RapidPlan model for gastroesophageal carcinoma cancer (proton version)

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Purpose, applicability and reference:

- The model is designed to be used for treatment plans of gastroesopheal junction.
- The model was developed for patients with gastro-esophageal carcinoma. Application to the upper and medial tracts of the esophagus should be carefully validated.
- The model supports a single target structure and was designed for a dose prescription of 41.4Gy (RBE) in 23 fractions.
- The dose-volume constraints at the basis of the cohort of plans used for the model training were derived from the institutional guidelines (inclusive of the QUANTEC recommendations) and inspired to the ALARA principles.

The scientific reference for this model is: Celik et al. Acta Oncologica: 2021 Mar;60(3):285-292.doi: 10.1080/0284186X.2020.1845396. Epub 2020 Nov 10. Knowledge-based intensity-modulated proton planning for gastroesophageal carcinoma

Note *RapidPlan knowledge-based planning and its models are not intended to replace clinical decisions, provide medical advice or endorse any particular radiation plan or treatment procedure. The patients' medical professionals are solely responsible for and must rely on their professional clinical judgment when deciding how to plan and provide radiation therapy.*

Note *You should validate every DVH estimation model before using it clinically. This applies to any model, whether Varian provided, peer provided or the models you create yourself.*

Model definition:

Patient selection:

The cohort of 60 patients were used, presented with advanced (sT3cNx cM0) adenocarcinoma of the gastroesophageal junction.

Target and OAR contouring and planning guidelines:

Contouring of the target volumes and organs at risk is responsibility of the end users of the model. Here a summary of what was done on the cohort of patients used for the model training and validation.

Contouring was performed according to institutional and consensus-based guidelines (Wu A, Bosh W, Chang D et al. Expert consensus contouring guidelines for intensity modulated therapy in esophageal and gastroesophageal junction cancer. Int J Radiat Biol Oncol Phys. 2015,92(4):911-920.

The entire oesophageal wall, including any disease that extended through the wall, was contoured as the GTV as well as any PET/CT-avid or enlarged lymph nodes. The clinical target volume (CTV) included the peri-oesophageal and mediastinal lymph nodes as well as the submucosal spread along the oesophagus (corresponding to a 3-4cm expansion on the GTV superiority and inferiorly and a 1.0 – 1.5cm radial expansion). A planning target volume (PTV) was generated, adding 0.7cm isotropically to the CTV consistency with earlier studies and reporting purpose.

Organs at risks (OAR): lungs, whole heart (atrial and ventricular left and right chambers and coronaries), the oesophagus, the liver, the kidneys, the spleen, the stomach, the bowels and the spinal canal.

Treatment planning guidelines:

The dose prescription of 41.4Gy (RBE) in 23 fractions.

The plans were normalized to 100% as the mean dose to the PTV.

The target and OARs planning aims were defined as:

The dose coverage of the target:

- Mean dose = 41.4Gy 5RBE)
- GTV and CTV: $V_{98\%} \geq 98.0\%$
- PTV: $V_{98\%} \geq 90.0\%$ and $V_{95\%} \geq 95.0\%$; minimize the near to maximum dose ($D_{1\%}$)

The dose limits for the OARs:

- Lungs: mean dose ≤ 12Gy; $V_{20Gy} \leq 20\%$
- Heart: mean dose ≤ 10Gy; $V_{30Gy} \leq 10\%$
- Liver: mean dose ≤ 15Gy
- Kidneys: mean dose ≤ 15Gy; $V_{20Gy} \leq 32\%$
- For all other OARs, the aim was to minimise the dose (mean or near-to-maximum) as much as achievable without compromising the coverage of the target.

IMPT plans were created using pencil beam spot scanning from ProBeam proton system. All patients were planned with a class solution geometry defined by two posterior oblique fields with gantry angles set to 150° and 220°. Robust optimization was performed for the CTV to account for setup and range uncertainties considering ± 3mm shifts in the isocentre along the x-y-z coordinates and ±3% in beam range.

Users shall use the model with care if significant deviations from this geometry would be introduced.

In the model, a set of rules for the creation of individualized planning objectives was defined as listed in table 1.

Table 1. CTV, PTV and OARs objectives implementation in the RapidPlan model.

