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Case Study 2

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Pelvic Conformal Planning with Hip Prosthesis and CT Artifacts

History of Present Illness: Patient is an 85 year old female with a history of stool urgency for several years with occasional blood in the stool. She reported rare occurrences of stool incontinence beginning around or before October 2014. A flexible sigmoidoscopy in October 2014 showed a large hemi-circumferential polypoid lesion starting 0.5 cm above the dentate line and extending 5 cm into the rectum, and involving around 75% of the rectal circumference. The lesion was described as a Paris II morphology[1] laterally spreading tumor with 2 sessile components. Biopsies were taken from 6 sites in the 2 sessile components. Pathologic evaluation of the biopsy samples showed tubulovillous adenoma with no evidence of high grade dysplasia or invasive carcinoma. The pathologist noted that the biopsy samples may represent superficial sampling of an underlying invasive carcinoma. Surgical intervention was offered but the patient declined any type of intervention. In February 2015, a CT of the abdomen and pelvis showed what appeared to be a rectal filling defect larger than what had previously been described, but lack of CT contrast made accurate size determination difficult. Moderate fecal stasis with fecal material in the distal small bowel was noted. In March 2015, after continuing to experience urgency and occasional incontinence, another flexible sigmoidoscopy was performed. A large fungating non-obstructing mass covered the entire circumference of the rectal canal from the anal verge to 5 cm into the rectum. The physician performing the procedure described the lesion as overtly malignant in appearance. Biopsies were taken with cold forceps, but the pathologic findings from the biopsy samples still showed only tubulovillous adenoma with no evidence of carcinoma. With strong suspicion of underlying malignant disease, the patient was offered palliative radiation therapy, which she accepted.

Past Medical History: Patient reported lumbago and joint inflammation of the back subsequent to a lumbar laminectomy in 2000. Patient has been diagnosed with essential hypertension, hypercholesterolemia, coronary atherosclerosis, and aortic stenosis. She suffered a heart attack requiring quadruple bypass surgery in 2002. Patient had gall bladder surgery at an unknown date. Patient has been diagnosed with type 2 diabetes mellitus, which has led to chronic kidney disease and neuropathy. Cataracts and senile macular degeneration have also been diagnosed. Patient has also suffered from osteoporosis, and underwent right hip replacement surgery in 2006. She has used a wheelchair for mobility outside the home and a walker or cane inside the home for several years.

Social History: Patient is widowed with 1 daughter. Patient has never smoked or used smokeless tobacco. Patient denies using alcohol and recreational drugs. Patient's family history includes diabetes in mother, brother, and sister. Her sister has also had cancer.

Medications: Patient tests her blood glucose four times daily with Accu-Chek lancets, strips, and reader. She injects insulin lispro (Humalog) prior to meals. Patient takes iron supplements (Ferrogels Forte) and vitamin supplements (Ocuvite Eye Health Formula) daily, as well as a multivitamin (Viactiv) and psyllium fiber supplement (Metamucil) twice daily. Hypercholesterolemia is treated with atorvastatin (Lipitor) daily. Hypertension is treated with furosemide (Lasix) daily and carvedilol (Coreg) twice daily. Peripheral neuropathy pain is managed with pregabalin (Lyrica) 2-4 times daily. Patient began using fentanyl (Duragesic) patches to manage pain during treatment.

Diagnostic Imaging: The patient's rectum was examined with flexible sigmoidoscopy in October 2014, revealing a large polypoid lesion starting 0.5 cm above the dentate line, extending 5 cm into the rectum, and wrapping around 75% of the circumference of the rectum. The morphology was Paris II with 2 sessile components, from which 6 biopsy samples were taken. Superficial fragments of tubulovillous adenoma were noted, with no evidence of high grade dysplasia or carcinoma, but underlying invasive carcinoma was suspected. A followup CT of the abdomen and pelvis in February 2015 showed that the lesion appeared to be larger, but lack of CT contrast made precise measurement difficult. Fecal stasis with fecal material present in the distal small bowel was noted. A second flexible sigmoidoscopy procedure was performed to examine the rectum in March 2015. The lesion was non-obstructing, but wrapped around the entire circumference of the rectum. The lesion was fungating and overtly malignant in appearance. Biopsy samples once again showed only tubulovillous adenoma. Patient was referred for palliative radiation therapy and a simulation CT was acquired in April 2015 on a Philips Brilliance 16 slice CT at 120 kV and 3 mm slice thickness.

Radiation Oncologist Recommendations: A multidisciplinary board met to discuss management options. Despite the lack of biopsy-proven malignancy, the board concluded that the size and growth of the tubulovillous mass pointed to a high probability of an underlying malignancy. Since the patient's quality of life was severely limited by symptoms of urgency and occasional fecal incontinence, a course of palliative radiation therapy was recommended. A 3D conformal technique was recommended in order to reduce radiation dose to nearby organs at risk.

The Plan (Prescription): The patient was prescribed a total dose of 2500 cGy delivered in 5 fractions of 500 cGy, at a rate of two fractions per week. The radiation oncologist specified that 95% of the prescription dose should be delivered to at least 95% of the planning target volume (PTV), and the maximum point dose in the PTV should not exceed 107% of the prescription dose. No more than 30% of the small bowel was allowed to receive 40 Gy or higher. The bladder was allowed to have no more than 50% coverage at 45 Gy. The remaining femoral head was limited to a maximum of 40 Gy covering 15%.

