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Physics Contribution

Accuracy of Real-time Couch Tracking During 3-dimensional Conformal Radiation Therapy, Intensity Modulated Radiation Therapy, and Volumetric Modulated Arc Therapy for Prostate Cancer

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Summary

This simulation study analyzed the geometric and dosimetric accuracy of real-time couch tracking for prostate cancer. Fifteen prostate trajectories with large motion of >5 mm for 25% of the treatment time were simulated, and couch tracking reduced this motion to <1 mm for 94% of treatment time. Couch tracking achieved excellent dosimetric accuracy independent of the treatment delivery technique of 3D-CRT, step-and-shoot IMRT, and VMAT. Feasibility and accuracy in clinical practice need to be investigated.

Purpose: To evaluate the accuracy of real-time couch tracking for prostate cancer.

Methods and Materials: Intrafractional motion trajectories of 15 prostate cancer patients were the basis for this phantom study; prostate motion had been monitored with the Calypso System. An industrial robot moved a phantom along these trajectories, motion was detected via an infrared camera system, and the robotic HexaPOD couch was used for real-time counter-steering. Residual phantom motion during real-time tracking was measured with the infrared camera system. Film dosimetry was performed during delivery of 3-dimensional conformal radiation therapy (3D-CRT), step-and-shoot intensity modulated radiation therapy (IMRT), and volumetric modulated arc therapy (VMAT).

Results: Motion of the prostate was largest in the anterior−posterior direction, with systematic ($\sum$) and random (σ) errors of 2.3 mm and 2.9 mm, respectively; the prostate was outside a threshold of 5 mm (3D vector) for 25.0%±19.8% of treatment time. Real-time tracking reduced prostate motion to $\sum = 0.01$ mm and $\sigma = 0.55$ mm in the anterior−posterior direction; the prostate remained within a 1-mm and 5-mm threshold for 93.9%±4.6% and 99.7%±0.4% of the time, respectively. Without real-time tracking, pass rates based on a γ index of 2%/2 mm in film dosimetry ranged between 66% and 72% for 3D-CRT, IMRT, and VMAT, on average. Real-time tracking increased pass rates to minimum 98% on average for 3D-CRT, IMRT, and VMAT.

Conclusions: Real-time couch tracking resulted in submillimeter accuracy for prostate cancer, which transferred into high dosimetric accuracy independently of whether 3D-CRT, IMRT, or VMAT was used. © 2013 Elsevier Inc.

Keywords: Prostate cancer, Intrafractional uncertainties, Real-time tracking, Phantom study, Intensity modulated radiation therapy

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Introduction

Systematic differences in rectal filling between treatment planning and delivery result in systematic displacements of the target volume, which has been demonstrated to decrease biochemical control in external-beam radiation therapy of prostate cancer (1). Today, this issue of internal prostate motion is addressed by image guided radiation therapy (IGRT), whereby the prostate or implanted markers can be visualized and setup errors can be corrected online before each treatment fraction. This leaves intrafractional prostate motion as a significant source of uncertainty: large and irregular variation of the prostate position during radiation therapy delivery has been described (2, 3), and these intrafractional uncertainties create the risk of decreased target coverage if not compensated by adequate safety margins or real-time adjustment of the irradiation.

Two approaches are currently under investigation for continuous adjustment of irradiation to these spatial changes during treatment fraction. One aims at synchronous adaptation of the irradiation beam to the moving target, either by using a dynamic multileaf collimator (DMLC) (4-6) or by moving a gimbaled X-ray head (7) or the entire linear accelerator, which is installed on an industrial robot. An alternative approach is real-time adaptation of the patient position via a robotic treatment couch such that the target remains fixed in relation to the linear accelerator geometry and irradiation beam (8, 9).

Quality assurance and safety issues will be highly important in the work-flow of any real-time tracking solution, because motion of the target will result in immediate adaptation of radiation therapy without the possibility for "classical" verification as it is practiced in IGRT (eg, review of radiation therapist physicist, or clinician). This quality assurance is considered to be complex for the MLC tracking approach, especially because of potential interplay effects between MLC motion due to real-time tracking and due to dynamic fluence-modulated radiation therapy. In contrast, the quality assurance is considered to be straightforward for couch tracking, for which the treatment delivery part will remain unchanged: displacements of the target relative to the isocenter during real-time tracking need to be measured, and their dosimetric consequences can be estimated using established methodology.