Structure	Constraint type	Volume	Dose	Priority
PTV and CTV	Upper	0%	101%	Generated
	Lower	100%	99.0%	Generated
Lungs (left/right)	Upper	20%	Generated	Generated
	Mean	–	Generated	Generated
	Line	Generated	Generated	Generated
Heart	Upper	Generated	30.0 Gy(RBE)	Generated
	Mean	–	Generated	Generated
	Line	Generated	Generated	Generated
Coronaries	Mean	–	Generated	Generated
	Line	Generated	Generated	Generated
Atria (left/right)	Mean	–	Generated	Generated
	Line	Generated	Generated	Generated
Ventricle left	Upper gEUD	2.0 (#)	Generated	Generated
	Mean	–	Generated	Generated
	Line	Generated	Generated	Generated
Ventricle right	Mean	–	Generated	Generated
	Line	Generated	Generated	Generated
Oesophagus	Upper gEUD	30.0 (#)	Generated	Generated
	line	Generated	Generated	Generated
Stomach	upper	0.1%	Generated	Generated
	Mean	–	Generated	Generated
	Line	Generated	Generated	Generated
Bowel bag	Upper	0.1%	Generated	Generated
	Mean	–	Generated	Generated
	Line	Generated	Generated	Generated
Kidneys (left/right)	mean	–	Generated	Generated
	Line	Generated	Generated	Generated
Spinal cord	upper	0.1%	Generated	Generated
	Mean	–	Generated	Generated
	Line	Generated	Generated	Generated
Liver	mean	Generated	Generated	Generated
	Line	Generated	Generated	Generated
Spleen	Upper	1.0%	Generated	Generated
	Mean	–	Generated	Generated
	Line	Generated	Generated	Generated

CTV: clinical target volume; PTV: planning target volume; gEUD: generalised equivalent uniform dose; (#) the α parameter of gEUD.

Model Training:

The model was trained on a set of 45 cases planned according to the methods described above.

Model Validation:

The model was tested on a cohort of 15 independent cases, not used for the training.

The results of the comparison between manual and RapidPlan based plans was detailed in the base reference. Table 2 & 3 provides a short summary of the findings comparing manual and automated plans for some relevant dosimetric parameter.

Table 2. Summary of the planning objectives and average results (uncertainty expressed as 1 standard deviation) for the gross target volume (GTV), the clinical target volume (CTV) and for the planning target volume (PTV).

	Objective	IMPT (training set)	IMPT (validation set)	IMPT_RP (validation set)	*p*
GTV					
Mean [Gy(RBE)]	41.4	41.5 ± 0.3	41.5 ± 0.1	41.4 ± 0.1	.07
$D_{1\%}$ [Gy(RBE)]	Minimise	42.6 ± 0.6	42.6 ± 0.4	42.5 ± 0.4	–
$V_{98\%}$ [%]	≥98	98.9 ± 1.6	98.4 ± 1.9	99.1 ± 1.1	.03
CTV					
Mean [Gy(RBE)]	41.4	41.5 ± 0.1	41.5 ± 0.1	41.4 ± 0.1	–
$D_{1\%}$ [Gy(RBE)]	Minimise	42.8 ± 0.6	43.0 ± 0.5	42.8 ± 0.4	–
$V_{98\%}$ [%]	≥98	98.2 ± 1.5	97.2 ± 1.9	98.7 ± 1.1	.02
PTV					
Mean [Gy(RBE)]	41.4	41.4 ± 0.0	41.4 ± 0.0	41.4 ± 0.0	–
$D_{1\%}$ [Gy(RBE)]	Minimise	43.1 ± 0.6	43.5 ± 0.4	43.3 ± 0.3	.1
$V_{98\%}$ [%]	≥90	91.5 ± 3.4	89.3 ± 2.9	91.4 ± 2.2	.05
$V_{95\%}$ [%]	≥95	97.7 ± 1.4	96.4 ± 2.0	97.5 ± 0.9	.1
HI [%]	Minimise	5.6 ± 1.8	6.3 ± 2.2	5.9 ± 1.2	.01

Data are reported for the manual plans in both the training and validation sets (IMPT) and for the RP-based plans (IMPT_RP) in the validation set. The statistical significance is between manual and RP based plans in the validation dataset.
GTV: gross tumour volume; CTV: clinical target volume; PTV: planning target volume. D_x dose received by x volume; V_x: volume receiving x dose; HI: homogeneity index; IMPT: intensity modulated proton therapy; IMPT_RP: intensity modulated proton therapy with RadidPlan. *p*: Statistical significance.