Patient Setup/Immobilization: The patient's simulation CT was acquired in the supine position with arms down and hands comfortably folded across the chest (Figure 1). A foam wedge and pillow supported the head, and the lower portions of the legs were immobilized with a custom Alpha Cradle mold. The patient was scanned with a comfortably full bladder. With the patient still on the table, the radiation oncologist localized the treatment isocenter on the CT console and the table was moved to match the radiation oncologist's isocenter to the room's laser origin. Three point setup tattoos were marked at right lateral, anterior, and left lateral laser intersections. The isocenter coordinates were saved and sent to the treatment planning system along with the CT.

Anatomical Contouring: Simulation CT images were transferred to a Varian Eclipse 11.0.47 treatment planning system (TPS). A body contour was automatically generated by the CT acquisition console and this contour was transferred with the CT images. The radiation oncologist contoured the gross tumor volume (GTV), clinical target volume (CTV), and PTV. The dosimetrist contoured the bladder, the left femur, the metal portion of the right hip prosthesis, and the small bowel. The CT scan showed significant streaking artifacts originating from the metal hip prosthesis. Every slice of the PTV had at least minor streaking, and around a third of the slices of the PTV exhibited severe streaking (Figure 2). Contouring individual streaks would have been prohibitively time consuming, so the physicist and dosimetrist decided to prepare several density override contours for inhomogeneity correction testing. The dosimetrist created a density override structure representing all soft tissue by contouring all dense bony anatomy with a Hounsfield unit (HU) threshold and then performing a Boolean subtraction of bones from the patient's body contour (Figure 2). A variant of the bony anatomy contour was also prepared which included the lower density spongy bone and marrow spaces inside the bones and not just the high density cortical bone. From this second bony anatomy contour, a second soft tissue density override contour was generated using the same Boolean method as the first one. The purpose of the second set of overrides was to allow evaluation of the effect of preserving the original HU values of spongy bone and marrow.

Beam Isocenter/Arrangement: Isocenter placement and beam arrangement were performed on a Varian Eclipse 11.0.47 TPS. The plan isocenter chosen by the radiation oncologist during simulation was too far superior to allow wedges to be applied to one of the fields because of the required jaw opening for the large field. The original isocenter was preserved as a patient setup location and a new isocenter was created 4.86 cm directly inferior to the old point, requiring only a single shift by therapists during setup (Figure 3). The new isocenter location allowed the independent jaws to open more symmetrically, permitting the use of wedges in all fields (Figure 4). The radiation oncologist recommended a 3D conformal four field plan to be delivered on a Varian Clinac 21 EX. The traditional four field arrangement comprising an anterior-posterior (AP) and posterior-anterior (PA) opposed pair and a right lateral (RLAT) and left lateral (LLAT) opposed pair could not be used on the patient because the RLAT field would pass directly through the metal hip prosthesis. Alternatives to the four field box in the presence of hip prostheses have been proposed,[2,3,4] but these techniques are usually geared towards treatment of the prostate, when rectal sparing is included among the goals. To treat a rectal case, a different four field arrangement comprising an AP field, a LLAT field, a left posterior oblique (LPO), and a right posterior oblique (RPO) was created (Figure 5). This arrangement avoided entrance dose passing through the hip prosthesis, and it maximized the radial distribution of the central axis entry and exit angles of the four fields, allowing a much more conformal treated volume than the rectangular treated volume typically delivered by a traditional four field box. All fields were set up with 23 MV photons. The AP, LLAT, LPO, and RPO gantry angles were 0, 90, 135, and 225 degrees respectively. The AP, LPO, and RPO fields had a 90 degree turn applied to the collimator to allow electronic dynamic wedges (EDWs) on each field to bias the delivered dose from one side to another in the gantry plane to achieve better dose uniformity. The LLAT field used a 0 degree turn of the collimator to allow an EDW to bias the dose in the superior direction, further improving overall dose uniformity. Multileaf collimators (MLCs) were used on all four fields and were auto-fitted to the PTV with a 0.7 cm margin.

Treatment Planning: Planning for delivery on the Varian Clinac 21 EX was performed on a Varian Eclipse 11.0.47 TPS. A dose calculation point was placed at the isocenter location. All beams were set to 23 MV. Dose weighting of each beam was initially kept equal at 25% per beam. The CT streaking artifacts originating from the right hip prosthesis varied in severity from total obfuscation of the underlying anatomy to small but inappropriate negative or positive shifts in HU values along streak paths. The physicist and dosimetrist tested several strategies for dealing with the CT artifacts. The simplest strategy was to disable inhomogeneity correction and calculate dose with the entire body set at water density. This strategy was rejected because several of the beams passed through dense bony structures such as the sacrum, femur, and pelvic bones. A hybrid inhomogeneity correction approach was tested in which the bony structures were contoured and everything other than bony anatomy was overridden to water density. Two override structure variants were tested; one with only the dense cortical bone preserved at original HU values, and one with both dense cortical bone and the contained spongy bone and marrow preserved and original HU values. The difference between these two plans was negligible, so the plan that only preserved cortical bone was selected based on ease of preparing the contours. As a final validation, the plan was calculated with inhomogeneity correction enabled and no attempt to override any densities. The resulting change in monitor unit (MU) values was within 1% of hybrid override plan (Figure 6). Since the plans did not show significant differences, and the delivery technique was a simple 3D conformal technique, the physicist recommended abandoning the hybrid density override technique and using normal inhomogeneity correction methods based purely on the imaging. This approach greatly simplified documentation for future planners in the event of a recurrence that requires addition treatment.

