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Prostate IMRT

Influence of daily setup measurements and corrections on the estimated delivered dose during IMRT treatment of prostate cancer patients

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ABSTRACT

Purpose: To evaluate the impact of marker-based position verification, using daily imaging and an off-line correction protocol, by calculating the delivered dose to prostate, rectum and bladder.
Methods: Prostate cancer patients ($n = 217$) were treated with IMRT, receiving 35 daily fractions. Plans with five beams were optimized taking target coverage (CTV, boost) and organs-at-risk (rectum and bladder) into account. PTV margins were 8 mm. Prostate position was verified daily using implanted fiducial gold markers by imaging the first segment of all the five beams on an EPID. Setup deviations were corrected off-line using an adapted shrinking-action-level protocol. The estimated delivered dose, including daily organ movements, was calculated using a version of PLATO's dose engine, enabling batch processing of large numbers of patients. The dose was calculated ± inclusion of setup corrections, and was evaluated relative to the original static plan. The marker-based measurements were considered representative for all organs.
Results: Daily organ movements would result in an underdosage of 2–3 Gy to CTV and boost volume relative to the original plan, which was prevented by daily setup corrections. The dose to rectum and bladder was on average unchanged, but a large spread was introduced by organ movements, which was reduced by including setup corrections.
Conclusions: Without position verification and setup corrections, margins of 8mm would be insufficient to account for position uncertainties during IMRT of prostate cancer. With the daily off-line correction protocol, the remaining variations are accommodated adequately.
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Several clinical studies have shown a beneficial effect of an increased radiation dose for the treatment of prostate cancer [30,32,45], preferably by using a simultaneously integrated boost [8,29]. To ascertain accurate target coverage with the clinically prescribed dose [37,40], a planning target volume (PTV) with margins around the target volumes is created, accounting for delineation and setup uncertainties and organ motion during the treatment course. Most margin recipes prescribe isotropic margins, based on homogeneous dose distributions. However, to prevent the high-dose region to extend too much especially in the rectum, a margin reduction at the dorsal side of the PTV is desired [9,27]. Unfortunately, for prostate cancer the tumour cells are predominantly located at the dorsal side, i.e. in the peripheral zone of the prostate [10]. The challenge is to achieve a sufficiently high dose to the peripheral zone of the prostate and adequate sparing of the rectum. To successfully deliver such an inhomogeneous dose distribution, IMRT has become the standard treatment of choice.

The dose prescribed to the prostate is higher than the tolerance dose for the rectum. Therefore, reliable and accurate position verification and setup corrections during treatment are of vital importance, in order to minimize the systematic component of the setup deviations. Most clinical studies that aimed at boosting the prostate applied position verification based on imaging of the bony anatomy [15,45]. This is, however, only partly successful, especially for correction of setup deviations in anterior–posterior direction [5,27]. Since then technology has improved significantly, and detection of the prostate position itself has become feasible. For instance, some form of CT-based imaging can be installed on the treatment machine [11,20,33], enabling better visualization of soft tissue and internal organs. Besides, implanted fiducial gold markers proved to be reliable markers of prostate position over the course of radiation treatment [2,17,25,44]. Their position can be easily and automatically detected with EPI [26,28], allowing fast and accurate determination of setup deviations. In contrast to position verification, daily on-line setup correction is often too

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time-consuming and labour-intensive and therefore not yet standardly applied in all radiotherapy institutes. Instead, off-line decision protocols are used [14,16,39], in which residual small errors are inevitable.

In the University Medical Center Utrecht, a large number of prostate cancer patients have been treated with IMRT with implanted fiducial gold markers [17,27,39]. Prostate position was evaluated after off-line evaluation of EPIs, and setup deviations (translations) were corrected using an adapted shrinking-action-level protocol [4,39]. The aim of the present study was to investigate retrospectively whether the inhomogeneous IMRT dose distribution could be delivered adequately to the target volumes, notably the peripheral region of the prostate, while sparing organs-at-risk, using the off-line marker-based correction protocol and given the applied margin recipe. It was aimed to obtain an estimate of the clinically applied dose by recalculation of the dose distribution for all patients including daily organ movements (translations and rotations), without and with inclusion of setup corrections. Inclusion of the clinically applied setup corrections in the calculations results in dose distributions which can be considered representative of the actual treatment, and will be referred to as the "estimated delivered dose". Within this study we have no data on deformations of the prostate and organs-at-risk. It has been shown that deformations of prostate and seminal vesicles during the course of radiotherapy are small, therefore correction for only setup deviations and organs motion should be sufficient [18]. In contrast, deformations in organs-at-risk (rectum and bladder) can be considerable, and drive the rotation and translation of the prostate [22,34–36,41]. Despite this limitation in the method to estimate the clinically applied dose, it is a useful tool to achieve a higher accuracy in evaluation of the clinical dose distributions, in relation to the clinical outcome.