Table 3. Summary of the planning objectives and average results (uncertainty expressed as 1 standard deviation) for the main organs at risk investigated in the study).

	Objective	IMPT (training set)	IMPT (validation set)	IMPT_RP (validation set)	*p*
Lungs					
Mean [Gy(RBE)]	≤12	3.0 ± 1.3	3.1 ± 1.2	3.1 ± 1.3	–
V_{20Gy} [%]	≤20	5.9 ± 3.5	5.6 ± 2.7	5.7 ± 2.8	–
Whole heart					
Mean [Gy(RBE)]	≤10	4.7 ± 2.0	4.8 ± 1.0	4.6 ± 1.5	–
V_{30Gy}	≤10	6.4 ± 3.0	6.9 ± 1.8	6.6 ± 2.6	–
Left ventricle					
Mean [Gy(RBE)]	Mimimise	2.7 ± 2.1	2.7 ± 1.0	2.6 ± 1.2	–
$D_{0.1\ cm3\%}$ [Gy(RBE)]	Mimimise	38.9 ± 6.9	40.3 ± 3.4	39.7 ± 4.3	.06
Left anterior descending artery					
Mean [Gy(RBE)]	Mimimise	0.1 ± 0.2	0.1 ± 0.1	0.1 ± 0.1	–
$D_{0.1\ cm3}$ [Gy(RBE)]	Mimimise	0.2 ± 0.3	0.2 ± 0.3	0.2 ± 0.3	–
Liver					
Mean	≤15	3.8 ± 1.7	3.4 ± 1.3	3.6 ± 1.5	.06
Left kidney					
Mean [Gy(RBE)]	≤15	2.6 ± 2.4	2.2 ± 2.2	2.2 ± 2.5	.1
V_{20Gy} [%]	≤32	3.9 ± 5.9	2.3 ± 2.8	2.0 ± 3.4	–
Right kidney					
Mean [Gy(RBE)]	≤15	1.1 ± 0.8	0.7 ± 0.7	0.9 ± 1.2	–
V_{20Gy} [%]	≤32	0.3 ± 0.7	0.2 ± 0.3	0.5 ± 1.0	–
Stomach					
Mean [Gy(RBE)]	Mimimise	15.6 ± 7.6	15.6 ± 7.6	15.4 ± 8.4	–
$D_{1\%}$ [Gy(RBE)]	Mimimise	41.0 ± 8.2	42.4 ± 0.9	42.6 ± 0.7	.03
D_{1cm3} [Gy(RBE)]	Mimimise	42.3 ± 8.4	42.9 ± 1.1	43.3 ± 0.8	.1
Spleen					
Mean [Gy(RBE)]	Mimimise	5.1 ± 3.4	5.4 ± 1.2	5.6 ± 3.9	–
$D_{1\%}$ [Gy(RBE)]	Mimimise	24.2 ± 9.8	26.4 ± 9.4	25.5 ± 11.7	–
Bowels					
Mean [Gy(RBE)]	Mimimise	09. ±1.0	0.5 ± 0.6	0.7 ± 0.9	.02
$D_{1\%}$ [Gy(RBE)]	Mimimise	11.0 ± 12.0	7.0 ± 7.2	9.1 ± 11.0	.01
D_{1cm3} [Gy(RBE)]		15.4 ± 13.7	16.9 ± 9.1	18.9 ± 14.4	.02
Spinal canal					
$D_{1\%}$ [Gy(RBE)]	Mimimise	23.4 ± 3.7	22.9 ± 3.2	22.7 ± 3.1	–
$D_{0.1\ cm3\%}$ [Gy(RBE)]	Mimimise	25.1 ± 3.5	24.0 ± 2.8	24.3 ± 2.9	–

Data are reported for the manual plans in both the training and validation sets (IMPT) and for the RP-based plans (IMPT_RP) in the validation set. The statistical significance between manual and RP based plans in the validation dataset. D_x: dose received by x volume; V_x: volume receiving x dose; IMPT: intensity modulated proton therapy; IMPT_RP: intensity modulated proton therapy with RadidPlan. *p*: Statistical significance.