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Plan 1 – Wedge Pair with Anterior-Posterior (AP) Matching Field

Two CTs of the head and neck were selected for evaluation as candidates for mock parotid treatment plans. Both CTs were scanned in the supine position. One was scanned with a neutral head position and one was scanned with the neck flexed in a chin-up position. Normal anatomy structures were contoured on both scans. On each scan, a GTV was created by making a copy the left parotid contour. A PTV was created on each scan by adding a 1 cm margin to the GTV and then cropping the contour back inside the body contour where necessary.

Isocenters for wedge pair plans were established on each scan by finding an approximate centroid of the PTV in the X and Z dimension, and then setting the Y position at the level of the bottom of the laryngeal incisure or at the top of the thyroid cartilage if the incisure could not be resolved on the scan. Fields for wedge pair plans were created for both scans at 45 degree and 135 degree gantry positions. A source to axis distance (SAD) of 100 cm was used. Multileaf collimators (MLC) were fitted with a 5 mm margin around the PTV. The fields were cropped in the Y direction at the level of the isocenter if necessary. This allowed an AP field for lower neck nodes to match cleanly using a half beam block technique (Figure 1). The AP field for neck nodes was created with its medial margin approximately 2-3 mm from the spinal cord, its inferior margin approximately 1 cm inferior to the clavicle, its lateral margin cutting through the 2/3 point of the clavicle, and its superior margin at the level of the isocenter.

Upon examination of the beam's eye view (BEV) of each of the wedge pair field, the eyes, lenses, and optic nerves were in the exit path of the left posterior oblique (LPO) on the CT with the head in a neutral position. The optic structures were not in the treatment field on the chin-up scan, but the left submandibular gland was partially in field. The left cochlea, brain stem, and spinal cord were in the exit path of the left anterior oblique (LAO) field on both scans.

The neutral position was rejected because of the involvement of the optic structures, and planning continued on the chin-up scan. Both gantry angles were adjusted 5 degrees anteriorly to 40 degrees (LAO) and 130 degrees (LPO) in order to better conform to the shape of the medial surface of the PTV and to provide more margin between the exit path of the LAO and the

contralateral cochlea. The contralateral parotid was completely spared in either set of angles (Figure 2).

Couch position was left at 0 degrees, but the collimators in both field were turned to 90 degrees to allow the use of electronic dynamic wedges (EDW) instead of physical wedges. A 45 degree EDW was configured for both fields with the heels of each wedge facing towards each other (LAO heel facing posterior and LPO heel facing anterior). Field energy for both fields was set to 6 MV and weighting was set with both fields equal. The AP field covering the neck nodes was set to 6 MV and 0 degrees gantry rotation (Figure 3). It used a 15 degree hard wedge with the heel facing the midline.

Dose conformality in the resulting plan was good, but the most superficial portions of the GTV and PTV did not receive full prescription dose. The plan was recalculated with 5 mm bolus added. After renormalizing the plan such that the 95% of prescription isodose line covered the medial edge of the PTV, the superficial areas were covered completely. Despite the better superficial coverage, this plan was rejected due to high skin dose and high likelihood of skin toxicity.

In order to evaluate the bolus-free plan, structures called GTVeval and PTVeval were created by cropping the GTV and PTV 5 mm from the edge of the body contour. Both the original targets and the cropped targets were evaluated through dose volume histogram (DVH) analysis (Figure 4). Tolerance and goal doses for various organs at risk (OR) were copied from Loyola University Health System's standard head & neck tables (Figure 5).

Plan 2 – Photon/Electron Mixed Beam

An alternate plan was created using a mixed beam of 6 MV photons and 16 MeV electrons in approximately a 1:4 ratio. The couch was rotated to 355 degree and the gantry was moved to 85 degrees for both beams to provide an en face entrance angle (Figure 6). The MLCs on the photon beam were fitted with a 0.5 cm margin around the PTV and a custom electron block was created with a 1 cm margin around the PTV. Both beams were configured to use a source to surface distance (SSD) of 100 cm.

The electrons covered the majority of the parotid, and the photons supplemented the coverage on the deeper portions of the parotid. The superficial coverage provided by the electrons meant that a bolus was not required. Overall, the plan was much hotter throughout the

PTV in order to achieve coverage to the distal (medial) edge of the PTV (Figure 7). The maximum dose was 80.4 Gy with a prescription dose of 60.0 Gy. The shaping of the high dose regions was also irregular, especially downstream of the outer ear and near the ear canal (Figure 6).

The PTV was not completely covered, but the values were close to their goals, so the miss was classified as a minor deviation (Figure 8). The dose to the left cochlea, however was more than double the tolerance dose, which is a major deviation. The right cochlea met its constraint, but it still received a mean of 9.7 Gy. The salivary glands in the mixed beam plan are a source of concern. The left parotid is the target, so it was taken well beyond its tolerance dose. The left submandibular gland also had its tolerance dose exceeded by around 30 Gy. The right parotid and right submandibular gland were both taken to around half of their tolerance doses. The dose to the spinal cord was 5 Gy below tolerance, but based on the electron beam's extreme sensitivity to surface shape around the ear, this did not seem like a comfortable safety margin.

