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Poster: Physics track: Intrafraction motion management

PO-0919

Impact of system latency on 4D SABR lung plans delivered using MLC tracking

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Purpose/Objective: To theoretically and practically evaluate the effect of system latency on 4D SABR lung plans delivered using MLC tracking, and to determine the threshold latency, below which the impact on delivered dose is negligible.
Materials and Methods: Five SABR lung patients were retrospectively studied. VMAT treatment plans using 6 MV flattened conformal arcs were created for an Agility MLC with a prescription of $D_{95\%}$ = 55 Gy in 5 fractions. Breathing motion was assumed to follow a $\sin^6(t)$ trajectory in the superior-inferior direction with a peak-peak amplitude of 20 mm, a time period of 4s and a system latency of between 0 ms and 500 ms. The offset of the MLC aperture with respect to the GTV as a function of time, resulting from the latency, was calculated and a histogram of aperture offsets created. This was used to superpose dose distributions calculated in Pinnacle[3] for complete treatment plans offset at intervals of 1 mm. This was repeated for a range of superior-inferior ITV margins designed to overcome the MLC offset due to latency. The impact of the latency on GTV $D_{95\%}$ for the plan was evaluated. The zero-margin treatment plans were then delivered to a Delta[4] phantom positioned on a motion platform. The treatment plans were firstly delivered to the static phantom and then delivered with varying deliberate system latencies of 0 ms to 500 ms in 100 ms steps. The MLC adjustment latency (69 ms) was overcome using a linear regression algorithm for the 0 ms case, and was included in the overall system latency for the other cases. The measured dose was compared to that for the static phantom using a gamma index for 1% and 1 mm.
Results: Figure 1a shows the calculated mean GTV $D_{95\%}$ for various latencies and ITV margins. If the maximum drop in $D_{95\%}$ due to latency is considered to be 2% (dotted line in figure), a system latency of around 150 ms is acceptable. If a 1-mm ITV margin is used, a system latency of 350 ms is acceptable. However, using an ITV margin increases the volume of normal tissue irradiated, with lung V_{13Gy} increasing from 3.7% to 5.7% as the margin is increased from 0 mm to 5 mm. Figure 1b shows the mean (±1 SD) percentage of measurement points within 1% and 1 mm of the static measured dose for varying latency. Latencies of less than 200 ms show negligible impact on the dose distribution.

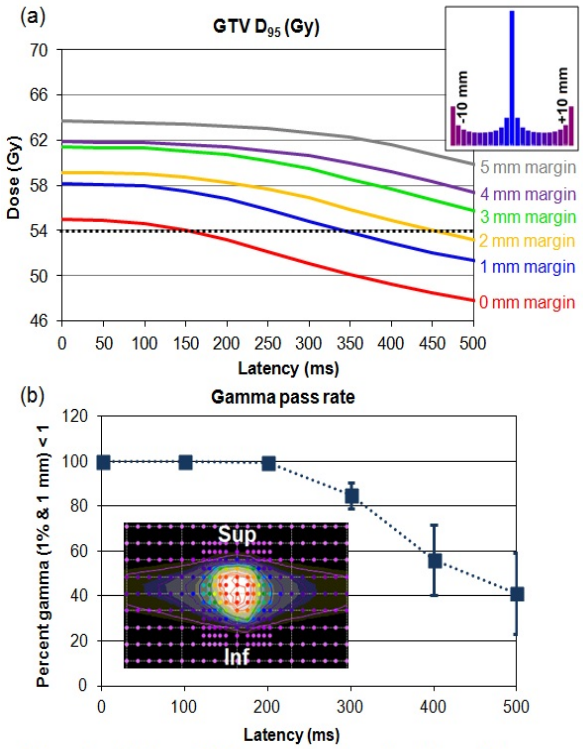

Figure 1. (a) Mean GTV coverage as a function of latency. Inset: histogram of aperture position relative to GTV. (b) Gamma pass rate for tracked delivery vs static delivery as a function of latency. Inset: typical Delta4 distribution.

Conclusions: The modelling study shows that, for the sinusoidal motion trajectory considered, a system latency of less than 150 ms has a negligible impact on the dose distribution delivered using SABR with MLC tracking. A much larger latency is acceptable if a 1-2 mm ITV margin is used. The result for the absence of an ITV margin is confirmed by the experimental study, in which the Agility MLC is shown to successfully track the GTV during the VMAT delivery. The desired system latency can be accomplished either using a tracking system with an inherently fast response or using a motion predictor to reduce the effective latency.
We are grateful to Elekta AB (Stockholm, Sweden) for their collaboration on this project.

PO-0920

Intra-fraction motion detection with Triggered Imaging for prostate cancer patients with implanted gold seeds

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Purpose/Objective: Intra-fraction motion during prostate cancer radiation is a known phenomenon. Discrepancies up to 5mm were seen in gold seed match between before- and mid treatment 2D kV-imaging. The recently released imaging application Triggered Imaging (TI, Varian Medical Systems, Palo Alto CA) allows to generate kV images at predefined intervals during irradiation. The application can automatically detect fiducial markers to monitor intra-

fraction motion. This study describes our first results using this application.