The patient’s right hip prosthesis required an asymmetrical field arrangement in order to avoid passing any entering beams through the prosthesis. In order to achieve the best uniformity in the asymmetrical field arrangement, the RPO field had a 60 degree EDW to pull dose anteromedially, towards the area that would have been covered by a RLAT field. Five percent of the total plan weight was shifted from the AP field to the RPO field in order to compensate for the heavy wedging, resulting in a 20/25/25/30 split between AP, LLAT, LPO, and RPO respectively. A 30 degree EDW was used on the LPO field to push dose anteriorly, and a 10 degree EDW on the AP field pushed dose to the right. The LLAT field had a 10 degree EDW pushing dose superiorly.

The wedging, field weighting, and high beam energy allowed tight conformity and high dose uniformity across the PTV. The planning goal of 95% coverage by the 95% of prescription isodose line was more than met with 99% coverage (Figure 7). The goal of keeping the maximum point dose below 107% of the prescription dose was easily met with only a 103.3% hot spot. The constraints on the bowel, bladder, and femoral head were automatically met because the prescription dose of 25 Gy was far less than the 40 or 45 Gy plan constraints. Dose conformality around the PTV was maximized to the extent possible in order to keep low dose out of these structures as a precaution (Figures 8, 9, 10).

Quality Assurance/Physics Check: The MUs calculated for each field in Eclipse were evaluated by running a computerized second check with RadCalc 6.2 and looking for agreement. The largest deviation between Eclipse and RadCalc MU values for any field was 1.1%, with a total MU difference of 0.5% (Figure 6). Treatment parameters, treatment schedules, plan documentation, setup imaging, and billing codes were loaded and/or set up in Mosaiq 2.30.04D4 by the dosimetrist and verified by the physicist. Ion chamber verification of field MUs was not performed because ion chamber QA is not routinely performed on 3D conformal plans.

Conclusion: Hip prostheses introduce pelvic planning challenges both by excluding some gantry angles from consideration and by creating CT density artifacts that have the potential to obscure anatomic details and/or misrepresent the physical density of tissues with streaks or higher or lower than true density. An effective alternative to a four field box arrangement that avoids a hip prosthesis can be created by rotating both the lateral beam on the affected side and the PA beam 45 degrees each, such that they become RPO and LPO fields. This arrangement was successfully used to produce a tightly conforming plan with high dose uniformity. CT artifacts were found to have a much smaller effect than anticipated on the overall dose calculation with a four field arrangement of 23 MV beams. This might be explained by a volume averaging effect across the relatively large (9x9x14 cm) target area which included both too-bright and too-dark streaks. It is also possible that the choice of windowing and leveling may cause streaking artifacts to appear more severe than they truly are in terms of their ability to affect dose calculations. A strategy to create a hybrid inhomogeneity correction scheme that leaves bone densities untouched but overrides soft tissue densities was tested but found to be unnecessary in this case. A more thorough test of this scatter artifact compensation strategy in a different body region such as head and neck may be warranted.

References

1. Inoue H, Kashida H, Kudo S et al. The Paris endoscopic classification of superficial neoplastic lesions: esophagus, stomach, and colon. *Gastrointest Endosc*. 2003;58(6 Suppl):S3-43.
2. Carolan M, Dao P, Fox C, Metcalfe P. Effect of hip prostheses on radiotherapy dose. *Australas Radiol*. 2000;44(3):290-5.
3. Reft C, Alecu R, Das IJ, et al. Dosimetric considerations for patients with hip prostheses undergoing pelvic irradiation. Report of the AAPM Radiation Therapy Committee Task Group 63. *Med Phys*. 2003;30(6):1162-82. http://dx.doi.org/10.1118/1.1565113
4. Agapito J. Radical radiation therapy for carcinoma of the prostate in patients with a single hip prosthesis: a technique analysis using dose-volume histograms. *Med Dosim*. 2001;26(3):243-50. http://dx.doi.org/10.1016/S0958-3947(01)00070-X

Figures

Figure 1. Patient setup during CT simulation with pillows under head and Alpha Cradle mold immobilizing the lower legs.