Plan 3 – Volumetric Modulated Arc Therapy (VMAT)

The third plan variant was an intensity modulated radiotherapy (IMRT) technique. Fixed beam IMRT was not used because of the proximity of air to the optimization target. The planning system used was not commissioned with intermediate dose calculation capabilities for fixed beam IMRT, leading to difficulty achieving a good plan. VMAT (RapidArc) was chosen because the RapidArc optimizer had intermediate dose calculation enabled. It also allowed the optimizer more freedom in choice of gantry angles for dose delivery.

Two partial arcs were configured, ranging from 300 degrees clockwise to 160 degrees, and from 160 degrees counterclockwise to 300 degrees (Figure 9). The 300 degree stop point was chosen because it prevented entrance dose from passing through the right parotid, which needed to be spared in the absense of a functioning left parotid. The 160 degree stop point was chosen because it was approximately tangential with the skin over the target area. It also prevented large amounts of dose from passing through the cerebellum. Both choices of stop points prevented dose from entering through the spinal cord and brain stem. The right cochlea was also protected from entrance dose by these choices.

The PTVeval contour, which was already cropped 5 mm from the surface of the body contour, was chosen as the optimization structure for the RapidArc plan. Normal Tissue

Optimization (NTO) settings forced the optimizer to begin tapering the dose down starting at 4 mm beyond the PTVeval structure. High priority optimization goals of 100 coverage of the PTVeval with 60.0 Gy and 0% coverage with 61.0 Gy were configured.

After optimization, conformality of both the 95% and 100% of prescription isodose lines around the PTVeval structure were excellent. The PTV itself was not adequately covered by the 95% isodose line, but the PTVeval was fully covered by 95% (Figure 10). Every other constraint was met, some by a wide margin (Figure 11). This plan was by far the easiest of the three final plans to produce, and it produced what are inarguably the best results for target coverage and OR sparing. VMAT is not the best technique to use in every scenario, but in this case, it was a clear winner.

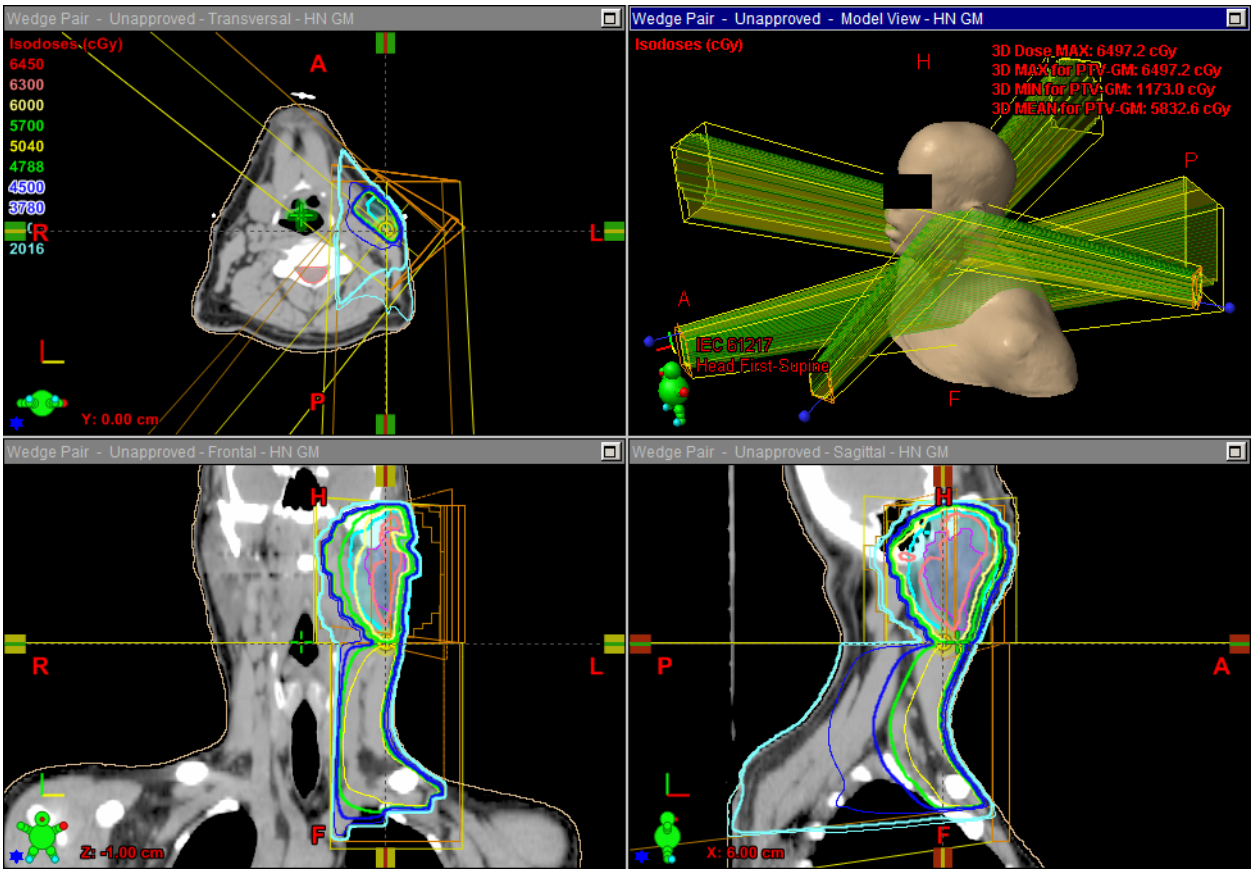

Figure 1. Axial, sagittal, and coronal and 3D rendered views of an ipsilateral wedge pair and AP neck node field matched at a shared isocenter with a half beam block technique. Isodose lines show 60.0 Gy prescription to the wedge pair and 50.4 Gy to the neck nodes.

