Master's Thesis Engineering Technology

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Development and Clinical Validation of One-Click Batch VMAT Prostate Planning Using Dynamic Adjustment of Optimization Parameters

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Introduction

Automated treatment planning methods can improve plan quality, standardization, and efficiency in radiotherapy [1]. Despite recent advancements, manual optimization is often still required. This study evaluates a fully automated fine-tuning process for prostate volumetric modulated arc therapy (VMAT) planning. The script dynamically adjusts optimization parameters to improve plans initially generated using a knowledge-based planning model.

Method

200 prostate cancer patients were randomly selected from the clinical database. The prescribed dose was 60 Gy to the prostate, and 44 Gy to the seminal vesicles, delivered in 20 fractions. Anisotropic margins were applied from the clinical target volume to the planning target volume, with a 6 mm expansion laterally and an 8 mm expansion in all other directions. All patients were treated using VMAT with two opposing full arcs, a beam energy of 6 MV, and collimator rotations set to 30° and 330°, respectively. A new treatment plan was generated for each patient using the automated script. The full workflow that was used for generating new plans is illustrated in Figure 1. The objectives and priorities incorporated into the script are listed in Table 1. Dose-volume histogram (DVH) parameters and plan complexity were used to evaluate differences between the initial knowledge-based generated plan (RP) and the fine-tuned plan (FT). Statistical analysis of the results was performed using the Wilcoxon signed-rank test.

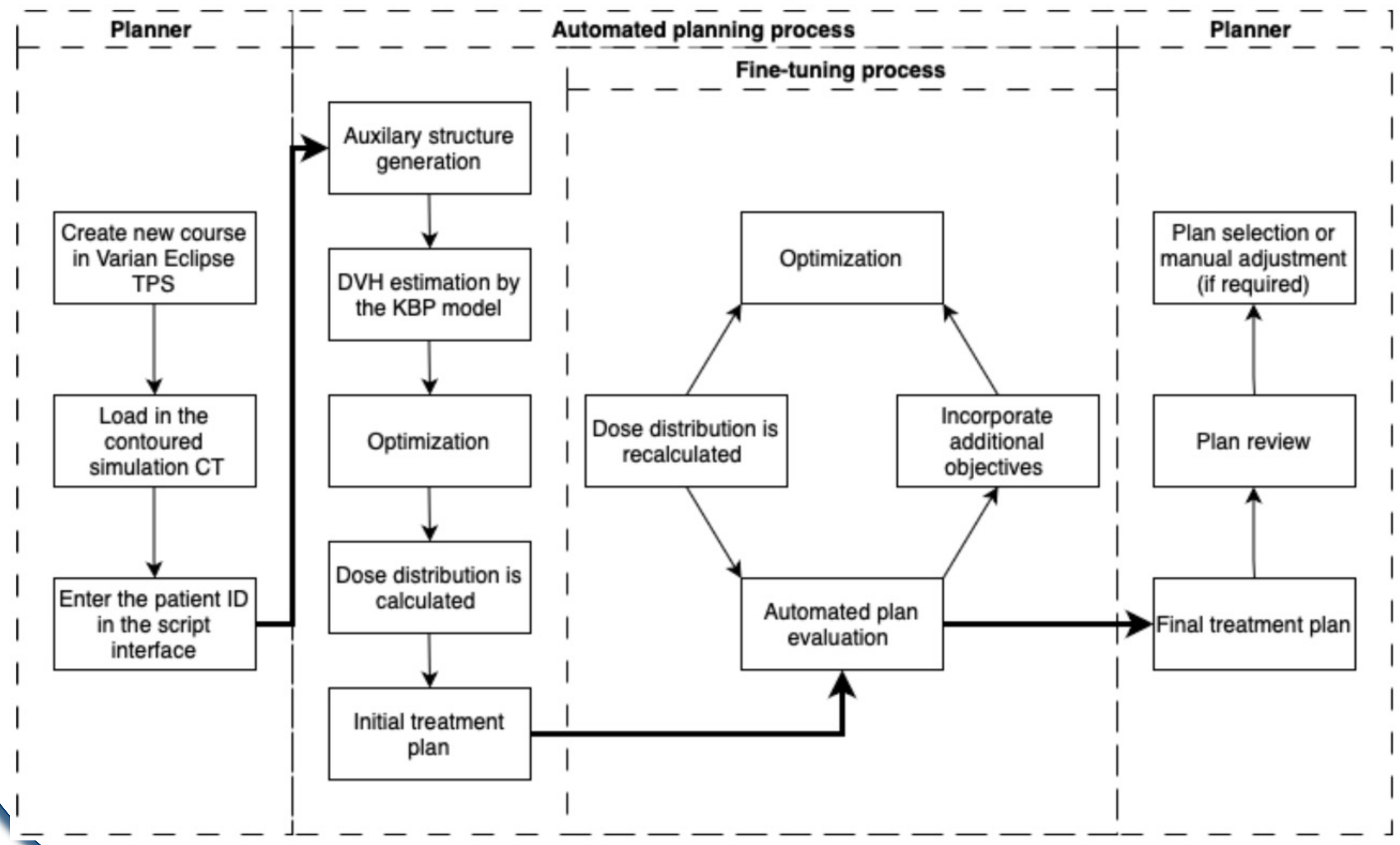

Figure 1: Workflow for generating new treatment plans

Table 1: Objectives and priorities for each structure [2]

