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# Knowledge-based treatment planning: An inter-technique and inter-system feasibility study for prostate cancer

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ABSTRACT

*Purpose:* Helical Tomotherapy (HT) plans were used to create two RapidPlan knowledge-based (KB) models to generate plans with different techniques and to guide the optimization in a different treatment planning system for prostate plans. Feasibility and performance of these models were evaluated.
*Material and methods:* two sets of 35 low risk (LR) and 30 intermediate risk (IR) prostate cancer cases who underwent HT treatments were selected to train RapidPlan models. The KB predicted constraints were used to perform new 20 KB plans using RapidArc technique (KB-RA) (inter-technique validation), and to optimise 20 new HT (KB-HT) plans in the Tomoplan (inter-system validation). For each validation modality, KB plans were benchmarked with the manual plans created by an expert planner (EP).
*Results:* RapidPlan was successfully configured using HT plans. The KB-RA plans fulfilled the clinical dose-volume requirements in 100% and 92% of cases for planning target volumes (PTVs) and organs at risk (OARs), respectively. For KB-HT plans these percentages were found to be a bit lower: 90% for PTVs and 86% for OARs. In comparison to EP plans, the KB-RA plans produced higher bladder doses for both LR and IR, and higher rectum doses for LR. KB-HT and EP plans produced similar results.
*Conclusion:* RapidPlan can be trained to create models by using plans of a different treatment modality. These models were suitable for generating clinically acceptable plans for inter-technique and inter-system applications. The use of KB models based on plans of consolidated technique could be useful with a new treatment modality.


## 1. Introduction

Helical and volumetric arc-modulated RadioTherapy (VMAT) employ inverse planning processes that optimise the dose distribution of arc-deliveries according to constraints set by planners on treatment planning systems (TPS). Since the optimal achievable dosimetry is unknown at the beginning of the optimisation, the ability of the planners is a primary factor to obtain a good plan. Moreover, each plan tailored to a specific patient generally requires many rounds of trial and error optimisation. Therefore, the final result is highly related to experience and planning time of the planner or institution.

RapidPlan™ (Varian Medical Systems, Palo Alto, USA) is a commercially knowledge-based planning solution integrated in Eclipse TPS that generates automated constraints based on a model trained by libraries of specific plans. These models use the geometrical features of treatment plans included in the library to predict a range of achievable OARs DVHs for a new patient plan. Moreover, the system suggests a list of objectives and penalties to perform a knowledge-based (KB) optimisation process suitable for the optimisation module of Eclipse. The RapidPlan was investigated and validated for clinical practice in several studies [1–8]. These studies demonstrated that RapidPlan can produce good quality plans when employing the same technique of the model library plans (VMAT and fixed-gantry IMRT). It is important to use plans which have consistently high quality because the model is based on the mean values of dosimetric features of the majority of the training set plans. Therefore, few good plans in the training set are not enough to obtain a model with good performances [9]. However, not in all institutes, a significant number of good quality plans are easily

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available, for one particular anatomical region, technique and modality; the number of patients treated in the institute and the experience of the individual planner become critical factors, especially when a new radiotherapy techniques are clinically introduced in the Institute. KB models, trained with plans created from a consolidated different technique, should be useful to compensate for the lack of planning experience. This study investigated the potential of RapidPlan applied to different treatment techniques and optimisation systems: the capability of two prostate cancer models trained by HT plans to produce knowledge-based RapidArc (KB-RA) plans and to predict the dosimetry of new HT plans (KB-HT) was tested.

## 2. Methods and materials

### 2.1. Knowledge based optimisation engine

RapidPlan was introduced in the Eclipse treatment planning system (Varian Medical Systems, Palo Alto, USA) from its release13.5 [9]. In order to configure a model in RapidPlan, a set of geometric and dosimetric information are extracted from a group of selected available treatment plans (N > 20). A combination of Principal Component Analysis and regression techniques (PCA regression [10]) extracts the features that are used in the automated model based dose volume objectives prediction tool (DVH estimation phase) [9]. In a second phase, called DVH Estimation, the DVH ranges for the structures defined in the model are predicted for any new patient. These predicted DVH are specific for the new patient anatomy derived from the features extracted in the model training. The optimization objectives, as line objectives, are created from the predicted DVH, following the lower boundary of the estimate.