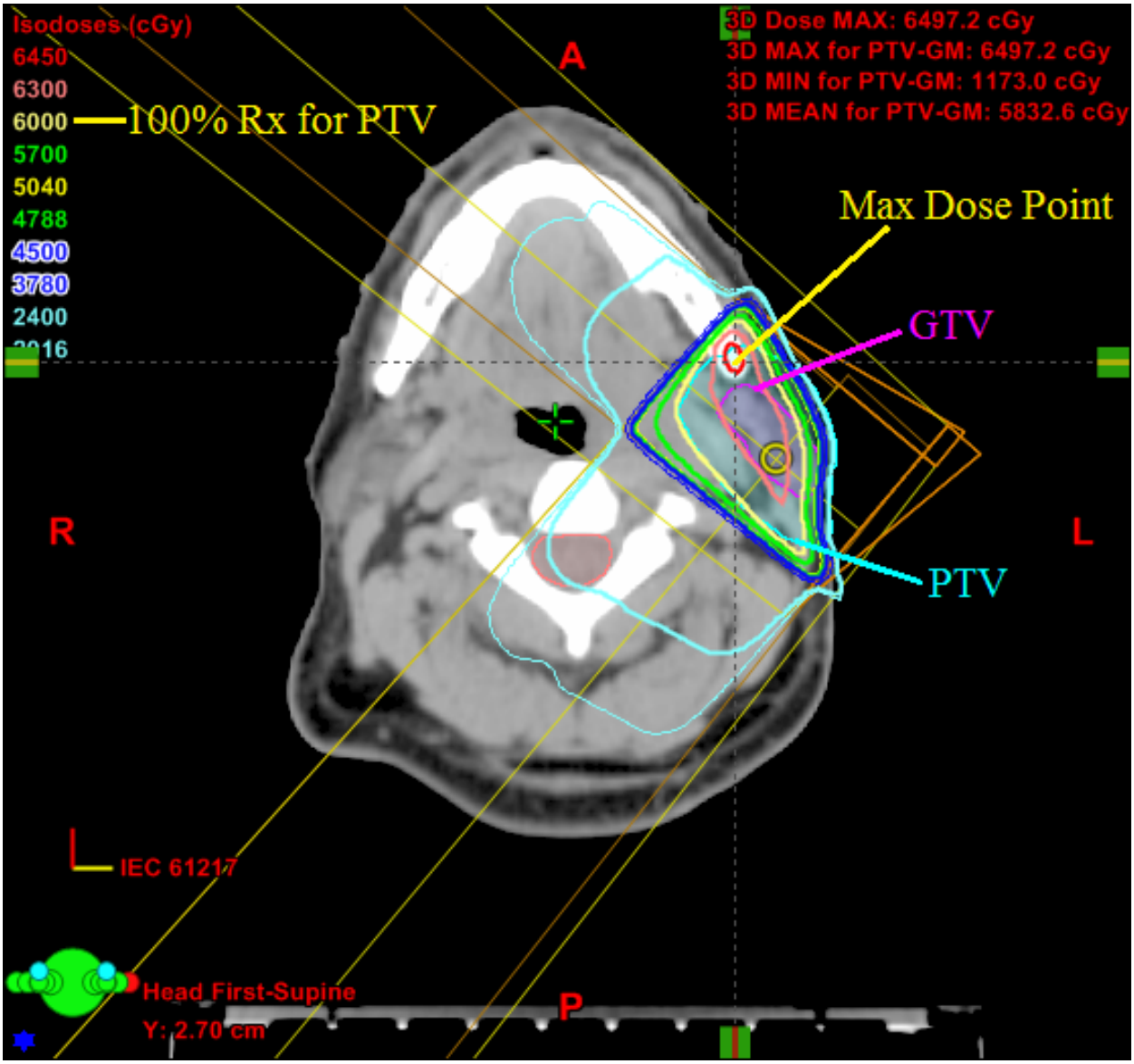

Figure 2. Axial cross-section of wedge pair portion of Plan 1, cutting through the maximum dose point. Isodose values are 107.5% and 105% of 60 Gy, as well as 100%, 95%, 75%, and 40% of both 60 Gy and 50.4 Gy intermingled.

