World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

Simulation of ITV and GTV doses in SBRT treatment of lung cancer

Adekunle Job *

Department of Radiotherapy, Kuopio University Hospital, Puijonlaaksontie 2,70210 Kuopio, Affiliate of University of Eastern Finland.

World Journal of Advanced Research and Reviews, 2025, 26(01), 3601-3612

Publication history: Received on 14 March 2025; revised on 21 April 2025; accepted on 23 April 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.26.1.1345

Abstract

Background: Stereo-tactic body radiation therapy (SBRT) has emerged as a highly effective treatment for early-stage non-small cell lung cancer (NSCLC) and metastatic lung tumors. Its ability to deliver high doses of radiation precisely to the tumor while sparing surrounding healthy tissue makes it a preferred option for inoperable cases. Accurate dose distribution assessment is critical for optimizing treatment plans and minimizing toxicity risks.

Objective: This study aims to analyze the dose distribution of SBRT in lung cancer treatment using Monte Carlo simulations and experimental verification. By evaluating dose accuracy and its impact on surrounding tissues, the study seeks to improve treatment precision and patient safety.

Methods: We employed Monte Carlo-based simulations to model radiation dose distributions for lung tumors treated with SBRT. The simulated dose distributions were compared with experimental measurements using ionization chambers and film dosimetry in a lung-equivalent phantom. Key parameters, including dose heterogeneity, tumor coverage, and organ-at-risk (OAR) exposure, were analyzed to validate the treatment planning system (TPS).

Results: Preliminary findings indicate that Monte Carlo simulations provide higher accuracy in predicting lung dose distributions compared to conventional algorithms. Differences in calculated vs. measured doses highlight the need for improved heterogeneity corrections in TPS.

Conclusion: Monte Carlo simulations offer a reliable approach for evaluating SBRT dose distributions in lung cancer patients. Their integration into clinical workflows could enhance treatment planning accuracy, ultimately improving therapeutic outcomes while minimizing toxicity risks.

Keywords: SBRT; PTV; GTV; ITV; VMAT; 4DCT; DCA; PlanningCT; MAXCT; MEANCT

1. Introduction

The introduction of type B and C dose calculation algorithms to clinical treatment planning software has significantly improved dose prediction accuracy in low-density materials such as lungs. However, improved calculation accuracy has created new challenges to the use of modern inverse planning techniques and the concept of dose normalization when target volume includes density inhomogeneities.

To avoid creating overly complicated and non-robust treatments conventional type A algorithms are recommended in the optimization of intensity-modulated radiotherapy treatment for lung tumors. After optimization, the dose distribution is calculated using the type b (or c) algorithm and the dose is normalized typically to 95% coverage of PTV.

* Corresponding author: Adekunle Job

However, due to the intrinsic differences in dose calculation algorithms, PTV normalization has been reported to cause inconsistent and excessive GTV doses in lung tumors. Furthermore, type A algorithms are not available in all treatment planning software. Thus, artificially increasing the density of low-density areas within the PTV area is used to increase the robustness of the treatment plans. However, there are no general guidelines on how electron density overrides should be used.

Finally, to avoid the creation of overly complex treatment plans, conformal arcs with limited modulation might be more suited for lung SBRT treatments than VMAT technique. However, for targets located close to critical structures such as a heart or a ribcage acceptable treatment plan quality might not be reached with conformal techniques. The aim of this work is to investigate the effect of treatment planning techniques and planning CT density overrides on ITV and GTV dose on the simulated SBRT treatment of lung tumors.

2. Methods

2.1. Treatment setup

Four lung cancer patients treated for lung cancer were selected for the study. For each patient planning CT and 4D CT are acquired in free breathing. GTV is delineated on one breathing phase on the 4D CT, and the contour is propagated to other breathing phases. ITV is determined as a union of the breathing phase specific GTV structures. Subsequently, PTV is created as an outer margin around the ITV structure.

Three planning CTs are created for each patient for the treatment planning task. Electron densities within PTV are filled to 0.8 to create "Plannings", and a maximum and mean intensity projections are calculated based on 4D CT to create "MAXCT" and "MEANCT", respectively. Subsequently, volumetric modulated arc (VMAT), dynamic conformal arc (DCA), and conformal arc (3DCA) treatment plans are created for each planning CT and its projections in Monaco treatment planning software. The treatment plans are carried out with the fractionation of 5 x 11 Gy.

Lung treatment is simulated using MIM SureCalc™ Monte Carlo algorithm. Created treatment plans are recalculated into each breathing phase in 4D CT and final dose is accumulated into ITV and GTV. Subsequently, the simulated dose is compared with the planned original dose to evaluate the robustness of the treatment. Finally, the consistency of GTV, ITV and PTV doses among the patients are evaluated.

The comparison between planned original and simulated plans is performed using minimum dose, mean dose, maximum dose and D95 value of a dose volume histogram (DVH), where D95 is the minimum dose that is delivered to 95 % of the tumor volume.

2.2. Film measurements

To evaluate the accuracy of the method used to simulate the patient treatments, a treatment planning process described above is repeated for 4D lung phantom CIRS Dynamic Thorax Phantom with an insert for Gafchromic EBT III films. Created VMAT treatment plans for all different CTs (PlanningCT, MAXCT, MEANCT) of the phantom are irradiated into the moving 4D phantom with a 6 MV photon beam.

To compare the results, a batch of Gafchromic films are calibrated in RW3 slab phantom (PTW) in the depth of five centimeters and with the total thickness of the phantom being 30 centimeters. Films were marked with pen prior to irradiation to indicate the positions of the films. Calibration films were irradiated with an Elekta Infinity linac, SSD of 95 cm, gantry angle of zero, a 6 MV photon beam and with doses of 0 MU, 100 MU, 400 MU, 700 MU and 1000 MU. Films were used to determine optical density of irradiated and non-irradiated films. A full Gafchromic film slab was scanned to correct scanner inhomogeneities. Irradiated and controlled films in both cases, calibration and phantom irradiation, were scanned 24 hours after the initial irradiation with an Epson perfection v750 pro scanner and the red channel was selected for analysis.