### 2.2. Model's library

Two models were trained, employing HT prostate treatments plans: a model for low risk prostate cancer (LR), using 35 plans delivering 70 Gy/28 fractions to prostate gland only, and a model for intermediate risk prostate cancer (IR) using 30 simultaneous integrated boost (SIB) plans delivering 70 Gy to prostate gland (PTV1) and 56 Gy to proximal seminal vesicles (PTV2) in 28 fractions [11,12]. All the selected HT treatments plans were simulated by expert users with Tomoplan (v3-4, Accuray) and performed at our institute between 2010 and 2012. The modulation factor ranged from 2.5 to 3.0, the pitch was 0.215 and the field width 2.5 cm. The clinical prescription and dosimetric requirements for PTVs coverage and OAR dose sparing are listed in Table 1. Prior to their inclusion in the library, all plans were checked by a medical physicist and structures were validated by a radiation oncologist to prevent outliers. The percentage of the plans included in the training set that have met the clinical requirements are reported in Table 1.

### 2.3. Models configuration

Model trainings were performed using selected treatment plans which were exported from the HT TPS and linked in Eclipse (v.13.6) to a virtual RapidArc (RA) plan. The RA plans were realized with two full arcs of 30°/330° complementary collimator angles and 6 MV photon beams. We used a simulated VMAT technique to match the HT technique as closely as possible: both HT and RA plans use the same/similar photon energies and, if the delivery time is not considered a hard constraint, it should be possible to mimic the dose distribution obtained with one system on the other (tools available in commercial treatment planning system have proven this [13,14]). Subsequently, the RapidPlan performed the data extraction and the model training for each set of treatment plans. This procedure is extensively described in the Varian reference manual and previous publications [8,9]. Briefly, during these phases, each OAR structure was divided into different functional sub-structures: out-of-field, leaf-transmission, in-field, overlap. To perform model training, some geometrical and dosimetric features were calculated [9] for each structure/sub-structure, employing the combination of principal component analysis and regression techniques. The principal component scores were used as input for the regression model. The result was a set of coefficients providing an evaluation of the principal component scores of the DVH from the geometric parameters. A first evaluation of the model goodness was performed by using the statistical tool embedded in RapidPlan system, where the number of possible outliers is identified in the regression of the principal components according to the Cook's distance, or to the studentised residual [9]. At the end of the process, the two RapidPlan models were successfully characterized for rectum, bladder, femoral heads and PTVs.

**Table 1**
Dosimetric clinical requirements for the planning with the percentage of plans (KB – EP, training set plans) meeting the criteria. Max and min referred as the dose received to 1 $cm^3$ of volume.

| | | Training Set | EP-RA | EP-HT | KB-RA | KB-HT |
|---|---|---|---|---|---|---|
| *Desirable Objectives* | | | | | | |
| PTV1 | $V_{70\ Gy} \geq 95\%$ | 100% (n = 65) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) |
| | $D_{2\%} < 107\%$ | 100% (n = 65) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) | 70% (n = 20) |
| | $D_{98\%} > 95\%$ | 100% (n = 65) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) |
| PTV2 | $V_{56\ Gy} \geq 95\%$ | 100% (n = 30) | 100% (n = 10) | 100% (n = 10) | 100% (n = 10) | 90% (n = 10) |
| Rectum | $V_{50\ Gy} < 35–45\%$ | 100% (n = 65) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) | 70% (n = 20) |
| | $V_{60\ Gy} < 25–30\%$ | 100% (n = 65) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) |
| | $V_{65\ Gy} < 15–20\%$ | 100% (n = 65) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) | 95% (n = 20) |
| | $D_{max} < 70$ Gy | 59% (n = 65) | 55% (n = 20) | 60% (n = 20) | 35% (n = 20) | 10% (n = 20) |
| Bladder | $V_{60\ Gy} < 35\%$ | 100% (n = 65) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) |
| Femoral Heads | $V_{45\ Gy} < 5\%$ | 100% (n = 65) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) |
| | $D_{max} < 48$ Gy | 100% (n = 65) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) |
| *Acceptable Objectives* | | | | | | |
| PTV1 | $V_{70\ Gy} \geq 93\%$ | 100% (n = 65) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) |
| | $D_{2\%} < 110\%$ | 100% (n = 65) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) |
| | $D_{98\%} > 90\%$ | 100% (n = 65) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) |
| Rectum | $D_{max} < 72$ Gy | 100% (n = 65) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) |
| Bladder | $V_{60\ Gy} < 50\%$ | 100% (n = 65) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) |
| Femoral Heads | $D_{max} < 50$ Gy | 100% (n = 65) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) | 100% (n = 20) |