1. **Describe the patient positioning, the setup, and fields used.**

All craniospinal patients treated at my clinical site, UW Hospital, are planned for treatment on Tomotherapy using the IMRT Tomo Helical technique. As such, patients are positioned head first and supine with their arms at their sides in a full body fix that is molded around them. The patients are instructed to grasp the mold with their hands as it is being formed to ensure the same position every treatment. A custom head sponge and Aquaplast mask are used to immobilize the patient's head. Below are images of the patient positioning and setup for an actual craniospinal case treated at my internship site.

Figure 1. Patient positioning for a craniospinal treatment.

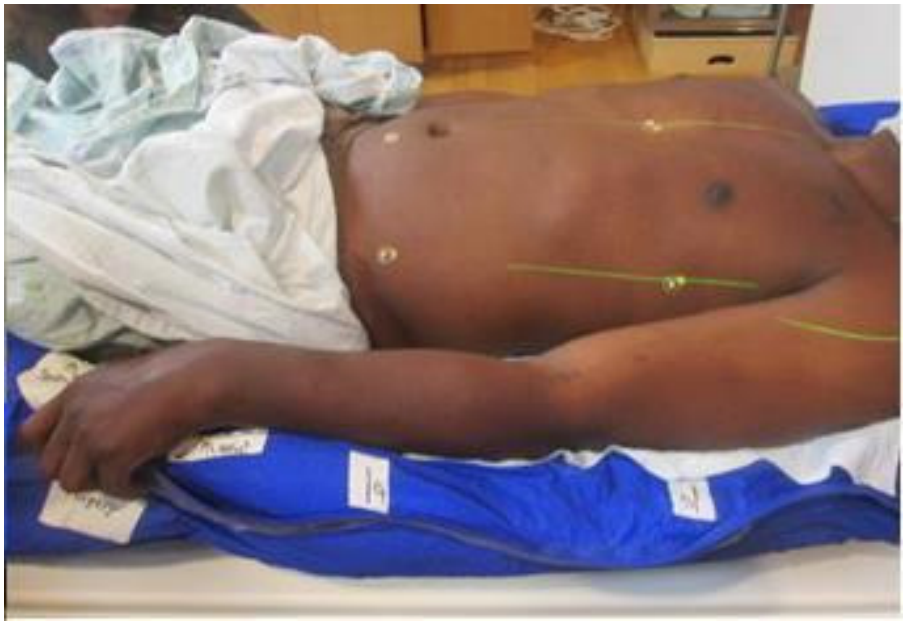

Figure 2. Arm and grasping hand placement during treatment.

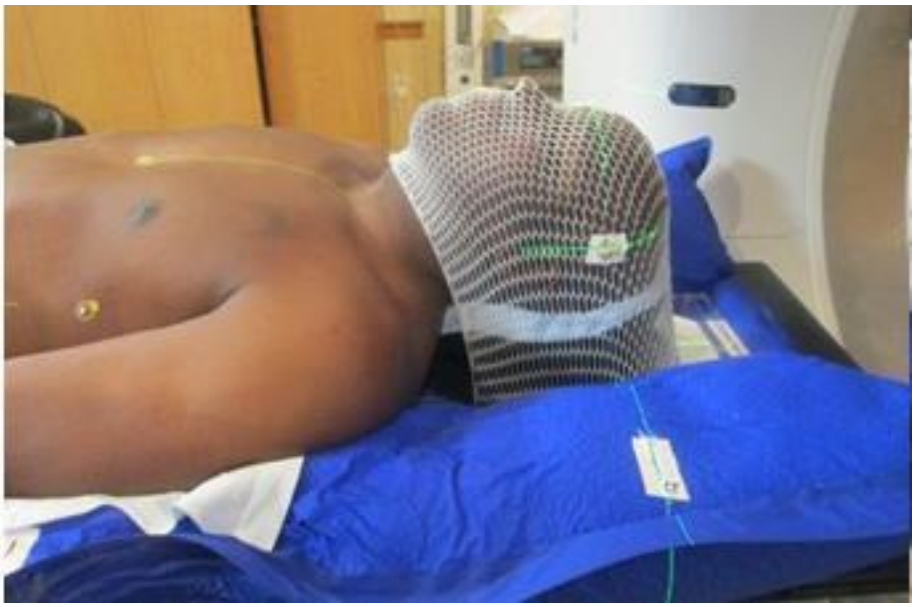

Figure 3. Aquaplast mask and custom head sponge for immobilization of patient's head.

a. Include field borders and anatomy encompassed.

With Tomotherapy Helical IMRT plans, field borders are defined automatically by the treatment planning system (TPS) after designating which structure (or structures) is the target and entering the constraints for the surrounding structures of interest to be optimized on. Since the beam is continuously on as it is rotating around the patient, all of the patient's anatomy was encompassed.

b. Describe the blocking—be specific about what is blocked and why.

As this plan is a Tomo helical IMRT, I did not create blocks with MLCs used to designate the treatment fields. That being said, when optimizing the plan in the Tomotherapy TPS I can completely block or directionally block structures. By designating a structure as completely blocked it means that no beams can enter or exit through the structure. Directionally blocking a structure means that no beams can enter through the structures, but they may still exit through it. For this case, I completely blocked the left and right lenses (Lens Lt and Lens Rt) and directionally blocked the 5 mm expansions I created for the lenses (Lens_L_PRV05 and Lens_R_PRV05). This allowed me to achieve the "ideal" constraint for the maximum dose to the lenses to be less than 7 Gy. In my plan, the maximum dose to the left lens was 5.53 Gy and the maximum dose to the right lens was 5.25 Gy.

c. Describe the setup (SAD, SSD, etc.) and why it was chosen.

This was a SAD setup because the beam is continuously on as it is rotating around the patient. A helical plan would not be achievable with an SSD setup because there is no consistent SSD as the distance from the source to the skin surface would always be changing as the gantry moved around the patient. With a SAD setup, the isocenter is located within the patient and is the same distance for every angle the gantry travels through around the patient. All Tomotherapy treatments are isocentric.

2. Describe how your plan was normalized.

a. If calc points were used, describe their location and rationale behind their location.

Calculation points were not used because Tomotherapy prescribes to a volume (or volumes) that is designated as the target.

b. If the plan was normalized volumetrically, how did you assess/adjust your target coverage?

Normalization in the Tomotherapy TPS is a little different than in Pinnacle or Eclipse in that you designate a minimum percentage of the target volume that you would like to get the prescription dose prior to optimization. In this case, I started by designating a minimum of 95% of the PTVs receive the prescription dose of 36 Gy. As I was optimizing, I noticed that the spinal coverage was extremely good, with 100% of the PTV_Spine receiving the full prescribed dose. I continuously lowered the percent of the minimum volume to receive 36 Gy until I was still achieving optimal coverage. I ended up designating a minimum of 80% of the PTV_Spine to get 36 Gy. By doing this, I decreased the hot spots in the PTV_Spine and still achieved 99.823% of the PTV_Spine receiving 36 Gy. Similarly, since I was not achieving the desired coverage for the PTV_Brain, I increased the minimum percentage I wanted to recieve 36 Gy to 95.5% of the opt_PTV_Brain (the PTV_Brain minus the 3 mm expansion of the optic nerves) to get 36 Gy. I designated a minimum of 94% of the PTV_OpticNerve_Total (the optic nerves that overlap with the PTV_Brain) to get 32 Gy. By prescribing 32 Gy to 94% of the PTV_OpticNerve_Total, I was able to control the max dose to the optic nerves while still achieving coverage of that area.

