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Review paper

Comparison between two treatment planning systems for volumetric modulated arc therapy optimization for prostate cancer

Caroline Lafond [a,b,c,*], Frédéric Gassa [d], Christophe Odin [e], Gaël Dréan [b,c], Justine Even [a], Renaud De Crevoisier [a,b,c], Pascal Pommier [d], Jean-Pierre Manens [a,b,c], Marie-Claude Biston [d]

[a] Radiation Oncology Department, Centre Eugène Marquis, Rennes, France
[b] Université de Rennes 1, LTSI, France
[c] INSERM, U1099, France
[d] Radiation Oncology Department, Centre Léon Bérard, Lyon, France
[e] Institut of Physics of Rennes, IPR/UMR CNRS 6251, University of Rennes I, Rennes, France

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ABSTRACT

Purpose: To investigate the performances of two commercial treatment planning systems (TPS) for Volumetric Modulated Arc Therapy (VMAT) optimization regarding prostate cancer. The TPS were compared in terms of dose distributions, treatment delivery parameters and quality control results.
Materials and methods: For ten patients, two VMAT plans were generated: one with Monaco TPS (Elekta) and one with Pinnacle TPS (Philips Medical Systems). The total prescribed dose was 78 Gy delivered in one 360° arc with a Synergy® linear accelerator equipped with a MLCi2®.
Results: VMAT with Monaco provided better homogeneity and conformity indexes but lower mean dose to PTVs than Pinnacle. For the bladder wall ($p = 0.019$), the femoral heads ($p = 0.017$), and healthy tissues ($p = 0.005$), significantly lower mean doses were found using Monaco. For the rectal wall, VMAT with Pinnacle provided a significantly ($p = 0.047$) lower mean dose, and lower dose into 50% of the volume ($p = 0.047$) compared to Monaco. Despite a greater number of monitor units (factor 1.5) for Monaco TPS, the total treatment time was equivalent to that of Pinnacle. The treatment delivery parameter analysis showed larger mean MLC area for Pinnacle and lower mean dose rate compared to Monaco. The quality control results gave a high passing rate (>97.4%) for the gamma index for both TPS but Monaco provided slightly better results.
Conclusion: For prostate cancer patients, VMAT treatment plans obtained with Monaco and Pinnacle offered clinically acceptable dose distributions. Further investigations are in progress to confirm the performances of the two TPS for irradiating more complex volumes.

Introduction

Volumetric modulated arc therapy (VMAT) is a new radiotherapy technique which allows to achieve treatment plans of similar or improved quality compared to fixed-field intensity-modulated radiation therapy (IMRT) while reducing the treatment time per fraction [1]. In practice, to obtain highly modulated dose distributions delivered efficiently, a treatment planning system (TPS) with a powerful optimization and segmentation algorithm is required.

While a lot of users are in the process of replacing fixed-field IMRT by VMAT, or directly implementing VMAT in their radiotherapy department, there is a lack of information concerning the relative performances of the mainly used TPS for VMAT planning. To our knowledge, only three studies deal with this topic [2–4]. In Rao et al., ERGO++ (Elekta, Crawley, UK) was compared to Pinnacle (Philips Medical Systems, Madison, WI) direct machine parameter optimization (DMPO) combined with a home-made arc-sequencer and Pinnacle SmartArc inverse planning module [2]. In Masi et al., the performances of Monaco (CMS-Elekta, Crawley, UK) were compared to ERGO++ and Oncentra (Nucletron-Elekta) [3]. Finally, in Wiezorek et al., VMAT plans obtained with Monaco and Eclipse (Varian Medical System, Palo Alto, CA) were evaluated [4]. In these studies, the comparisons were made by fixing common planning objectives on PTVs and OARs and comparing the dosimetric results

* Corresponding author. Centre Eugène Marquis, Rue de la bataille Flandres Dunkerque, CS44229, 35042 Rennes Cedex, France. Tel.: +33 2 99 25 31 27.
E-mail address: c.lafond@rennes.unicancer.fr (C. Lafond).

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and treatment delivery efficiency (number of monitor units and treatment time).

The aim of the present study was to investigate the performances of two TPS that have not been compared yet in VMAT mode, both using different approaches for VMAT plan optimization: Monaco based on a two-stage constrained optimization [5] and Pinnacle SmartArc [6]. This work was performed by two institutions. The aim was to compare VMAT plans performed by Monaco and Pinnacle regarding to dosimetric performances and treatment delivery specificities. We therefore fully put in evidence the differences observed in terms of dose distributions, delivery efficiency, treatment delivery parameters (mean dose rate, mean segment area) and quality control results on 10 prostate cancer cases.

Materials and methods

Patients

Ten prostate adenocarcinoma patients referred to our institutions for a radical external beam irradiation to the prostate and seminal vesicles (SV) were considered for this dosimetric comparative analysis.

Anatomic data acquisition, volumes definition and dose

Organs at risk [rectal wall (5 mm thickness), bladder wall (7 mm thickness), femoral heads (FH)] and target volumes (prostate, SV) were delineated on dedicated 2 mm-thick CT slices.

The first clinical target volume (CTV1) comprised the prostate and SV. The CTV2 was limited to the prostate only. Planning target volumes (PTVs) were automatically generated adding a 3D 1 cm uniform margin around the CTVs, except in the posterior direction, where a 0.5 cm margin was added to protect the rectum.