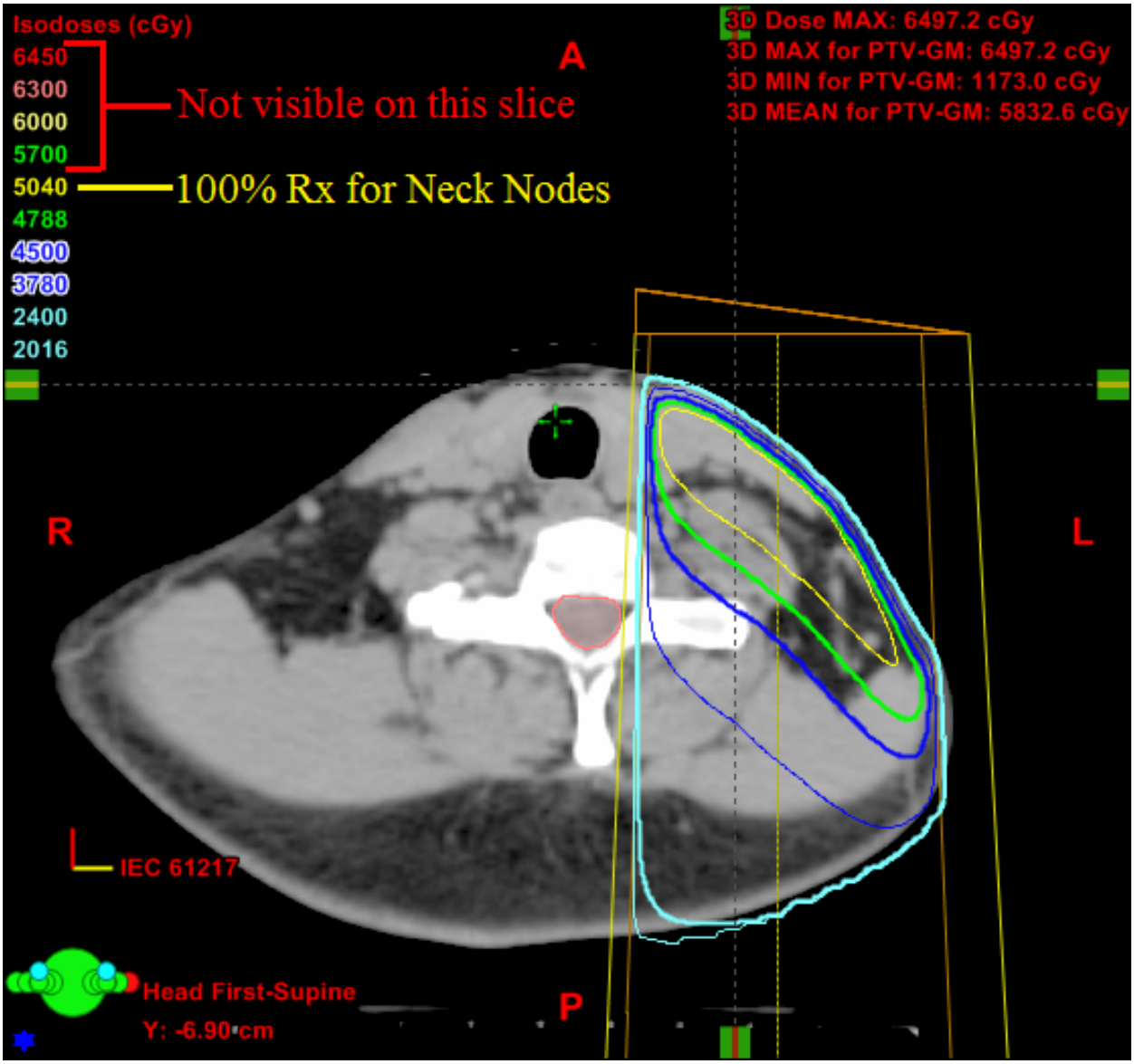

Figure 3. Axial cross-section of Plan 1 at a level just above the clavicle, showing dose distribution of the AP beam.