Materials and Methods: A total of 11 prostate cancer patients with implanted gold seeds were treated on the Truebeam 2.0 machine with two RapidArc beams (Varian Medical Systems, Palo Alto, CA). In the planning system (Eclipse 11.0, Varian Medical Systems, Palo Alto CA) ,the gold seeds on the planning CT are defined as markers. For patient setup, the gold seeds are lined up using two orthogonal 2D kV images. After the setup procedure, TI is applied during both beams at an interval of 5 seconds, resulting in 12 images per beam. For each marker a circular overlay is projected onto the acquired kV image, centered at the projected location of the corresponding reference marker determined during treatment planning. The diameter of this circle is set to 1.2cm which corresponds to a maximum allowed limit for marker displacement which is related to the PTV margin (Fig 1). Each marker is automatically detected on each acquired kV image and its center of gravity is indicated by a cross. A color coding is used to indicate whether the marker in or outside this limit.

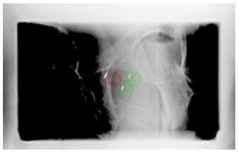

Figure 1. In this figure the auto detection showed three coloured circles. Green means the gold seed is projected within the limit, red means the gold seed is outside the limit.

If one or more gold seeds exceed the limit on two consecutive kV images the beam is manually stopped, while TI continues. If the intra-fraction motion persists on the next triggered kV image, the beam is interrupted and the patient setup procedure is repeated using two orthogonal 2D kV images.

Results: TI was applied for 11 patients. For the total of 144 fractions, 7 fractions showed excessive intra-fraction motion of one or more gold seeds persistent in three consecutive triggered kV images, leading to beam interruption and re-setup. Average and maximum shifts applied in re-setup were: 0.32cm (0.65cm) , 0.29cm (0.52cm) and 0.11cm (0.30cm) in lateral, longitudinal and ventrodorsal directions, respectively (Table 1).

Patient	Fraction	Lateral (cm)	Longitudinal(cm)	Ventrodorsal (cm)	Shift magnitude
A	8	0.37	0.52	0.04	0.64*
	10	0.65	0.37	0.13	0.76*
	15	0.26	0.11	0.09	0.30
B	7	0.41	0.41	0.06	0.58
	10	0.03	0.15	0.09	0.18
C	1	0.07	0.11	0.07	0.15
	3	0.45	0.39	0.30	0.67*
	Average	**0.32**	**0.29**	**0.11**	**0.47**

Table 1: Re-setup shifts and magnitudes after persistent excessive intra-fraction motion of gold seeds detected with Triggered Imaging. Shift magnitudes larger than the 0.6cm PTV margin are indicated with an asterisk (*).

In these 11 patients, 3456 Triggered Images were obtained. In 94 (2.7%) of these images we found that TI did not correctly locate one or more of the gold seeds.

Conclusions: Triggered Imaging in combination with auto-detection provides a powerful tool to monitor tumor motion during treatment for patients with implanted fiducial markers. We have developed a strategy to avoid unnecessary re-setup for only temporary deviations. For 3 of these 7 beam holds shift magnitudes needed to realign the gold seeds exceeded our 0.6cm PTV margin, indicating that intra-fraction re-setup was justified.

However, the auto-detection algorithm needs further improvement to be more robust for deviations in initial marker locations.

PO-0921

Determining intra-fraction motion in breast radiotherapy using supine cine-MRI

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Purpose/Objective: Novel hypofractionated partial-breast radiotherapy (RT) treatments, performed before or after breast conserving surgery (BCS), are being developed for low-risk breast cancer patients. Since these techniques focus on dose delivery in fewer fractions, the purpose is to determine intra-fraction motion using supine magnetic resonance imaging (MRI), ensuring high soft-tissue contrast and high temporal resolution.

Materials and Methods: 22 female early-stage breast cancer patients were scanned on a 1.5 T wide bore MRI (Ingenia, Philips) in supine RT position, before and/or after BCS. This resulted in 20 pre- and 18 post-BCS scans. Two multi-slice balanced steady state free precession (cine-MRI) sequences were applied, oriented through the tumour (bed) as delineated on 3D pre-/postoperative MRI. They were alternately acquired in the transverse and sagittal plane, every 0.3 s during 2 min. The ipsilateral breast and clinical target volume (CTV = tumour (bed) + 15 mm) were transferred onto a reference frame in the respective cine-MRI series. Subsequent slices were rigidly registered on the breast with an extension, i.e. registration was limited to translations and rotations. Delineations were transformed accordingly. For motion determination, the *P95* was derived, defined as a distance ensuring 95% coverage, for all delineations, in all in-plane directions, during the entire 2 min.

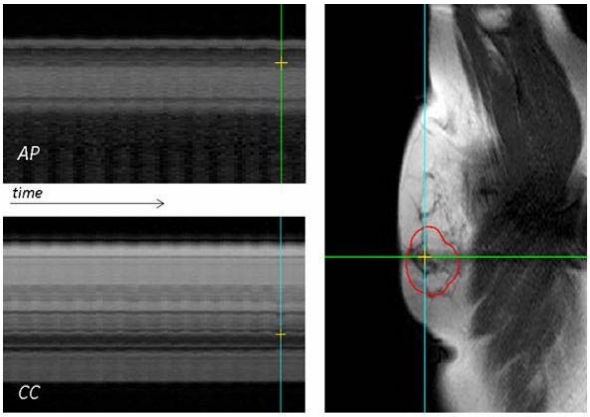

Figure 1: Time-stacks (left) of two perpendicular lines through the yellow indicator in the corresponding sagittal plane (right), acquired with an interval of 0.6 s during 2 min, and an in-plane resolution of 1 mm on preoperative cine-MRI. The time-stacks show intra-fraction motion of a breast tumor in the anterior-posterior (AP, top) and caudal-cranial directions (CC, bottom) of one patient. The CTV delineation is depicted in red.

Results: Motion artifacts induced registration errors in several cine-MRI series, which were excluded after visual inspection. Analysis was performed on 16 sagittal and 19