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Fractionated changes in prostate cancer radiotherapy using cone-beam computed tomography

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ABSTRACT

The high mobility of the bladder and the rectum causes uncertainty in radiation doses prescribed to patients with prostate cancer who undergo radiotherapy (RT) multifraction treatments. The purpose of this study was to estimate the dose received by the bladder, rectum, and prostate from multifraction treatments using daily cone-beam computed tomography (CBCT). Overall, 28 patients with prostate cancer who planned to receive radiation treatments were enrolled in the study. The acquired CBCT before the treatment delivery was registered with the planning CT to map the dose distribution used in the treatment plan for estimating the received dose during clinical treatment. For all 28 patients with 112 data sets, the mean percentage differences (± standard deviation) in the volume and radiation dose were 44% (± 41) and 18% (± 17) for the bladder, 20% (± 21) and 2% (± 2) for the prostate, and 36% (± 29) and 22% (± 15) for the rectum, respectively. Substantial differences between the volumes and radiation dose and those specified in treatment plans were observed. Besides the use of image-guided RT to improve patient setup accuracy, further consideration of large changes in bladder and rectum volumes is strongly suggested when using external beam radiation for prostate cancer.

Introduction

The use of external beam radiation in radiotherapy (RT) for prostate cancer is one of the most useful treatments in clinics currently.[1] In RT, a major problem in delivering a sufficiently high dose of radiation to the prostate is the proximity of radiosensitive structures, such as the bladder and the rectum. Previous studies have recommended establishing clear constraints on the dose-volume relationship during radiation treatment planning for prostate cancer to protect critical organs.[2-5] However, an increase in radiation-induced genitourinary morbidity following RT for prostate cancer has been reported in several studies.[6,7]

The bladder and rectum are highly mobile and change position, volume, and shape during a course of RT, which creates uncertainty regarding the dose delivered to the organs.[7,8] In addition, intrafraction prostate motion is a critical concern in the fractionated treatment of prostate cancer in RT.[9] The initial radiation treatment plan based on patient anatomy obtained using planning computed tomography (CT) is, therefore, not likely to include an accurate estimate of the actual delivered dose to the bladder and the rectum when the multifractionated RT is performed. Considering the changes in the bladder and the rectum, there is a risk of introducing marginal or geographic error in dose delivery to the bladder and the rectum surrounding the prostate. Therefore, further investigation in the doses delivered to the prostate and the surrounding critical organs, considering the changes in the volume and position of organs that occurs during the course of multifractionated RT, is necessary.

A cone-beam CT (CBCT) scanner integrated with a linear accelerator is a powerful tool for image-guided patient alignment and dose verification.[10,11] In RT, precise patient setup is clinically critical because even a few millimeters of displacement can result in substantial dose deviations. To reduce such deviation, the use of CBCT for patient setup before each fraction treatment to ensure that the patient is positioned in agreement with the treatment

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plan based on the planning CT is necessary, as the course of treatment requires approximately 5 to 8 weeks. CBCT scanners are becoming a piece of equipment that is used daily in the treatment room.

It is well known that the bladder and the rectum are mobile organs and their volumes vary. How much the volume variation can be and how the volume variation affects the radiation dose delivered to the volumes were the questions this study tried to answer. The present study used CBCT to investigate the variations in the volume and radiation dose received by the bladder, rectum, and prostate regarding the clinical fractionated treatment, compared with those specified in the treatment plans.

Methods and Material

Patients and treatment planning

Overall, 28 patients with prostate cancer were retrospectively selected in our institution. The eligibility criteria included informed consent according to the protocol approved by the scientific ethics committees of our institution, and all the patients signed the written agreement. The number of CBCT taken for each case was different. We investigated the same 4 fractions; the CBCT data sets of the 1st, 7th, 14th, and 20th fraction from the entire treatment were selected and analyzed for each case. A total of 112 sets of treatment data were analyzed in this study. Overall, 14 patients received intensity-modulated RT and 14 patients were treated using volumetric-modulated arc therapy with 10-MV photon beams. The Eclipse Treatment Planning System, Eclipse v. 8.6.15 (Varian Medical System, Inc., Palo Alto, CA) was used for treatment planning and dose calculation. The prescribed dose was 180 or 200 cGy per fraction for a total number of fractions between 25 and 35. All the patients were instructed to empty their rectum and bladder and to drink 500 mL of water to fill their bladders 1 hour before the planning CT scan and each RT session. The clinical target volume of the prostate and volumes of the bladder and the rectum were manually delineated by the radiation oncologist overseeing the planning process. An extra 6-mm margin except 4 mm in the posterior direction was expanded for planning target volume on tumor to take account of the setup uncertainties in treatment delivery. The constraints involving the organs at risk were established according to the Radiation Therapy Oncology Group guidelines.[5]

Volume delineation, registered CBCT, and dose estimation in fractions

Daily image-guided patient repositioning based on CBCT images was performed in the clinical treatments according to our clinical protocol. A radiation oncologist with 18 years of experience manually delineated the outer walls of the prostate, bladder, and rectum in the CBCT images for all the patients to avoid interobserver variance (the same physician delineated the contours during the treatment planning). The bladder, rectum, and prostate were the main structures analyzed in this study. CBCT was reconstructed on the same image matrix, and the resolution was matched to the planning CT using linear interpolation. A rigid 3-dimensonal registration method, in which the correlation coefficient was applied as the cost function to register CBCT to the planning CT, was implemented. Next, the contours on the CBCT were copied to the planning CT, and the received fractional doses of clinical treatments were estimated based on the planning dose distribution with the copied contours.

