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Original paper

Reducing inter- and intra-planner variability in radiotherapy plan output with a commercial knowledge-based planning solution

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ABSTRACT

Purpose: This study measured to which extent RapidPlan can drive a reduction of the human-caused variability in prostate cancer treatment planning.
Methods: Seventy clinical prostate plans were used to train a RapidPlan model. Seven planners, with different levels of planning experience, were asked to plan a VMAT treatment for fifteen prostate cancer patients with and without RapidPlan assistance. The plans were compared on the basis of target coverage, conformance and OAR sparing. Inter-planner and intra-planner variability were assessed on the basis of the Plan Quality Metric formalism. Differences in mean values and InterQuartile Ranges between patients and operators were assessed.
Results: RapidPlan-assisted plans matched manual planning in terms of target coverage, homogeneity, conformance and bladder sparing but outperformed it for rectum and femoral heads sparing. 8 out of 15 patients showed a statistically significant increase in overall quality. Inter-planner variability is reduced in RapidPlan-assisted planning for rectum and femoral heads while bladder variability was constant. The inter-planner variability of the overall plan quality, IQR of PQM%, was approximately halved for all patients. RapidPlan assistance induced a larger increase in plan quality for less experienced planners. At the same time, a reduction in intra-planner variability is measured with a significant overall reduction.
Conclusions: The assistance of RapidPlan during the optimization of treatments for prostate cancer induces a significant increase of plan quality and a contextual reduction of plan variability. RapidPlan is proven to be a valuable tool to leverage the planning skills of less experienced planners ensuring a better homogeneity of treatment plan quality.

1. Introduction

Large variations of radiotherapy treatment quality have been observed between institutions [1–3] or among planners [4–7], and many authors reported the need for a study focused on its accurate quantification [1,4,3,6,8].

The operator's experience has been indicated as the main cause of this variability [4–6] and the difficulty of the planner to a priori asses the attainable tradeoff between the PTV coverage and OAR sparing has been also shown to contribute [1,6,9,10]. Knowledge Based Planning (KBP) have been suggested as a solution to reduce this variation [1].

KBP systems has been developed as a machine learning process designed to assist the human planner in the effort to efficiently achieve an optimal dose distribution [11]. KBP have been also employed as plan quality assurance tool [12,13], to prevent the poor clinical outcomes correlated with sub-optimal plans [14,15], and as a knowledge sharing tool to facilitate planner learning curve [1,5,9,16,17].

The recent investigations about the capability of KBP systems to reduce the human-caused variability are affected by some limitations. Cross-institutional comparisons have been performed on large databases without a common cohort of patients [1,3,10], treatment of a single patient has been planned by many planners [4,5] or many plans have been administered to a single experienced operator [18,19].

This study present the attempt to overcome some of these

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limitations using a robust and systematic approach to correctly quantify the impact of the RapidPlan KBP system (Varian Medical Systems, Palo Alto, CA) on inter- and intra-planner variability. Seven planners with different levels of clinical planning experience were asked to plan a VMAT treatment for the same cohort of prostate patients with and without the support of RapidPlan. To address the problem more effectively, instead of the troublesome and clinically questionable analysis of the average DVHs, the PQM formalism has been employed. This novel measure is gaining attention in the community and allowed to assess whether RapidPlan assistance affected differently the performances of planners with different degrees of experience.

2. Materials and methods

2.1. Planners

Six planners in our department consisting of physicists and dosimetrists with different degrees of expertise in RT planning were involved in the study. They were ranked by the total number of planned VMAT treatments (from 100 to 700). An internship student, without prior experience in IMRT or VMAT planning, was also involved to fully investigate the benefits of RapidPlan in an educational pathway.

2.2. Patient selection

For this study we have chosen eighty-five patients treated for radical prostate cancer, between 2016 and 2017 at our institute. PTV was obtained adding to a GTV, the prostate gland, a posterior margin of 5 mm and 7 mm margin in all the other directions. Rectum, bladder and femoral heads were delineated as OARs. The contouring procedure was undertaken by two dedicated radiation oncologists.

All the patients were treated with Volumetric Modulated Arc Therapy using 1 or 2 full arcs and 6-MV photons delivered with a Millennium 120 MLC based on Varian Unique linac. The treatments were planned with Eclipse and Progressive Resolution Optimizer (PRO) v. 11 to deliver 78 Gy or 70 Gy (PTV) over 39 or 28 fractions [20,21].

The planning goals were to fully cover the PTV with 95% of the prescribed dose limiting the overdosage to 110% of the prescribed dose. All plans were optimized according to our department prostate radical treatment protocol which is based on RTOG 0126 (see Table 2).

