Quantitative evaluation of a fully-automated planning solution for prostate-only and whole-pelvic radiotherapy

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Purpose/Objective:

To evaluate an end-to-end pipeline for normo-fractionated prostate-only and whole-pelvic cancer treatments that requires minimal human input and generates machine-deliverable plan as output.

Material/Methods:

In collaboration with TheraPanacea, a treatment planning pipeline that takes as input a planning CT with organs-at risk (OAR) and planning target volume (PTV) contours, the targeted linac machine and the prescription dose was developed. The primary components are (i) dose prediction by a single deep learning model for both localizations and (ii) direct aperture VMAT plan optimization that seeks to mimic the predicted dose. The deep learning model was trained on 238 cases and a held-out set of 86 cases was used for model validation. An end-to-end clinical evaluation study was performed on another 40 cases (20 prostate-only, 20 whole-pelvic). First, a quantitative evaluation was performed based on dose-volume histogram (DVH) points and plan parameters metrics. Then, the plan deliverability was assessed via portal dosimetry using global gamma index. Additionally, the reference clinical manual plans (MP) were compared with the automated plans (AP) in terms of monitor unit (MU) numbers and modulation complexity scores (MCSv). Wilcoxon signed rank test was used for the statistical analysis. Bonferroni correction was applied, and the significance level was set at 0.002.

Results:

The average generation time for the AP was 4.4 minutes and 13.4 minutes on a server equipped with 4 NVidia 3070 GPUs. The quality of the AP was comparable to MP for both indications (Table 1 and Table 2). For the prostate localization, high dose PTV coverage was slightly better for MP, while low dose PTV coverage and homogeneity were improved for AP. The dose delivered to 50% of the rectum volume was significantly reduced for AP ($p=0.001$). There was no statistically significant difference in conformity indices between the two plans ($p> 0.2$). In the whole-pelvic localization, PTV coverage was marginally higher for MP, with an absolute difference of less than 1Gy. OAR protection was not significantly different between the plans ($p > 0.2$). Furthermore, the AP demonstrated successful deliverability and passed portal dose verification. Although the AP had a higher median total number of MUs, no statistically significant correlations were found between the gamma criteria and the number of MUs or MCSv.

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Table 1: Dose metric results (mean ± standard deviation) for PTVs and organs at risk (OAR) for the automated and manual treatment plans for prostate-only localization. Values are bolded where $p < 0.002$.

		Auto	Manual	p-value
PTV2	**$D_{98\%}$ (Gy)**	**74.12 ± 0.33**	**74.7 ± 0.53**	**0.0003**
	$D_{95\%}$ (Gy)	75.99 ± 0.05	76.33 ± 0.47	0.006
	$D_{50\%}$ (Gy)	80.71 ± 0.57	80.20 ± 0.51	0.003
	$D_{2\%}$ (Gy)	82.48 ± 0.61	82.17 ± 0.84	0.100
	HI	0.10 ± 0.01	0.09 ± 0.01	0.002
	CI	0.90 ± 0.02	0.90 ± 0.02	0.705
PTV1	**$D_{98\%}$ (Gy)**	**58.53 ± 1.71**	**56.55 ± 1.78**	**3.63E-5**
	$D_{95\%}$ (Gy)	**60.97 ± 2.69**	**58.96 ± 2.95**	**4.77E-5**
	$D_{50\%}$ (Gy)	79.76 ± 0.79	79.47 ± 0.62	0.050
	$D_{2\%}$ (Gy)	82.38 ± 0.62	82.07 ± 0.83	0.097
	HI	**0.30 ± 0.02**	**0.32 ± 0.02**	**0.0003**
	CI	0.61 ± 0.02	0.61 ± 0.04	0.793
Rectum	**$D_{50\%}$ (Gy)**	**22.60 ± 3.60**	**25.22 ± 4.01**	**0.0001**
	D_{mean} (Gy)	29.88 ± 3.32	31.36 ± 3.71	0.003
	$D_{2\%}$ (Gy)	74.47 ± 1.10	74.74 ± 0.48	0.247
Bladder	$D_{50\%}$ (Gy)	36.14 ± 13.71	36.06 ± 13.65	1
	D_{mean} (Gy)	40.55 ± 8.75	40.20 ± 8.55	0.452
	$D_{2\%}$ (Gy)	79.36 ± 0.63	79.26 ± 0.42	0.4
Femoral Head	$D_{0.1\%}$ (Gy)	39.40 ± 5.40	38.18 ± 8.31	0.674
	$D_{5\%}$ (Gy)	32.48 ± 4.44	31.35 ± 7.31	0.261

Table 2: Dose metric results (mean ± standard deviation) for PTVs and organs at risk (OAR) for the automated and manual treatment plans for whole-pelvic localization. Values are bolded where $p < 0.002$.

		Auto	Manual	p-value
PTV2	$D_{98\%}$ (Gy)	74,50 ± 0,33	74,90 ± 0,78	0.017
	$D_{95\%}$ (Gy)	**76,09 ± 0,17**	**76,72 ± 0,63**	**0.0004**
	$D_{50\%}$ (Gy)	80,21 ± 0,25	80,31 ± 0,58	0.605
	$D_{2\%}$ (Gy)	82,06 ± 0,51	81,99 ± 0,72	0.765
	HI	0,10 ± 0,01	0,10 ± 0,01	0.716
	CI	0,90 ± 0,02	0,88 ± 0,02	0.023
PTV1	**$D_{98\%}$ (Gy)**	**53,02 ± 0,69**	**53,97 ± 1,15**	**0.0013**
	$D_{95\%}$ (Gy)	54,48 ± 0,60	54,90 ± 0,96	0.153
	$D_{50\%}$ (Gy)	58,06 ± 0,58	57,71 ± 0,83	0.131
	$D_{2\%}$ (Gy)	81,33 ± 0,50	81,32 ± 0,71	0.701
	HI	0,49 ± 0,02	0,47 ± 0,02	0.015
	CI	0,78 ± 0,02	0,78 ± 0,02	0.248
Rectum	$D_{50\%}$ (Gy)	27,33 ± 4,81	29,42 ± 4,40	0.179
	D_{mean} (Gy)	33,47 ± 3,51	35,05 ± 3,68	0.114
	$D_{2\%}$ (Gy)	74.60 ± 1.13	74,55 ± 1,24	0,627
Bladder	$D_{50\%}$ (Gy)	50,84 ± 10,86	49,60 ± 11,40	0.165
	D_{mean} (Gy)	50,33 ± 7,05	49,35 ± 7,30	0.202
	$D_{2\%}$ (Gy)	79,16 ± 0,41	79,14 ± 0,81	0,409
Bowell	V_{30Gy} (cc)	281,62 ± 86,34	300,64 ± 90,01	0.216
	V_{40Gy} (cc)	151,74 ± 49,14	164,94 ± 49,33	0.070
Femoral Head	$D_{0.1\%}$ (%)	45,80 ± 3,81	46,52 ± 4,43	0.330
	$D_{5\%}$ (%)	36,31 ± 3,19	37,57 ± 4,33	0.019

Conclusion:

This study shows the feasibility of a deep learning-based fully automated treatment planning pipeline that generates high quality plans that are competitive with manually made, clinically-approved in terms of dosimetry and machine deliverability.

Keywords: Autoplanning, VMAT, prostate cancer