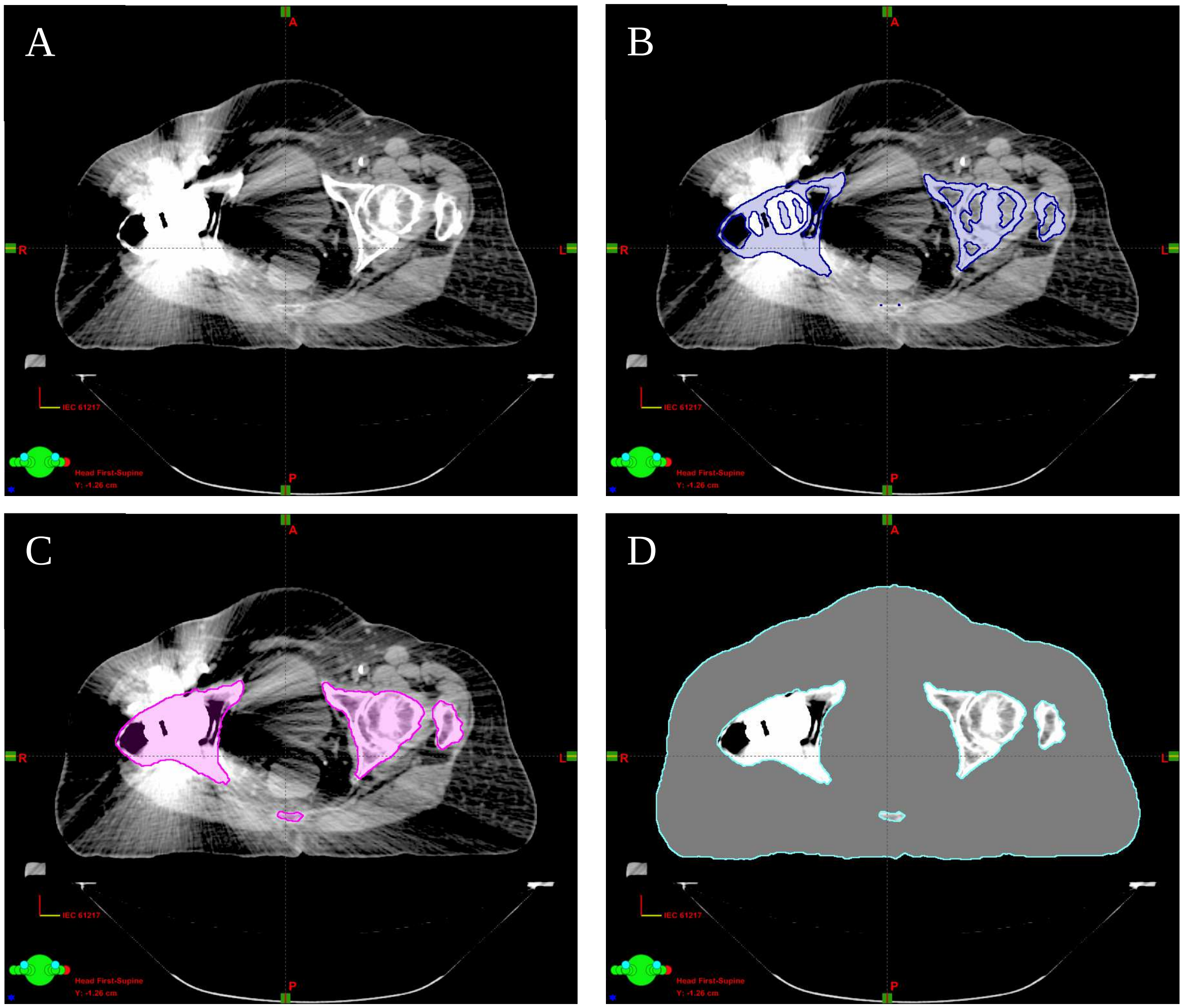

Figure 2. A) CT axial slice showing extensive light and dark scatter artifacts caused by metal hip prosthesis. B) Contour of dense bony strcutures generated with HU threshold technique and manual editing. C) Contour of dense bony structures with hole filling and manual editing to include spongy bone and marrow. D) Soft tissue override contour made by subtracting the bone contour from the body contour, allowing the natural density of bones to remain while eliminating scatter artifacts in soft tissue.

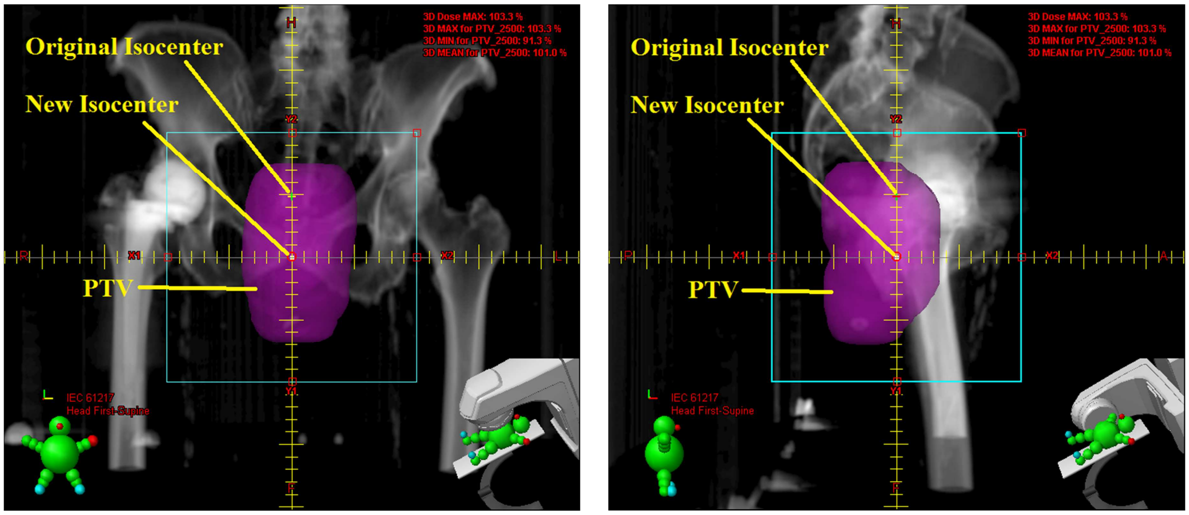

Figure 3. AP (left) and RLAT (right) setup fields showing the PTV and the locations of the original isocenter and the new more centralized plan isocenter.