2.3. Model configuration and validation

Data from seventy patients were imported in Eclipse v.13.7 and used to train and validate the RapidPlan model. The model was configured following the recommendation of the Varian operator's manual and suggestions from the literature [22–25]. Any outlier identified by RapidPlan was carefully re-checked and eventually replanned. The model was validated through a closed- and open-loop process as proposed in the literature [23–26]. The details of the process are given in a previous publication form the same group [27].

The RapidPlan model was configured with the list of objectives given in Table 1.

2.4. Planning protocol

The remaining fifteen patients from the initial group, all treated with a prescription of 78 Gy, were used to conduct the prospective study in two subsequent phases. First, during routine clinical activity, data from each patient were copied, renamed and distributed to every planner as a clinical treatment to be optimized following a standard manual approach (manual planning). After the introduction of RapidPlan, the entire patient sample was anonymized with univocal IDs and administered to the planners to be optimized with the assistance of RapidPlan (RapidPlan assisted planning). This strategy was adopted to minimize possible bias due to planners' memory.

Table 1
Summary of the optimization objective used in RapidPlan-assisted planning. The *gen.* indicates those values generated by RapidPlan on the basis of the prostate model. D_{presc} indicates the prescription dose.

ROI	Optimization Objective			
	Objective Type	D [Gy]	V [%]	Weight
PTV	Lower	77.22	100	130
	Upper	79.56	0	120
Rectum	Upper	*gen.*	0, 10, 30, 50, 80	*gen.*
Bladder	Upper	*gen.*	0, 10, 30, 60	*gen.*
Femur L	Upper	*gen.*	0, 50	*gen.*
Femur R	Upper	*gen.*	0, 50	*gen.*
Body	Normal Tissue Objective	DistanceFromTargetBorder = 0.2 cm StartDose = 100 EndDose = 50 FallOff = 0.2 cm^{-1}		100

All plans were created to be delivered with the same Linac respecting the original clinical set-up. All the planners were forced to maintain the isocenters identified during the CT-simulation. In both the planning procedures planners were left free to set the treatment geometry: one or two full arcs and an arbitrary collimator angle.

During the manual planning phase operators were free to set DV optimization constraints and draw ghost structures for dose containment. Conversely, during the RapidPlan assisted planning, they were provided with the DVH predictions given by RapidPlan and were limited to use and modify, but not delete, the set of predefined optimization objectives generated by the RapidPlan model. In addition, planners were not allowed to draw ghost structures to support the optimization. This method allows to make full use of RapidPlan capability which inherently takes into account the relative geometrical relationship when predicting the DVH curves. All plans were normalized to cover the 100% of the PTV with 76.44 Gy (95% of the prescription dose) in 39 fractions.

2.5. Plan evaluation

The dosimetric features of *manual* and *RapidPlan assisted* plans were compared on the basis of DVH metrics based on RTOG 0126 and complementary low-dose DVH points. In detail: 1. The near minimum dose ($D_{98\%}$), the near maximum dose ($D_{2\%}$), the Homogeneity index [($D_{2\%}$ − $D_{98\%}$)/78 Gy] and conformity index [$V_{100\%}/V_{PTV}$] for the PTV; 2. V_{30Gy}, V_{40Gy}, V_{50Gy}, V_{60Gy}, V_{65Gy}, V_{70Gy} and Mean Dose for the rectum and bladder; 3. the Mean Dose and the D_{1cc} for the femoral heads.

Together with the standard DVH metric used in clinical practice, to simplify the overall scoring of plans and to limit the subjectivity of judgment, the Plan Quality Metric (PQM) was adopted as a global measure of quality. PQM was first introduced by Nelms [6] and is now implemented in PlanIQ software (v2.1.1, Sun Nuclear Corp., Melbourne, FL).

PQM is a user-defined metric intended to compare the quality of treatment plans. It gathers into a single number the judgment of quality expressed by a clinical team on the basis of its knowledge and experience. It is built through a list of submetrics, e.g. DVH metrics, which should schematically represent the peculiar goals of the treatment (Table 2). To each metric, the user associates a numerical scoring function to model as accurately as possible the judgment criteria of the clinicians (Fig. 1). The PQM is the sum of the score obtained by each submetric and measures how much the plan adheres to the list of identified goals. The percentage PQM (PQM%), i.e. the ratio of the achieved score to the maximum achievable, thus represents a relative measure of plan goodness.

For the purpose of this work, PQM offered a prompt and objective method to compare the quality of different plans pertaining to the same