To convert film optical density to dose the images of the scanned films were processed and calibrated with Matlab using a single channel film dosimetry method described in the paper by Andre Micke et al. [1]. The calibration curve of the graph used to analyze the films is shown in Figure 1. After the processing, the results of the film measurements are compared with calculated dose distributions to verify the accuracy of the treatment simulations.

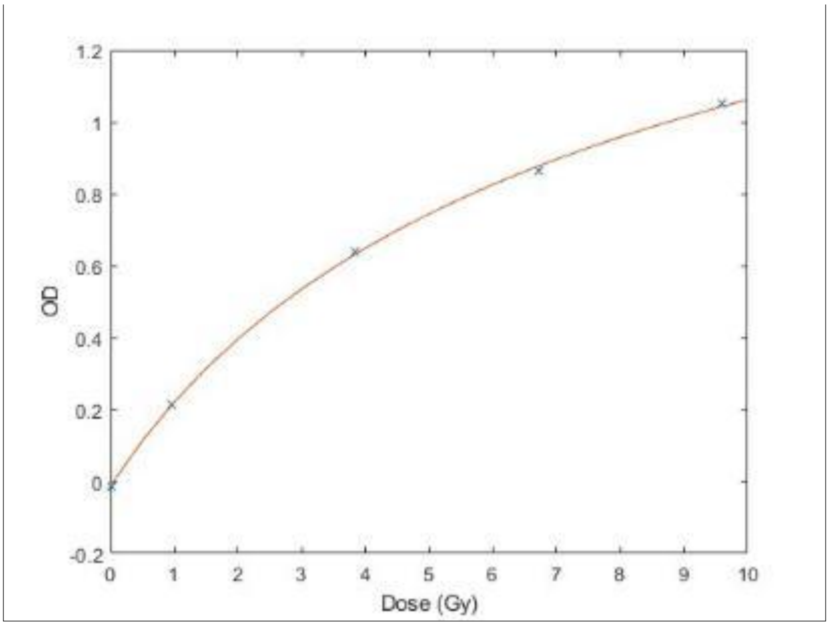

Figure 1 The dose calibration curve of the films

3. Results

3.1. Dose to ITV

Treatment technique specific and CT specific mean values of the parameters (min, mean, max, D95) across all the patients are listed in Table 1 for originally calculated plans and Table 2 for simulated plans. The dose volume histograms (DVH) for all patients, treatment techniques and CTs can be found in Figures 5-8 in Appendix 1.

When comparing parameters for treatment techniques listed in Table 1, it can be noticed that all the averaged values for DCA plans are consistently higher than corresponding parameters for VMAT or CA plans. However, parameters for VMAT are lower than those for CA plans, apart from minimum dose and D95. The same average values for different CTs (Table 1) show lowest values for PlanningCT, whilst MAXCT and MEANCT have similar values across all the parameters.

Table 1 Average values for originally calculated plans in ITV

	min	**mean**	**max**	**D95**
VMAT	56.065 ± 6.074	62.596 ± 3.756	67.187 ± 3.125	59.608 ± 4.786
DCA	57.047 ± 3.775	65.286 ± 3.145	70.715 ± 4.261	60.998 ± 3.154
CA	54.868 ± 5.139	64.578 ± 3.362	70.445 ± 5.055	59.141 ± 3.847
PlanningCT	54.920 ± 5.943	62.894 ± 4.190	69.008 ± 4.363	58.215 ± 5.299
MAXCT	56.068 ± 5.357	64.787 ± 2.854	69.127 ± 3.276	61.061 ± 3.022
MEANCT	56.992 ± 3.712	64.778 ± 3.353	70.212 ± 5.582	60.470 ± 2.750

Average values for simulated plans are listed in Table 2. Also, in this case for treatment techniques, the results are similar to originally calculated case. DCA has the highest values throughout all parameters. VMAT has lower mean and maximum values, but higher minimum and D95 values, compared to CA. For CT specific values, MAXCT yields the lowest values for all parameters, while MEANCT values, on the other hand, are consistently higher than those for other CTs.

Table 2 Average values for simulated plans in ITV

	min	mean	max	D95
VMAT	56.030 ± 5.963	62.069 ± 3.531	66.012 ± 3.710	59.295 ± 4.310
DCA	57.175 ± 3.393	64.709 ± 2.779	69.458 ± 3.687	60.496 ± 2.481
CA	55.058 ± 4.879	64.121 ± 3.783	69.065 ± 4.861	58.950 ± 3.761
PlanningCT	55.707 ± 5.538	63.464 ± 3.983	68.240 ± 4.301	59.166 ± 4.529
MAXCT	54.957 ± 5.374	62.713 ± 2.734	66.938 ± 2.899	58.860 ± 3.429
MEANCT	57.600 ± 3.119	64.722 ± 3.621	69.357 ± 5.353	60.716 ± 2.427

The differences between the originally calculated values and simulated values in ITV can be seen in Table 3. For treatment technique types, VMAT tends to generate lower minimum and maximum values and CA lower mean and D95 values. DCA tends to generate the highest mean and D95 values, while CA generates the highest minimum and maximum values.

The CT which stands out the most, when comparing the difference of original and simulated plan values in Table 3, is MAXCT, which values are visibly higher than those of PlanningCT and MEANCT. When comparing PlanningCT and MEANCT, it can be noticed that MEANCT values have generally smaller differences when it comes to comparing the similarity between original and simulated plans, apart from maximum dose.

