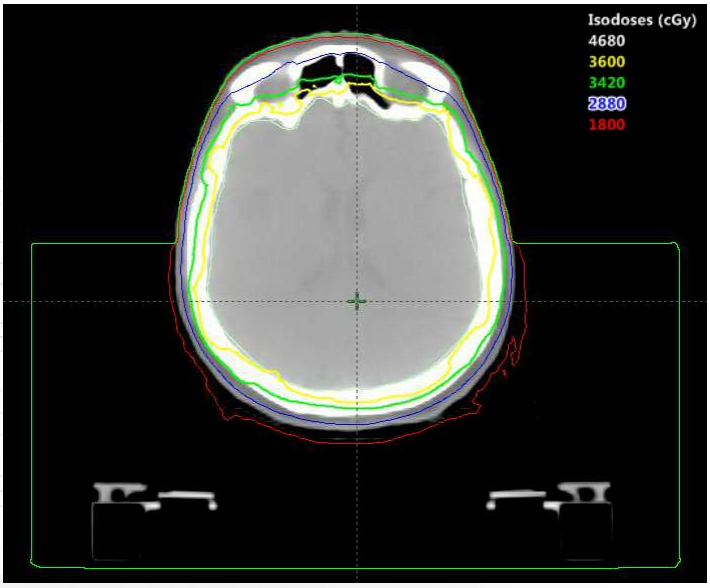
Axial slice - brain



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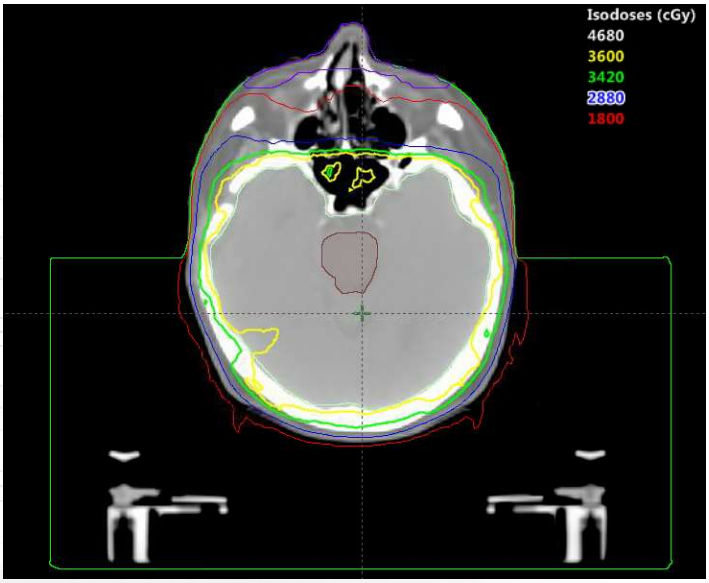
Axial slice - brain



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Axial slice - brain

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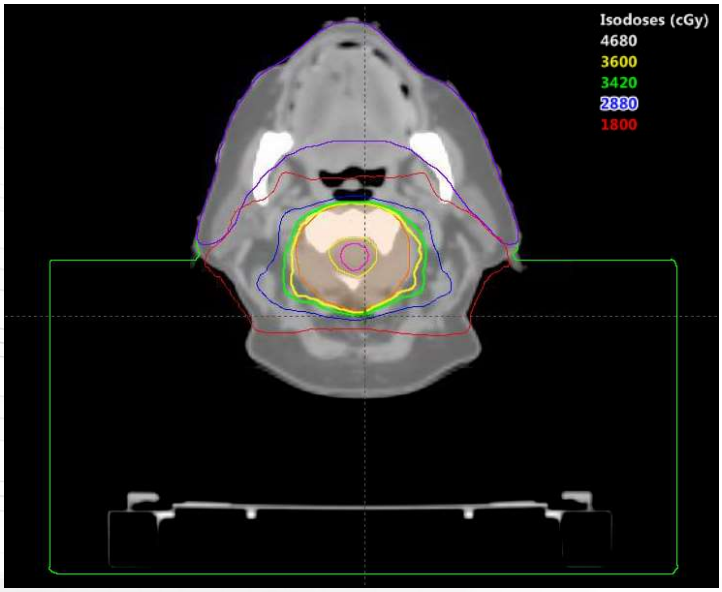
Axial slice - neck



