A TREATMENT PLANNING STUDY COMPARING VMAT WITH 3D CONFORMAL RADIOThERAPY FOR PROSTATE CANCER USING PINNACLE PLANNING SYSTEM

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Received August 6, 2012

Abstract. In Romania, during the last 40 years the most common method for treating malignant tumours with ionizing radiation was cobalt therapy, using $^{60}$Co source for radiation dose delivery. Since 2001, dedicated linear accelerators (linac) have been acquired for this type of specialized treatment. The precision, flexibility, and accuracy of the beam produced by the linac had replaced the $^{60}$Co utilization. One of the most recent techniques for cancer treatment in Europe is volumetric modulated arc therapy (VMAT), implemented for the first time by Otto Karl in 2008. In this study we are comparing the treatments plans for prostate cancer using 3D conformal radiotherapy (CRT) radiotherapy with VMAT technique. We compared the dose distribution obtained using 3D CRT with 6 static treatment beams with the distribution achieved by using dual arc VMAT optimized with SmartArc algorithm. A dose of 74 Gy was prescribed to prostate and minimum 54 Gy to seminal vesicles, delivered in 37 fractions. Dose distribution for prostate tumours is more easily achieved with VMAT technique than with 3D CRT. As for the concerns regarding the organs at risk (OAR), VMAT provides a better protection by comparison with CRT, concurrently respecting the dose limits, specified in the Radiation Therapy Oncology Group (RTOG) 0415 trial protocol. Also, the time of treatment delivery is shorter for VMAT technique.

Key words: volumetric modulated arc therapy, 3D radiotherapy.

1. INTRODUCTION

Radiation therapy has been used to treat prostate cancers for decades. It plays an important role in the curative management of patients with early stage disease and also in the palliation of symptoms associated with advanced or metastatic disease.

* Paper presented at the Annual Scientific Session of Faculty of Physics, University of Bucharest, June 22–23, 2012, Bucharest – Magurele, Romania.
Technical developments have led to incremental improvements in the delivery of high dose radiation therapy for the curative treatment of prostate cancer. With the medical linear accelerators that were designed and developed during the 1970s, the physicians were able to administer high doses of radiation to deep structures within the body, while sparing the superficial tissues. Despite the fact that high energy X-ray beams spare superficial normal tissues, organs at risk located in a large volume around the tumour often received a high dose of radiation. This large treatment volume was necessary to ensure that the whole tumour volume is adequately covered [1].

The goal of three-dimensional conformal radiation therapy (3D CRT) is to have the prescribed radiation dose distribution shaped like the target volume (hence the term “conformal”). In the past, radiation therapy plans were reviewed in a single exposure. Unfortunately, both the shape of the human body and of the tumor volume vary widely from one individual to another, so that they are not amenable to simple radiation therapy techniques. 3D CRT allows the physicist to achieve a volumetric adaptation to the target volume and the normal tissues, which is not contingent upon arbitrary and regular geometric shapes [1].

Although 3D CRT has facilitated the augmentation of the target dose and the reduction of the dose given to the normal tissues in certain sites, the volumetric modulated arc therapy (VMAT) leads to even greater improvements in the radiation therapy treatments. In VMAT, the radiation is delivered by the rotation of the linac gantry along one or more arcs, with the beam continuously on. By this technique a number of parameters can be varied, including the multi-leaf collimator (MLC) aperture shape, the fluence-output rate (dose rate), the gantry rotation speed, and the MLC orientation [2].

Conventional 3D CRT treatment planning is manually optimized. The physicist chooses all beam parameters, such as the number of beams, beam directions, shapes and weights, the computer calculating then, the dose distribution. Based on the result, the physicist modifies various parameters in an attempt to optimize the dose distribution. With VMAT, dose distributions are inversely determined, meaning that the treatment physicist must specify in advance the desired dose distribution, and then the computer will calculate a set of beam intensities that will produce, as closely as possible, the desired dose distribution.

2. MATERIALS AND METHODS

To make a comparative study between the two radiotherapy methods we used the parameters from Philips CT Big Bore and from the Elekta Synergy Linear Accelerator with the energy of 6 MeV. After the acquisition of CT images, the radiotherapist is contouring the target volumes and the organs at risk (Fig. 1). The prescribed doses of 74 Gy for planning target volume PTV\textsubscript{2} (prostate) and 54 Gy for PTV\textsubscript{1} (prostate + seminal vesicles) were applied in 37 fractions.
In this study we have compared the dose distribution obtained with two radiotherapy techniques: 3D CRT and VMAT. In both cases the objective was to obtain uniform dose distributions in the tumour volume, with good protection of the organs at risk (bladder, rectum, and femoral heads). For the creation of both treatment plans we used the Pinnacle Planning System from Philips (version 9.0). For the 3D CRT, six beams with 6MeV photon energy and different weights, were used as can be seen in Table 1. The beam isocentre was placed in the centre of PTV2.