Table 3 Averaged differences between originally calculated and simulated plans in ITV

	min	mean	max	D95
VMAT	0.035 ± 1.372	0.527 ± 1.774	1.175 ± 1.814	0.313 ± 1.818
DCA	-0.128 ± 1.386	0.576 ± 1.620	1.257 ± 0.964	0.502 ± 1.814
CA	-0.190 ± 1.289	0.457 ± 1.531	1.380 ± 0.634	0.190 ± 2.230
PlanningCT	-0.787 ± 1.046	-0.570 ± 1.097	0.768 ± 0.768	-0.950 ± 1.347
MAXCT	1.112 ± 0.748	2.074 ± 1.097	2.188 ± 0.971	2.201 ± 1.013
MEANCT	-0.608 ± 1.201	0.056 ± 1.245	0.855 ± 1.315	-0.245 ± 1.677

With these results, it seems that the simulations made with a combination of MEANCT or PlanningCT, regardless of the treatment technique, would yield the most consistent result compared to the originally calculated plans. The worst combination would on the other hand be treatment technique plans with MAXCT.

3.2. Dose to GTV

In figures 9-12 in Appendix 2, DVH curves for ten individual GTV delineations and their average is shown for all treatment techniques and CTs for all patients. Maximum and minimum dose values for each CT for all treatment techniques are shown in Table 4.

For VMAT plans MAXCT yields the lowest and MEANCT the highest minimum values. Meanwhile, the lowest maximum value can be seen for MEANCT and the highest for PlanningCT for VMAT plans. For DCA plans, the highest and lowest minimum values are found in PlanningCT and MEANCT, respectively. For maximum values the highest can be found in PlanningCT and the lowest in MAXCT. For CA plans, the lowest minimum value is for MAXCT and highest for MEANCT. The lowest maximum value is for MAXCT and highest for MEANCT.

With these results VMAT plans seem to generate the lowest minimum and maximum dose values in GTV regardless of the CT used. DCA and CA techniques on the other hand seem to be consistent with each other.

Table 4 Simulated dose range to GTV structures for all treatment techniques and CTs

		min	max
VMAT	PlanningCT	57.81 ± 5.68	67.63 ± 4.46
	MAXCT	56.79 ± 4.31	66.06 ± 2.19
	MEANCT	58.93 ± 4.22	65.05 ± 16.13
DCA	PlanningCT	60.85 ± 4.55	71.14 ± 5.41
	MAXCT	59.95 ± 3.89	70.10 ± 3.71
	MEANCT	59.40 ± 4.20	70.61 ± 3.33
CA	PlanningCT	59.28 ± 3.60	68.82 ± 2.52
	MAXCT	58.27 ± 4.12	67.49 ± 1.95
	MEANCT	62.10 ± 4.36	70.59 ± 13.38

3.3. Dose to PTV

Treatment technique specific and CT specific averaged values of the parameters (min, mean, max, D95) across all the patients are listed in Table 5 for originally calculated plans and Table 6 for simulated plans.

When comparing the treatment techniques of the original plans in Table 5, the parameters for DCA technique are higher than those for the rest of the plans, apart from mean value. The lowest values can be seen with VMAT plans consistently throughout the parameters. When comparing the CTs of the original plans, it can be noticed that MEANCT has the highest values and PlanningCT has the lowest. The results are similar to the dose to ITV results.

Table 5 Average values for original plans in PTV

	min	mean	max	D95
VMAT	46.92 ± 3.03	59.31 ± 2.65	67.30 ± 3.29	52.58 ± 1.86
DCA	49.57 ± 1.63	61.43 ± 1.54	70.72 ± 4.26	54.59 ± 0.37
CA	47.45 ± 4.07	61.50 ± 3.01	70.45 ± 5.06	53.63 ± 3.37
PlanningCT	47.10 ± 3.68	59.85 ± 3.33	69.10 ± 4.45	52.93 ± 3.11
MAXCT	47.39 ± 3.71	61.01 ± 1.73	69.14 ± 3.25	53.53 ± 2.40
MEANCT	49.46 ± 1.35	61.39 ± 2.52	70.21 ± 5.58	54.34 ± 0.84

Table 6 Average values for simulated plans in PTV

	min	mean	max	D95
VMAT	46.93 ± 2.93	59.07 ± 2.45	66.31 ± 3.67	52.62 ± 1.67
DCA	49.85 ± 1.64	61.19 ± 1.45	69.46 ± 3.69	54.66 ± 0.45
CA	47.54 ± 4.12	61.33 ± 3.39	69.07 ± 4.86	53.73 ± 3.4
PlanningCT	47.33 ± 3.60	60.27 ± 3.06	68.40 ± 4.22	53.32 ±2.84
MAXCT	47.38 ± 3.80	59.74 ± 1.92	67.04 ± 2.79	53.07 ± 2.53
MEANCT	49.62 ± 1.5	61.58 ± 2.85	69.39 ± 5.34	54.63 ± 0.91

For simulated plans in Table 6, the results are similar to the calculated original plans. VMAT technique achieves the lowest values, while highest values can be seen for DCA plans, apart from mean value, which is highest for CA plans. For different CTs, values for MEANCT are consistently higher, while values for MAXCT are generally lower than those of the PlanningCT, apart from the minimum value. In this case, the results are also similar to the results seen for ITV.

The difference between original calculated plans and simulated plans can be seen in Table 7. VMAT technique generates the lowest minimum, maximum and D95 values, while the lowest mean value is created by CA. The highest minimum value can be seen with DCA plans, the highest maximum and D95 with CA plans, and VMAT and DCA have the highest mean value.

The difference in values for CTs in Table 7, shows the lowest minimum value for MAXCT, lowest mean and D95 values for MEANCT, and the lowest maximum value for PlanningCT. On the other hand, the highest minimum value is for PlanningCT, and the highest mean, maximum and D95 values for MAXCT.

With these results in PTV, it seems that the simulations made with a combination of MEANCT or PlanningCT, together with VMAT, would yield the most consistent result compared to the originally calculated plans. The worst combination would on the other hand be plans made with treatment technique DCA or CA with MAXCT.