3. **Provide an in-depth description of the treatment planning process (energy, gantry, couch, collimator angles, technique, etc.) and the evaluation process of the plan outcome.**

I began planning by importing the DICOM and structure set into MIM. I reviewed the structures that were already contours and created planning structures that I would use during optimization in the Tomo TPS. I created 5 mm expansions of the lenses, kidneys, thyroid, parotids, and submandibulars and 3 mm expansions of the optic nerves. These structures were used during optimization to help achieve the desired constraints. To create a conformal and tight plan, I created two ring structures. The RingHD (high dose ring) is a 1.3 cm ring created off the 5 mm expansion of the PTVs. The Normal is a 5 cm ring created off the RingHD. I edited these rings to not extend past the external contour.

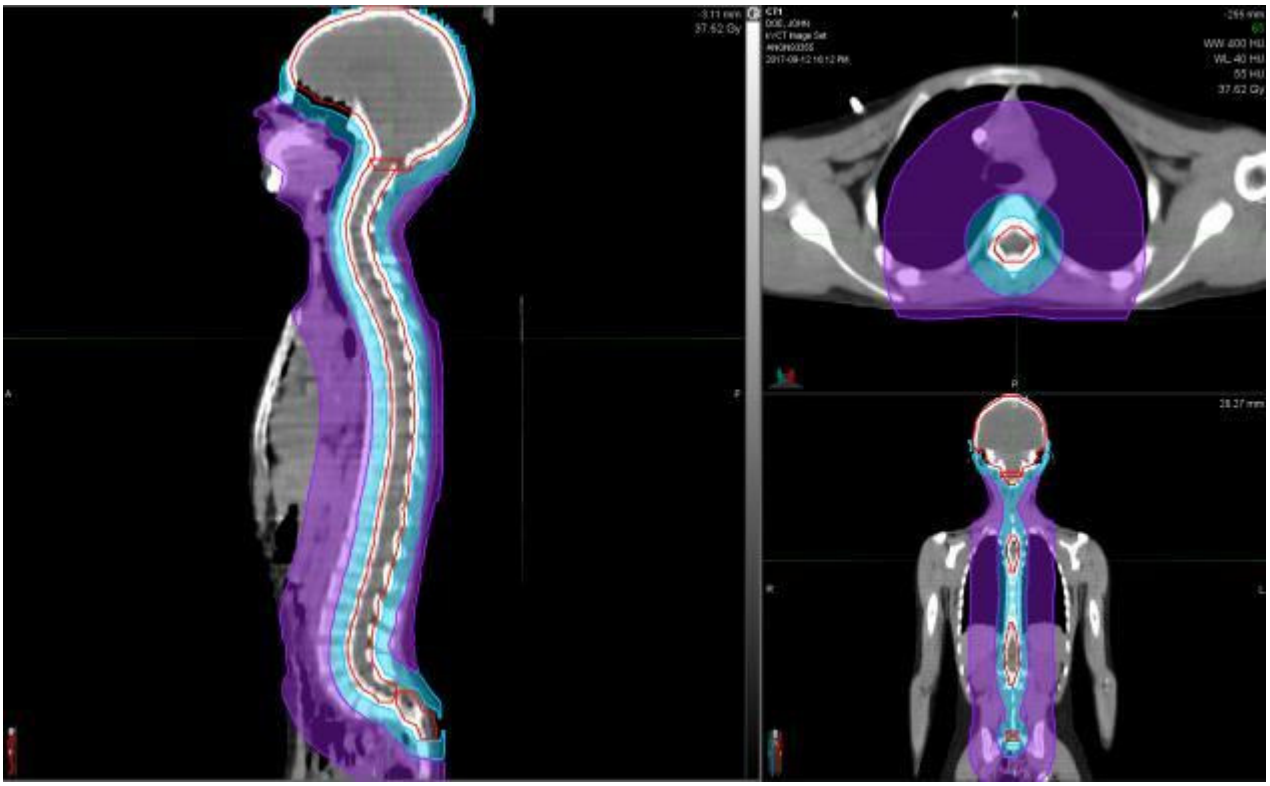

Figure 4. Visualization of the RingHD and Normal ring planning structures I optimized on.

Since the maximum dose constraint for the optic nerves was 34 Gy and they overlapped with the PTV_Brain that was to receive 36 Gy, I created an opt_PTV_Brain structure by cropping out the 3 mm expansions of the optic nerves and PTV_OpticNerve_Total structure which was the optic

nerves within the PTV. I did this to be able to control the dose to the optic nerves better during optimization. Once I was finished with my contours, I exported the CT and structure set to the Tomo TPS.