The total prescription dose was 46 Gy to the PTV1 and an additional 32 Gy to the PTV2 using a standard fractionation (2 Gy per fraction, 5 days a week) for a total dose of 78 Gy using a sequential technique.

A dose objectives set was fixed for PTVs and OARs: for PTV1: 95% of the PTV covered by 97% of the prescribed dose, and less than 5% of the PTV receiving more than 107% of the prescribed dose; PTV2: 95% of the PTV covered by 95% of the prescribed dose; Rectum: maximum dose (into 1.8 cc) $<$ 76 Gy, V72 $\leq$ 25%, V60 $\leq$ 50%; Bladder V70 $\leq$ 25%, V60 $\leq$ 50%; Femoral heads: V50 $\leq$ 5%.

Treatment planning

For each patient, two VMAT plans were generated: one with Monaco 3.0 (CMS-Elekta Ltd, Crawley, UK) and one with Pinnacle 9.0 (Philips Medical Systems, Madison, WI).

The irradiation was delivered, using 6-MV photons with an Elekta Synergy® machine equipped with a Cone-Beam Computed Tomography (CBCT) device (XVI®) and with a multi-leaf collimator (MLCi2®) consisting of 40 paired leaves, each measuring 1 cm in width at the isocenter. The possible dose rate values were 25 MUs/min, 50 MUs/min, 100 MUs/min, 200 MUs/min and 400 MUs/min. For each treatment plan a single 360° arc was used.

Monaco planning

For Monaco planning, the optimization constraints were established on the basis of biological cost functions (i.e. Serial or parallel complication model for OARs and Poisson cell kill function for the PTVs). The prescription template applied to all patients is given in Table 1. The optimization was first performed in a constrained mode, meaning that all constraints to the OARs are treated as hard constraints and all optimization criteria must be met. Conversely, the constraints to the targets are considered as objectives. The pareto mode which gives priority to PTV coverage was used secondarily to achieve the PTV coverage detailed above.

Sequencing parameters used for PTV1 and PTV2 irradiation were: 124 control points (CP) to achieve in practice 120 CP; target dose rate 300 MUs/min; minimum segment width 0.5 cm; fluence smoothing: low.

For final Monte Carlo dose calculations, a calculation grid of 3 mm and a 3% variance were used. With these parameters, the time needed for final dose calculation was about 10 min on an Intel Xeon CPU 3 GHz and 12 GB RAM platform. The time for optimization stage and adjusting the prescription parameters was about 20 min.

Pinnacle planning

For Pinnacle planning, inverse optimization was performed using the SmartArc algorithm [6]. The optimization objectives were defined with physical dose points. The template is shown in Table 1. The arc sampling parameter was fixed at 3° to obtain 120 CP for the full arc. The delivery time parameter was fixed at 180 s firstly; then was eventually increased to 240 s to allow more dose modulation for the most complex cases. Final dose was computed with a collapsed cone algorithm using a dose grid resolution of 3 mm. With these parameters, the time needed for optimization and final dose calculation was about 13 min on an Intel quadruple-Core (Xeon) 2.8 GHz and 16 GB RAM platform. Time for parameters adjustment was 10 min.

Preliminary work

Although this study was performed by two institutions, an important number of constraints were set to limit the influence of the planners and planning philosophy of the two hospitals. First, a preliminary comparison study was performed on a water-equivalent cylindrical phantom with a C-Shape target surrounding a central avoidance structure (data not shown) as described by the AAPM task group 119 [7]. This preliminary work allowed to harmonize both planning methods and to verify that for a simple geometry both institutions were able to produce plans of similar quality regarding dose distribution and delivery efficiency.

Treatment plans comparisons

Dose distribution

In order to limit the uncertainties on DVHs calculations between both TPS, the results were evaluated in the ARTiView 1.12 software (Aquilab, Lille, France) by comparing DVHs for targets and OARs (mean dose and doses at selected points of the DHVs). Patient-averaged DVHs were compared. In addition, several quality indexes for PTV1 and total plans were assessed: homogeneity index (HI) was calculated as $(D_{5\%}-D_{95\%})/D_{\mathrm{mean}}$ within the PTV; $D_{5\%}$ and $D_{95\%}$ being the dose received by 5 and 95% of the PTV [8]; conformity index (CI) was calculated as the ratio between the volume of the reference isodose ($V_{95\%}$) and the PTV volume (V_{PTV}) [$V_{95\%}/V_{\mathrm{PTV}}$] [9]; healthy tissue coverage index (HCO) evaluates the percentage of reference isodose which is outside the PTV volume. HCO was calculated as $[100 * (1 - (V_{\mathrm{PTV},\,95\%}/V_{95\%}))]$; $V_{\mathrm{PTV},\,95\%}$ was the volume of PTV covered by the reference isodose.

Statistical analysis used two-sided Wilcoxon-signed rank test, a nonparametric test, calculated with PASW Version 18.0.0 (SPSS Inc., Chicago, IL). A value of $p < 0.05$ was considered statistically significant.

To underscore the spatial localization differences between the two TPS, a patient-averaged dose distribution was performed. To