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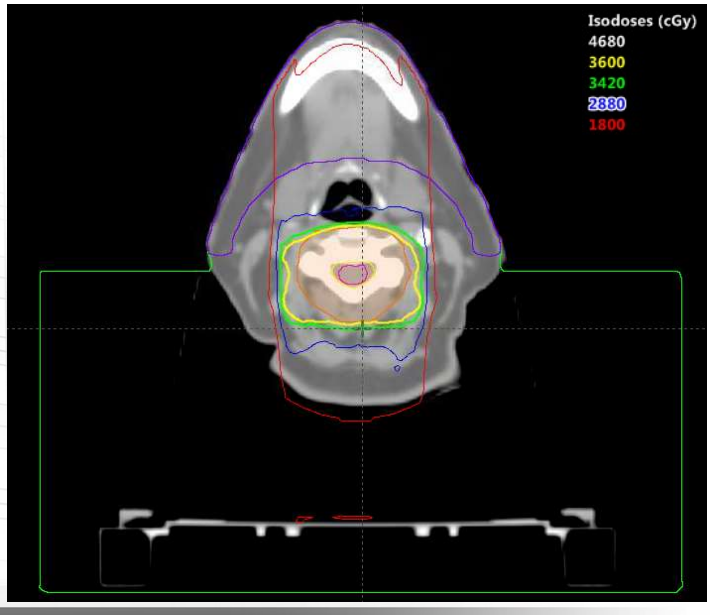
Axial slice - neck



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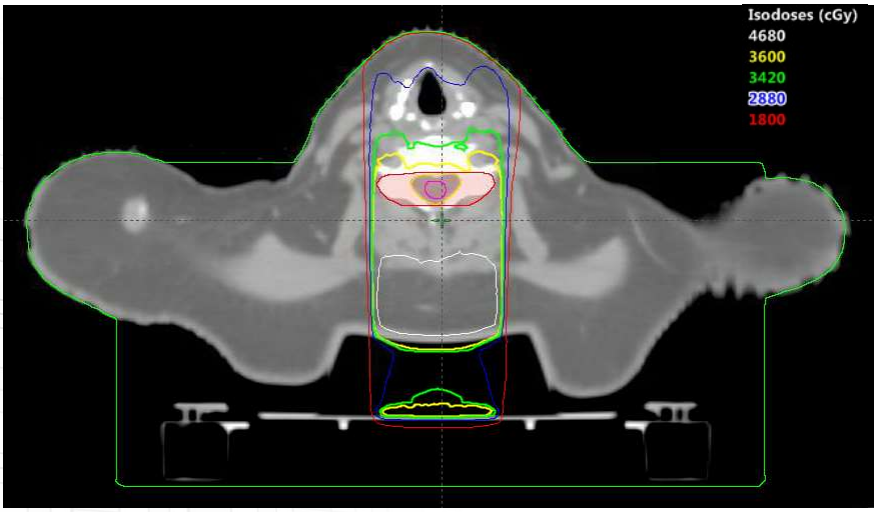
Axial slice - neck



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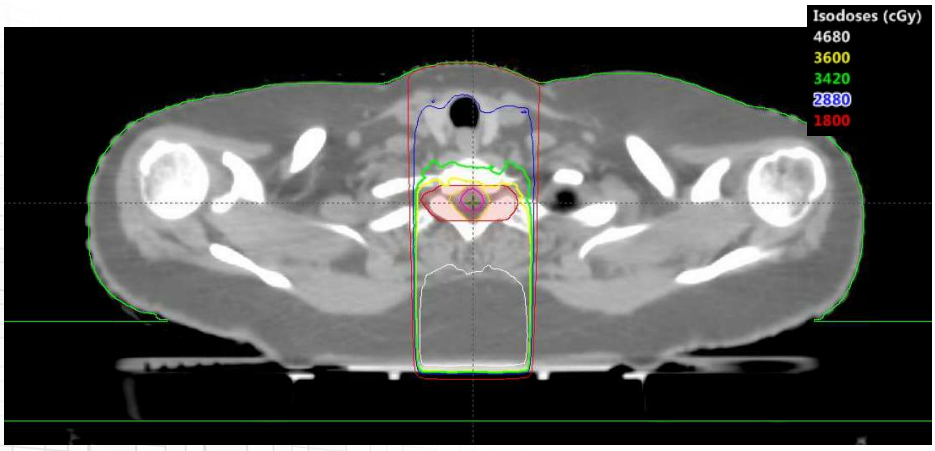
Axial slice - chest



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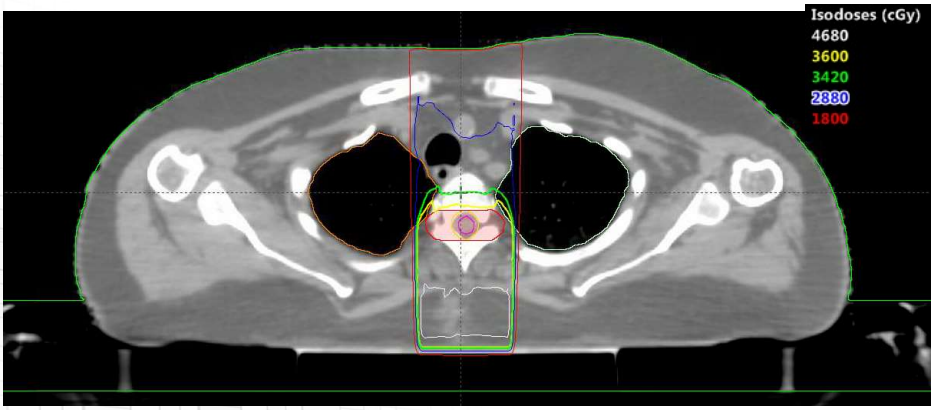
Axial slice - chest