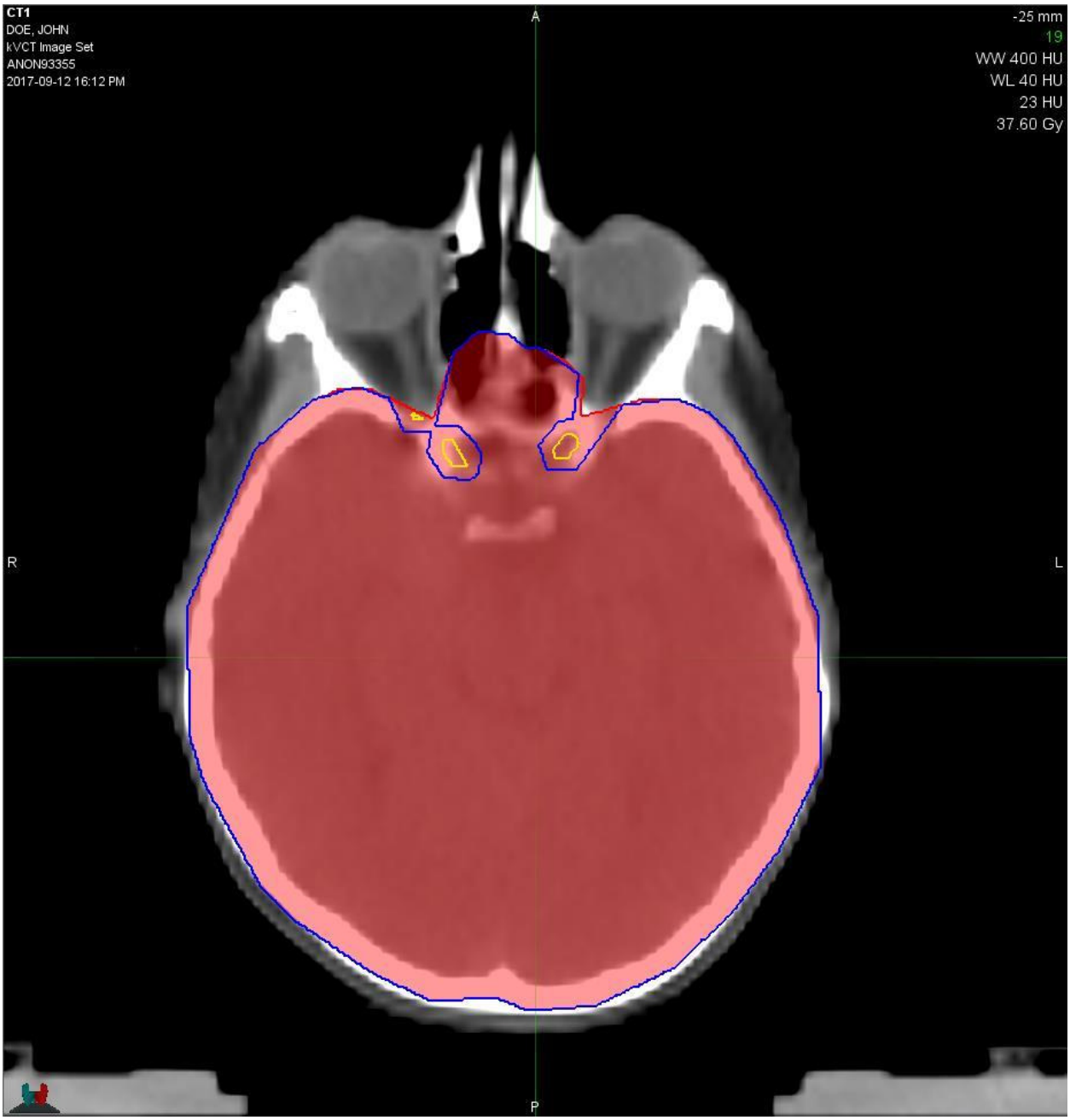

Figure 5. Visualization of the PTV_Brain (seen in red), opt_PTV_Brain (seen in blue), and the PTV_OpticNerve_Total (seen in yellow).

After reviewing and simplifying the points of the structures, I proceed to the "ROIs" tab where I designate which structures are targets (PTV_Spine, PTV_Brain, opt_PTV_Brain, and PTV_OpticNerve_Total) and ordered the surrounding structures based on their overlap with other structures, somewhat like Russian nesting dolls, as the TPS will not see a structure if it is within another structure that is ordered above it. This is also where I designate which structures I would like to completely block (lenses) and directionally block (5 mm lens expansions). After this, I proceed to the "Plan Settings" tab.

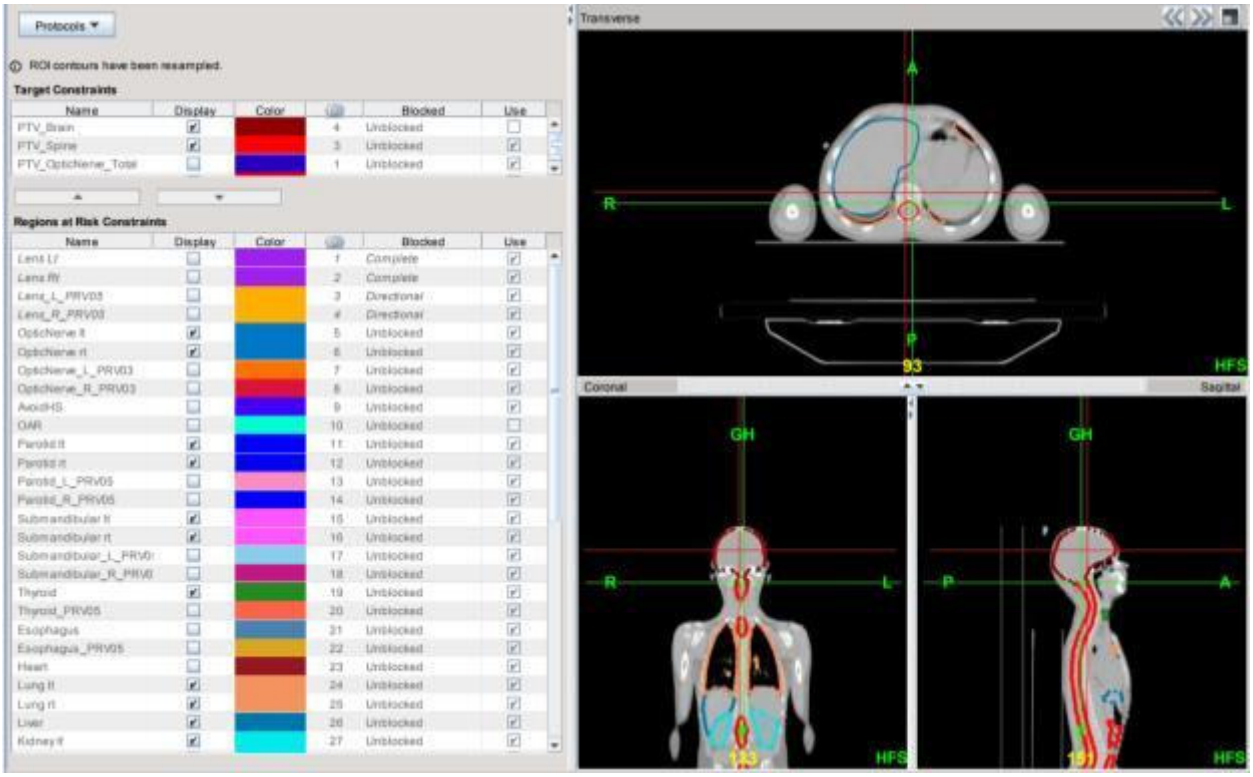

Figure 6. "ROIs" tab in the Tomo TPS.

On the "Plan Settings" tab, I shifted the patient so that the target volumes were more centered and moved the lasers to the BBs (if there were BBs placed during simulation). This is also where I set the plan parameters. The beam energy used was 6 MV as this is the only energy available on Tomotherapy machines. I set the delivery mode as TomoHelical, the plan mode as IMRT, the field width as 5.048 cm, the jaw mode as dynamic, and the pitch as 0.430. Though a smaller field width might have resulted in better dose sparing to surrounding structures, it would significantly increase the treatment length of time. As the dose per fraction was Once all the parameters were set, I moved on to the "Optimization" tab.

