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Effect of intrafractional prostate motion on simultaneous boost intensity-modulated radiotherapy to the prostate: A simulation study based on intrafractional motion in the prone position

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ABSTRACT

Although the prostate displacement of patients in the prone position is affected by respiration-induced motion, the effect of intrafractional prostate motion in the prone position during "simultaneous integrated boost intensity-modulated radiotherapy" (SIB-IMRT) is unclear. The purpose of this study was to evaluate the dosimetric effects of intrafractional motion on SIB-IMRT to a dominant intraprostatic lesion (IPL) using measured motion data of patients in a prone position, fixed with a thermoplastic shell. We obtained 2 orthogonal x-ray fluoroscopic images at the same moment every 0.2 seconds for 30 seconds before and after treatment, once weekly, from 7 patients with localized prostate cancer with detectable prostatic calcification. Prostate displacements in the left-right (LR), anteroposterior (AP), and superoinferior (SI) directions were calculated using the prostatic calcification as a fiducial marker. We defined the displacement between pretreatment and posttreatment as baseline drift (BD). An SIB-IMRT plan was generated in which each IPL + 3 mm received a dose of 94.5 Gy, whereas the remainder of the prostate + 7 mm received a dose of 75.6 Gy in 9 fields. A simulated plan of dose blurring was generated by the convolution of isocenter-shifted plans using measured motion data in 30 seconds and motion in 30 seconds + distance between pretreatment and posttreatment position (BD) for each of the 7 patients. The motion in 30 seconds mainly reflected respiration-induced motion. The mean displacements of BD were 1.4 mm (− 3.1 to 8.2 mm), − 2.2 mm (− 9.1 to 1.5 mm), and − 0.3 mm (− 5.0 to 1.8 mm) in the AP, SI, and LR directions, respectively. The differences in the target coverage with $V_{90\%}$ of the IPL and $V_{100\%}$ of the prostate between the simulated plan and original plan were − 3.9% to − 0.3% and − 0.6% to 1.1% for respiration-induced motion and 3.1% to − 67.8% and 3.6% to − 13.3% for BD with respiration-induced motion, respectively. The large motion of BD resulted in an inadequate coverage by the prescribed dose of the SIB-IMRT to the IPL. A 7-mm margin is recommended when real-time tracking techniques are not applied. The effect of respiration-induced motion was small, so long as a 3-mm margin was added.

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Introduction

Advances in radiotherapy delivery techniques, such as intensity-modulated radiotherapy (IMRT), allows delivery of higher radiation doses to the prostate while minimizing the dose to normal tissues.[1] It has been demonstrated that biochemical disease-free survival improves with dose escalation to the prostate.[2] Therefore, curative radiotherapy using IMRT for the treatment of prostate cancer is now performed widely.

However, because of the vicinity of the bladder and the rectum to the prostate, dose escalation to the entire prostate also results in increased toxicity.[3] One option to address this problem of increased complications with increased doses is to better focus the dose escalation onto a dominant intraprostatic lesion (IPL).

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Several authors have recently reported the results of implementing simultaneous boost in patients with IMRT.[4-7]

In our institution, patients with prostate cancer are treated with IMRT in the prone position, fixed with a thermoplastic shell. Although Bittner *et al.*[8] and Wilder *et al.*[9] reported that both the prone and the supine positions resulted in similar magnitudes of intrafractional prostate motion, Butler *et al.*[10] found significantly greater net intrafractional prostate displacement of patients in the prone position than that in the supine position. Although there is no consensus for optimal treatment position, respiration-induced motion in the prone position has been reported widely.[11-14] Dawson *et al.*[12] reported prostate motion of up to 5 mm in normal respiration and up to 10 mm in deep breathing in the superoinferior (SI) direction. A thermoplastic shell can also contribute to large respiratory-induced prostate motion.[15]

Because a treatment plan with a complex dose distribution, such as the simultaneous integrated boost (SIB) to an IPL, tends to be created by intricate movements of multileaf collimators, the SIB-IMRT plan can theoretically be affected more strongly by intrafractional organ motion than by regular prostate IMRT. To our knowledge, no reported study has examined the effect of intrafractional prostate motion in the prone position with a thermoplastic shell on the SIB-IMRT plan.

Thus, the aim of this study was to evaluate the dosimetric effects of intraprostatic motion on SIB-IMRT to a dominant IPL using measured motion data from patients in the prone position.

Methods and Materials

Patients' characteristics

We enrolled 7 patients with localized prostate cancer with prostatic calcification who underwent definitive external beam radiation therapy with a Vero4DRT (marketed as the MHI-TM2000; Mitsubishi Heavy Industries, Ltd., Japan, and Brainlab AG, Feldkirchen, Germany)[16] in this study. The patients were participants in a clinical trial that evaluated intrafractional prostate motion.

The clinical trial was approved by the institutional review board (registration number C594) and registered at the University Hospital Medical Information Network Center (clinical trial registration number UMIN000006906). All patients provided written informed consent.

Patient setup

Details of our setup protocol were reported previously.[17,18] Briefly, patients were immobilized in the prone position with a thermoplastic shell (Hip Fix system; CIVCO Medical Solutions, Kalona, IA) that extended from the midthigh to the upper third of the leg in combination with a vacuum pillow (Vac-Lok system; CIVCO Medical Solutions) and a leg support. Planning computed tomography (CT) scans (LightSpeed RT; GE Healthcare, Waukesha, WI) were obtained at 2.5-mm slice thickness. Patients were instructed to empty their bladder and rectum ~1 hour before the CT simulation. At each treatment, patients were required to void the bladder and the rectum with timing identical to that established in the CT simulation.

