

ADAPTIVE RADIATION THERAPY: IMPACT OF IMAGE GUIDANCE ON THE RECTUM SPARING FOR A PROSTATE CANCER

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ABSTRACT

Adaptive radiation therapy aims to correct the treatment by taking into account anatomical changes as determined from on-board imaging. It requires imaging, dose delivery verification and the plan adaptation if the dose delivery verification shows that the initial plan is no longer clinically acceptable. The roles of imaging and dose verification calculations are considered using the clinical data for the prostate cancer patient. Daily pre-treatment imaging allows for correction of the patient position and to evaluate the dose distributions delivered at each fraction. Two scenarios were considered: 1) dose distribution calculated for each fraction in the case where the patient was positioned using image-guidance and 2) simulation of the treatment if patient was positioned using only external marks and room lasers. Key dosimetric parameters for the planning and clinical target volumes as well as for the rectum were calculated and analyzed.

Key words: image guidance, prostate cancer, tomotherapy, dose distribution.

RESUMEN

La terapia de radiación adaptativa tiene como objetivo la corrección del tratamiento para tomar en cuenta los cambios anatómicos. Esto requiere tomar imágenes en transcurso del tratamiento, verificar la dosis recibida para diferentes órganos durante la irradiación y una adaptación del plano en caso si el plano inicial no es aceptable clínicamente. Consideramos la función de la corrección de la posición del paciente y de los cálculos de la dosis recibida en cada fracción del tratamiento de un paciente con cáncer de próstata. Analizamos dos escenarios: 1) cuando la distribución de dosis está calculada para el paciente en la posición del tratamiento actual y 2) la simulación de un tratamiento con paciente en la posición determinada por marcos externos y los láseres. Calculamos y analizamos los parámetros dosimétricos para los volúmenes de los blancos planificados y clínicos, así como del recto.

Palabras claves: terapia guiada por imágenes, cáncer de próstata, tomoterapia, distribución de dosis.

I. INTRODUCTION

External beam radiation therapy has been very effective in treating cancer alone or in combination with surgery, chemotherapy, and brachytherapy. Intensity modulated radiation therapy (IMRT) is a technique that delivers high levels of radiation to the tumor and provides sharp dose gradients to spare surrounding healthy tissues [1]. Calculated IMRT treatment plans are prepared using CT studies performed several days before the start of actual radiation delivery that takes several weeks depending on the fractionation schedule. Several investigations revealed significant inter-fraction changes in patient anatomy. Most interest has been focused on cases of head and neck cancer where weight loss is quite common accompanied by shrinkage of the parotid glands [2-9]. For prostate cancer patients, target position changes daily in spite of efforts to keep it stable by prescribing bladder and rectal preparation. The introduction of image-guided radiotherapy (IGRT) through various on-board imaging devices assists in correcting daily patient set-up and reduces a portion of the uncertainty [10]. These corrections aim to place the target in the same position as in the planned CT relative to the calculated dose distribution in all treatment fractions. Due to proximity of the rectum to the prostate gland there is a probability of acute and late side effects such as rectal bleeding and fistula. In this communication we investigate the effect of IGRT daily corrections on the dose delivery to the rectum and correlate these findings with the daily correction shifts.

II. MATERIALS AND METHODS

Treatment data for the 74 years old male with high risk (PSA = 10, Gleason score 7) prostate cancer was used for this analysis approved by the institutional ethics board. This patient was chosen because the radiation therapists noticed large variations of the rectal volume and shape during treatment course and they were concerned about overdose to the rectum. Kilovoltage CT (kVCT) study was performed on the Philips Big Bore Brilliance CT Simulator 7 days before the radiation treatment start. The kVCT study was transferred to Pinnacle³ (version 9, by Philips Medical System, Madison, WI) treatment planning system for contouring followed by a transfer of the DICOM files for kVCT study

and structures to the TomoTherapy planning station (version 4.0) where a treatment plan to deliver 78 Gy in 39 fractions was created. The patient was positioned on the treatment couch using external marks and room lasers. Daily megavoltage CT (MVCT) studies were taken immediately before every fraction of radiation delivery on our Hi-ART TomoTherapy system (Accuray, Madison, WI). The MVCT study has been matched to the planning kVCT study initially in the automatic mode using voxel-based mutual information algorithm [11], followed by a careful inspection of the fusion result by two radiation therapists who applied manual corrections if needed. The resulting position correction shifts were recorded for each treatment fraction. The TomoTherapy Planned Adaptive module (version 4.0) was used for creating the merged images where the MVCT data replaced the kVCT data in the sub-volume covering the planning target volume imaged during pre-treatment scan. The rectum was outlined on the MVCT studies. Two dose distributions were calculated for each of 39 fractions using a radiation fluence pattern of the corresponding day: 1) for the patient positioned as during actual treatment and 2) for the patient positioned using external marks and room lasers in order to simulate the radiation delivery without image guidance. The following dosimetric parameters were recorded for each fraction: doses to 99% and 1% (D99% and D1%) to the planning target volume (PTV) and the clinical target volume (CTV), doses to 15% D15% and to 15 cm³ (D15cc) to the rectum.