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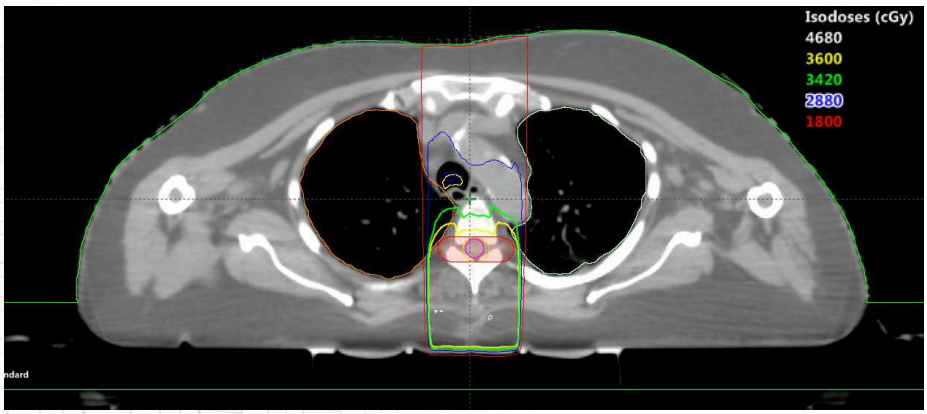
Axial slice - chest



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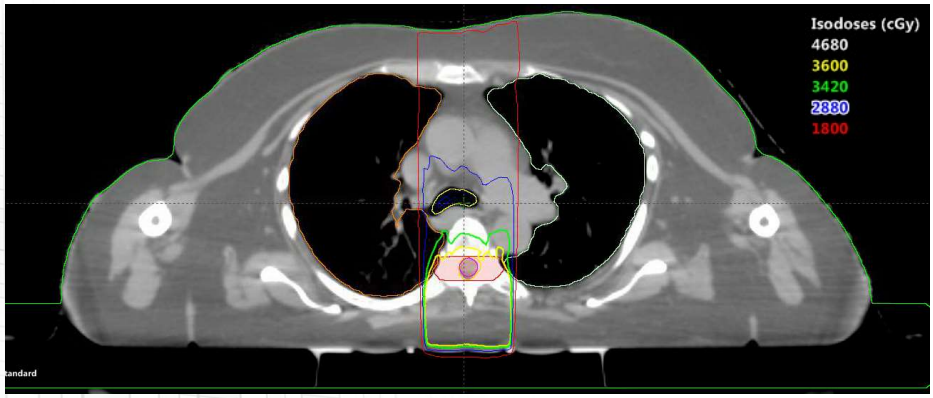
Axial slice - chest



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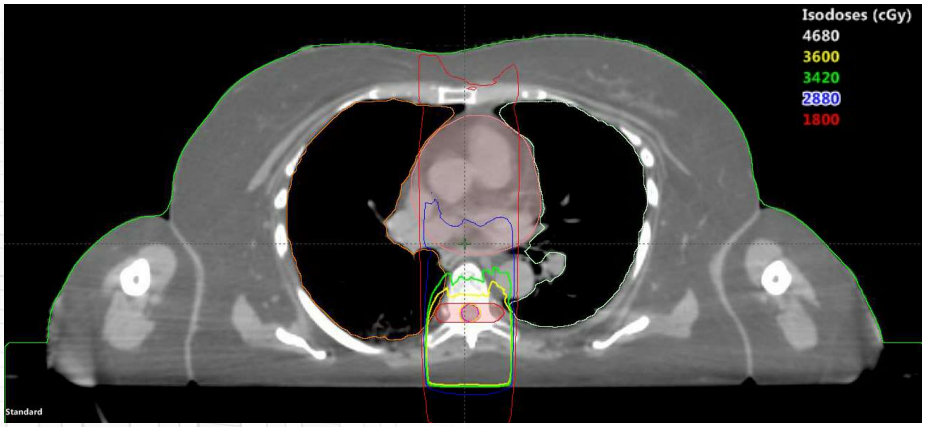
Axial slice - chest



