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Volume modulated arc therapy

Real-time dynamic MLC tracking for inversely optimized arc radiotherapy ☆

Marianne Falk [a,*], Per Munck af Rosenschöld [a], Paul Keall [b], Herbert Cattell [c], Byung Chul Cho [b], Per Poulsen [b,d], Sergey Povzner [c], Amit Sawant [b], Jens Zimmerman [a], Stine Korreman [a]

[a] Department of Radiation Oncology, Rigshospitalet, Copenhagen University Hospital, Denmark; [b] Stanford University, Stanford, CA, USA; [c] Varian Medical Systems, Palo Alto, CA, USA; [d] Department of Oncology, Aarhus University Hospital, Denmark

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ABSTRACT

Background and purpose: Motion compensation with MLC tracking was tested for inversely optimized arc radiotherapy with special attention to the impact of the size of the target displacements and the angle of the leaf trajectory.

Materials and methods: An MLC-tracking algorithm was used to adjust the MLC positions according to the target movements using information from an optical real-time positioning management system. Two plans with collimator angles of 45° and 90°, respectively, were delivered and measured using the Delta[4®] dosimetric device moving in the superior–inferior direction with peak-to-peak displacements of 5, 10, 15, 20 and 25 mm and a cycle time of 6 s.

Results: Gamma index evaluation for plan delivery with MLC tracking gave a pass rate higher than 98% for criteria 3% and 3 mm for both plans and for all sizes of the target displacement. With no motion compensation, the average pass rate was 75% for plan 1 and 70% for plan 2 for 25 mm peak-to-peak displacement.

Conclusion: MLC tracking improves the accuracy of inversely optimized arc delivery for the cases studied. With MLC tracking, the dosimetric accuracy was independent of the magnitude of the peak-to-peak displacement of the target and not significantly affected by the angle between the leaf trajectory and the target movements.

Treatment of tumours that move intra-fractionally is a well known issue of concern in radiotherapy [1,2]. Cases of lung tumour movements with peak-to-peak displacements of up to 25–30 mm have been presented in the literature [3,4]. Radiotherapy of tumours moving with large amplitudes requires an enlargement of the treated volume to ensure that the tumour is covered throughout the treatment, or alternatively some other compensation for the tumour displacements must be employed. One of the great difficulties in radiotherapy is to give a good treatment of the tumour but at the same time spare healthy tissue and critical organs and an enlargement of the treated volume may not be a favourable solution if the tumour is located close to an organ at risk. Respiratory gating has the disadvantage of increased treatment time since the dose delivery only is asserted when the tumour is within a certain position range [5]. This study is focused on the compensation of tumour movements using the multi leaf collimator (MLC) to reshape the beam according to the instantaneous position of the tumour, referred to as MLC tracking. Several previous studies have reported promising results for this method for IMRT [6,7]. Intensity-modulated arc therapy (IMAT) was first proposed by Yu [8] in 1995 as treatment delivery using multiple superimposed arcs with varying field shapes. The technique was later refined by Otto [9] in 2007 with a novel aperture-based algorithm for treatment planning optimization. For this study, the implementation of this technique by Varian Medical Systems, RapidArc®, was used. RapidArc® plans are created using inverse optimization and delivered in one (or several) rotations of the gantry. The field shape, dose rate and gantry speed are varied during the delivery to give a high dose to the target while minimizing the dose to the surrounding tissues. A 2 Gy fraction can be delivered in less than 2 min (one arc) and requires in general fewer monitor units (MU) than IMRT treatments. [10,11] In a study reported earlier, the feasibility of MLC tracking for RapidArc® therapy was shown [12]. The purpose of the present study is to evaluate the performance of MLC tracking for RapidArc® delivery with special attention to the impact of the magnitude of the target movements and the angle of the MLC leaf trajectory with respect to the target movement.

Materials and methods

The difference in dosimetric accuracy of RapidArc® plan delivery with and without the influence of MLC tracking was evaluated for a moving target. Two RapidArc® plans were created in Eclipse™ ver. 8.5 treatment planning system (TPS) using inverse optimiza-

☆ The work was done at the Department of Radiation Oncology, Rigshospitalet, Blegdamsvej 9, DK-2100 Copenhagen, Denmark.

* Corresponding author. Address: Department of Radiation Oncology, 3994 Rigshospitalet, Blegdamsvej 9, DK-2100 København, Denmark.
E-mail address: Marianne.falk@rh.regionh.dk (M. Falk).

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tion. The plans were created with identical settings, apart from the collimator angle which was set to 45° (plan 1) or 90° (plan 2), respectively. Collimator angle 45° has been shown to be preferable for RapidArc® plans [9], while collimator angle 90° has the leaf trajectory parallel to movements in the superior–inferior (SI) direction which has been shown to be favourable for MLC tracking [6]. The plans used a single clock-wise arc with gantry angles spanning 300° from 210° to 150° (to avoid intersection of the incoming beam and the rails of the couch), 6 MV and a maximum dose rate of 600 MU/min. The same CT data of a patient with a lung tumour was used for both plans. The target had a size of about 3.1 cm (SI) × 3.6 cm (AP) × 3.1 cm (LR) (volume of 12.42 cm^3) and was located in the right lower lobe. The prescribed dose was 2 Gy and the number of monitor units were 370 (plan 1) and 410 (plan 2). To enable the plans for MLC tracking, the jaws were forced set to 13 cm × 13 cm to prevent them from covering the target as it moved during the delivery (although not necessary for the direction perpendicular to target movement in the 90° collimator rotation plan, both jaws were retracted for consistency reasons). After the optimization, the plans were recalculated for the Delta$^{4®}$ dosimetric phantom (ScandiDos, Inc.), and the dose matrix was imported to the Delta$^{4®}$ analysis software.