III. RESULTS AND DISCUSSION

Figure 1 demonstrates change of the rectal volume between the time of the planning kVCT scan and MVCT scan performed before the first treatment fraction. An example of the MVCT image data interpolated in the planning kVCT study is shown in Fig.1 (lower panel) where one can see kVCT image outside 40 cm field-of-view for the MVCT.

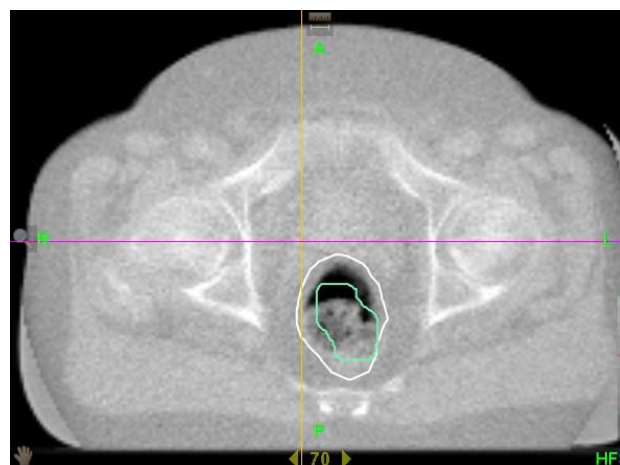
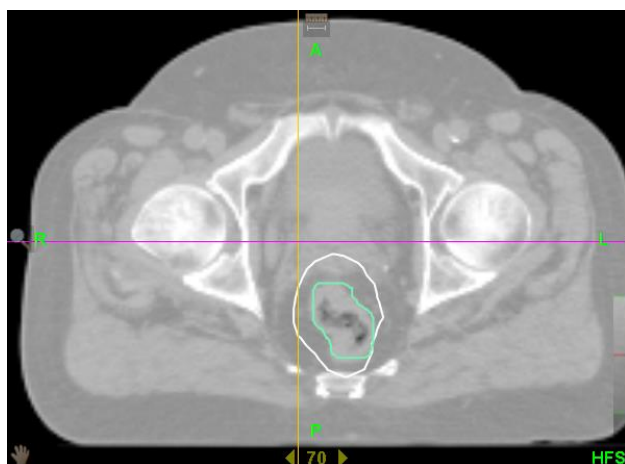


Figure 1. Kilovoltage CT image where the rectum is contoured by the blue line (upper panel) and the same slice of the MVCT image for the first fraction (lower panel) with the white contour of the rectum.

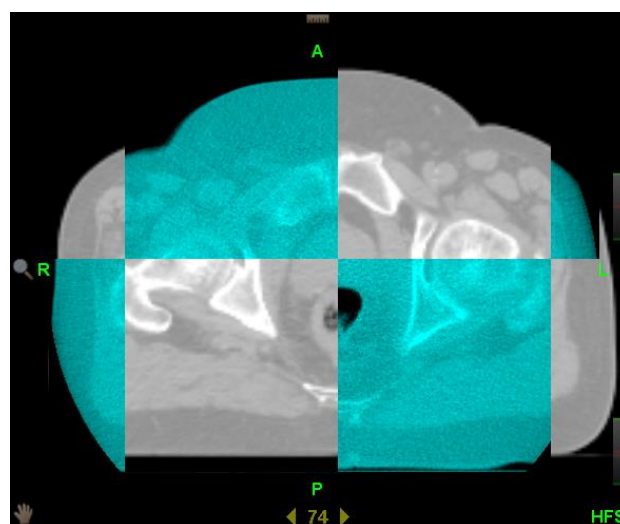


Figure 2. Fused MVCT (blue) and kVCT (grey) image for the first fraction obtained after matching the target.

The radiation therapists used the prostate gland interface with the rectum as the major alignment reference. Typical merged MVCT/kVCT image that illustrates observed changes of the rectum during the treatment course is shown in Fig. 2.