Volumes and dose variations

Overall, 4 daily sessions of CBCT were selected to investigate the deviations from the treatment plan regarding volumes and doses. The percentage differences (PDs) of the target/organ volumes and delivered mean doses (D_{mean}) between the fractions and the plans were calculated as the difference divided by the value in planning. The average volumes and doses with standard deviations derived from the 4 data sets of treatments were calculated and compared with that in treatment plans. Statistical analyses were conducted using the independent-samples t-test. A p value of 0.05 was considered to be statistically significant.

Results

Figure 1 shows the planning CT and dose distribution with the bladder (Fig. 1A) and rectal (Fig. 1B) contours from the treatment plan and the corresponding contours based on CBCT data of the 4 fractions in the treatment course as an example. The bladder and rectal contours from the treatment plan are shown in red, and the copied organ contours based on the CBCT of fraction-1, -7, -14, and -20 are superimposed. The multifractionated dose-volume histograms for the bladder, prostate, and rectum for a selected patient, patient 7, who exhibited the maximal difference in radiation dose in the prostate, are shown as an example in Fig. 2.

The PDs of the volumes for the bladder, prostate, and rectum are shown in Fig. 3 whereas the corresponding dose PDs are shown in Fig. 4. For all the 112 data sets from the 28 patients, the mean PDs ($\pm$ standard deviation) in the volume and radiation dose were 44% ($\pm$ 41) and 18% ($\pm$ 17) for the bladder, 20% ($\pm$ 21) and 2% ($\pm$ 2) for the prostate, and 36% ($\pm$ 29) and 22% ($\pm$ 15) for the rectum, respectively.

The statistical data of the PD of the volumes and doses over the 28 cases are shown in the Table. The maximums of the PDs in the dose received by the bladder, prostate, and rectum were 85%, 13%, and 54%, respectively, in our patient cohort. The median value of the average differences in volume among all of the patients was 33 cm^3 (range: 3 to 148 cm^3) for the bladder, 4 cm^3 (range: 1 to 25 cm^3) for the prostate, and 16 cm^3 (range: 2 to 54 cm^3) for the rectum. The median value of the average difference in radiation dose was 18 cGy (range: 5 to 48 cGy) for the bladder, 3 cGy (range: 0.2 to 11 cGy) for the prostate, and 26 cGy (range: 2 to 63 cGy) for the rectum.

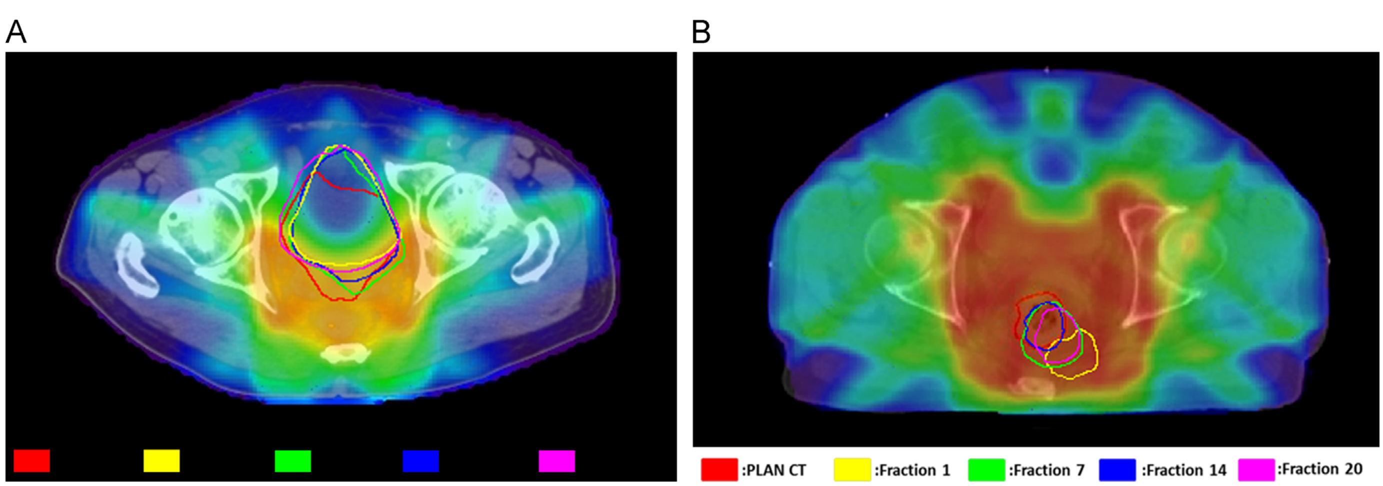

Fig. 1. The planning CT with (A) the bladder and (B) the rectum contours from treatment plan and the corresponding organ contours copied from CBCT data of different treatment fractions for patient 8 as an example. The contours of the bladder and the rectum from the treatment plan was shown in red, and the copied contours of fraction-1, -7, -14, and -20 were superimposed on the planning CT. The original dose distribution is also superimposed on the CT. (Color version of figure is available online.)