We have previously evaluated the geometric accuracy of real-time couch tracking for lung cancer, for which the speed of tumor motion limited the achievable accuracy (9). It was the aim of this simulation study to evaluate the geometric and dosimetric accuracy of real-time couch tracking for prostate cancer, in which the slower speed of prostate motion might be more favorable for the couch tracking approach.

Methods and Materials

Prostate trajectories

Intrafractional motion trajectories of 15 prostate cancer patients were the basis for this phantom study. Motion had been measured with the Calypso System, in which electromagnetic markers are implanted into the prostate and their motion is recorded with high frequency and accuracy. Details about the technique and accuracy of this system have been described by Balter et al (10). Trajectories with a stable target position at baseline were excluded from this study. All trajectories were provided by Calypso Medical (Seattle, WA) and represent cases with large prostate motion. Length of trajectories was between 3:32 minutes and 23:30 minutes (mean±standard deviation, 10:28±4:32 minutes).

Technique of real-time couch tracking

Details about the technique of real-time couch tracking have been described previously (9). An illustration of the study setup is shown in Fig. 1.

Briefly, a Plexiglas cylinder of 8.5 cm length and 9 cm diameter was used as prostate phantom. Films were inserted in the sagittal plane, and reflective infrared markers (markers$_{prostate}$) were attached to the phantom. A second set of infrared markers was rigidly attached to the treatment couch (markers$_{couch}$). An industrial 6-axis robot (MELFA Industrial Robot, RV-1A Series; Mitsubishi Electric, Ratingen, Germany) was used for delivery of the motion trajectories. The trajectory data, containing time-stamps and positions, were read by a robot-player program that transformed the data into possible robot paths using Bezier fit and sent the movement commands to the robot. Motion of the reflective markers was monitored with the Polaris infrared camera (NDI, Waterloo, ON, Canada). In-house-developed software was used for read-out of the Polaris camera and for transformation of markers$_{prostate}$ and markers$_{couch}$ data into linear accelerator room coordinates. Both position data were sent to other in-house-developed software that calculated the difference between markers$_{prostate}$ and markers$_{couch}$. Any change of this difference compared with the initial setup was considered as prostate motion. The necessary table motion for compensation was calculated, and the corresponding movement command was sent to the robotic HexaPOD couch (Medical Intelligence, Schwabmuenchen, Germany) by the software for real-time tracking. Experiments were performed without postprocessing of the motion data: no prediction or model for prostate motion was used. Counter-steering was performed only as a reaction to the observed changes in the relationship between markers$_{prostate}$ and markers$_{couch}$.The maximum motion range of the HexaPOD is ±30 mm in lateral and longitudinal directions and ±40 mm in vertical direction. The maximum velocity is 8 mm/s, and the maximum acceleration is approximately 30 mm/s^2. Only translational and no rotational motion correction was performed.

Geometric accuracy of real-time couch tracking

We first evaluated the accuracy of the Mitsubishi robot and the Polaris infrared camera system. Motion of the prostate phantom,

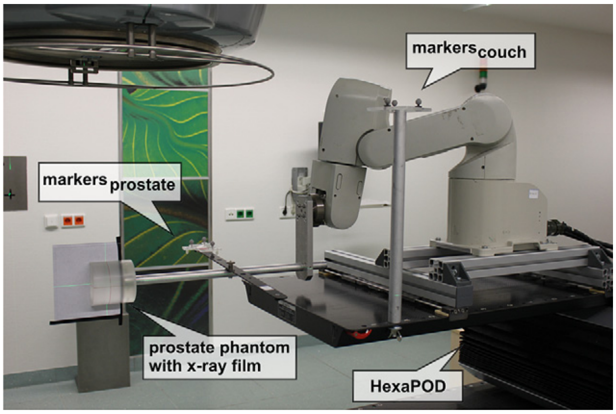

Fig. 1. Overview of the setup.