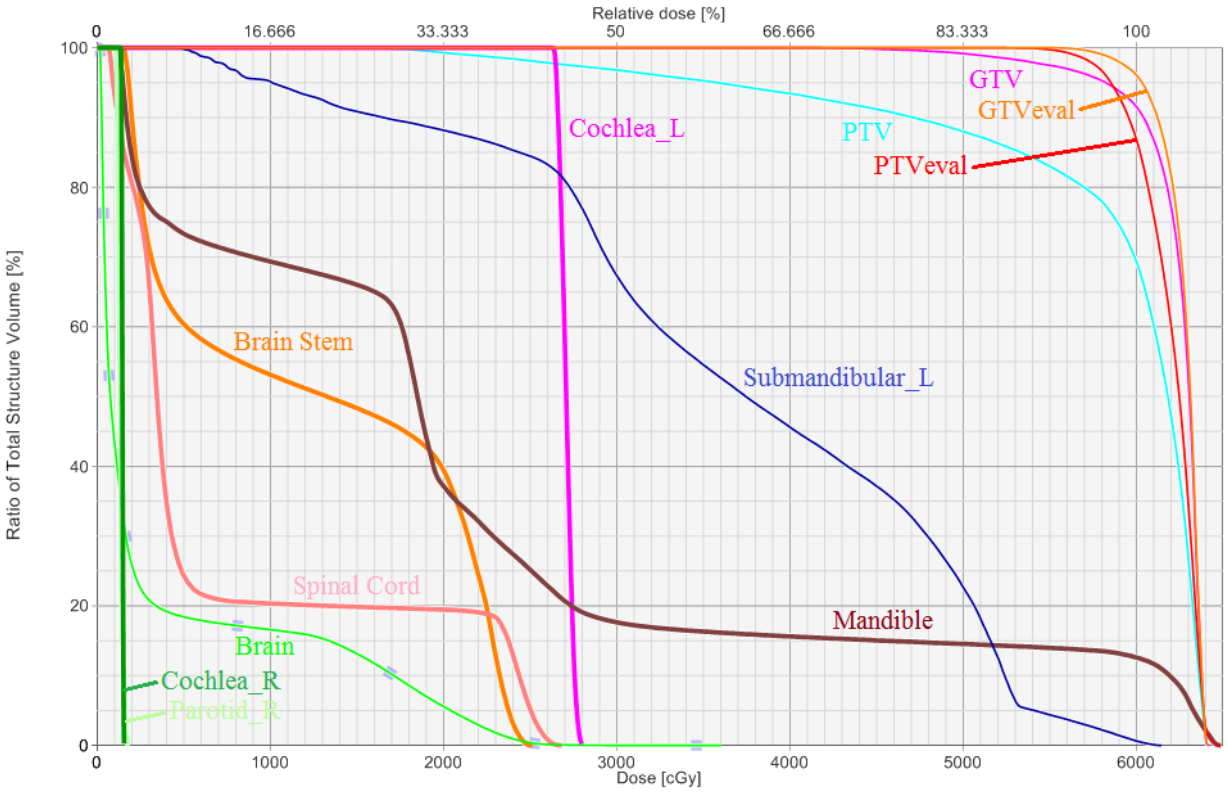

Figure 4. DVH of Plan 1 showing slight difficulty achieving coverage of the target volumes.

Plan 1 Score Card

Contour	Goal	Achieved	Evaluation
GTV	V60Gy = 100%	91.6%	Major Deviation
GTVeval	V60Gy = 100%	96.1%	Major Deviation
PTV	V95%Rx = 100%Vol V100%Rx > 95%Vol	79.9% 69.2%	Major Deviation Major Deviation
PTVeval	V95%Rx = 100%Vol V100%Rx > 95%Vol	98.4% 87.0%	Minor Deviation Major Deviation
Eye_R	Max < 35 Gy	1.5 Gy	Pass
Eye_L	Max < 35 Gy	1.4 Gy	Pass
Lens_R	Max < 8 Gy	1.0 Gy	Pass
Lens_L	Max < 8 Gy	1.0 Gy	Pass
OpticNerve_R	Max < 52 Gy	1.2 Gy	Pass
OpticNerve_L	Max < 52 Gy	1.3 Gy	Pass
Chiasm	Max < 50 Gy	1.6 Gy	Pass
Cochlea_R	Mean < 25 Gy	1.4 Gy	Pass
Cochlea_L	Mean < 25 Gy	27.1 Gy	Minor Deviation
Brain	Max < 60 Gy	36.1 Gy	Pass
BrainStem	Max < 50 Gy	25.1 Gy	Pass
SpinalCord	Max < 45 Gy	26.8 Gy	Pass
Mandible	Max < 70 Gy	65.0 Gy	Pass
Parotid_R (contralateral)	Mean < 20 Gy V22 Gy < 50% Vol	1.3 Gy 0%	Pass Pass
Parotid_L (ipsilateral)	unconstrained	n/a	n/a
Submandibular_R	Mean < 39 Gy	1.9 Gy	Pass
Submandibular_L	Mean < 39 Gy	37.0 Gy	Pass

Figure 5. Score card showing Plan 1 (Wedge Pair + AP) goal dose levels for targets and ORs, as well as an evaluation of whether the goals were met.