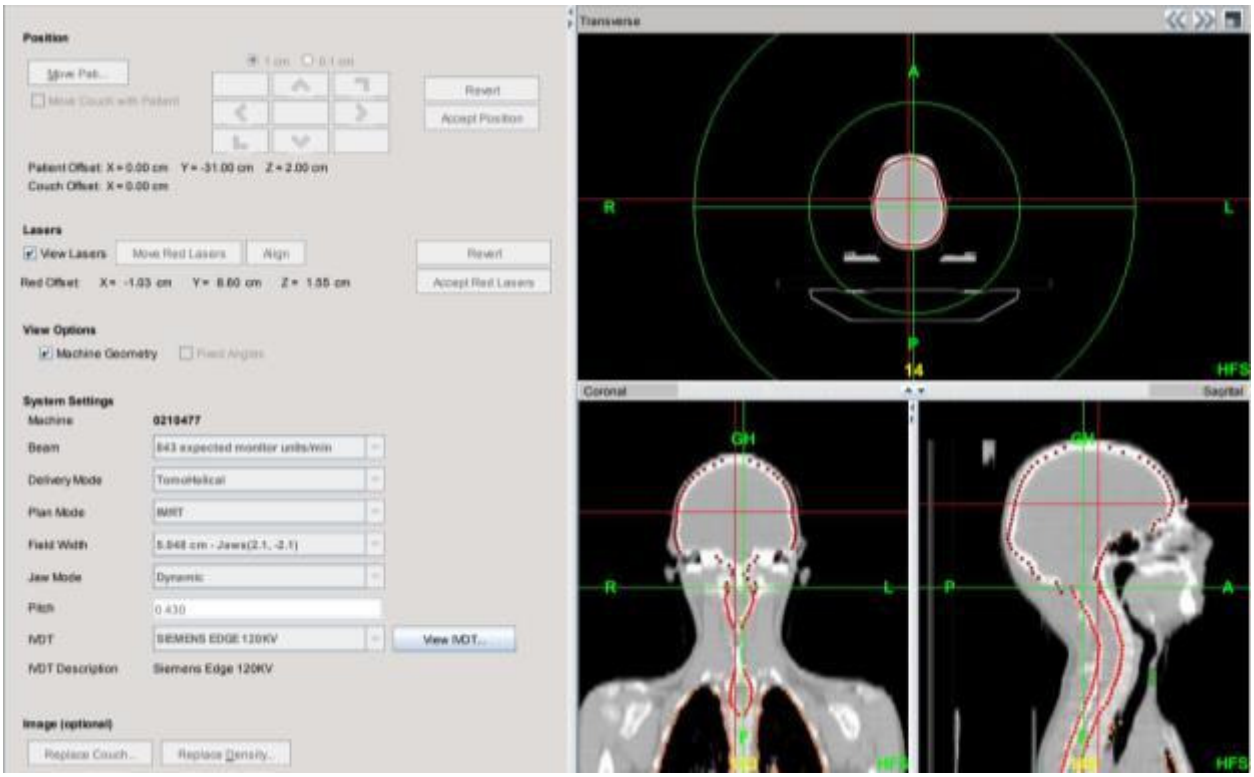

Figure 7. "Plan Settings" tab in the Tomo TPS.

On the "Optimization" tab, I put in all my constraints for my surrounding structures and target volumes. I started my modulation factor at 3.5, but was able to decrease it slightly to 3.2. By decreasing my modulation factor, the delivery time decreased, but this also caused the plan to become slightly "hotter". I continuously evaluated my targets and surrounding structures and pushed on the constraints as needed. This was all done on a "normal" (0.4 cm x 0.4 cm) dose grid. Once I was satisfied with the plan, I proceeded to the "Fractionation" tab and completed a final dose on a 0.178 cm x 0.178 cm dose grid. The duration of this treatment was 9.1 minutes.

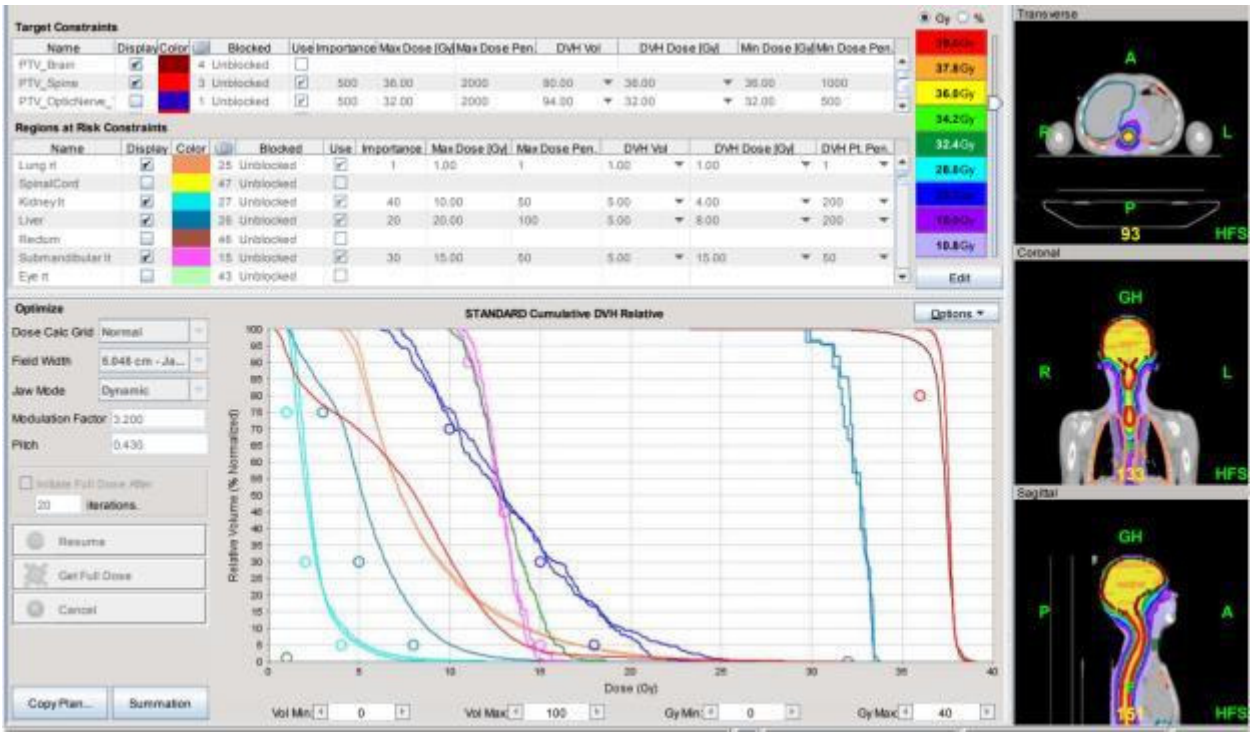

Figure 8. "Optimization" tab in the Tomo TPS.

a. Do you have any research to cite that helped you determine beam energy, beam arrangement?

Though I created my plan using the standard process and procedure for CSI cases at my clinical internship site, I did find an article that compared conformal 3D, IMRT delivered on a linear accelerator, and helical IMRT delivered on Tomotherapy unit CSI plans. In this study completed by Sharma et al[1], it was found that IMRT Tomo helical plans showed promising potential to be the superior planning technique as it eliminated the need for field junctions, resulted in optimal target volume coverage, increased plan conformality, and reduced dose to surrounding structures through optimization. Although the average length of treatment was longest for the Tomo helical IMRT plans, this was outweighed by the benefits of this treatment technique. The treatment time for the plan I created was 547.8 seconds (9.13 minutes), not including the time for imaging and alignment prior to delivering the treatment.

b. Print or capture images of the plan showing the isodose coverage of your volumes. Label these images so that they are easy to interpret.