Materials and methods

Patients and treatment

Between 2003 and 2005, over 300 patients with stage T3Nx/0Mx/0 prostate cancer were treated with IMRT at the department of Radiation Oncology of the University Medical Center Utrecht. Patients were prescribed 70 Gy to the prostate plus seminal vesicles (CTV) in 35 daily fractions of 2 Gy, with an integrated boost delivering in total 76 Gy to the prostate (35×2.17 Gy). Patients were treated on one of the five Elekta SL 15 linear accelerators equipped with a multi-leaf collimator with 1 cm wide leaves at an energy of 10 MV.

For daily position verification during treatment, two or three fiducial gold markers (diameter 1 mm, length 5 mm, Heraeus GmbH, Hanau, Germany) were implanted in the prostate [17,39]. One week after marker implantation, a planning CT scan was made with 3 mm slices on a Philips Aura CT scanner (Philips Medical Systems, Best, The Netherlands). Resolution of the CT data set was $1 \times 1 \times 3$ mm^3. Patients received IMRT through a five beam step-and-shoot technique. IMRT plans were sequenced such that the largest segment per beam direction was delivered first (close-in). During each fraction, portal images of the first segment of all the five beams were made on-line using an iView-GT amorphous silicon flat-panel detector (Elekta Ltd., Crawley, UK). In these portal images, the markers were automatically detected off-line using in-house developed software, and their position was reconstructed in 3D [26,28]. From the reconstructed marker positions, the deviation of the center of mass of all the markers was determined with respect to the planning CT (the reference position), resulting in translations in three directions and in three rotations. These daily setup deviations (translations only) were corrected off-line using an adapted shrinking-action-level (SAL) protocol [39]. The adapted SAL protocol corrects deviations if they persist above a shrinking threshold of $\alpha/\sqrt{N}$, with $\alpha = 6$ mm in each direction and N being the number of fractions considered. After a correction, N is reset to 1. The maximum number of fractions over which the setup deviation is averaged is $N_{max} = 4$. When at N_{max} no correction is needed, a running average over the past N_{max} fractions is determined each day and is compared to the action level. For the analysed group of patients, the uncorrected and corrected setup deviations are summarized in Table 1, by the mean systematic error M, the standard deviation of systematic positioning errors Σ, and the random positioning error σ, before and after applying setup corrections [39].

IMRT planning and dose prescriptions

Target volumes and organs-at-risk were delineated in the CT data set by a physician using the in-house developed software package VolumeTool. Organ contours are delineated in the CT images, but their coordinates are not strictly associated with the CT voxels and therefore may not be discrete. The relevant contours for this study were (Fig. 1):

- CTV: clinical target volume, i.e. prostate plus seminal vesicles.
- BV: boost volume, i.e. the prostate.
- Rectum, delineated from 3 CT slices cranial of the PTV until 3 CT slices caudal of the PTV.
- Bladder, delineated until 3 CT slices cranial of the PTV.

The entire organ circumference of rectum and bladder has been delineated. To account for delineation and setup uncertainties and organ motion [17], a PTV (planning target volume) around the CTV with 8 mm margins, and an EBV (extended boost volume) around the BV with 8 mm margins excluding overlap with rectum

Table 1
Setup deviations (translations and rotations) based on the daily prostate marker imaging, before and after applying the off-line adapted SAL correction protocol, for all 217 patients. M: mean systematic error; Σ: standard deviation of systematic positioning errors; σ: random positioning error; x: only translations are corrected.

	Translation	Uncorrected	Corrected		Rotation	Uncorrected	Corrected
Translations				*Rotations*			
M (mm)	Vertical	2.8	0.3	M (°)	Vertical	0.2	x
	Lateral	−0.3	0.07		Lateral	0.4	x
	Longitudinal	0.3	−0.02		Longitudinal	0.3	x
Σ (mm)	Vertical	4.6	1.0	Σ (°)	Vertical	2.7	x
	Lateral	2.1	0.9		Lateral	6.5	x
	Longitudinal	3.0	1.2		Longitudinal	2.6	x
σ (mm)	Vertical	3.5	4.0	σ (°)	Vertical	1.4	x
	Lateral	1.9	2.2		Lateral	4.8	x
	Longitudinal	2.2	2.5		Longitudinal	1.9	x