**Table 1**

<table>
<thead>
<tr>
<th>Beam Angles</th>
<th>Beam Weights</th>
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<td>30°</td>
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<td>90°</td>
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<td>270°</td>
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<td>330°</td>
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After the target volumes and normal tissues are defined and contoured on the CT scan, the next step in 3D CRT is the virtual simulation. A beam's-eye-view display allows the physician to appreciate the target volume from the same...
perspective as the radiation treatment source. This view allows the radiation oncologist to adapt the radiation field to the contour of the target. As we can see in Fig. 2, the stair step edges of the field are a computer simulation of a multi-leaf collimator (MLC). This stair step has a little effect inside the patient. The radiation scatter and additive effects of multiple radiation beams create a smooth outline of the radiation dose distribution around the target volume.

For VMAT treatment we used a single nearly complete counterclockwise arc from $178^\circ$ to $182^\circ$, as illustrated in Fig. 3; in this way the patient was treated from all angles, in one 360-degree rotation. The major conceptual advantage of VMAT over standard 3D CRT is that since the radiation source is rotating around the patient, all angles are available to deliver radiation to the target, thus avoiding critical structures; also, the time is used efficiently because the delivery does not stop between different beam angles [3].

VMAT technique is based on inverse planning. In addition to the activities performed for 3D CRT, before performing the optimizations we added the objectives, the dose constraints for organs at risk, and maximum dose for the target volume. It is desired to have a uniform dose of 74 Gy covering PTV₁ (prostate), while for PTV₂ (prostate and seminal vesicles) the target dose is 54 Gy.
After specifying the objectives in accordance to the RTOG 0615 trial protocol, the optimization was made using SmartArc. This method with a ‘continuously variable dose rate’ option allows the dose rate to be chosen for each of the control points during optimization. For this plan we used 91 control points per arc and a single beam with 2 arcs; a gantry spacing of 4° was chosen as a starting point. In addition to optimization parameters, MLC motion was restricted from one control point to the next, by constraining MLC movements to < 0.46 cm/deg. The maximum delivery time was set to 60 s. Once the final plan was obtained, a segment weight optimization (SWO) was performed to see if further improvements were possible. Limiting the MLC motion between control points (to 0.4 cm/deg) allowed us to achieve a faster delivery time (~ 20 % faster) for similar dosimetric plan quality in prostate case [4].

3. RESULTS AND DISCUSSIONS

For nearly all analyzed dosimetric points, the VMAT technique allowed lower doses to normal critical structures by comparison with 3D CRT. The doses to the PTV and critical structures were evaluated for both plans by the analysis of dose-volume histograms and dose distributions. Our dosimetric analysis confirmed that VMAT did not lead to significant improvements in target coverage when compared with conventional 3D CRT planning. For almost all PTV1 (prostate), the target coverage and dose uniformity were excellent with standard 3D techniques. Therefore, it was not surprising that significant further improvement was not
observed with VMAT for PTV coverage. However, it can be seen in Fig. 4, that dose received by organ at risk and soft tissue is less for VMAT techniques than 3D CRT.

![Fig. 4 – Dose distributions in target volume and organ at risk for 3D CRT (left) and for VMAT technique (right). It can be seen, that maximum point dose (76.8 Gy for 3DCRT and 75.3 Gy for VMAT) is located inside PTV for both techniques, but it has different values (for 3D CRT is higher than for VMAT technique).](image)

Analyzing dose volume histograms for both plans, one can see that doses for rectum and bladder are significantly lower with VMAT in comparison with 3D CRT. Also, it can be observed that the volume of rectum which receives 70 Gy is much smaller for VMAT than for 3DCRT. It is known from RTOG 0415 trial that the volume of rectum which can receive 70 Gy is less than 7% of the whole organ. Analyzing dose volume histogram (Fig. 5), it can be seen that 29% of rectal volume receives 70 Gy in 3D CRT technique and this limits the dose that can be administered to the target volume (this is unacceptable in the context of prostate cancer treatment).

![Fig. 5 – Dose Volume Histograms obtained for 3D CRT (right) and VMAT techniques (left). It can be seen that mean doses for the same volume of organs at risk are higher for 3D CRT than for VMAT technique.](image)
In these conditions, the maximum dose that can be applied for prostate in 3D CRT technique is 66 Gy. Considering the fact that curative dose for prostate is 70 Gy (according RTOG 0415 trial), it may be concluded that by using 3D CRT technique it is not possible to deliver the dose necessary to ensure a good probability of tumour control and adequate sparing of organs at risk.

Another advantage of VMAT technique is the reduced treatment time in comparison with 3D CRT for the same dose administration. This aspect is very important for a better comfort of patients during treatment.

4. CONCLUSIONS

Compared to 3D CRT, VMAT resulted in significantly reduced normal tissue complications for rectum, bladder, and soft tissue. This study demonstrates that VMAT achieves superior normal tissue protection (especially for rectum) as compared to 3D CRT, with similar dose delivering to the target volume.

Acknowledgement. This paper is supported by the Sectorial Operational Programme Human Resources Development (SOP HRD), financed from European Social Fund and by the Romanian Government under the contract number SOP HRD/107/1.5/S/82514

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