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Original article

Comparison of multi-leaf collimator tracking and treatment-couch tracking during stereotactic body radiation therapy of prostate cancer

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ABSTRACT

Purpose and background: Motion mitigation during prostate stereotactic body radiation therapy (SBRT) ensures optimal target coverage while reducing the risk of overdosage of nearby organs. The geometrical and dosimetrical performance of motion mitigation with the multileaf-collimator (MLC tracking) or the treatment couch (couch tracking) were compared.

Material and methods: For ten prostate patients, SBRT treatment plans with integrated boosts were prepared using volumetric modulated arc technique. For the geometrical evaluation, a lead sphere at the beam isocenter was moved according to five prostate motion curves (i) without mitigation, (ii) with MLC tracking or (iii) with couch tracking. During irradiation, MV images were taken and the over-/underexposed areas were evaluated.

Material and methods: For the dosimetrical evaluation, the plans were applied to a dosimetric phantom. Dose distributions with and without mitigation were evaluated inside the target structure and organs at risk.

Results: The median over-/underexposed area was reduced significantly from 2.02 cm^2 without mitigation to 1.00 cm^2 and 0.45 cm^2 with MLC and couch tracking. Closest dosimetrical agreement to the static references was achieved with couch tracking.

Conclusions: MLC and couch tracking at a conventional linear accelerator significantly improved the accuracy of prostate SBRT in the presence of motion, whereby couch tracking showed slightly better performance than MLC tracking.

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Active motion mitigation during radiotherapy treatments of moving targets can be used to reduce the high-dose treatment volume and thereby spare the healthy tissue. Stereotactic body radiation therapy (SBRT) has been shown to be an effective treatment for localized prostate cancer [1], however it could further profit from on-line motion mitigation. First, the prostate shows systematic and erratic motion which can reach up to 10 mm [2–4]. This motion is conventionally considered by increasing the target volume with a safety margin, but this simultaneously increases the dose to the adjacent organs. With on-line motion mitigation throughout the treatment, this margin could be reduced. Second, SBRT aims to deliver high target doses with steep dose gradients in only a few treatment fractions. To maximally exploit SBRT, high accuracy in dose delivery is required.

On-line motion mitigation can be performed at a conventional linear accelerator either by following the target motion with the treatment field through constant adaptation of the multileaf-collimator (MLC tracking [5,6]), or by counter-movement of the patient with the treatment couch according to the target motion (couch tracking [7,8]).

Studies on prostate treatment improvement have been performed for MLC tracking [9,10] and couch tracking [11]. Moreover, both have been compared in a few studies. A multi-institutional study [12] compared real-time adaptive therapy with robotic, gimbaled, MLC and couch tracking. The four modalities were found to perform similarly. Other studies [13,14] compared MLC and couch tracking directly for prostatic motion traces. They found better motion mitigation for couch tracking, especially for high-modulated treatment plans [13].

These studies focused their evaluation on the target dose distribution of a few treatment plans with a homogeneous dose prescription. For an extensive comparison of MLC and couch tracking, we included dosimetry of the nearby organs, a two level

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dose prescription and a larger patient cohort in combination with various distinct motion trajectories.

Material and methods

Treatment planning

For ten prostate cancer patients, SBRT treatment plans with integrated boost to the index lesion were generated as described in Ehrbar et al. [11] using volumetric-modulated arc therapy (VMAT). A mean dose of 5 × 8 Gy = 40 Gy was prescribed to the planning target volume (PTV) around the index lesion (PTV_{index} = - index lesion plus 3-mm margin), and a lower dose of 5 × 7 Gy = 35 Gy to the PTV around the prostate ($PTV_{prostate}$ = - prostate plus 5 mm). Rectum, bladder and urethra were contoured as organs at risk (OAR). The rectum, bladder and urethra maximum dose (D0.1 cc) was restricted to 36.25 Gy and the distal rectum wall to maximal 35 Gy. To test whether the tracking performance also depends on the MLC orientation, two treatment plans were created for each patient, one with collimator rotations around 0° (range: 350°–10°) and one with 90° (80°–100°).

Motion traces

Five prostate motion traces were selected to show a variety of possible prostate displacements during radiotherapy treatments (see Ehrbar et al. [11] for details). These traces were recorded by Ehrbar et al. [11] (Trace 1) and Langen et al. [13] (Trace 2–5). The used sections of the traces are shown in Fig. 1 together with the temporal displacement fraction and mean offset for each motion trace.