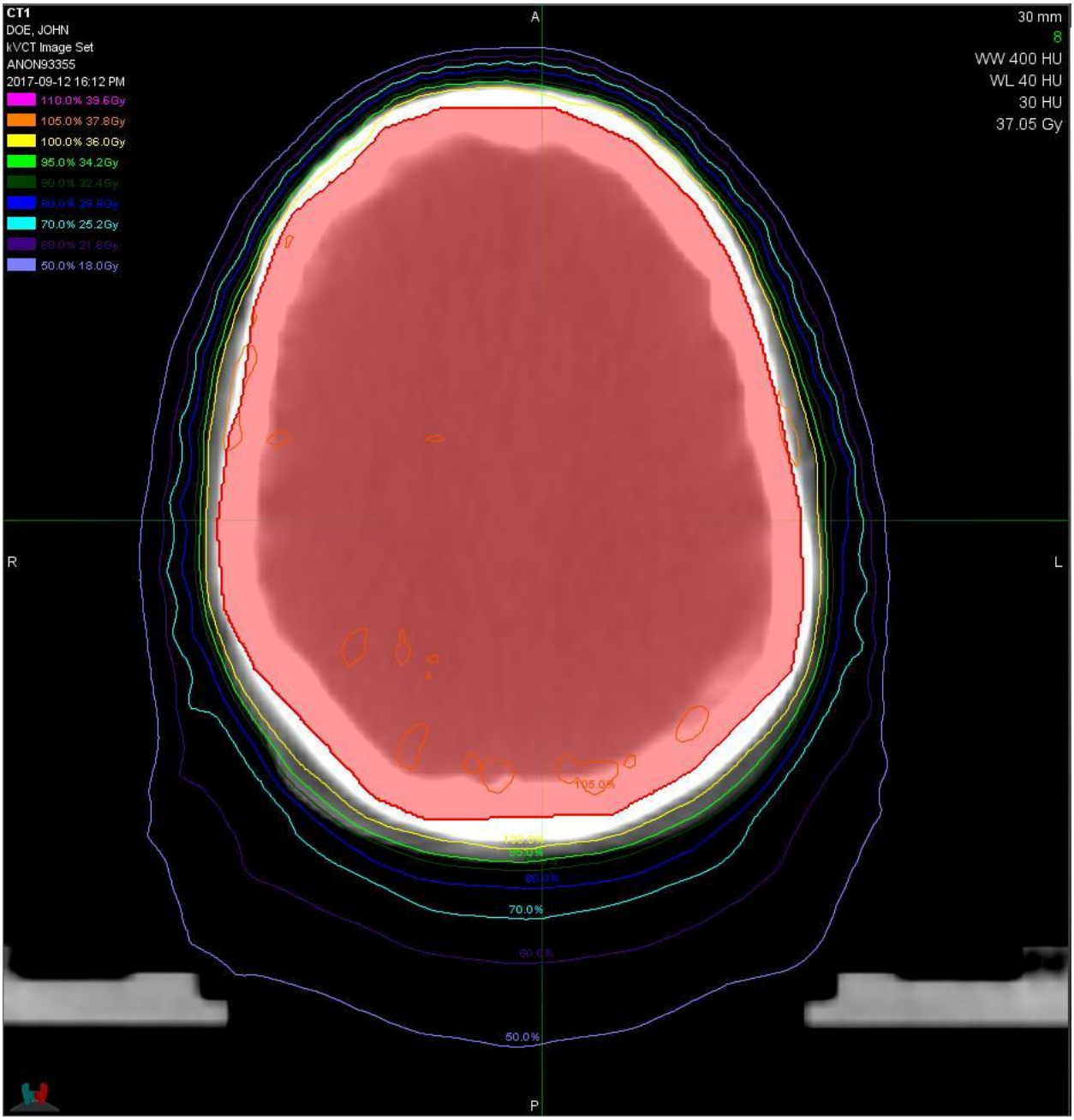

Figure 9. Axial view of the isodose lines for the PTV_Brain, seen in red.

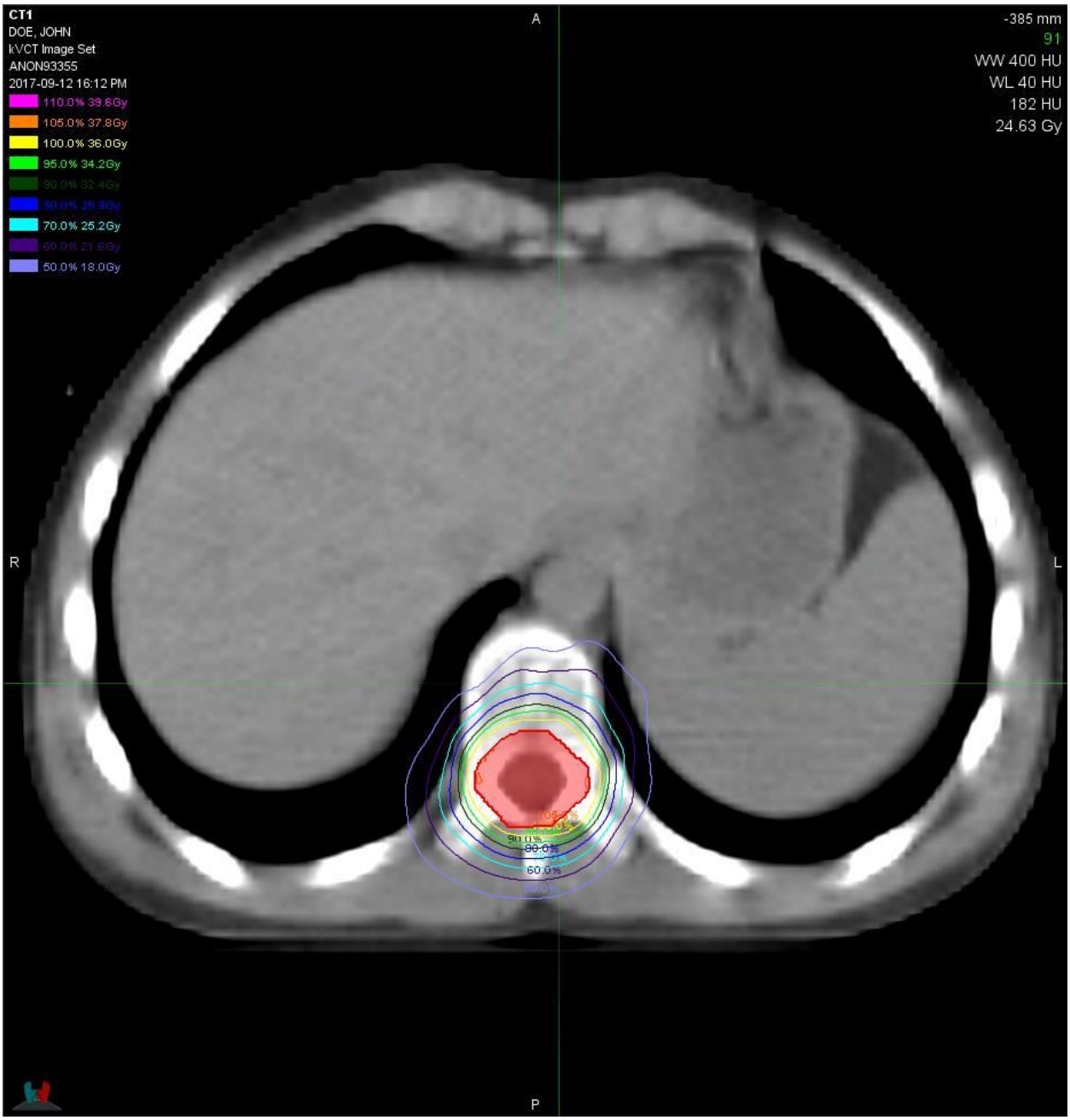

Figure 10. Axial view of the isodose lines for the PTV_Spine, seen in red.