The plans were delivered using a Varian 2300ix linear accelerator with RapidArc® capabilities. An MLC-tracking controller was adjusting the positions of the leaves, using a 3D MLC-tracking algorithm to recalculate the planned MLC positions (from the TPS) to best fit the instantaneous location of the target [6,13]. Information about the phantom target actual location was obtained from the real-time position monitoring system RPM™ (Varian Medical Systems, Inc.). The RPM™ system uses a marker block with two or six reflective markers that are optically tracked. In this MLC tracking experiment the 6-dot marker block is positioned on the phantom to move in correlation with the target, and the location of the marker block is determined by recording infra-red light reflecting off the markers. For this study, the target moved only in the SI direction and the RPM tracking camera was also pointed generally in the SI direction. In this configuration the RPM system with 6-dot marker block can track movements in the anterior-posterior (AP) and lateral directions with higher accuracy and precision than the SI direction (the system is mainly used for gating purposes based on AP movements). The low SI direction accuracy is within specifications for this motion direction. To minimize the transmission between the closed leaf tips, arising from the extended jaw positions, the non-participating leaves were moved to the side by the tracking system, placing the gaps underneath one of the x-jaws. A number of adjacent leaf pairs were kept at the centre in case of the target moving non-parallel to the leaf trajectory and requiring new leaf pairs to be opened. In this case, the next adjacent leaf pair would return from the side to compensate for this and keeping the number of adjacent central leaf pairs constant. The MLC-tracking controller is today a non-clinical research tool and the development of it is ongoing.

Lung tumour movement was simulated using a motion platform (Standard Imaging, Inc.) which was programmed to form sinusoidal motion in the superior–inferior (SI) direction with peak-to-peak distances of 5, 10, 15, 20 and 25 mm and a cycle time of 6 s. The motion range was chosen to span that observed by Seppenwoolde et al. [3] in their fluoroscopic analysis of lung tumour motion, and the cycle time was within the cycle time span reported. The platform carried a Delta$^{4®}$ dosimetric device and the plans were delivered to the phantom, which was ether static or moving as described above. The Delta$^{4®}$ system uses two orthogonal detector arrays with p-Si diodes separated by 0.5 cm in the central 6 cm × 6 cm area of the detector arrays and by 1 cm on the remaining area (in total 20 cm × 20 cm) [14].

Tests of the position-monitoring system

First, measurements were performed to test the RPM™ system's position drift, precision and accuracy. The drift was tested by acquiring RPM™ position information of a static marker block for 20 min. The experiment was first performed without calibration of the RPM system in between, then the system was calibrated and the whole experiment was repeated another two times. Linear regression was used to estimate the position drift over time. The RPM position precision was investigated in the same measurements by calculating the standard deviation of the measured values. The position accuracy was investigated in four 1 h measurements during which the marker block was moved between five different positions; 0 cm,+1 cm and −1 cm or 0 cm,+2 cm, −2 cm from the calibration position. The marker block was in total repositioned 30 times for every 1 h measurement, and the position was verified using a steel ruler.

States of setup

Dosimetric measurements were then performed in three different states of the setup:

(1) *Disconnected state.* In this state, the MLC-tracking controller was not connected, and the MLCs therefore followed the sequence exactly as given from the treatment plan in Eclipse. Measurements in this state were performed both with a static target and with motion.

(a) Static target.
(b) Moving target.

(2) *Connected reference state.* In this state, the MLC-tracking controller was connected, but was not receiving real-time information from the monitoring system. Instead a zero input file was used to simulate an entirely static target. Measurements in this state were only performed with a static target.

(3) *Connected tracking state.* In this state, the MLC-tracking controller was connected and receiving input from the monitoring system. Measurements in this state were performed with a moving target.

The measurements with a moving target were compared to static target reference measurements such that state 1b was referenced to state 1a, and state 3 was referenced to state 2. The reason for distinguishing between the disconnected state and the connected state and using two different references for the two, is the feature of the tracking system that moves the non-participating leaves underneath one of the jaws to reduce leakage. Since this action was only taken for the delivery in the connected tracking state, there would be a dosimetric difference due to the detector volume receiving leakage dose from those leaves if the disconnected state and the connected states were compared.

Evaluation

Gamma analysis was used for comparison of dosimetric measurements, within the software of the Delta$^{4®}$ system. The gamma index evaluation was performed with criteria 3% and 3 mm and 2% and 2 mm, respectively, with the dose deviation evaluated with respect to the isocentre dose. For the measurement with a moving target, detector points with doses in the range of 10–500% of the isocentre dose were included in the evaluation.