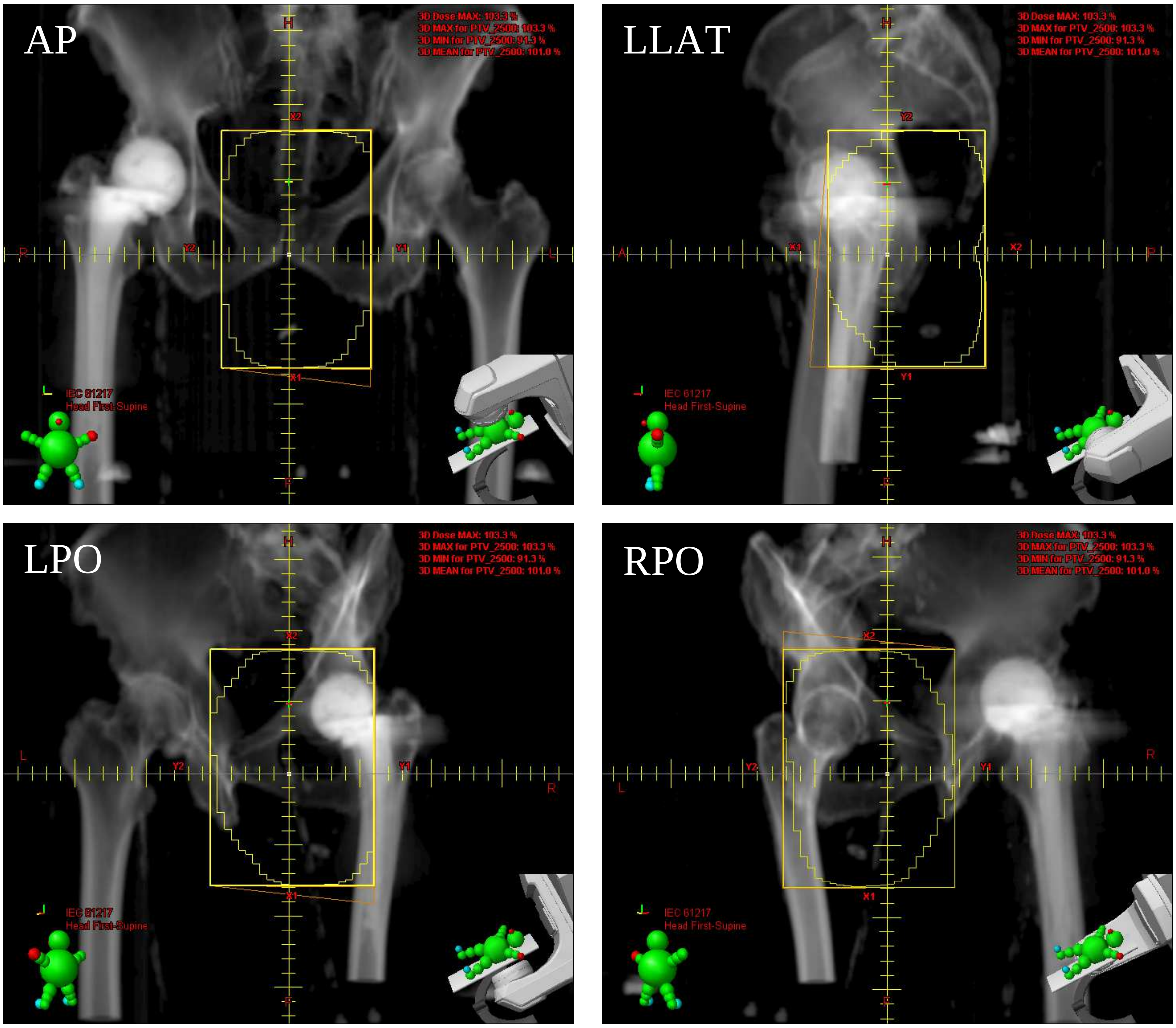

Figure 4. Digitally reconstructed radiographs showing field apertures for AP, LLAT, LPO, and RPO beams and wedge orientations.