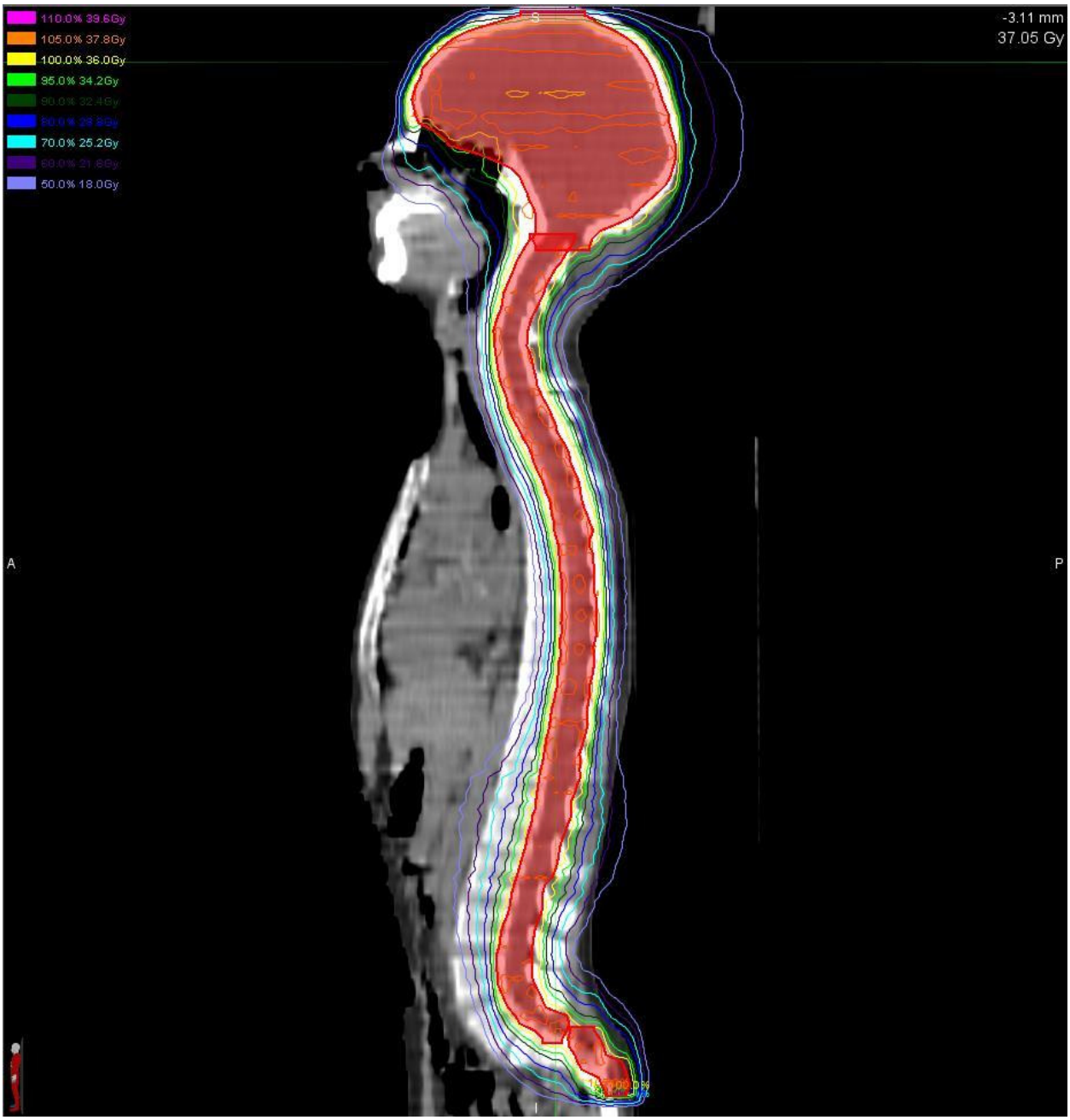

Figure 11. Sagittal view of the isodose lines for the PTV_Brain and PTV_Spine, seen in red.

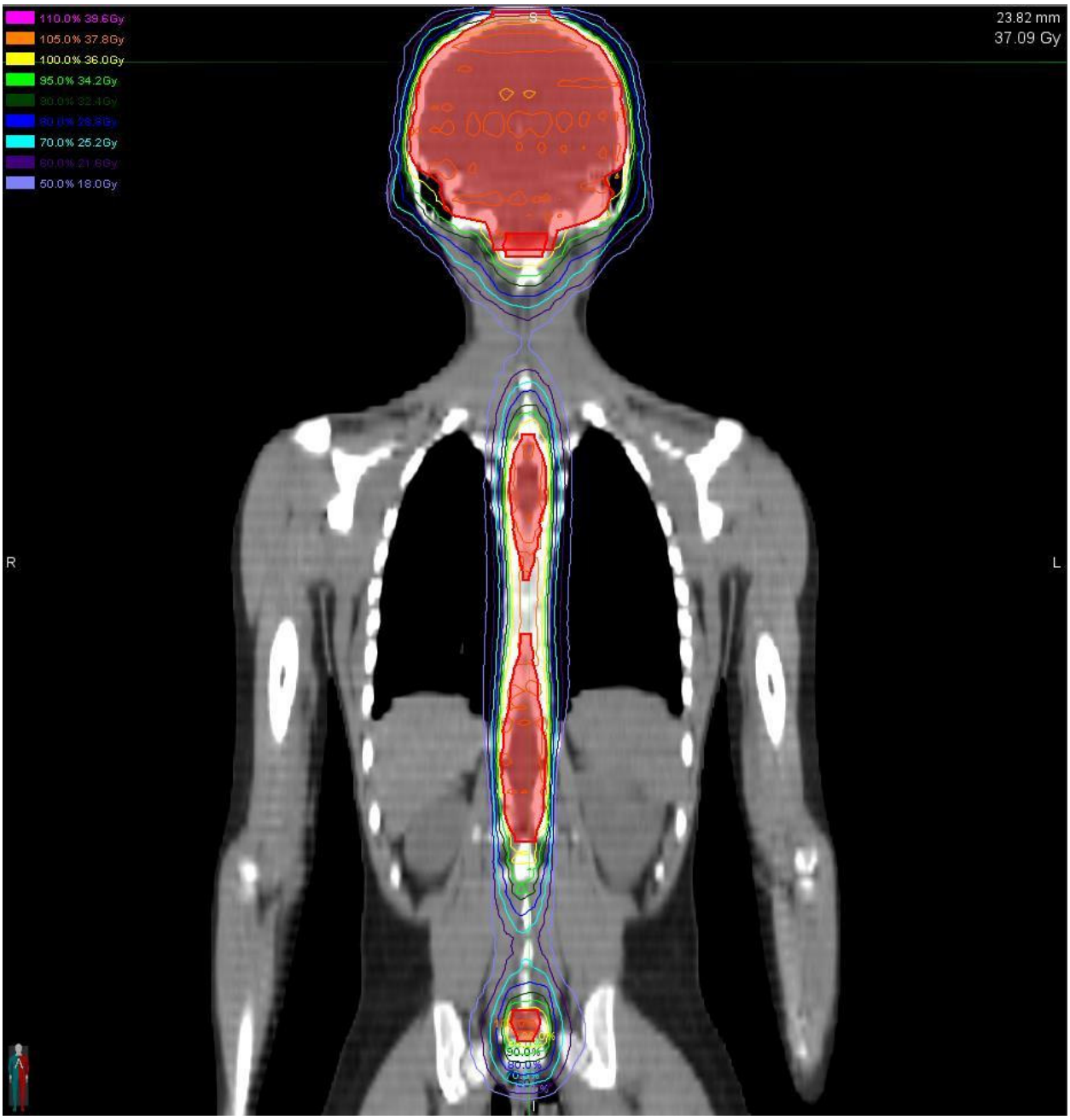

Figure 12. Coronal view of isodose lines for the PTV_Brain and PTV_Spine, seen in red.

c. Are there any hot or cold spots? If so, where are they located and why? If not, how was this prevented?

