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Monte Carlo-Based Treatment Planning and 3D Secondary Dose Check to Adjust PTV Coverage without Increasing OAR Dose for Conventional and Stereotactic Radiotherapy In Lung Cancer Patients

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INTRODUCTION

Monte Carlo (MC)-based treatment planning system (TPS; RayStation, RaySearch laboratories) and 3D secondary dose check software (VeriQA RT Montecarlo 3D, PTW) were commissioned and benchmarked against well-established TPS. This study investigates the dosimetric accuracy of Collapsed Cone (CC)-based clinical plans and compares them to MC optimized plans in a cohort of conventional and stereotactic lung cancer patients.

METHODS AND MATERIALS

Water phantom measurements were used for commissioning of both RayStation and VeriQA. RayStation CC plans of 34 patients (breast, head-and-neck, prostate, bladder, kidney, anus, cervix, stereotactic lung, glioma and multiple brain metastases) were recalculated in VeriQA with the MC algorithm (SciMoCa) dose-to-medium and dose-to-water (1% accuracy, grid size of the original plan). To investigate tissue heterogeneities effects, a cohort of 42 lung cancer patients was included: 10 treated with conventional radiotherapy (CRT) and 32 with stereotactic body radiotherapy (SBRT), all planned in RayStation v2023B. Adequate PTV coverage was defined as $PTV-V_{x>95\%}$, with $x=0.95D_{pres}$ (CRT) or $1.00D_{pres}$ (SBRT). For each patient, three plans were created and evaluated: (i) a CC-based clinical treatment plan (Initial CC), (ii) an MC-based plan recalculated from the clinical plan (Initial MC), and (iii) an MC-optimized plan (New MC) designed to achieve similar OAR doses as the Initial CC plan. Treatment plans were compared in terms of adequate PTV coverage and OAR doses (see Fig. 1). All relevant DVH comparisons are summarized in Table I.

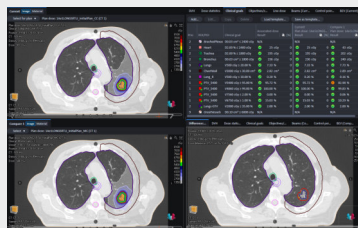


Figure 1. Dose distribution comparison between a clinical treatment plan optimized with the CC dose algorithm (top left) and the same treatment plan recalculated with a MC dose algorithm (bottom left). The dose difference shows an underdosage in the PTV (bottom right), consistent with reduced target coverage in the DVH (top right).

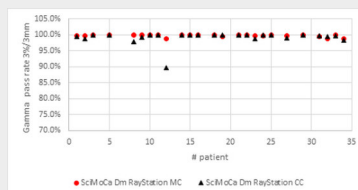


Figure 2. Results of gamma pass rate of external contour for the MC algorithm (SciMoCa) dose-to-medium in comparison to RayStation MC and CC calculations.

RESULTS

Mean pass rates of secondary dose calculation in VeriQA for 34 patients were $99.2 \pm 1.7\%$ for dose-to-medium and $99.0 \pm 1.2\%$ for dose-to-water (see Fig. 2).

For 42 lung patients, a significant reduction in PTV coverage was observed when recalculating clinical CC-based plans with the MC algorithm ($p = 0.02$, see Fig. 3). Average dose reductions not captured by CC were 12.3% (SBRT 3x18 Gy), 6.5% (SBRT 5x11 Gy), 4.6% (SBRT 8x7.5 Gy), and 6.7% (CRT 24x2.75 Gy). Optimization with MC significantly restored PTV coverage ($p = 0.03$) to levels comparable to the original CC-based plans, maintaining values above the 95% adequacy threshold. Non-significant variations were observed in OAR doses between CC-based and MC-optimized plans ($p > 0.05$).

Table I. Dosimetric comparison between the treatment plans — Initial CC-based plan, Initial MC plan, and New MC plan — per dose schema. Values are presented as mean $\pm$ 1 SD for target coverage (PTV) and relevant dose-volume histogram parameters for the most important organs at risk (lung-GTV, esophagus, heart, and bronchus).