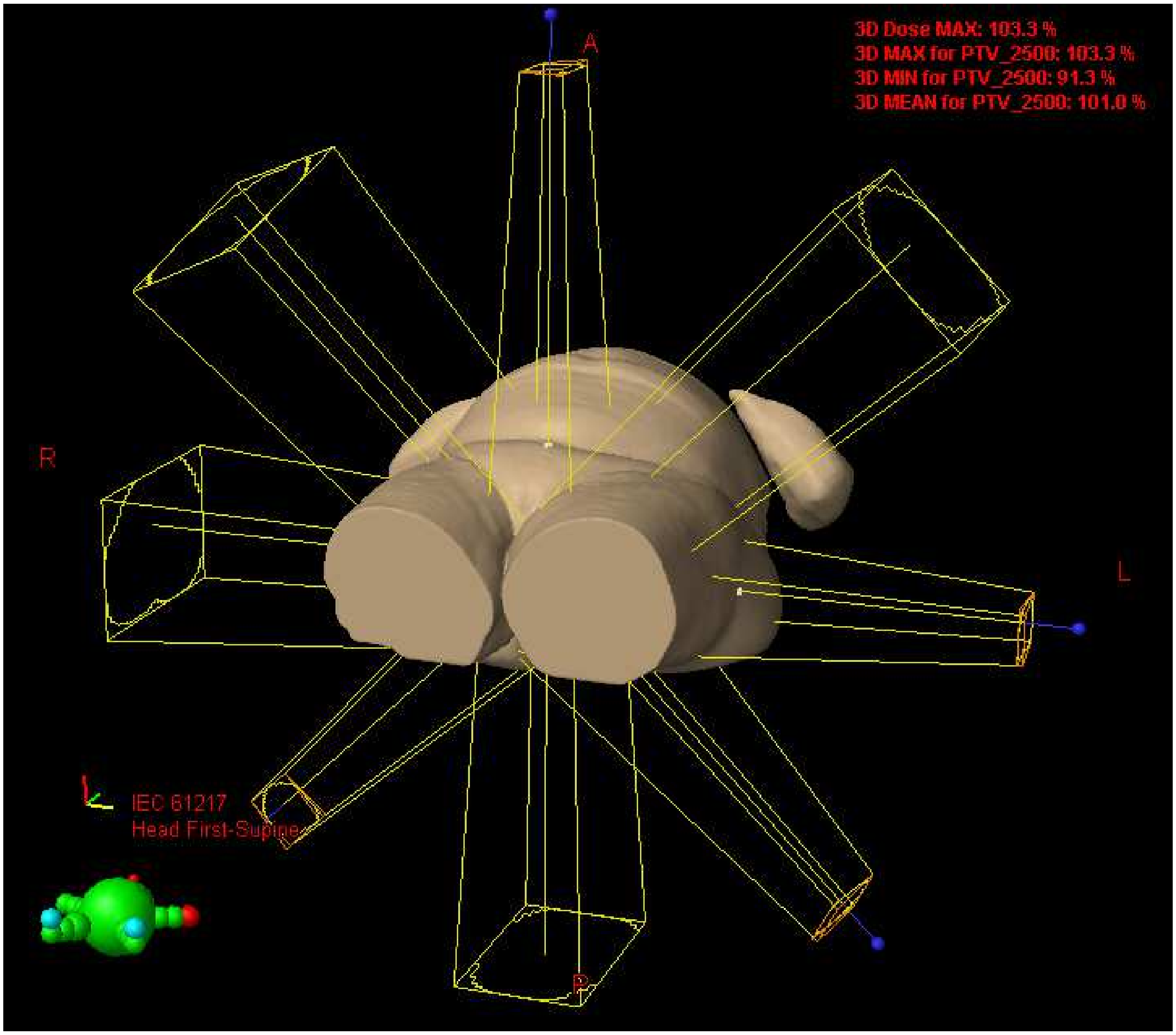

Figure 5. A 3D rendering of the patient's skin surface showing the arrangement of a four field plan that avoids entrance through the right hip.

	Eclipse MU Values With Various Inhomogeneity Correction Schemes			
Field	Override soft tissue minus dense bone	Override soft tissue minus all bone and marrow	No density override	Second MU check (RadCalc)
AP	119	119	119	119
LLAT	181	181	180	180
LPO	157	157	155	155
RPO	225	225	224	222

Figure 6. MU calculations with various inhomogeneity correction schemes, showing very little difference between techniques.

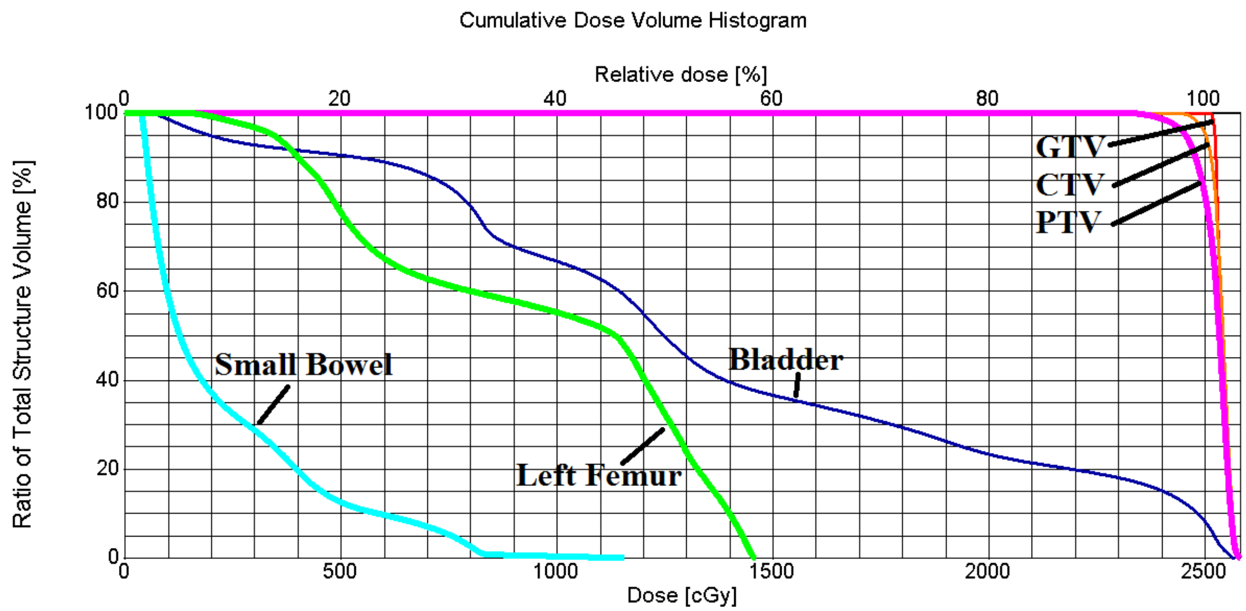

Figure 7. Dose volume histogram showing final dose coverage of targets and organs at risk.