Figure 3 present the results for position correction shifts of image guidance using MVCT scans prior to treatment and fusion with planning kVCT.

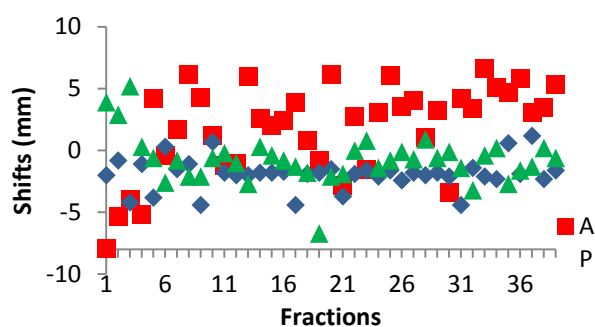


Figure 3. Patient position correction shifts in left-right (triangles), cranio-caudal (rhombos), and antero-posterior (squares) direction for 39 fractions.

The patient's position corrections in lateral direction were stable after a few initial fractions as the patient became accustomed to the procedure. A large spread of correction shifts in antero-posterior direction was due to large variations in rectal volume in the course of treatment shown in Fig. 4.

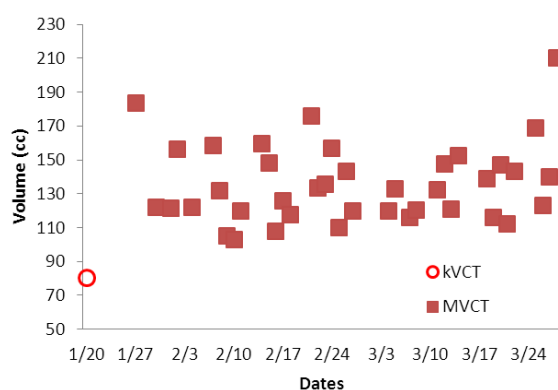


Figure 4. Rectal volume variation during treatment as determined by contours on the MVCT studies.

Table 1 present the calculated dosimetric data for the PTV, CTV, and rectum obtained for two fractions (1 and 35) where large position correction shifts based on pre-treatment MVCT imaging (7 mm in posterior direction and 5 mm in anterior direction, respectively) were applied. $D_{x\%}$, the minimum dose received by the hottest $x\%$ of the volume and the percentage of the rectal volume receiving at least 2 Gy (V_{2Gy}) were evaluated.

When the patient was moved posteriorly in fraction 1 to account for an increase of its volume from 80.6 cm³ in the planning image to 183.6 cm³, the rectum was moved out of the high dose region with a decrease of the volume exposed to 2 Gy or higher from 75.5 to 48.5 cm³ and the dose to 50% of the volume from 1.94 Gy to 1.44 Gy, while the planning target volume (PTV) was correctly positioned eliminating underdosed area in anterior part of the prostate. The dose reporting to 15 cm³ of the rectum is recommended as clinically most significant for evaluation [12]. In fraction 35, there was a position

correction in opposite direction: the patient was moved anteriorly that resulted in exposure of a larger rectal volume to the dose of 2 Gy or higher from 7 to 16.4 cm³ and the dose to 50% of the volume from 1 Gy to 1.14 Gy, while the planning target volume (PTV) was correctly positioned eliminating minor underdosed area in posterior part of the prostate. These results for the PTV coverage demonstrate the significance of high dose gradient as a change of only 2 mm in the correction shift resulted in large difference in the coverage. The influence of position correction for the clinical target volume (CTV) was very small in both cases because the correction shifts were within the PTV margin.

Table 1. Dosimetric parameters calculated to simulate a treatment in the position defined by the external marks (before) and after correction based on the image guidance information (after) in fractions 1 and 35. V_{2Gy} in cm³ and $D_{x\%}$ in Gy.

Structure		-7 mm shift		+5 mm shift	
		before	after	before	after
Rectum	V_{2Gy}	75.5	48.5	7.0	16.4
	D_{15cc}	2.05	2.06	1.8	2.01
	$D_{50\%}$	1.94	1.44	1.0	1.16
PTV	$D_{99\%}$	1.35	1.997	1.96	1.99
	$D_{1\%}$	2.04	2.07	2.04	2.03
CTV	$D_{99\%}$	1.92	1.998	2	2
	$D_{1\%}$	2.03	2.08	2.04	2.03

IV. CONCLUSIONS

Pre-treatment image guidance allowed for significant improvement of delivery the planned dose to the target with better sparing to the organs at risk. Plan adaptation in this particular case is not warranted as initial plan combined with pre-treatment imaging allowed for meeting the clinical objectives.

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