Dose schema	PTV		Lung-GTV		Esophagus	Heart	Bronchus
	$V_{100\%}(\%)$	$V_{100\%}(\%)$	$V_{25}(\%)$	$D_{mean}(\text{Gy})$	$D_{0.03cc}(\text{Gy})$	$D_2(\text{Gy})$	$D_{0.03cc}(\text{Gy})$
SBRT 55 Gy/5 fr (N=12)							
Initial CC plan	97.0 ± 1.0	0.1 ± 0.2	3.3 ± 1.6	2.8 ± 1.1	6.3 ± 5.3	2.6 ± 2.6	3.8 ± 4.2
Initial MC plan	90.5 ± 6.5	0.1 ± 0.2	3.3 ± 1.7	2.9 ± 1.2	6.4 ± 5.6	2.7 ± 2.6	3.8 ± 4.1
New MC plan	97.4 ± 1.0	0.2 ± 0.3	3.6 ± 1.6	3.0 ± 1.2	4.7 ± 3.3	3.0 ± 2.9	3.9 ± 4.0
	PTV		Lung-GTV		Esophagus	Heart	Bronchus
SBRT 60 Gy/8 fr (N=10)							
Initial CC plan	95.2 ± 5.3	0.0 ± 0.0	10.1 ± 5.7	5.8 ± 2.6	7.7 ± 4.7	13.1 ± 13.6	17.2 ± 17.1
Initial MC plan	90.6 ± 8.1	0.0 ± 0.0	10.3 ± 5.9	6.0 ± 2.7	7.8 ± 4.6	13.1 ± 13.4	17.4 ± 17.3
New MC plan	94.6 ± 4.2	0.3 ± 0.1	10.9 ± 5.6	6.1 ± 2.6	7.6 ± 3.8	13.1 ± 13.5	17.9 ± 18.6
	PTV		Lung-GTV		Esophagus	Heart	Bronchus
SBRT 54 Gy/3 fr (N=10)							
Initial CC plan	97.3 ± 1.6	0.4 ± 0.7	3.6 ± 2.2	2.5 ± 0.9	2.4 ± 2.2	2.2 ± 4.4	3.1 ± 3.6
Initial MC plan	85.0 ± 9.6	0.1 ± 0.2	3.6 ± 2.2	2.6 ± 0.9	2.5 ± 2.2	2.3 ± 4.3	3.2 ± 3.6
New MC plan	97.5 ± 1.1	0.3 ± 0.4	3.8 ± 2.4	2.7 ± 1.0	2.3 ± 1.4	2.7 ± 5.0	3.3 ± 3.7
	PTV		Lung-GTV		Esophagus	Heart	
CRT 66 Gy/24 fr (N=10)							
Initial CC plan	96.4 ± 1.3	0.0 ± 0.0	18.6 ± 7.1	10.5 ± 3.6	8.9 ± 8.4	6.5 ± 5.5	2.4 ± 3.0
Initial MC plan	89.7 ± 2.7	0.1 ± 0.1	18.7 ± 7.1	10.6 ± 3.6	8.6 ± 8.1	6.5 ± 5.4	2.4 ± 2.9
New MC plan	95.8 ± 0.9	0.1 ± 0.1	19.8 ± 7.7	11.2 ± 3.9	9.3 ± 8.8	6.7 ± 5.2	2.6 ± 3.1

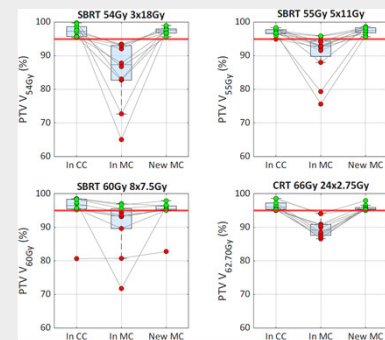


Figure 3. Comparison of PTV coverage among the treatment plans. Boxplots show the $PTV-V_{x>95\%}$ with $x = 0.95D_{pres}$ (CRT) or $1.00D_{pres}$ (SBRT) per plan - In CC plan (clinical CC-based plan), In MC plan (clinical CC-based plan recalculated with MC), and New MC plan (optimized plan with MC). The red horizontal line indicates the PTV coverage threshold (95%). Green and red dots represent individual patient values meeting or not meeting the coverage criterion, respectively. Results are shown for (a) SBRT 54 Gy in 3x18 Gy (b) SBRT 55 Gy in 5x11 Gy, (c) SBRT 60 Gy in 8x7.5 Gy, and (d) conventional CRT 66 Gy in 24x2.75 Gy dose schemas.

DISCUSSION

We consider this study to be relevant because it investigated the dosimetric accuracy in a wide variety of Collapsed Cone-based clinical plans and compares them to Monte Carlo optimized plans in a cohort of 10 conventional and 32 stereotactic lung cancer patients. MC-optimized plans restored PTV coverage by creating larger segments without increasing OAR doses. Additionally, all plans were verified by 3D secondary dose check software with the MC algorithm (SciMoCa) dose-to-medium.

CONCLUSIONS

Clinical CC-based plans inaccurately estimate PTV doses for lung cancer patients. MC-optimized plans improved PTV coverage without increasing OAR doses.

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