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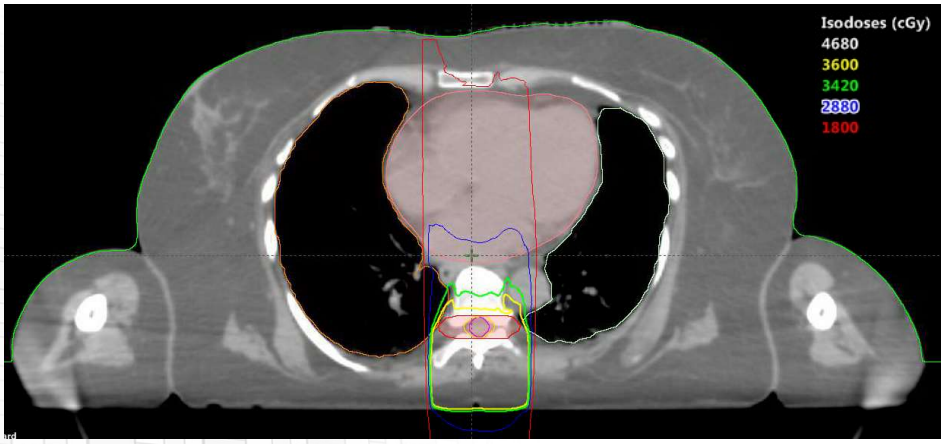
Axial slice - chest



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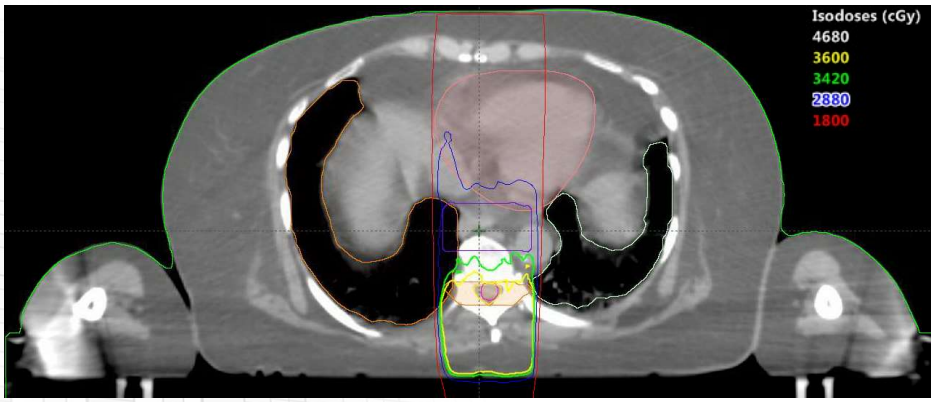
Axial slice - chest



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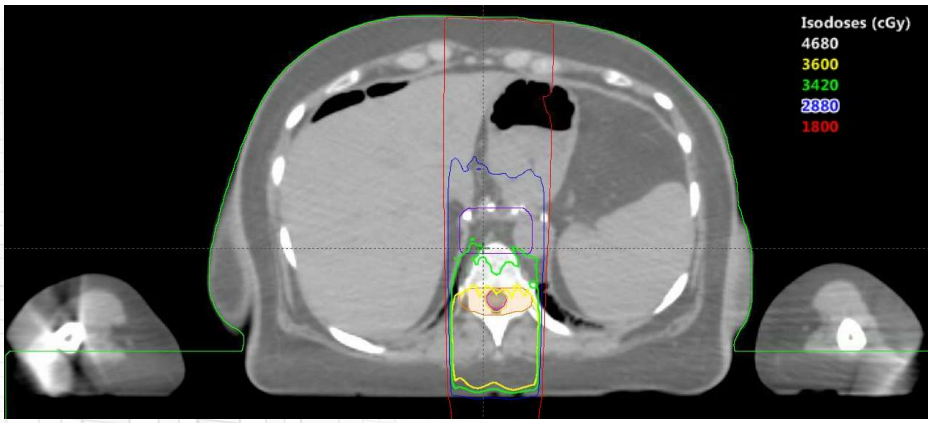
Axial slice - abdomen



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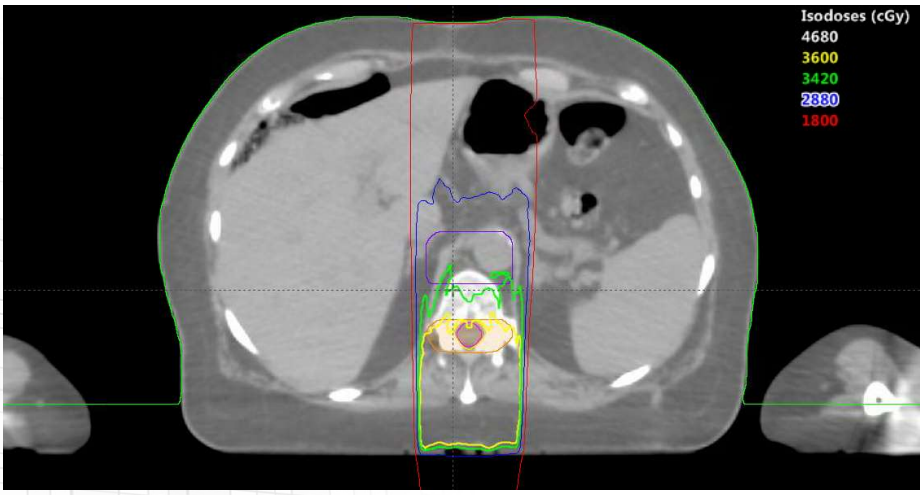
Axial slice - abdomen