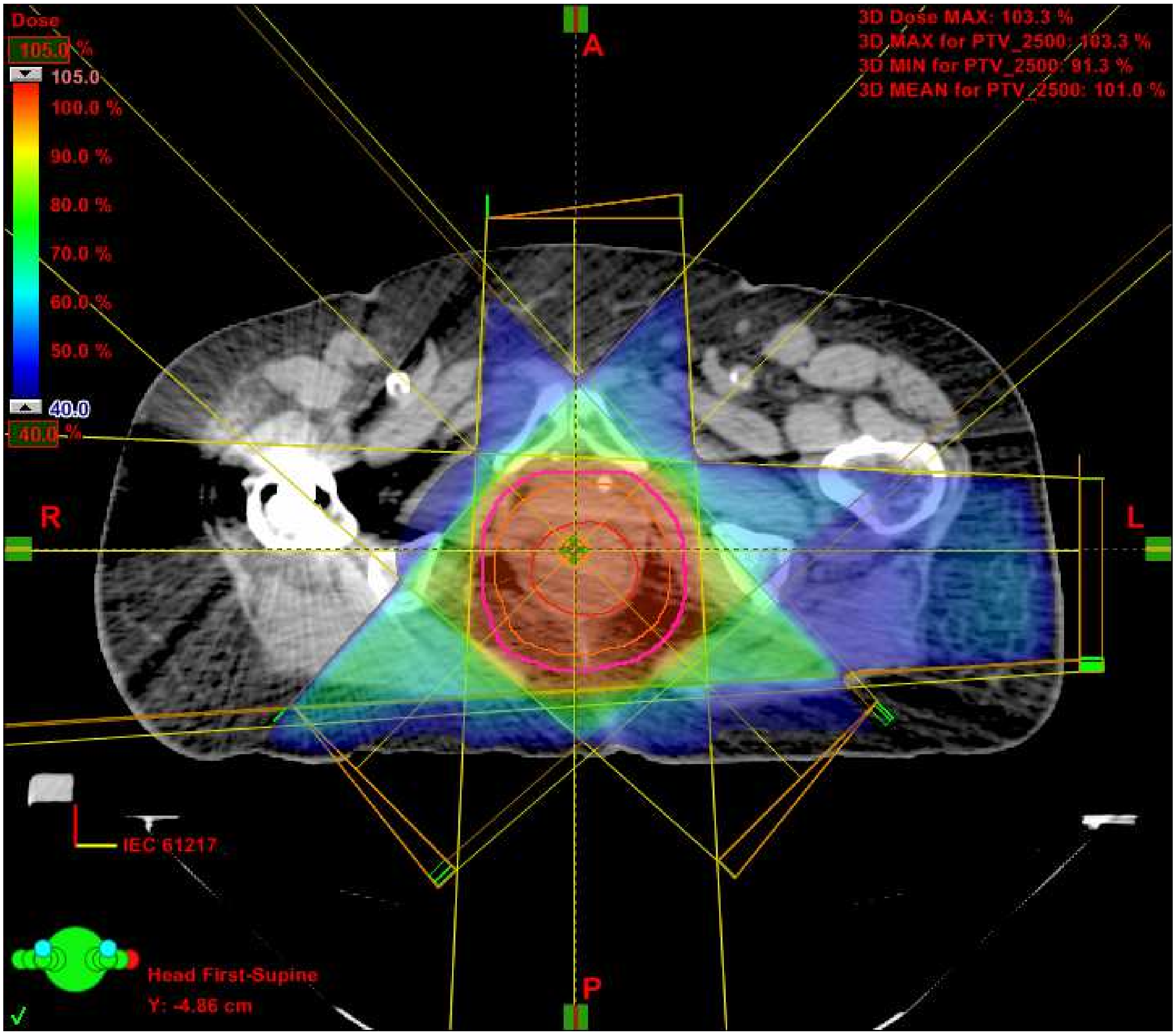

Figure 8. Axial slice through the plan isocenter showing GTV (red), CTV(orange), PTV (magenta), field arrangement, and total dose intensity.