Evaluation of intrafractional prostate motion

The Vero4DRT is equipped with 2 pairs of kilovolt (kV) x-ray imaging systems that can obtain x-ray fluoroscopic images and cone-beam CT (CBCT) images. For clinical practice, patients first underwent manual skin marking, and position correction was then performed using CBCT at each treatment. In this study, 2 orthogonal x-ray fluoroscopic images with a spatial resolution of 0.2 mm were taken simultaneously every 0.2 seconds for 30 seconds before and after treatment once weekly. In total, ~1800 pairs were acquired per patient. The treatment positioning was setup to calculate the intrafractional prostate motion.

Using in-house software, prostate displacements in the left-right (LR), anteroposterior (AP), and SI directions were calculated using these orthogonal images with the prostatic calcification as a marker.[19] If more than 1 calcification was identified within the prostate, the largest was used (Fig. 1). It has been reported that the displacements of intraprostatic calcification were equivalent to implanted markers in the 3 directions.[20]

Treatment planning for simultaneous boost to a dominant IPL

Pretreatment magnetic resonance imaging (MRI) was performed to delineate the region of the biopsy-proven IPL. MRI and CT fusion with treatment planning CT was performed using iPlan RT image (ver. 4.1.1; Brainlab AG) and verified manually by checking the center of the prostate in both the scans. The IPL was then contoured using an empirical algorithm.[21] An IMRT plan with simultaneous boost was generated with the IPL in the left peripheral zone beside the rectum using iPlan RT Dose (ver. 4.5.1; Brainlab AG). A 3-mm margin was established around this IPL. The IPL + 3 mm received a dose of 94.5 Gy in 2.25-Gy daily fractions, whereas the remainder of the prostate + 7 mm received a dose of 75.6 Gy in 1.8-Gy daily fractions. This prescription was determined by reference to a protocol reported previously.[6,7] Figure 2 shows a treatment planning image in the axial plane. Target coverage was satisfied because the $V_{90\%}$ of the IPL and the $V_{100\%}$ of the prostate were 96.9% and 96.4%, respectively. The doses to the at-risk organs were within the limits, *e.g.*, the $V_{70\ Gy}$ of the rectum and the $V_{65\ Gy}$ of the bladder were 10.2% and 25.0%, respectively. The maximum doses to the rectum, bladder, and urethra were 80.4, 78.8, and 79.6 Gy, respectively. An IMRT plan consisted of 9 beams at gantry

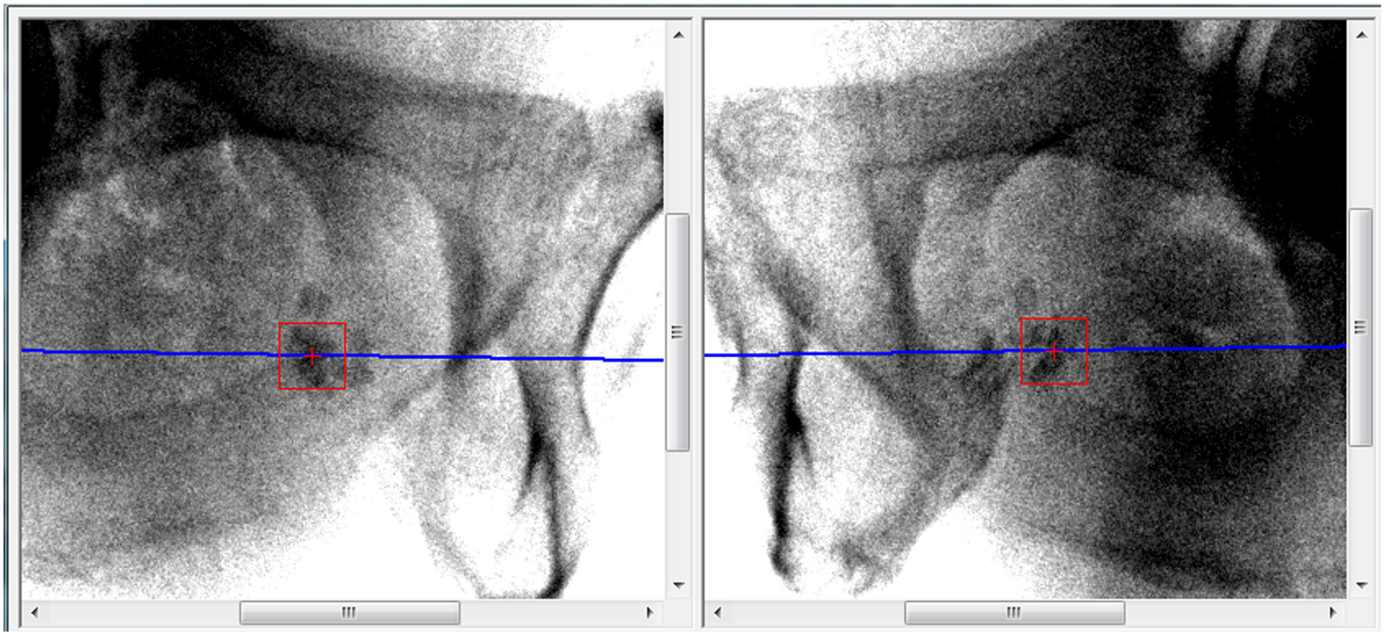

Fig. 1. An example of an in-house software image used to calculate the 3-dimensional positions of prostatic calcification. The centroid of the largest prostatic calcification is marked within the red square on the 2 orthogonal x-ray fluoroscopic images. (Color version of figure is available online.)

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