Table 7 Averaged differences between originally calculated and simulated plans in PTV

	min	mean	max	D95
VMAT	-0.01 ± 0.44	0.24 ± 1.29	0.98 ± 1.76	-0.04 ± 0.60
DCA	-0.28 ± 0.39	0.24 ± 1.07	1.26 ± 0.96	-0.07 ± 0.55
CA	-0.09 ± 0.36	0.17 ± 1.07	1.38 ± 0.63	-0.10 ± 0.64
PlanningCT	-0.23 ± 0.36	-0.43 ± 0.76	0.70 ± 0.73	-0.39 ± 0.5
MAXCT	0.01 ± 0.44	1.27 ± 0.87	2.10 ± 0.98	0.46 ± 0.40
MEANCT	-0.16 ± 0.40	-0.19 ± 0.88	0.82 ± 1.31	-0.29 ± 0.43

3.4. Film measurements

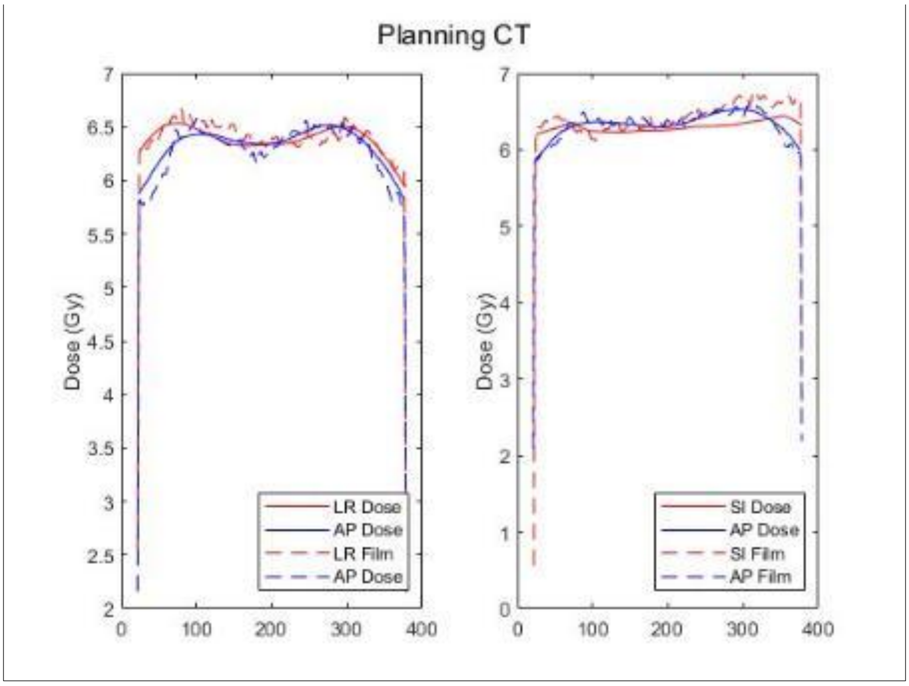

Figure 2 The dose distribution of the film, PlanningCT, VMAT, phantom

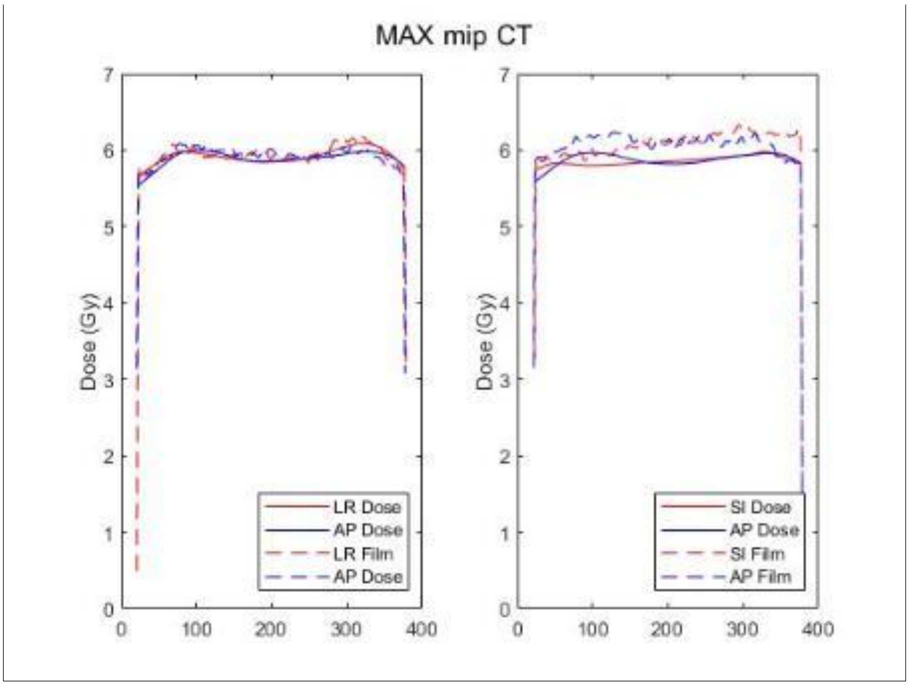

Figure 3 The dose distribution of the film, MAXCT, VMAT, phantom

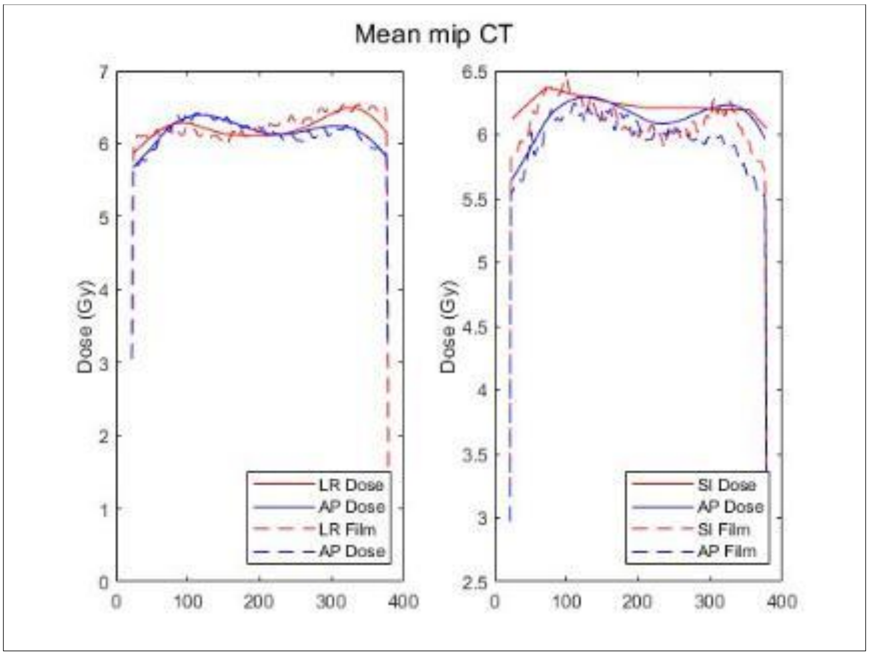

Figure 4 The dose distribution of the film, MEANCT, VMAT, phantom

The results of the film measurements for phantom VMAT plans for PlanningCT, MAXCT and MEANCT can be seen in Figures 2, 3 and 4, respectively. Irradiated curves for films have been rescaled ~12v% below the values of measurements and profiles have been plotted as middle as possible.

When comparing simulation and measured dose distributions for left-right (LR) and anterior-posterior (AP) position, the distribution for both directions seem to be comparable, especially in the MAXCT in left side in Figure 3. For the film, which was positioned superior-inferior (SI) and AP, the results are more inconsistent. Largest differences can be seen in inferior and posterior sides of the film.

All the lines are not consistent between simulated dose and irradiated dose, which could be a sign that the simulation does not correspond to reality. The 12 % level difference is unknown.

4. Discussion

For ITV, all the treatment techniques yield similar results when comparing the consistency between originally calculated and simulated plans, and best combined with PlanningCT or MEANCT.