The overall hot spot of the plan was 39.45 Gy (109.6%) and was located within the PTV_Spine, on the right side, at the level of the kidneys. Since I was pushing so hard on the optimization constraints for the kidneys, I was expecting the hot spot to be located here. I was able to prevent cold spots within the PTVs

by increasing the minimum dose penalties of the PTVs I was optimizing on. This ensured that the TPS was working to achieve the desired coverage. Similarly, I reduced the amount of hot spots by increasing the maximum dose penalties of the PTVs I was optimizing on. The rings I created and optimized on, RingHD and Normal, helped to suck the dose in and achieve the desired coverage of the PTVs and spare surrounding structures.

d. Identify the maximum dose location and explain if its location was acceptable.

The maximum dose of 39.45 Gy (109.6%) was located within the PTV_Spine at the level of the kidneys, closer to the right kidney. It is acceptable because it is within the PTV and it is not in an important structure, such as the spinal cord. When I optimize a plan, I always put maximum dose constraints of the prescription dose on all structures that are overlapping with the PTV to ensure that the hot spot is not located within them, but that they are still getting the desired dose.

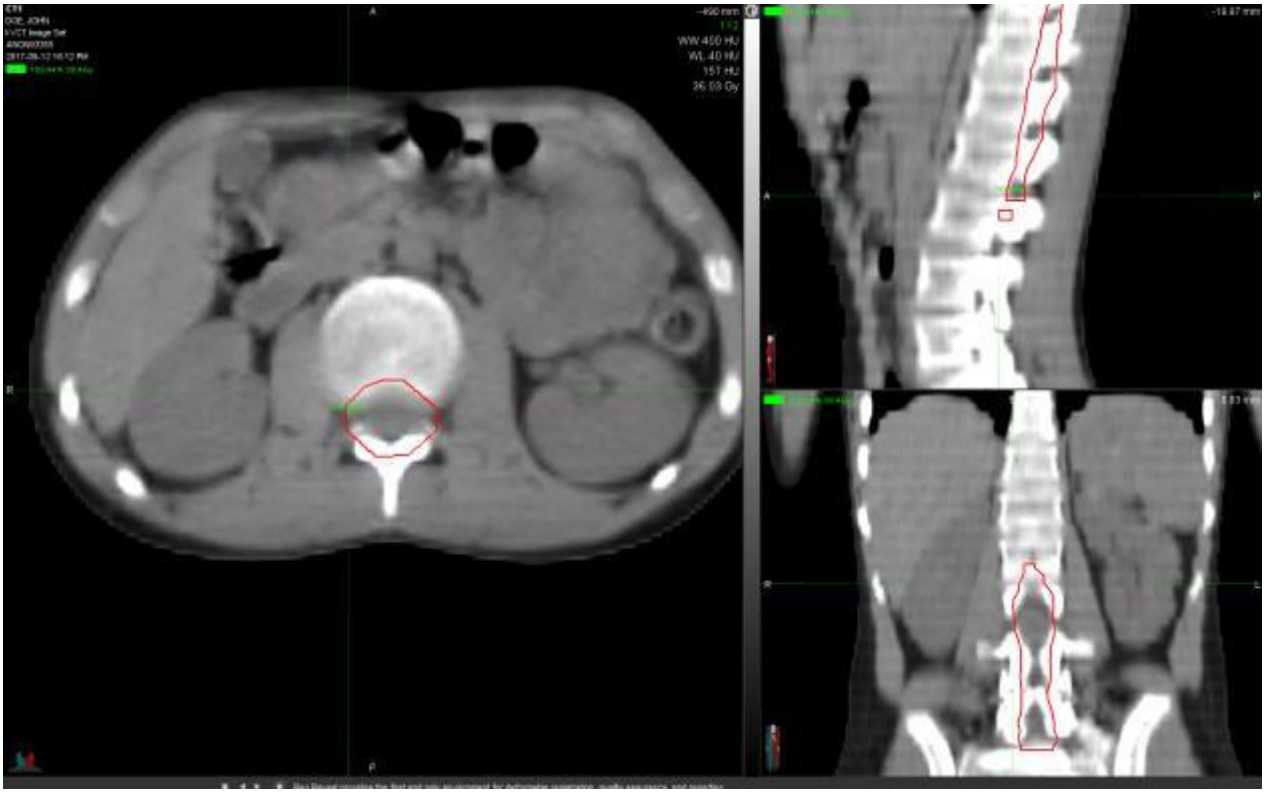

Figure 13. Depiction of the hot spot of the plan. The 39.4 Gy line is lime green and the hot spot can be seen within the PTV_Spine closest to the right kidney.

e. Give a detailed summary of your plan evaluation process.

The first thing I look at when evaluating a plan is the DVH. I analyze each of the structures to see which constraints are being met and which ones I need to push on harder to achieve the desired constraint. Once I am satisfied with the constraints, I look at the isodose lines in the axial, sagittal, and coronal planes. I pay close attention to the 110%, 105%, 100%, and 95% isodose lines. I look at the conformality and tightness of the isodose lines as well as any areas that are not covered by at least the 95% isodose line. I also look at where the hot spot is located and if there are areas of 105% in the surrounding structures. For this particular case, I was evaluating that 95% of the PTV_Spine and PTV_Brain were receiving 36 Gy and that the hot spot was not in the optic nerves.

4. Embed your ProKnow plan score sheet within your assignment. Discuss if tolerances could be achieved, and if not, why?

ProKnow

Scoring powered by PlanIQ™
Sun Nuclear Corporation

METRIC	RESULT	MIN REQ	IDEAL	POINTS	WEIGHT
Mean dose (Gy) to the HEART	6.479	30 ✓	26 ✓	3.00	3.00
Mean dose (Gy) to the KIDNEY RT	2.309	4 ✓	2 ☐	2.85	3.00
Mean dose (Gy) to the KIDNEY LT	2.288	4 ✓	2 ☐	2.86	3.00
Mean dose (Gy) to the LIVER	5.359	8 ✓	6 ✓	3.00	3.00
Volume (%) of the LUNG LT covered by 20 (Gy)	2.094	35 ✓	30 ✓	3.00	3.00
Volume (%) of the LUNG RT covered by 20 (Gy)	2.238	35 ✓	30 ✓	3.00	3.00
Maximum dose (Gy) to the LENS LT	6.506	10 ✓	7 ✓	3.00	3.00
Maximum dose (Gy) to the LENS RT	6.122	10 ✓	7 ✓	3.00	3.00
Maximum dose (Gy) to the OPTICNERVE LT	34.074	36 ✓	34 ☐	2.96	3.00
Maximum dose (Gy) to the OPTICNERVE RT	34.689	36 ✓	34 ☐	2.66	3.00
Mean dose (Gy) to the PAROTID LT	12.894	20 ✓	15 ✓	2.00	2.00
Mean dose (Gy) to the PAROTID RT	13.123	20 ✓	15 ✓	2.00	2.00
Mean dose (Gy) to the SUBMANDIBULAR LT	12.662	20 ✓	15 ✓	2.00	2.00
Mean dose (Gy) to the SUBMANDIBULAR RT	12.677	20 ✓	15 ✓	2.00	2.00
Maximum dose (Gy) to the THYROID	19.164	30 ✓	25 ✓	3.00	3.00
Volume (%) of the PTV_BRAIN covered by 36 (Gy)	95.307	90 ✓	95 ✓	20.00	20.00
Volume (%) of the PTV_BRAIN covered by 39.6 (Gy)	0.000	5 ✓	0 ✓	20.00	20.00
Volume (%) of the PTV_SPINE covered by 36 (Gy)	99.825	90 ✓	95 ✓	20.00	20.00
Volume (%) of the PTV_SPINE covered by 39.6 (Gy)	0.000	5 ✓	0 ✓	20.00	20.00
Volume (%) of the ESOPHAGUS covered by 18 (Gy)	19.369	35 ✓	34 ✓	3.00	3.00
Volume (cc) of the BOWEL_TOTAL covered by 25 (Gy)	4.331	180 ✓	179 ✓	3.00	3.00
TOTALS		21 (of 21)	17 (of 21)	126.32	127.00