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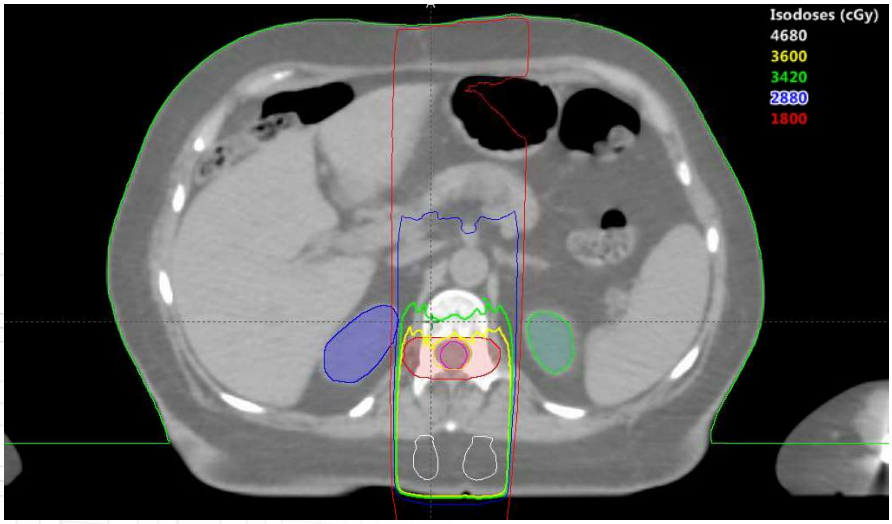
Axial slice - abdomen



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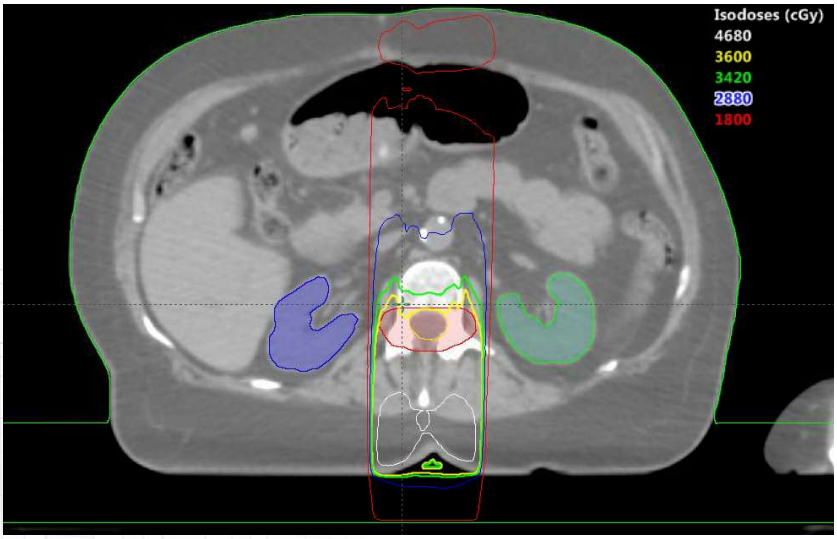
Axial slice - abdomen



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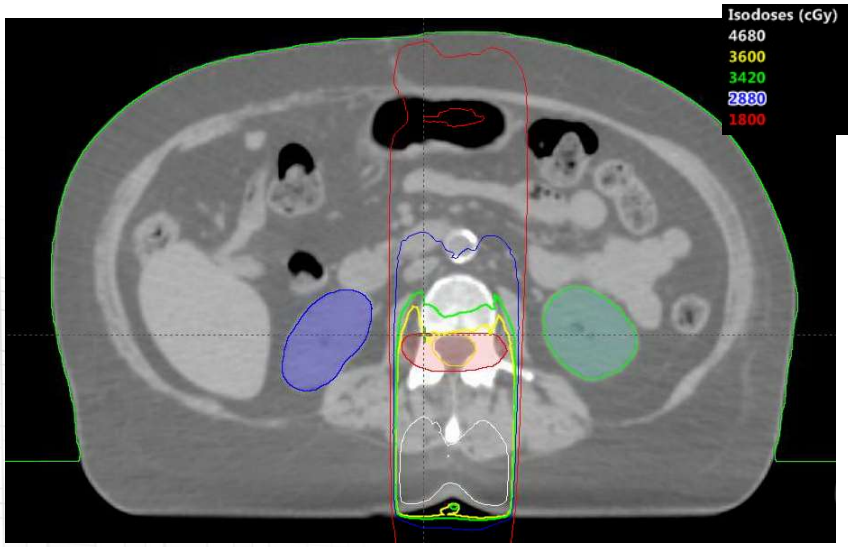
Axial slice - abdomen