For GTV, All the technique and CT combination pass the minimum dose requirements because of the scaling used to cover PTV. To avoid high maximum doses with VMAT plans, MEANCT seems to be the best pairing option, while PlanningCT the worst. With DCA plans, the differences between MEANCT and MAXCT are minimal, but both are still better than those with PlanningCT. With CA plans, on the other hand, MEANCT seems to be the worst pairing option, and MAXCT the best. Overall, minimum doses close to the prescribed total dose of 55 Gy and lowest maximum values can be achieved with VMAT plans.

For PTV, the difference for originally calculated and simulated plans, VMAT plans seem to be simulated the most accurately. Most variation can be found with DCA and CA values. The differences for CTs are the highest in MAXCT, and lowest in MEANCT.

Abbreviations

- SBRT: Stereo-tactic Body Radiation Therapy
- PTV: Planning Target Volume
- GTV: Gross Tumor Volume
- ITV: Internal Target Volume
- VMAT**:** Volumetric Modulated Arc Therapy
- 4DCT: 4 Dimensional Computed Tomography
- DCA: Dynamic Conformal Arc
- PlanningCT: Planning Computed Tomography
- MAXCT: Maximum Computed Tomography
- MeanCT: Mean Computed Tomography

5. Conclusion

Overall, the results for different treatment technique types and CTs are surprisingly similar. There is not enough data to determine a definite conclusion based on these measurements. The hypothesis in the beginning was that the corresponding simulation to an originally calculated treatment plan would be the most consistent with the combination of DCA and MEANCT, while plans with VMAT and/or PlanningCT would have yielded worse results. One explanation for this might be the simplicity of the VMAT plans, which due to the lack of modulation resembles plans created with DCA. With more complicated VMAT plans, there could be more differences influence calculations, which would lead to larger differences between original and simulated plans.

References

[1] Micke, Andre et al. “Multichannel film dosimetry with non-uniformity correction.” Medical physics vol. 38,5 (2011): 2523-34. doi:10.1118/1.357610

Appendix 1

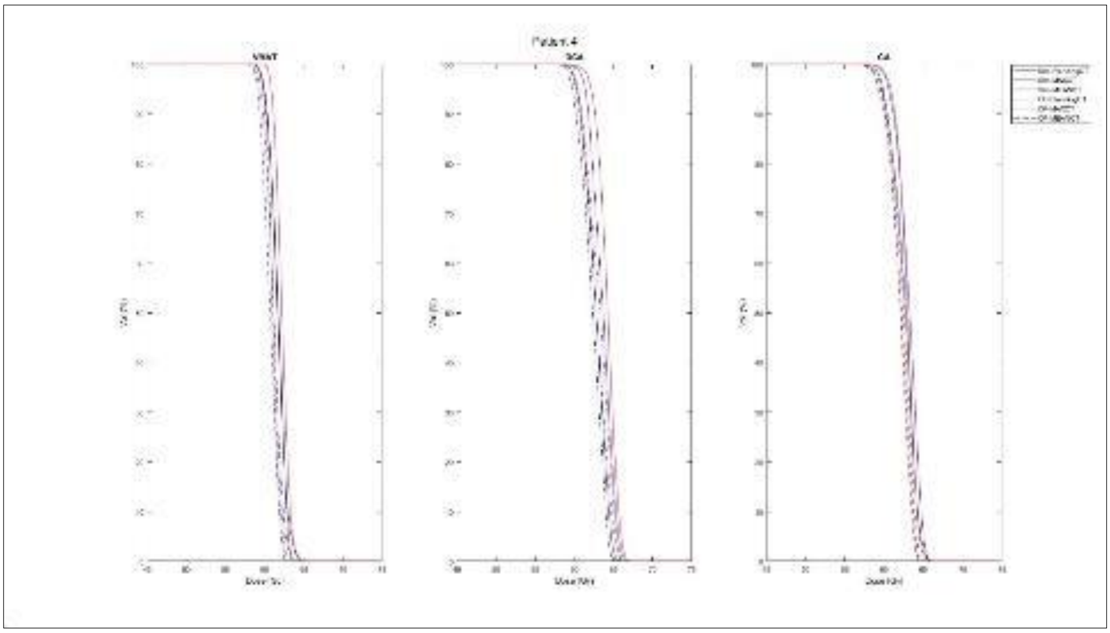

Figure 5 Original and simulated plans for all treatment techniques and CTs for patient 4