Figure 14. ProKnow plan score sheet for my submitted supine CSI plan.

The only constraints I had great difficulty meeting were for the kidneys. I used maximum DVH points on both the kidneys (Kidney lt and Kidney rt) and the 5 mm

expansions (Kidney_L_PRV05 and Kidney_R_PRV05) that I created to try and achieve the ideal constraints of maximum doses of 2 Gy to the kidneys. By pushing on the kidneys, it made the PTV_Spine close to the kidneys hot. I could have pushed harder to meet these constraints, but that would have resulted in a hotspot higher than 110%. Though the ProKnow plan score sheet shows that I did not meet the left or right optic nerve ideal constraints of maximum doses less than 34 Gy, my TPS showed a maximum dose of 33.47 Gy to the left optic nerve (OpticNerve lt) and 33.74 Gy to the right optic nerve (OpticNerve rt). I did not want to push any harder on the optic nerve optimization constraints because I did not want to undercover the PTV.

5. **Provide a DVH with the CTV/PTV and important surrounding critical structures with clear labels.**

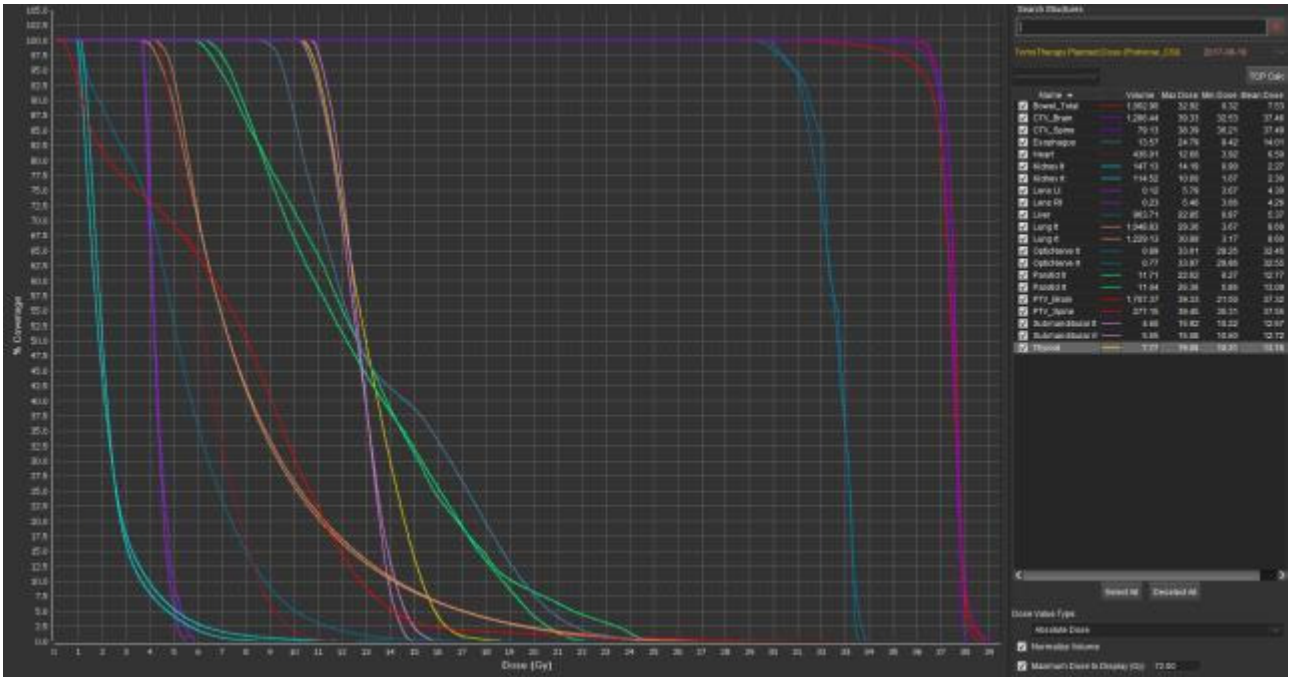

Figure 15. DVH including CTV_Brain, CTV_Spine, PTV_Brain, PTV_Spine, and important surrounding critical structures.

6. **Provide a reflection of what you learned from this planning assignment.**

Although I have observed a few CSI cases being planned, this was the first one that I got to plan on my own. I learned a great deal with regards to the structures. By cropping out the 3 mm expansion of the optic nerves (opt_PTV_Brain), I was able to better control the dose to the optic nerves. I have used this technique for other cases, such as prostate and abdomen, but I had not had to use it for a brain target volume, prior to this assignment. I was surprised with how well the coverage was for the PTV_Spine and feel that next time, I will try designating a lower minimum percent of the PTV_Spine

receiving 36 Gy to try and decrease the hot spot, as well as pushing harder on my kidneys to try and achieve mean doses less than 2 Gy, though the standard CSI treatment planning order at my clinical site designates mean doses of less than 14 Gy to the kidneys. I also learned that CSI plans require more iterations to get a more uniform and conformal plan. I typically let my IMRT Tomo Helical plans run for a maximum of 800 iterations, but I let this one run for 1,300 iterations which resulted in much less 105% within the PTV_Brain and PTV_Spine, as well as decreasing the mean to the kidneys. After speaking with the other dosimetrists at my clinical site, I learned that we transitioned to treating all CSI cases on Tomotherapy, as opposed to treating them on a linear accelerator, because it removed the need for feathering abutting fields, making it easier and more consistent for the therapists, and the time was significantly shorter for the patient. It also allowed for increased control over the dose to surrounding structures through optimization. Though this plan was challenging, I learned many valuable tidbits that I will be able to apply to plans for other areas of the body.

Reference

1. Sharma DS, Gupta T, Jalali R, Master Z, Phurailatpam RD, Sarin R. High-precision radiotherapy for craniospinal irradiation: evaluation of three-dimensional conformal radiotherapy, intensity-modulated radiation therapy and helical TomoTherapy. *The British Journal of Radiology*. 2009;82(984):1000-1009. doi:10.1259/bjr/13776022.