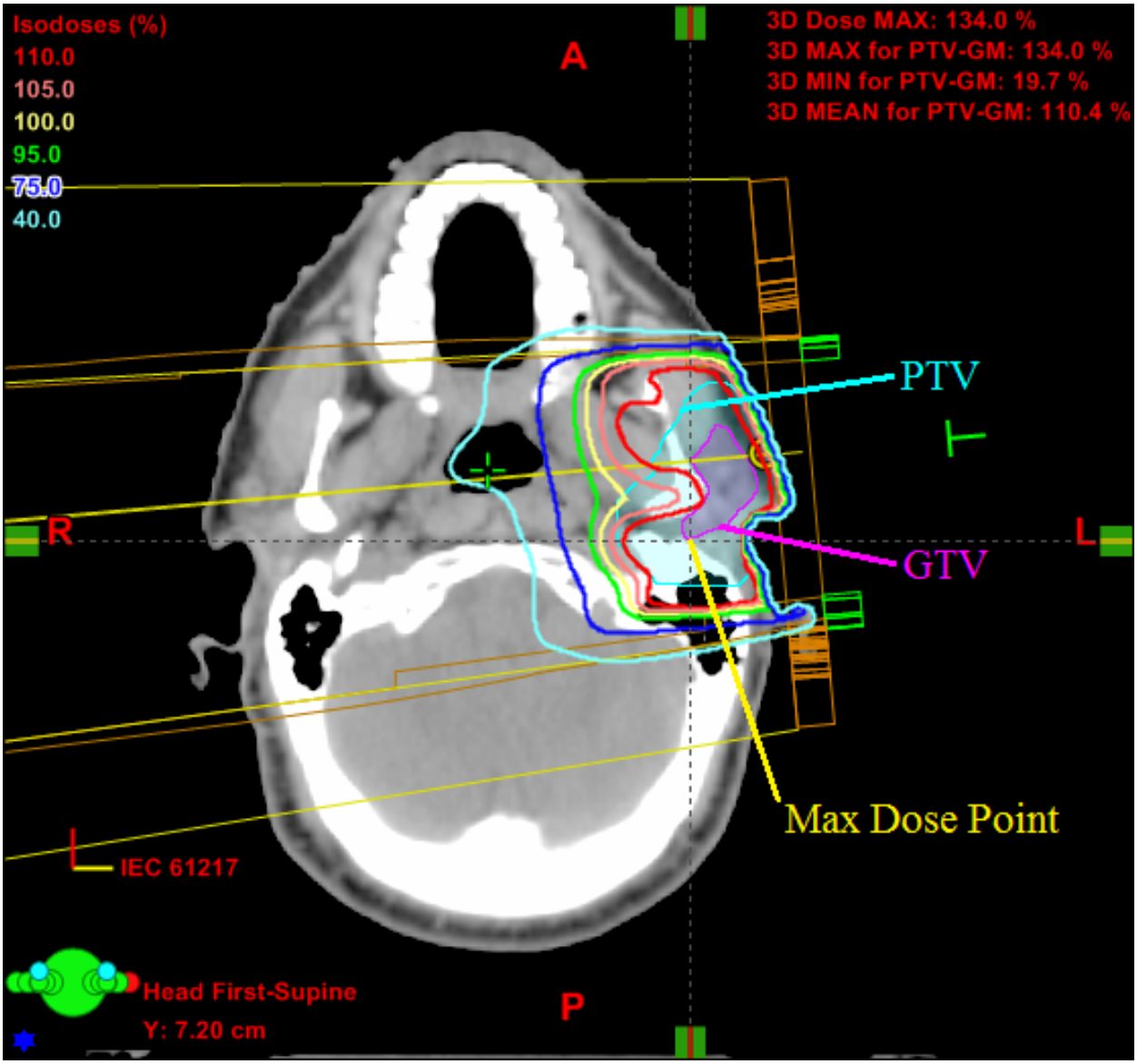

Figure 6. Axial cross-section of mixed beam plan at the level of the maximum dose point. Sensitivity of dose distribution to surface irregularities such as the external ear and ear canal are apparent.

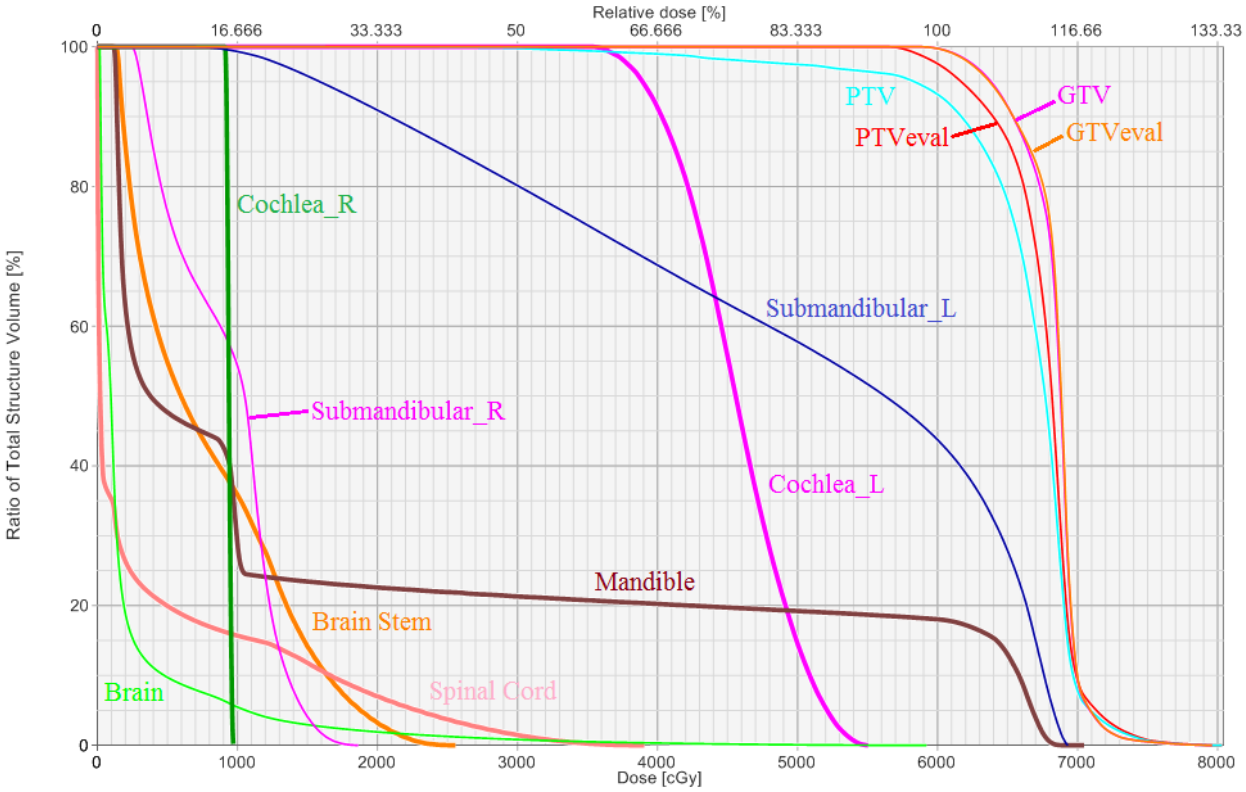

Figure 7. DVH of Plan 2 showing extremely high doses to targets required for adequate coverage, as well as tolerance-exceeding doses to the left cochlea and left submandibular gland.

