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Original research article

Utilization of cone-beam CT for offline evaluation of target volume coverage during prostate image-guided radiotherapy based on bony anatomy alignment

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ABSTRACT

Aim: To assess target volume coverage during prostate image-guided radiotherapy based on bony anatomy alignment and to assess possibility of safety margin reduction.
Background: Implementation of IGRT should influence safety margins. Utilization of cone-beam CT provides current 3D anatomic information directly in irradiation position. Such information enables reconstruction of the actual dose distribution.
Materials and methods: Seventeen prostate patients were treated with daily bony anatomy image-guidance. Cone-beam CT (CBCT) scans were acquired once a week immediately after bony anatomy alignment. After the prostate, seminal vesicles, rectum and bladder were contoured, the delivered dose distribution was reconstructed. Target dose coverage was evaluated by the proportion of the CTV encompassed by the 95% isodose. Original plans employed a 1 cm safety margin. Alternative plans assuming a smaller 7 mm margin between CTV and PTV were evaluated in the same way. Rectal and bladder volumes were compared with the initial ones. Rectal and bladder volumes irradiated with doses higher than 75 Gy, 70 Gy, 60 Gy, 50 Gy and 40 Gy were analyzed.
Results: In 12% of reconstructed plans the prostate coverage was not sufficient. The prostate underdosage was observed in 5 patients. Coverage of seminal vesicles was not satisfactory in 3% of plans. Most of the target underdosage corresponded to excessive rectal or bladder filling. Evaluation of alternative plans assuming a smaller 7 mm margin revealed 22% and 11% of plans where prostate and seminal vesicles coverage, respectively, was compromised. These were distributed over 8 and 7 patients, respectively.
Conclusion: Sufficient dose coverage of target volumes was not achieved for all patients. Reducing of safety margin is not acceptable. Initial rectal and bladder volumes cannot be considered representative for subsequent treatment.

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1. Background

Imaging technology drives advancement in radiation therapy. Different styles of image-guided radiation therapy (IGRT) are frequently discussed.[1,2] Unpredictable prostate position variation is the challenge for comparison of different IGRT strategies. Techniques of patient setup relative to external beam's isocenter have developed during the last decade. Historically, skin marks and setup lasers have been used. These are not adequate surrogates for prostate position and require extensive safety margins, which are incompatible with the delivery of the high radiation doses above 70 Gy which are currently used in routine practice.[3,4] Planar X-ray imaging techniques have enabled registration with skeletal anatomy, but recent studies have shown a poor correlation of prostate position and bony anatomy.[5] Prostate location variations were studied relative to the adjacent bony anatomy by Schallenkamp et al.[6] with the conclusion that a significant interfractional motion exists between the prostate and the pelvic bony anatomy. These move independently, therefore, the pelvic bony anatomy should not be used as a surrogate for prostate motion. Authors also suggest that fiducial markers are stable within the prostate and allow significant margin reduction when used for on-line localization of the prostate. The limited interuser variability and the marker stability make markers an ideal surrogate for the prostate position.[4] Another promising way of prostate image guidance is the use of in-room CT – helical on-rail CT or cone-beam CT (CBCT) – which provides 3D anatomic information directly in irradiation position. Compared to fiducial markers detected with planar imaging, the acquisition time is longer with CBCT and patient is exposed to a significantly larger additional radiation dose. Also the 3D image registration is more difficult and time-consuming.

Substantial positional variation of prostate over a 1-h period is caused by a variety of factors. The most significant predictor for intrafraction prostate motion is the status of rectal filling.[7] A full rectal state is invariably associated with mobile gas pockets responsible for elevated levels of prostate motion. While the apex is largely immobile, prostate motion is well described by rotation, but does undergo deformation due to rectal distension.[8] Effects of rectal motion during prostate radiotherapy with regard to rectal dose and clinical target volume (CTV) dose coverage were studied by Sripadam et al.[9] This study revealed instances of insufficient CTV coverage.

IGRT systems provide more information than is required for simple patient positioning. Utilization of cone-beam CT (CBCT) can provide 3D anatomic information directly in irradiation position. Such information enables reconstruction of a current dose distribution. CBCT was evaluated for treatment planning by Yoo and Yin[10] and Yang et al.[11] with the conclusion that CBCT could be used for verification planning to verify treatment delivery retrospectively.

Evaluation of the 'dose of the day' using post-treatment CBCT for IMRT prostate cancer patients with implanted markers was described by van Zijtveld et al.[12] The actual IMRT fluence maps delivered to a patient were derived from measured EPID-images acquired during treatment. Retrospective IMRT dose reconstruction based on CBCT and MLC log-file was described by Lee et al.[13]

2. Aim

The aim of the present study was to utilize the CBCT scans acquired before treatment for dose reconstruction purposes and hereby to assess target volume coverage during prostate image-guided radiotherapy based on bony anatomy alignment.

3. Materials and methods

3.1. *Patient characteristics*

Seventeen patients with adenocarcinoma of the prostate staged T2a–T3b N0 M0 were evaluated. Patients were treated using intensity modulated radiotherapy (IMRT) to the prostate with simultaneous integrated boost to the proximal part of seminal vesicles. Daily bony anatomy image-guidance was performed based on 2 orthogonal kV images. In order to assess target volume coverage, CBCT scans were acquired once a week in the treatment position immediately after bony anatomy alignment.

3.2. *Validation of dose calculation on CBCT*

A Siemens Somatom Sensation CT scanner (Siemens Medical Solutions, Erlangen, Germany) was used for acquisition of CT images (512 × 512 matrix, 0.98 mm pixel size, 3 mm slice thickness). CBCT images were acquired using Varian On-board imaging system (OBI®, Varian Medical Systems, Palo Alto, CA) and reconstructed using about 700 images in a "half-fan" projection with a bowtie filter acquired over 360° rotation. For CBCT reconstruction, 45 cm diameter and 12 cm axial length with 3 mm slice thickness and 512 × 512 matrix was used. The technique used was 125 kV, 80 mA, 25 ms.

The method to reconstruct the actually delivered dose based on pretreatment CBCT was first validated using phantom measurements. Dose profiles were compared for CBCT and CT images of inhomogeneous antropomorfic RANDO® phantom (The Phantom Laboratory, Salem, NY, USA). The images were imported into the Eclipse™ treatment planning system, version 8.1 (Varian Medical Systems, Palo Alto, CA). Plans based on CBCT and CT images were generated using (1) one 10 cm × 10 cm field and (2) five coplanar IMRT fields. 6 MV photon energy was used. Dose calculations were performed by a pencil beam convolution algorithm with Modified Batho heterogeneity correction. The dose calculation grid used was 0.25 cm. Dose was normalized to the isocenter with a prescription of 2 Gy. The resulting dose distributions and depth dose profiles on the central beam axis were compared.

3.3. *Radiotherapy planning and delivery*

Intensity modulated radiotherapy (sliding window technique) with five coplanar fields to the prostate plus the proximal 2/3 of seminal vesicles was planned and delivered. CT slices of 3 mm