Type	ID	Objective type	Vol (%)	Dose (Gy)	Priority
Target	PTV-high (60 Gy)	Lower	100	58.8	120
		Upper	0	61.8	120
Target	PTV-low (44 Gy)	Lower	100	43.56	120
		Upper	0	61.8	120
Body	External	Upper	0	63.9	550
Organ	Bladder	Upper	0	63	150
		Upper	4.5	54	120
		Upper	22.5	44.1	100
		Upper	45	36.9	100
		Upper	54	27.9	100
Organ	Rectum	Upper	0	54	150
		Upper	20	45	100
		Upper	33.9	36	100
		Upper	51	27	100
		Upper	61.4	23.4	100
		Upper	76.7	18	100
		Mean	/	27	100
Organ	Bowel	Upper	V58.5Gy x 0.9	52.7	80
		Upper	V41Gy x 0.9	36.9	80
		Upper	V36Gy x 0.9	32.4	80
Organ	Femoral heads	Upper	45	36.9	50

Results

In 165 of the cases, the knowledge-based generated plan required fine-tuning. Initially, 12 cases failed to complete the fine-tuning process. This problem was addressed by adding a constraint to the script. With this additional constraint, the fine-tuning algorithm resolved all unmet constraints in 104 of the cases. The specific constraints resolved by the fine-tuning process are shown in Table 2. The fine-tuning process reduced plan complexity in most cases. The reduction in plan complexity was confirmed by the statistical results, shown in Table 3. The results of the statistical analysis of the PTV coverage and DVH parameters are illustrated in Table 4 and Table 5. The Wilcoxon signed-rank test was used for the statistical analysis.

Table 2: Constraints resolved by the fine-tuning process

Boost D99% (%)	25
Boost D95% (%)	33
Boost D50% (%)	3
Boost V107% (cc)	40
Body V107% (cc)	64
Rectum V60Gy (cc)	62
Bladder V60Gy (cc)	15
Bowels V58,5 (cc)	1

Table 3: Results of the Wilcoxon signed-rank test for complexity metrics

	FT	**RP**	**p-value**	**Relative difference (%)**
Average CM	0.154±0.03	0.159±0.03	6.52E-03	-3.3
MU/Gy	338.6±48.0	353.8±39.1	1.80E-09	-4.3

Table 4: Results of the Wilcoxon signed-rank test for PTV coverage

	FT	**RP**	**p-value**	**Relative difference (%)**
Boost D99% (%)	91.80±0.83	91.14±1.52	1.15E-04	0.72
Boost D95% (%)	95.71±0.53	95.42±0.08	8.07E-03	0.30
Boost D50% (%)	100.29±0.13	100.30±0.19	5.40E-01	-0.01
Boost D5% (%)	103.25±0.21	103.46±0.28	2.23E-13	-0.20
Boost V107% (cc)	0.00±0.01	0.07±0.16	2.70E-18	-94.62

Table 5: Results of the Wilcoxon signed-rank test for DVH parameters

	FT	**RP**	**p-value**	**Relative difference (%)**
Body V107% (cc)	0.01±0.01	0.11±0.18	6.02E-20	-88.02
Rectum V60Gy (cc)	0.73±0.22	1.12±0.60	2.72E-13	-34.90
Rectum V50Gy (%)	9.80±3.68	9.39±3.42	1.64E-08	4.35
Rectum V40Gy (%)	16.19±5.26	15.53±5.24	1.52E-20	4.29
Rectum V30Gy (%)	23.17±7.92	22.05±6.90	1.47E-22	5.06
Rectum V26Gy (%)	26.70±8.55	25.06±7.54	1.01E-26	6.55
Rectum V20Gy (%)	33.04±10.28	30.65±8.63	1.09E-25	7.81
Rectum Dmean (Gy)	19.02±4.00	18.21±3.53	9.82E-24	4.44
Left Femoral V41Gy (%)	0.00±0.00	0.00±0.02	1.00E+00	-83.33
Right Femoral V41Gy (%)	0.01±0.05	0.02±0.15	6.88E-01	-67.80
Bladder V63,3 Gy (cc)	0.01±0.03	0.04±0.06	8.62E-06	-60.54
Bladder V60Gy (%)	2.81±1.07	3.11±1.58	3.15E-01	-9.59
Bladder V49Gy (%)	9.33±4.47	9.11±4.34	9.38E-06	2.41
Bladder V41Gy (%)	13.65±5.99	13.28±5.71	2.05E-09	2.75
Bladder V31Gy (%)	19.48±8.19	18.79±7.64	1.34E-17	3.66
Bowels V58,5Gy (cc)	0.01±0.09	0.01±0.11	1.00E+00	-5.30
Bowels V41Gy (cc)	1.06±2.34	1.08±2.38	3.15E-01	-1.36
Bowels V36 Gy (cc)	1.69±3.49	1.71±3.54	3.75E-01	-0.91

Conclusion

The results demonstrate that the fine-tuning algorithm, after the implementation of the additional constraint, effectively resolved unmet constraints of the knowledge-based plans in a significant number of cases. Most evaluated DVH parameters showed a statistically significant difference between the FT and the RP plan, however not all differences were clinically meaningful. The most notable differences were the reduction of the boost V107% and the body V107%, indicating a reduction of hotspots in the PTV and a reduction in the volume of the body that receives more than 107% of the prescribed dose. Additionally, the fine-tuning process reduced plan complexity in most cases. The results of the Wilcoxon signed-rank test indicate that although the observed reduction in complexity is small, it is statistically significant. The algorithm also increased efficiency of the planning process.

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