Plan 2 Score Card

Contour	Goal	Achieved	Evaluation
GTV	V60Gy = 100%	99.8%	~ Pass
GTVeval	V60Gy = 100%	99.8%	~ Pass
PTV	V95%Rx = 100%Vol V100%Rx > 95%Vol	95.9% 93.2%	Minor Deviation Minor Deviation
PTVeval	V95%Rx = 100%Vol V100%Rx > 95%Vol	99.9% 97.6%	~ Pass Pass
Eye_R	Max < 35 Gy	2.8 Gy	Pass
Eye_L	Max < 35 Gy	4.4 Gy	Pass
Lens_R	Max < 8 Gy	1.5 Gy	Pass
Lens_L	Max < 8 Gy	1.7 Gy	Pass
OpticNerve_R	Max < 52 Gy	3.9 Gy	Pass
OpticNerve_L	Max < 52 Gy	7.3 Gy	Pass
Chiasm	Max < 50 Gy	3.0 Gy	Pass
Cochlea_R	Mean < 25 Gy	9.7 Gy	Pass
Cochlea_L	Mean < 25 Gy	55.1 Gy	Major Deviation
Brain	Max < 60 Gy	59.2 Gy	Barely Pass
BrainStem	Max < 50 Gy	25.6 Gy	Pass
SpinalCord	Max < 45 Gy	39.1 Gy	Pass
Mandible	Max < 70 Gy	70.5 Gy	Minor Deviation
Parotid_R (contralateral)	Mean < 20 Gy V22 Gy < 50% Vol	11.7 Gy 0%	Pass Pass
Parotid_L (ipsilateral)	unconstrained	n/a	n/a
Submandibular_R	Mean < 39 Gy	18.7 Gy	Pass
Submandibular_L	Mean < 39 Gy	69.3 Gy	Major Deviation

Figure 8. Score card of Plan 2 (Mixed Beam) showing goal dose levels for targets and ORs, as well as an evaluation of whether the goals were met.

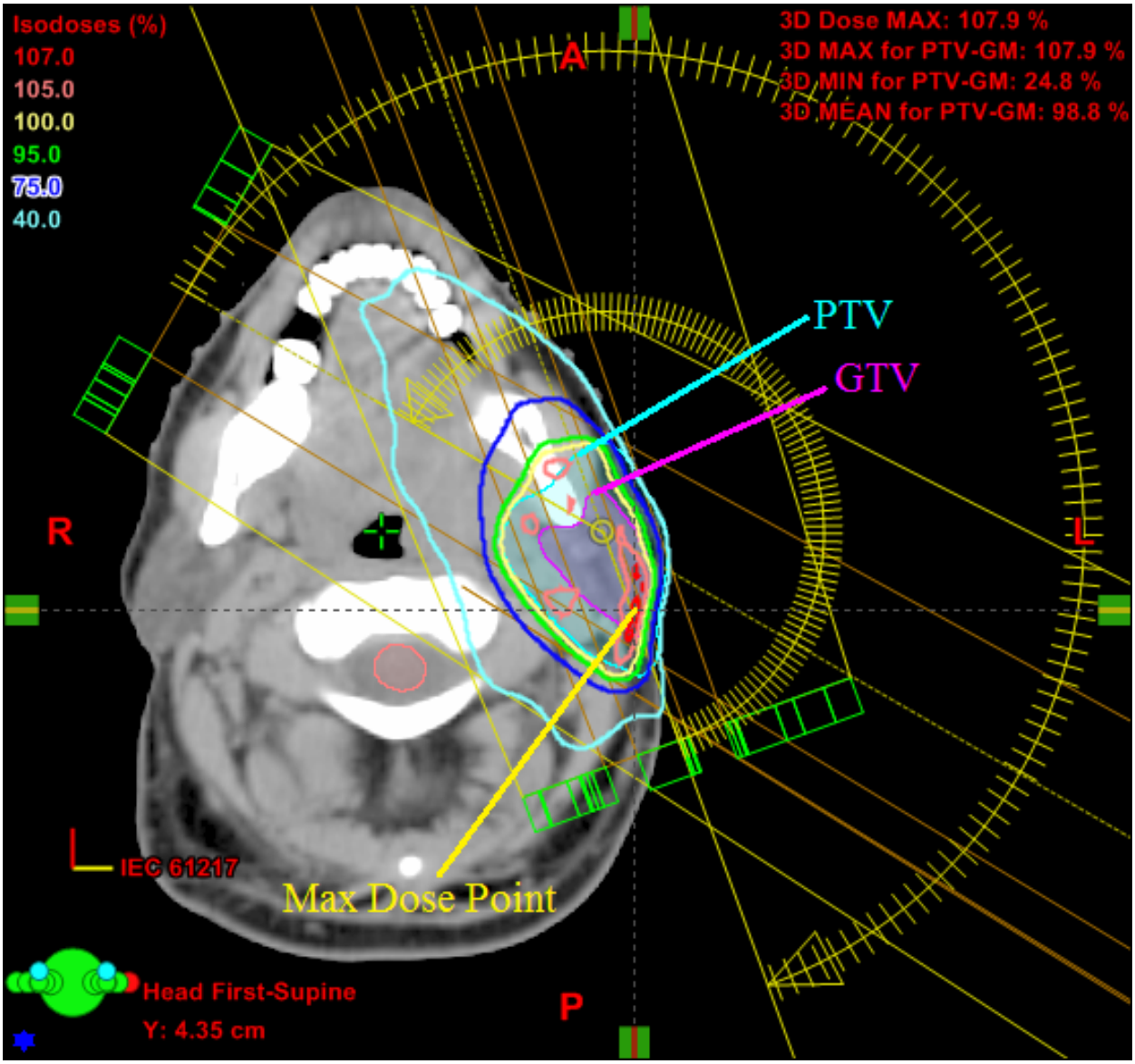

Figure 9. Axial cross-section of RapidArc plan showing excellent conformality of the 95% and 100% isodose lines to the PTV.