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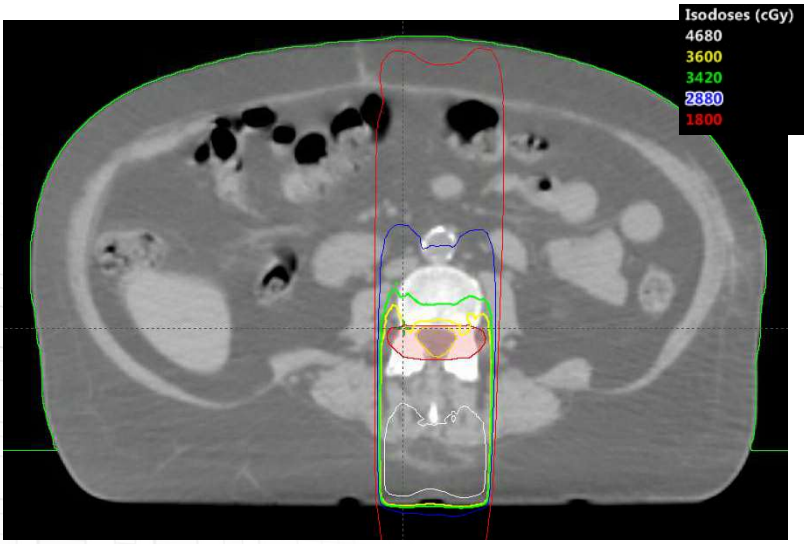
Axial slice - abdomen



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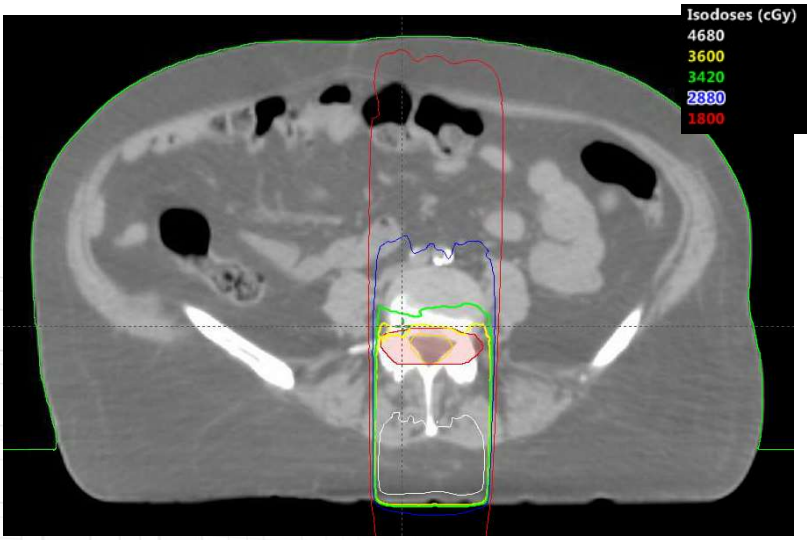
Axial slice - pelvis



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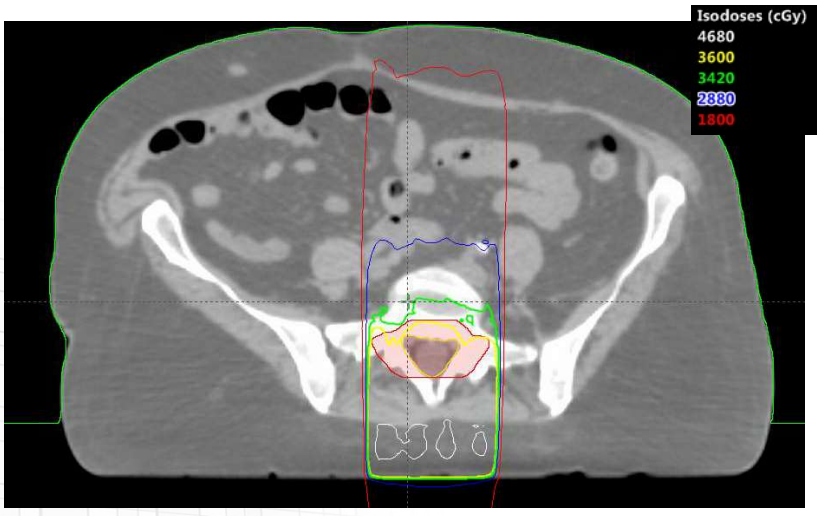
Axial slice - pelvis



