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Assessment of PTV Margins Accounting for Prostate Intrafraction Motion in SBRT with Online IGRT

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Abstract

Purpose: The aim of this work was to assess PTV margins suitable for SBRT of prostate cancer uncertainties after daily online correction. Moreover, intra-fraction prostate motion is analyzed with the aim to identify its main causes

Material and Methods: Between 2013 and 2014, 43 patients with low or intermediate risk prostate cancer were treated with 7-fraction SBRT in supine position, with implanted Fiducial Markers (FM), empty rectum and full bladder. The van Herk's formula was applied to calculate the PTV margins of prostate/seminal vescicles. To investigate the causes of organ motion, the bladder volume and the rectum wall distension and the treatment time.

Results: systematic increase of bladder and the rectal distension not influence the prostate displacement ($p = 0.55$ and $p = 0.32$ respectively). Significant correlation was observed between the intrafraction composite shift of the prostate volume and the elapsed treatment time ($p = 0.036$).

Conclusion: our data suggest a good control of intrafraction motion. The prostate intrafraction motion is shown to be dependent on elapsed treatment time.

Keywords: Prostate cancer; IGRT; Organ motion

Introduction

Radiotherapy for localized prostate cancer currently utilizes conformal techniques to improve survival rates, local control rates, and toxicity rates. The use of intensity-modulated radiotherapy, in particular, may enable even greater sparing of organs at risk, making dose escalation a realistic option or permitting a further reduction of treatment-related side effects. Nevertheless, accurate target (prostate) localization remains a crucial factor for optimal target dosing and normal tissue avoidance. Traditionally, target localization has relied on skin marks to infer prostate position, in conjunction with periodic pelvic bony anatomy portal imaging for verification. However, this technique neither takes into account the fact that bony anatomy and skin marks are not reproducibly related, nor does it take into account the fact that the prostate gland moves relative to both skin marks and bony anatomy [1]. Although intrafraction motion can be reduced using daily image guidance and custom immobilization devices, intrafraction motion continues to occur, and its mitigation has proven quite difficult to quantify. Nonetheless, systems have been used to quantify intrafraction motion, including megavoltage portal imaging [2], magnetic resonance imaging [3,4], kilovolt age radiographs [5], transabdominal ultrasound [6], and electromagnetic tracking systems [7]. Currently, a technique of growing interest is the use of intraprostatic fiducial markers [8,9] to serve as a surrogate of prostate position. With two-dimensional and three-dimensional (3D) imaging now an integral component of contemporary linear accelerators, fiducial-based image guidance has become a well-established technique not only for patient positioning and repositioning but also for target motion assessment during the course of treatment, albeit snapshots in time.

Purpose

There is little consensus on the magnitude of PTV margins for IGRT of the prostate cancer when a hypo fractionation scheme is applied and daily correction is required, rather than averaging over many fractions. The aim of this work was to assess PTV margins suitable for SBRT of prostate cancer uncertainties after daily online correction. Moreover, intra-fraction prostate motion is analyzed with the aim to identify its main causes (bladder filling, rectum distension, elapsed treatment time).

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Material and Methods

Between 2013 and 2014, 43 patients with low or intermediate risk prostate cancer were treated with 7-fraction SBRT in supine position, with implanted Fiducial Markers (FM), empty rectum and full bladder. To reduce organ motion, patients were premeditated with butyl scopolamine and rectum gas was removed before the treatment. At each session pre-treatment kV/kV imaging was acquired to align the patient by matching the FM's, while additional CBCT imaging was performed after treatment delivery to assess the intra-fraction motion. The van Herk's formula was applied to calculate the PTV margins of prostate/seminal vescicles. To investigate the causes of organ motion, the bladder volume and the rectum wall distension were estimated from each CBCT with respect to the simulation CT images. Intra-fractional changes of the rectal Anterior-Posterior (AP) diameter of the level of the centre of CTV were measured manually. The filling of the bladder was estimated based on measurements of AP (d_{AP}) and superior-inferior (d_{SI}) bladder distension in sagittal reconstruction [10]. Correlation between these anatomical factors and intrafraction PTV motion was assessed for each axis, as well as for the composite shift of the prostate volume. The treatment time elapsed from pre-treatment kV/kV to post-treatment CBCT imaging was also included in the statistical analysis.

Results

301 pre-treatment kV/kV images and 301 post-treatment CBCTs were analyzed. After daily IGRT correction, margins accounting for residual uncertainties are estimated 3 mm for AP, 3 mm for longitudinal axis and 2 mm for Lateral intra-fraction motion. A systematic increase of bladder filling with respect to simulation images was observed; however, these changes did not influence the prostate displacement ($p = 0.55$). Similarly, variations of the prostate position occurred independently from changes of the rectal distension ($p = 0.32$). A trend between internal prostate motion in the AP direction and elapsed treatment was observed ($p = 0.057$). Finally, a significant correlation was observed between the intrafraction composite shift of the prostate volume and the elapsed treatment time ($p = 0.036$).

Conclusion

This study investigated intra-fractional uncertainties of prostate position and filling of the rectum and urinary bladder during SBRT treatment of prostate cancer. Our data suggest a good control of intrafraction motion with butyl scopolamine medication and by careful emptying of the rectum before treatment. The prostate intrafraction motion is shown to be dependent on elapsed treatment time. Results in the literature were similar to our study with a tendency to increased intra-fractional uncertainties with longer treatment time. Margins of 3 mm were calculated for treatment times between 2-7 min [11], which in considerably less compared to the 6 mm margin for a treatment time of<10 min in our study In conclusion, in image-guided SBRT with online correction, PTV margins can be kept in the range of 3 mm provided that the elapsed treatment time is kept as low as possible.

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