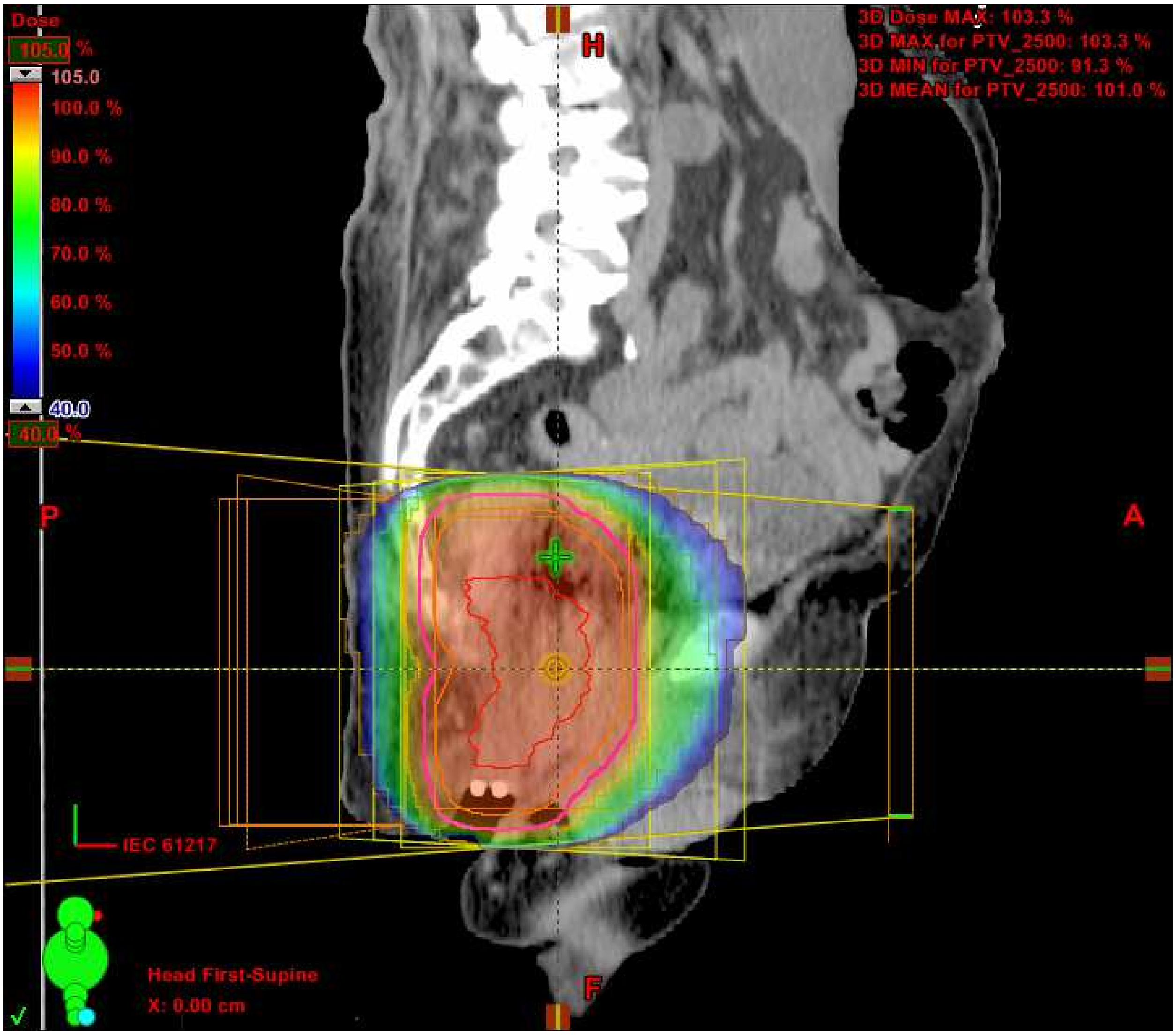

Figure 9. Sagittal slice through the plan isocenter showing GTV (red), CTV(orange), PTV (magenta), field arrangement, and total dose intensity.

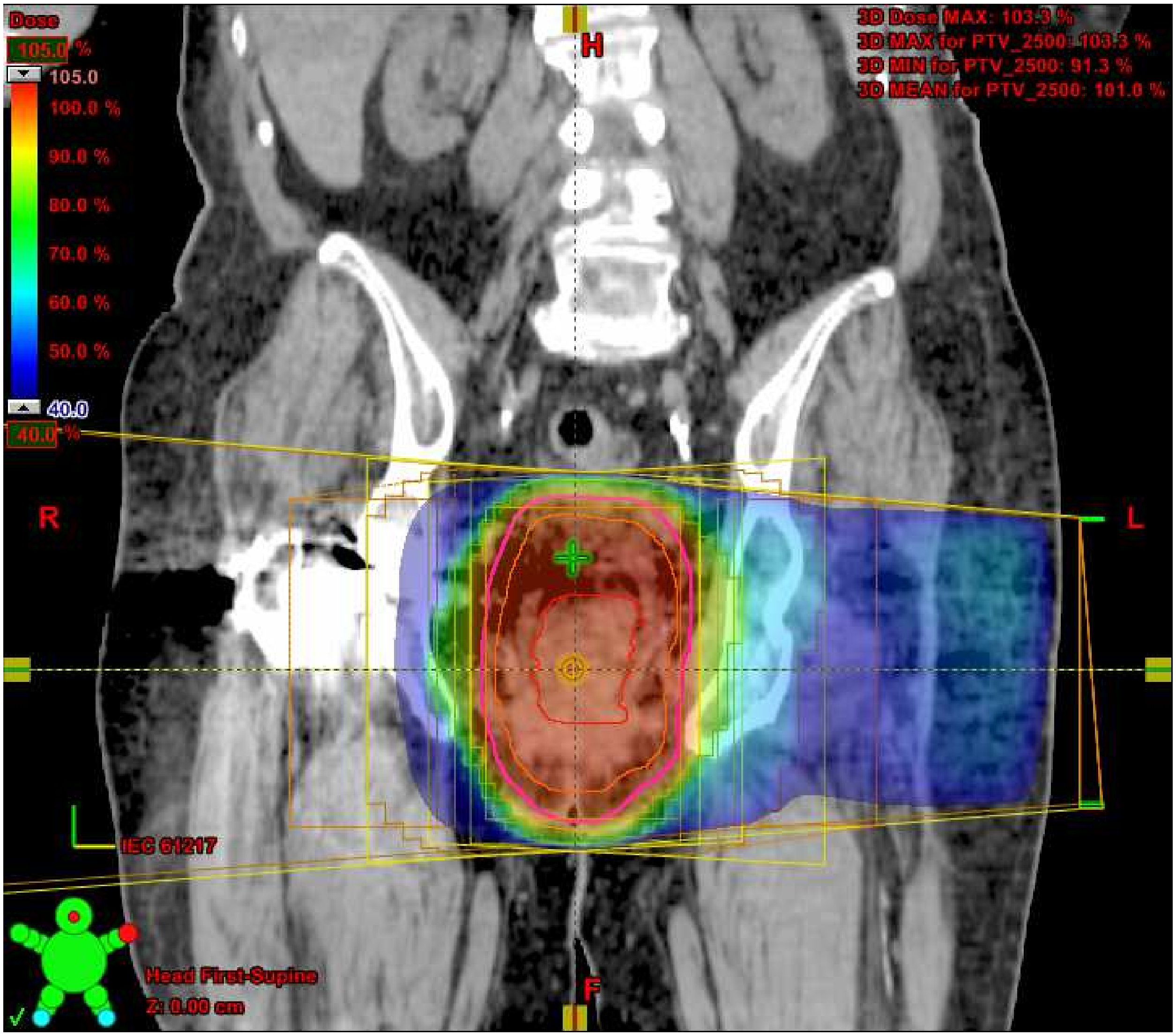

Figure 10. Coronal slice through the plan isocenter showing GTV (red), CTV(orange), PTV (magenta), field arrangement, and total dose intensity.