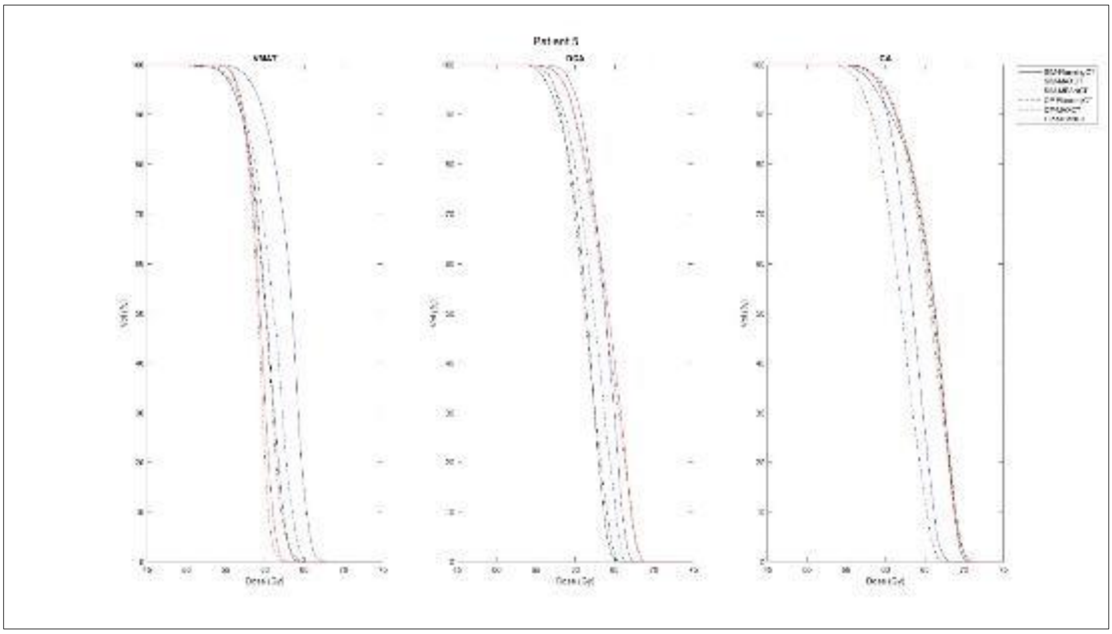

Figure 6 Original and simulated plans for all treatment techniques and CTs for patient 5

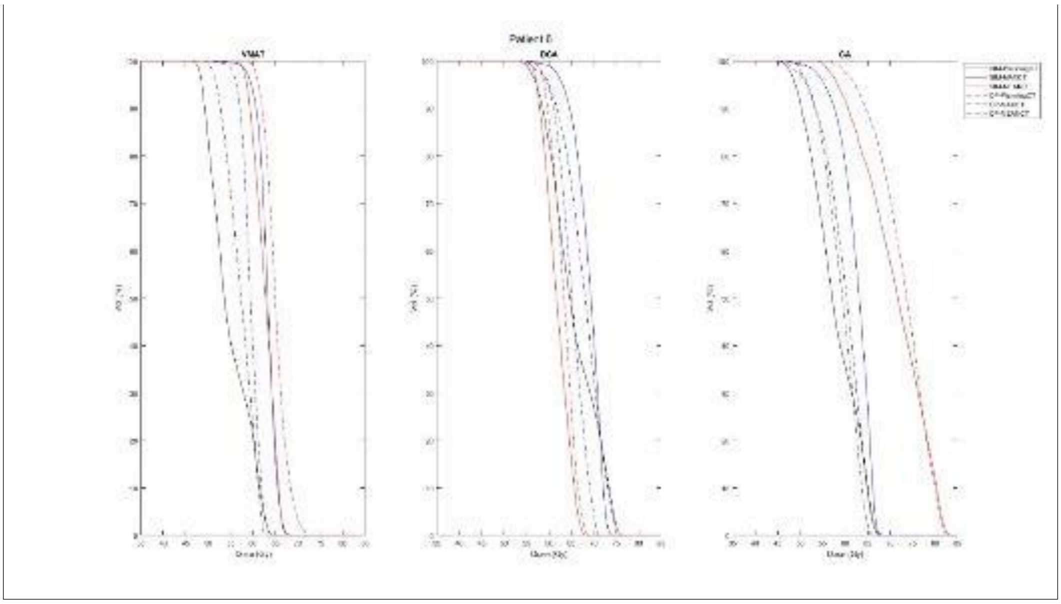

Figure 7 Original and simulated plans for all treatment techniques and CTs for patient 6

