



Original paper

Effectiveness of a simple and real-time baseline shift monitoring system during stereotactic body radiation therapy of lung tumors



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ABSTRACT

Purpose: This study aimed to clinically validate a simple real-time baseline shift monitoring system in a prospective study of consecutive patients undergoing stereotactic body radiation therapy (SBRT) of lung tumors, and to investigate baseline shift due to intrafraction motion of the patient's body during lung SBRT.

Methods: Ten consecutive patients with peripheral lung tumors were treated by SBRT consisting of four fractions of 12 Gy each, with a total dose of 48 Gy. During treatment, each patient's geometric displacement in the anterior–posterior and left–right directions (the baseline shift) was measured using a real-time monitoring webcam system. Displacement between the start and end of treatment was measured using an X-ray fluoroscopic imaging system. The displacement measurements of the two systems were compared, and the measurements of baseline shift acquired by the monitoring system during treatment were analyzed for all patients.

Results: There was no significant deviation between the monitoring system and the X-ray imaging system, with the accuracy of measurement being within 1 mm. Measurements using the monitoring system showed that 7 min of treatment generated displacements of more than 1 mm in 50% of the patients.

Conclusions: Baseline shift of a patient's body may be measured accurately in real time, using a monitoring system without X-ray exposure. The manubrium of the sternum is a good location for measuring the baseline shift of a patient's body at all times. The real-time monitoring system may be useful for measuring the baseline shift of a patient's body independently of a gating system.

1. Introduction

The management of respiratory motion and beam gating, which are offered by several manufacturers of stereotactic body radiation therapy (SBRT) machines, may reduce the target motion caused by respiration in patients undergoing treatment [1–8]. In particular, such treatment requires management of the intrafraction motion of the target and patient's body. It is assumed that the respiratory signal (waveform) from the patient will reflect the motion of the target due to respiration, although there is a tendency for breathing motion amplitude, which is the range from the end of inspiration to the end of expiration, to vary during treatment. Wu et al. [9] reported that respiratory motion is patient-specific and that there are changes in the baseline location over time, from one breathing cycle to another. This may be expressed as a baseline shift due to respiration. This baseline shift results from regular shallow or deep breathing. Another baseline shift may be defined as the geometric displacement of a patient's body due to intrafraction motion. This may increase the uncertainty of treatment and potentially diminish the benefits. Therefore, these baseline shifts due to breathing motion

and the intrafraction motion of the patient's body require correcting.

An increase in extended treatment time has been reported to increase the magnitude and probability of a baseline shift in the intrafraction motion of a patient's body from the initial setup to the end of treatment, with treatment times of 5–15 min resulting in a baseline shift of 1–5 mm [10]. Because the gating system cannot determine whether the baseline shift results from the intrafraction motion of a patient's body or is due to irregular breathing patterns, the radiation beam may be triggered during the wrong phase of the breathing cycle. If a baseline shift is caused by irregular breathing, patients should be trained to breathe properly; alternatively, the shift may be at least partially a result of the visual-audio feedback system [11]. If the visual guidance of the respiratory waveform shows motion of the marker on the abdomen and the waveform includes the baseline shift of the intrafraction motion of the patient's body, the visual guidance may misdirect the respiration gating system. Therefore, a reliable gating treatment requires differentiation of baseline shifts due to irregular breathing, from those due to intrafraction motion of the patient's body.

External surrogate movement-monitoring systems can infer tumor

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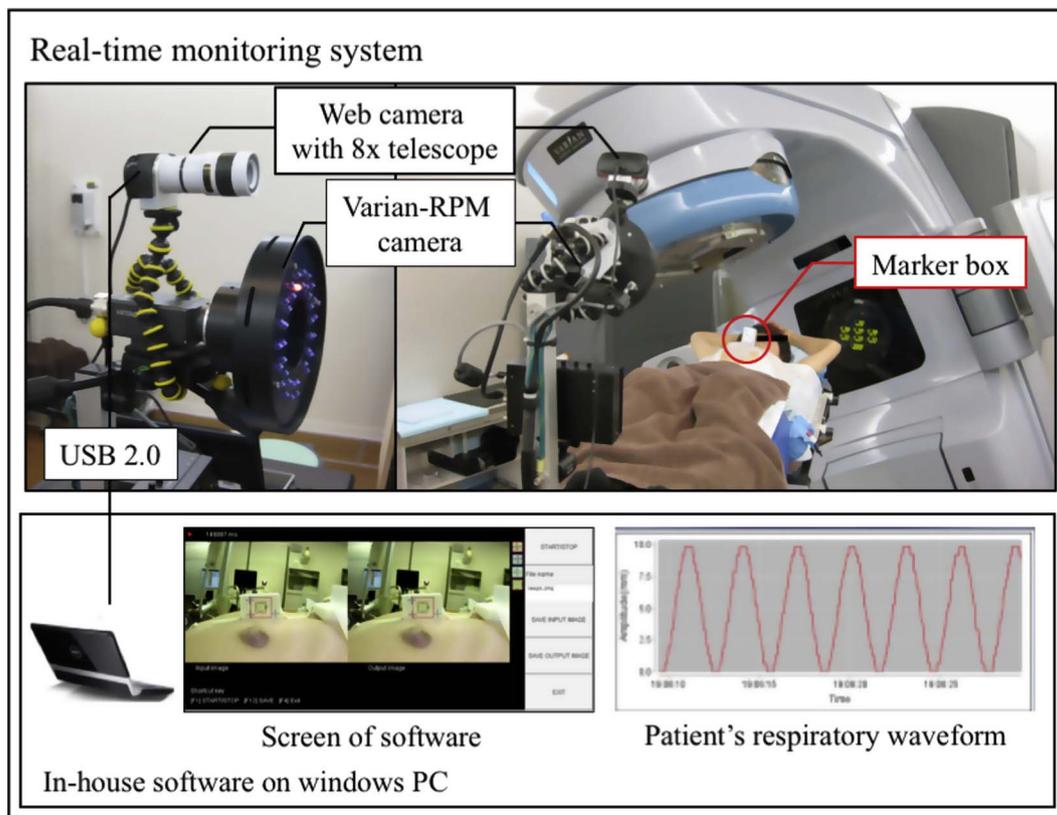