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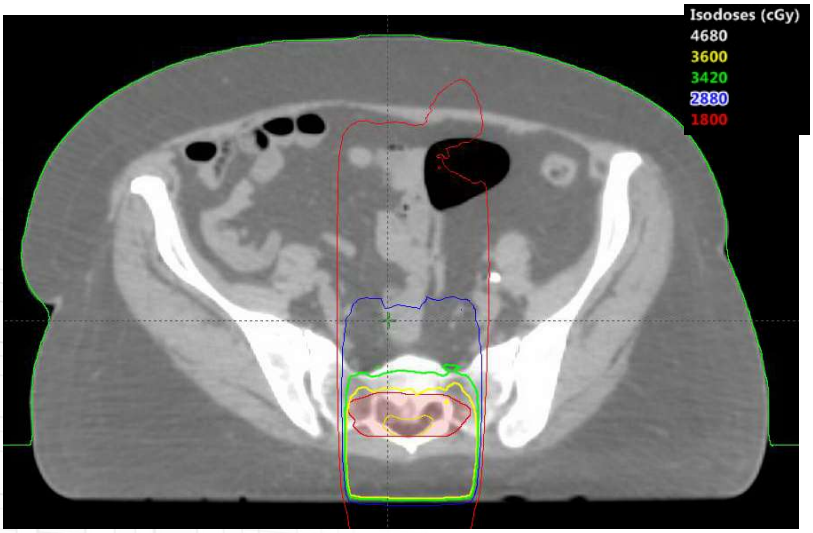
Axial slice - pelvis



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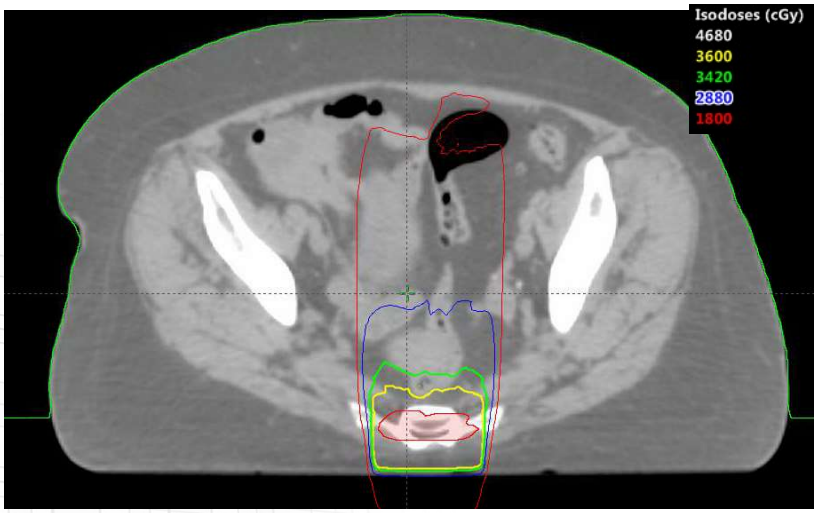
Axial slice - pelvis



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Axial slice - pelvis

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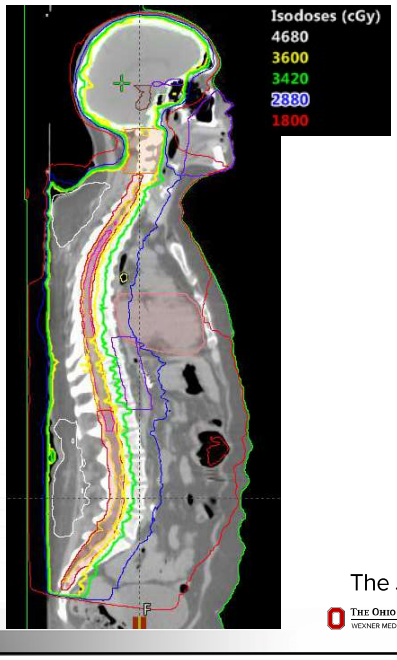
Plan sum

- Final plan sum dose distribution
- 4680cGy = 135% of rx



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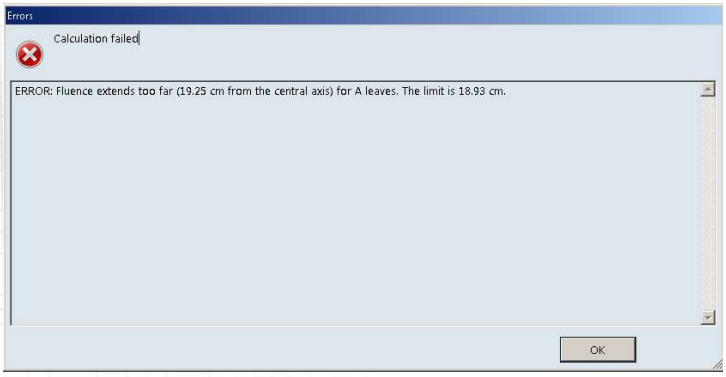
Field size limitations

- Max jaw size is 18.93cm for our machines for leaf travel so if leaves are open further than that on Upper and Lower Spine fields we must erase fluence or it won't calculate



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Dose Analysis

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Dose Analysis

- We try to keep organ doses as low as possible, the single PA field spine plans help to decrease dose to the lungs and kidneys
- Hot spots are still going to be in the 140-150% range for the spine plans, but should fall posterior in the patient
- Our physicians want to see dose uniformity and homogeneity, with no hot spots flaring anterior in the overlap region