MLC and couch tracking

Active motion mitigation with MLC or couch tracking was performed at a TrueBeam 2.0 linear accelerator (Varian Medical Systems, Inc., Palo Alto CA, USA). The TrueBeam was equipped with the High Definition 120 Leaf MLC and the PerfectPitch treatment couch. The system was employed in developer mode using the iTools-Tracking platform. This platform links the real-time position information of the target with the supervisor, which controls the MLC or couch position during the treatment. The position of the moving target was monitored with Calypso radiofrequency transponders (Varian Medical Systems, Inc., Palo Alto CA, USA) at a rate of 25 Hz and transferred to the iTools-Tracking software. A linear Kalman prediction filter is applied to the signal. For ongoing target motion, this filter is able to partially compensate for latencies caused by the time required for signal detection, signal processing and treatment adaptation. The predicted target displacement is then compensated with adaptation of the treatment field via the MLC or with counter-movement of the target via the treatment couch. The same tracking system was previously presented by Ehrbar et al. for couch tracking of lung tumors [15] and prostate tumors [11], and a similar system from the same vendor was studied by Hansen et al. [13] for MLC and couch tracking.

Geometrical performance

The geometrical performance of MLC and couch tracking was evaluated using mega-voltage (MV) fluoroscopy of a moving target. The target, a lead sphere with 10 mm diameter, was placed in the beam isocenter and moved in three dimensions with the HexaMotion stage (ScandiDos, Uppsala, Sweden). For position feedback, two Calypso transponders were placed on the lead sphere mount outside the treatment field. The twenty treatment plans were applied to the target and MV images were taken continuously at a rate of 7.7 Hz. These images show the lead sphere in respect to the MLC shaped field edges at different angular positions throughout the treatment. Each treatment plan was applied 16 times. First, one MV-image set was taken with the target in static position. This was used as the reference situation. Second, 15 MV-image sets were taken while the target was moved according to the five prostate motion traces during irradiation and with three modes of motion mitigation: no mitigation, MLC or couch tracking. The lead sphere was detected in each image with a template matching algorithm (see Fig. 2). The images were centered at the position of the lead sphere and a threshold was applied to create binary images. By comparison with the reference image at the same gantry angle, over- and underexposed areas at the field edges could be determined. This shows how well the motion was mitigated with MLC or couch tracking, since the relation between the lead sphere and the field edges should be the same for reference images and images

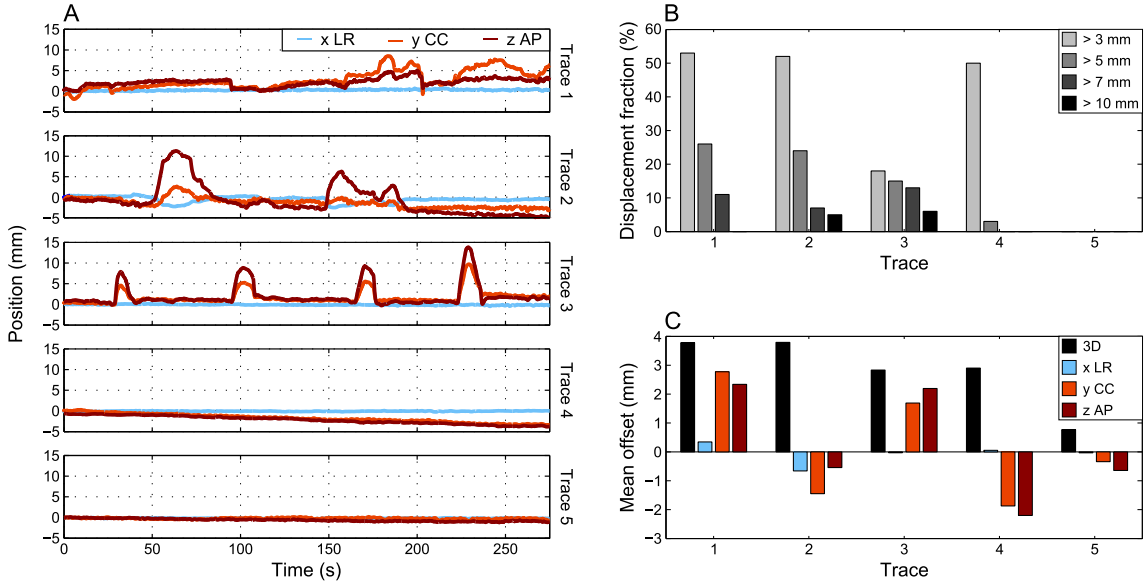

Fig. 1. (A) Sections of prostate motion traces (Trace 1–5). (B) Temporal fraction of 3D prostate displacement larger than 3, 5, 7 and 10 mm. (C) Mean values of the 3D, LR, CC and AP displacement for each trace.

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