Fig. 1. Example of the lung SBRT setup with the real-time monitoring system described in this study.

motion, although they can be limited by the need to verify the relationship with tumor motion, the potential for external marker placement to affect this correlation [12], and time-dependent characteristics [13]. Mori et al. [14] reported a great deal of variation in interfractional tumor position with external surrogate gating, which degraded the gating accuracy. They preferred to track the tumor position directly to avoid unpredictable changes in motion. The setup or internal margin of respiratory-gated treatment cannot be reduced unless baseline shift and variations in external/internal motion correlation are accounted for [15]. Surface monitoring of a single point of interest in the abdomen, such as is often used for positioning of a real-time patient monitoring (RPM) marker box, does not detect baseline shift due to the patient's intrafraction motion [16].

We have previously described a simple and flexible system for real-time monitoring of the baseline shift due to intrafraction motion of a patient's body [16,17]. This system consists of a charge-coupled device (CCD) camera, namely a webcam, and a personal computer, and can track the real-time motion of a marker box placed on the bony part of the chest wall. Previous studies were performed to understand the specifications of the system, including the spatial and temporal accuracy. These studies involved the collection of data from healthy volunteers, with the inclusion of several baseline shifts created by intentional movements of the treatment couch [16,17]. Thus, the system has not yet been clinically validated.

The present study was designed to assess the clinical effectiveness of the real-time monitoring system by comparing its accuracy in measuring the baseline shift due to intrafraction motion of a patient's body with that of a kilovoltage X-ray imaging system. We made these comparisons in 10 consecutive patients who underwent SBRT of the lungs. We also analyzed the measurements of intrafraction motion-related baseline shift of a patient's body that were acquired using the real-time monitoring system, which was used as an indirect internal surrogate during treatment.

2. Materials and methods

2.1. Patients, planning, and treatment

Between February 2012 and January 2013, 10 patients with a median age of 70.5 years (range: 43–82 years) undergoing SBRT for non-small-cell lung cancer were prospectively entered into the study. All 10 patients received four fractions of 12 Gy, for a total dose of 48 Gy. No explicit inclusion or exclusion criteria were specified for participation. All patients provided written informed consent and the study protocol was approved by our institutional review board.

All of the patients underwent four-dimensional computed tomography (4DCT) simulation on a 16-detector CT machine (Aquilion LB, Toshiba Medical Systems, Otawara, Japan) in conjunction with the Varian RPM system (Varian Medical Systems, Inc., Palo Alto, CA). Patients were immobilized using a HipFix® thermoplastic positioning system with Vac-Lok™ Cushions (Civco, Orange City, IA). The voxel size of the images was $1.07 \times 1.07 \times 2$ mm. Ten individual-phase 4DCT datasets were sent to a dedicated workstation running the Eclipse treatment planning system (Varian Medical Systems). A radiation oncologist delineated the clinical target volume in each of the 10 phases of the 4DCT datasets. A fusion of the clinical target volumes from the 10 phases of the 4DCT datasets was defined as the internal target volume (ITV). The planning target volume (PTV) was defined as the ITV with additional 5-mm uniform margins. Nine to ten photon beams (6 MV) were used to create a plan. All plans were normalized such that the 100% isodose line covered 95% of the PTV.

All treatments were performed using a Varian Trilogy linear accelerator equipped with an On-Board Imager (Varian Medical Systems, Inc., Palo Alto, CA), although all patients were treated using the gating. Cone-beam computed tomography (CBCT) was used to perform positional verification of the tumor. To verify each baseline shift due to intrafraction motion of the patient's body, the first set of orthogonal X-ray fluoroscopic 2-dimensional images (Flo_{1st}) were used for bony-

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