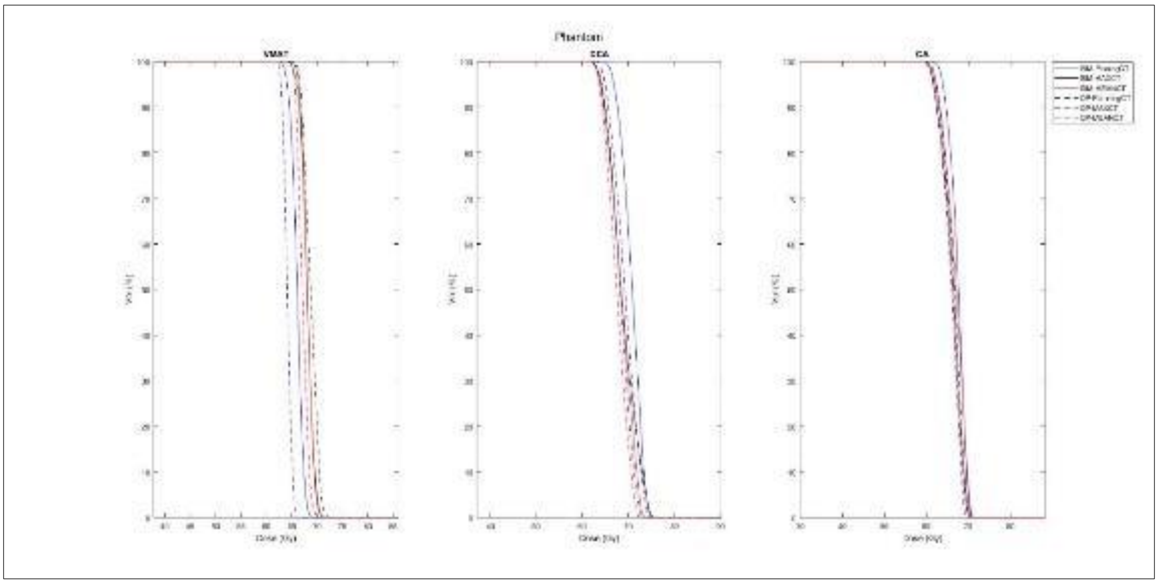

Figure 8 Original and simulated plans for all treatment techniques and CTs for the phantom