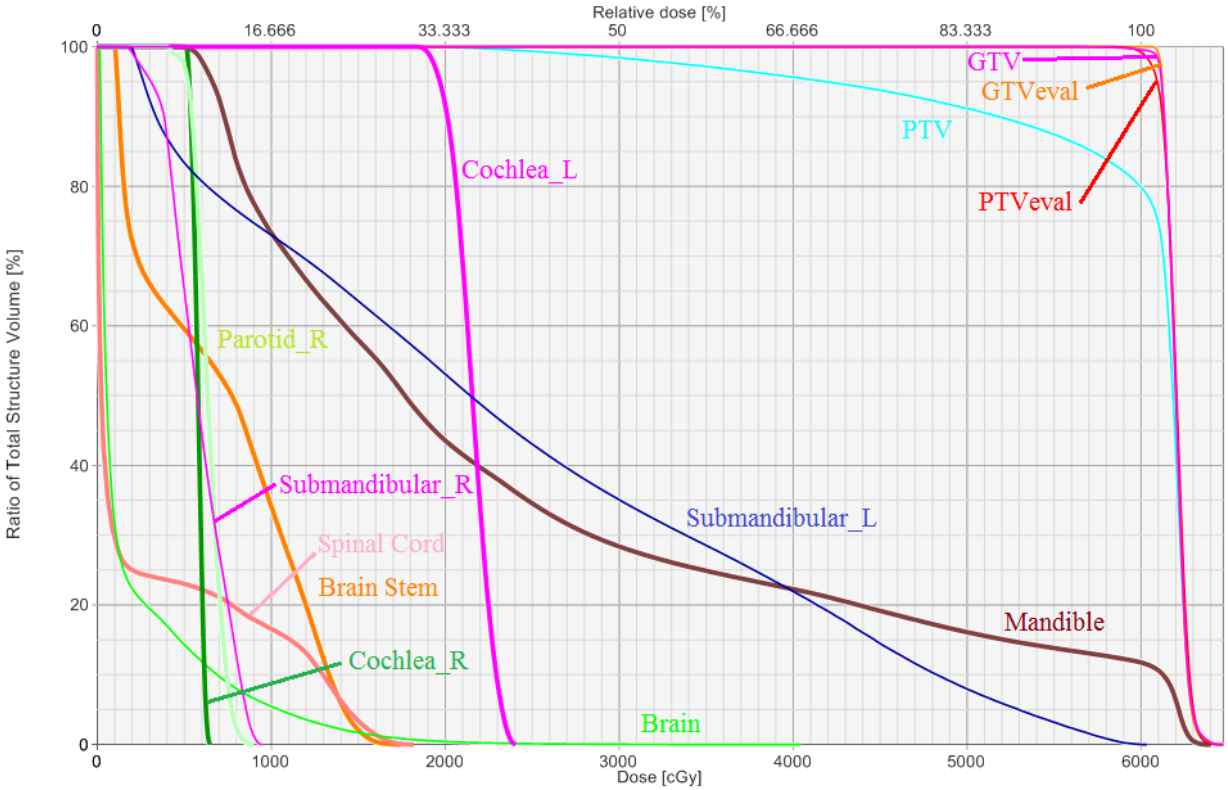

Figure 10. DVH of RapidArc plan showing good coverage of targets and good sparing of ORs.

Plan 3 Score Card

Contour	Goal	Achieved	Evaluation
GTV	V60Gy = 100%	99.6%	~ Pass
GTVeval	V60Gy = 100%	100%	Pass
PTV	V95%Rx = 100%Vol V100%Rx > 95%Vol	85.3% 80.0%	Major Deviation Major Deviation
PTVeval	V95%Rx = 100%Vol V100%Rx > 95%Vol	100% 99.3%	Pass Pass
Eye_R	Max < 35 Gy	1.1 Gy	Pass
Eye_L	Max < 35 Gy	1.4 Gy	Pass
Lens_R	Max < 8 Gy	0.8 Gy	Pass
Lens_L	Max < 8 Gy	1.0 Gy	Pass
OpticNerve_R	Max < 52 Gy	1.1 Gy	Pass
OpticNerve_L	Max < 52 Gy	1.2 Gy	Pass
Chiasm	Max < 50 Gy	1.1 Gy	Pass
Cochlea_R	Mean < 25 Gy	6.5 Gy	Pass
Cochlea_L	Mean < 25 Gy	24.1 Gy	Pass
Brain	Max < 60 Gy	40.4 Gy	Pass
BrainStem	Max < 50 Gy	17.5 Gy	Pass
SpinalCord	Max < 45 Gy	18.3 Gy	Pass
Mandible	Max < 70 Gy	64.1 Gy	Pass
Parotid_R (contralateral)	Mean < 20 Gy V22 Gy < 50% Vol	9.1 Gy 0%	Pass Pass
Parotid_L (ipsilateral)	unconstrained	n/a	n/a
Submandibular_R	Mean < 39 Gy	5.8 Gy	Pass
Submandibular_L	Mean < 39 Gy	23.9 Gy	Pass

Figure 11. Score card showing Plan 3 (RapidArc) goal dose levels for targets and ORs, as well as an evaluation of whether the goals were met.