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Dose Analysis

- Lung, kidney, oral cavity, and bowel doses follow the ALARA principle
- If we plan a boost to the brain, we use these constraints:

#1 is highest	Critical Structure (Priorities)
1	**Brainstem:** • Absolute Limit <1cc to >6000 cGy, Goal Limit <1cc to >5400cGy
2	**Optic Chiasm:** • Max Point Dose <5400 cGy
3	**Optic Nerves:** • Max Point Dose <5400 cGy
4	**Retinas:** • Max Point Dose Absolute Limit <5400 cGy, Goal Limit <4500 cGy
5	**Contralateral Cochlea:** • Limit Mean Dose < 3600 cGy. Goal Mean Dose <3000 cGy
6	**Ipsilateral Cochlea:** • ALARA
7	**Brain – PTV:** • <50% to >3000 cGy

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Treatment Delivery + Setup

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Treatment Delivery + Setup

- First day is a verification simulation where patient comes into our department and we do a full setup, take images, verify SSDs, but no treatment
- Helps to verify setup and shifts and make sure first day will run smoothly
- The imaging order is very precise to achieve the best setup possible

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Imaging Order

- Image upper spine with orthogonal pairs to get spine straight, move patient not the couch
- Shift to lower spine, image with orthogs to get spine straight, if patient is adjusted, must go back to upper spine and re-image to ensure still straight, don't apply shifts
- Once straight, move to brain and conebeam the brain, apply any shifts needed, treat brain
- Move to upper spine isocenter with inferior shift only, then treat
- Move to lower spine isocenter with inferior shift only, treat, done!

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Daily Setup

- Check SSDs
- Therapists ensure the spine is straight from imaging and if not, they move the patient, not the table
- Monitor the patient during treatment delivery to make sure they are not moving or fidgeting around
- Only inferior shifts are made from brain to the spine fields

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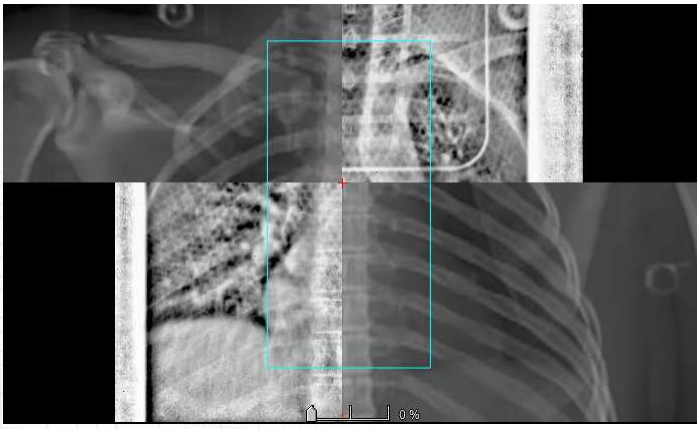
Imaging

- Daily imaging for upper spine



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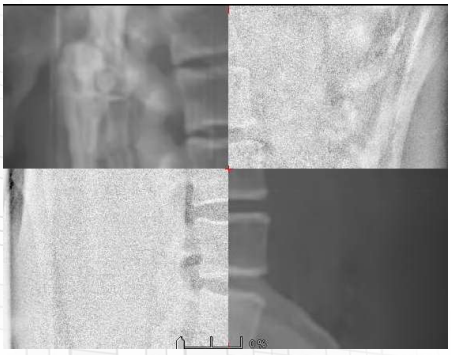
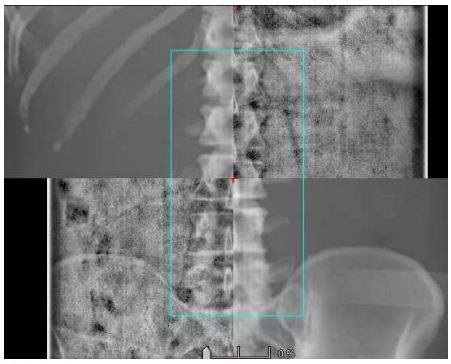
Imaging

- Daily imaging for lower spine





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Imaging

- CBCT brain

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Case numbers

- 12 total patients
- 3 pediatric – 3yo, 5yo, and 12yo
- 9 patients over the age of 18
  - 3 patients ages 18-28
- Treatment delivery time
  - on average beam on time is 6 min total
  - setup time can range from 25-40 minutes

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References

1. American Cancer Society
https://www.cancer.org/cancer/brain-spinal-cord-tumors-children/about/types-of-brain-and-spinal-tumors.html

https://www.cancer.org/cancer/brain-spinal-cord-tumors-adults.html

https://www.cancer.org/cancer/brain-spinal-cord-tumors-adults/about/key-statistics.html

2. National Cancer Institute

https://www.cancer.gov/types/brain/patient/adult-brain-treatment-pdq

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Thank You!

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To learn more about Ohio State's cancer program, please visit **cancer.osu.edu** or follow us in social media:

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