Appendix 2

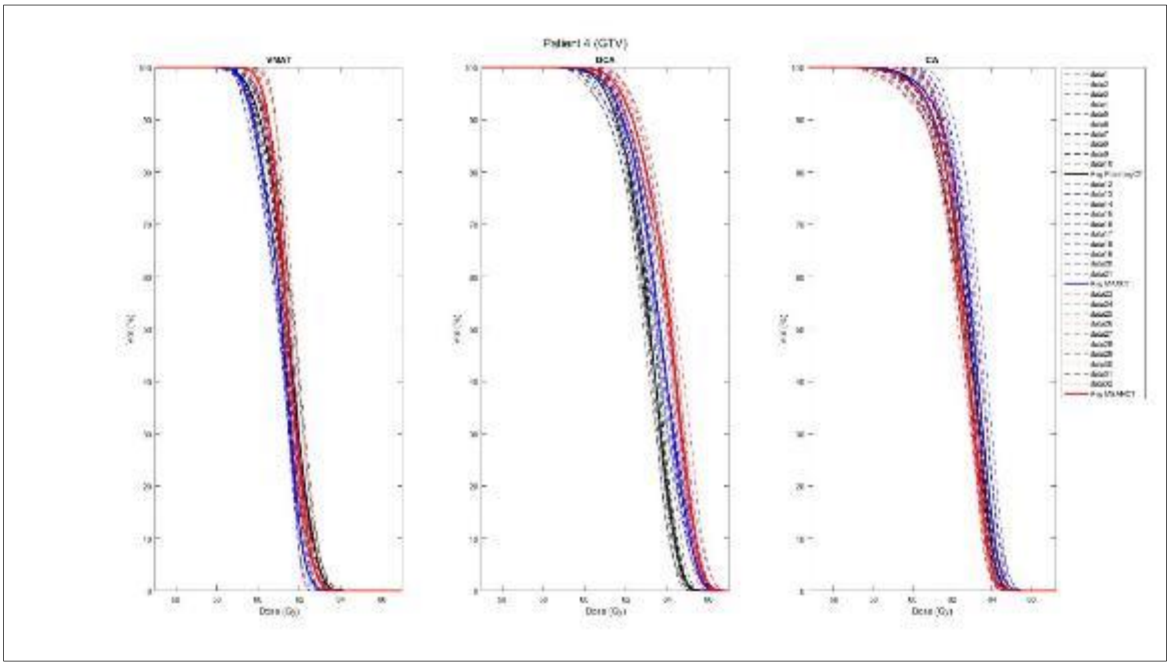

Figure 9 Dose to all GTVs for all treatment techniques and CTs for patient 4

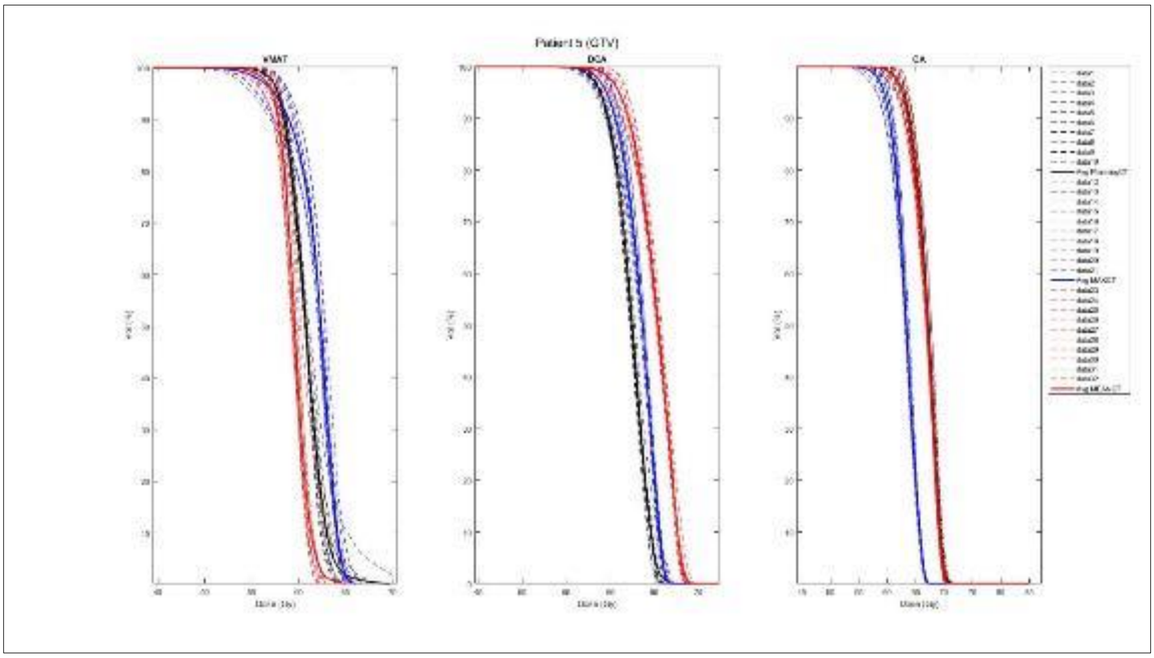

Figure 10 Dose to all GTVs for all treatment techniques and CTs for patient 5

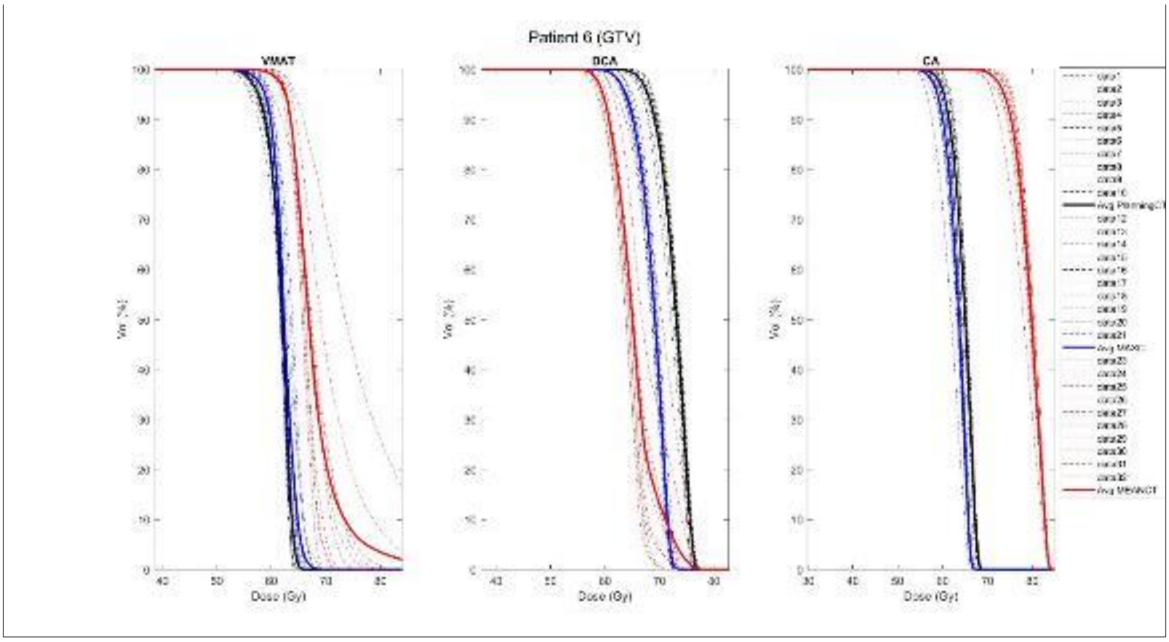

Figure 11 Dose to all GTVs for all treatment techniques and CTs for patient 6

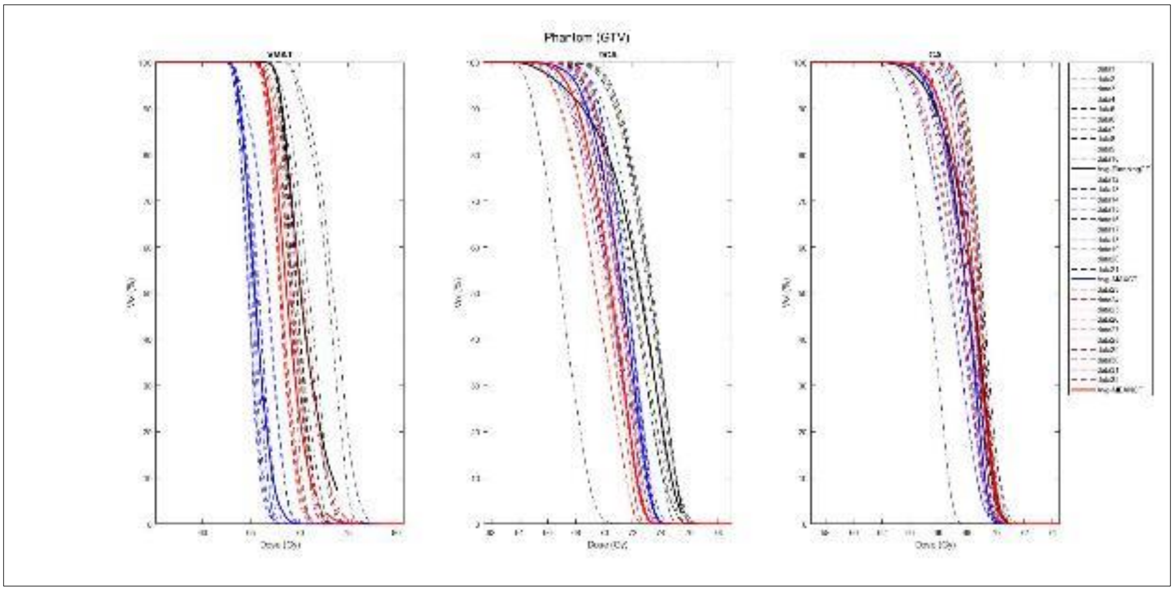

Figure 12 Dose to all GTVs for all treatment techniques and CTs for the phantom