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Proffered Paper 1613 | MLC tracking and dose accumulation validation on the MR-linac using a real-time deformable dosimeter

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Purpose/Objective:
Online MRI acquired on the MR-linac can capture the full complexity of anatomical motion during treatment delivery. This time-resolved anatomical information is increasingly used to facilitate novel dose accumulation and (real-time) plan adaptation techniques. Unfortunately, the current lack of MRI-compatible deformable motion phantom with time-resolved dosimetry capability severely obstructs the successful end-to-end validation and subsequent clinical introduction of new radiotherapy adaptation workflows. In this study, we validate a newly-developed MRI-compatible prototype of a deformable motion phantom with six integrated Plastic Scintillation Dosimeters (PSD) in the context of deformable multi-leaf collimator (MLC) tracking and dose accumulation on the MR-linac.

Material/Methods:
The QUASAR MRI4D motion phantom (IBA QUASAR, London, ON) was equipped with a deformable motion insert. Using a moveable piston, the phantom can achieve target translations of 20 mm (PSD1) and deformations of 10 mm

between end-inhale and end-exhale positions (Figure 1). Six HYPERSCINT PSDs (Medscint, Quebec City, QC) were integrated into the deformable insert to measure dose in real-time [1].

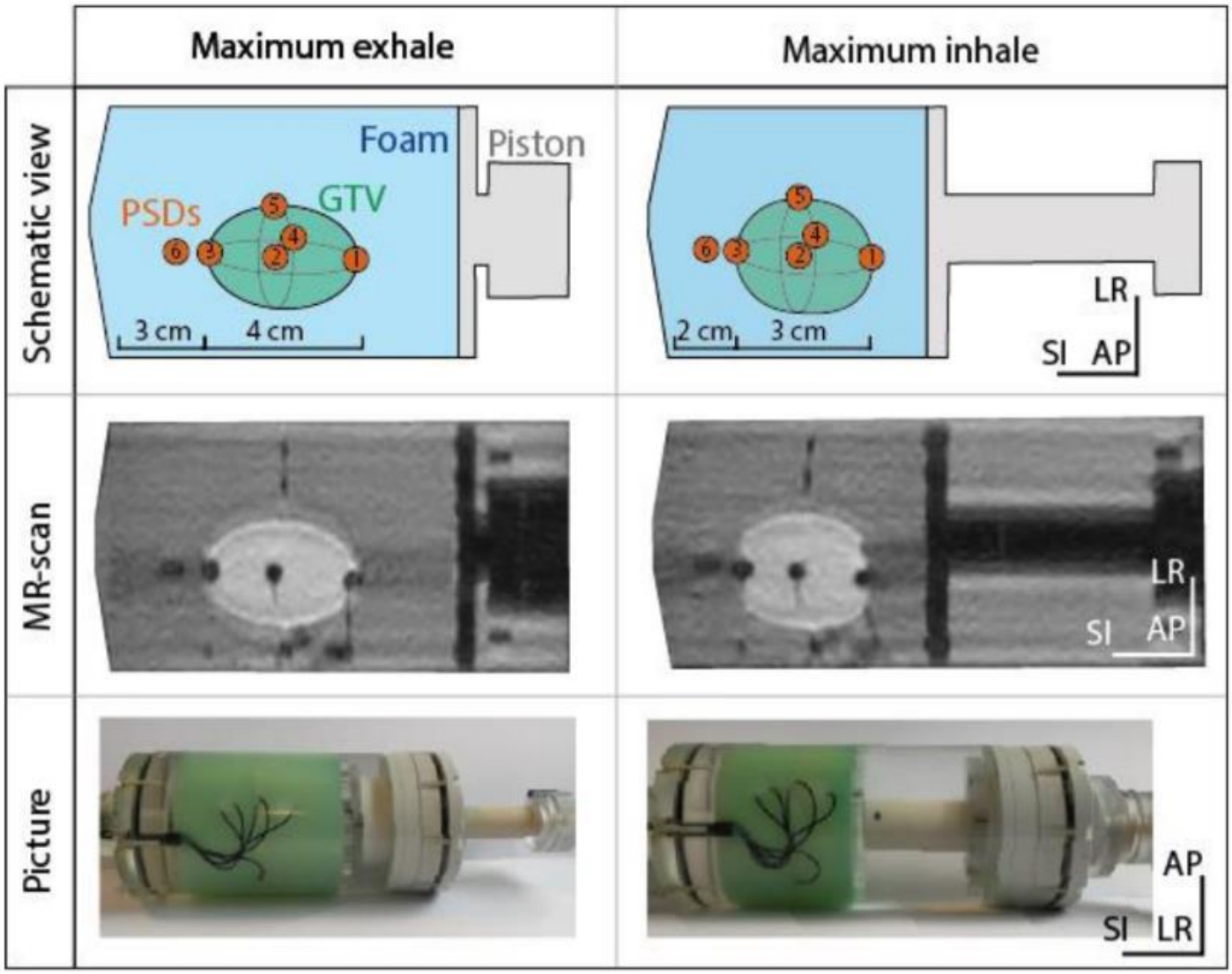

Figure 1. Schematic view, MR-scan and picture of the deformable insert at maximum exhale and maximum inhale piston position. In the schematic view the Plastic Scintillation dosimeters (PSDs), gross tumor volume (GTV), foam and piston are shown. The piston motion produces combined translations and deformations. The directional references are given: Anterior Posterior (AP), Left Right (LR) and Superior Inferior (SI).

Dose measurements and calculations were compared for a static beam (3.7x4.2 cm2) from gantry 0° with 400 MU on the 1.5T Unity MR-linac (Elekta AB, Stockholm, Sweden). PSDs receiving less than 10% of the maximum PSD dose were excluded from the analysis. The position of the PSDs' sensitive volume with 0.5 mm diameter was inferred based on the spherical casings. Eight piston positions were used ranging from 0 to -17.5 mm (step sizes of 2.5 mm). At each position, 3D MR scans were acquired (0.64x0.64x1.0 mm3). In this configuration, PSDs 1 and 6 moved in and out of the beam.

These measurements were then used to evaluate (deformable) dose accumulation. Deformation vector fields (DVFs) were generated between MR-scans and the reference scan, using an optical flow algorithm [2]. These DVFs were applied to dose maps and the accumulated dose in the reference position was obtained by summing warped dose distributions. The positional uncertainty [min, max] of the PSDs (on MRI) was accounted for by considering the neighboring voxels of the visual center.

Next, the setup was used to demonstrate the feasibility of deformable MLC tracking [3] on the Unity MR-linac in research mode while delivering a beam of 420 MU from gantry 0°. The dose was measured with an exposure time of 0.25 s. Coronal cine MR images were acquired (1.37x1.37x8 mm3, 4 Hz) to automatically identify the gross target volume (GTV). A tracking structure was created by expanding the GTV with a 4 mm margin. Four scenarios were compared. A: MLCs and phantom remained static. B: MLCs remained static while using sinusoidal motion (A=17.5 mm, P=5 s). C: Translational MLC tracking while using sinusoidal motion. D: Deformable MLC tracking while using sinusoidal motion. For scenarios C and D, the MLCs were adapted according to the tracking structure centroid (contour) using in-house developed software.

Results:
Static measurements and calculations showed good in-field agreement for PSDs 2-5 with absolute dose deviations of (1.0±0.7)%. Absolute dose deviations of (27.5±22.1)% (PSD 1) and (7.4±5.4)% (PSD 6) were measured. Considering the placement of PSD1 in a high dose gradient, measured and calculated doses matched within 1.5 mm.
Measured and accumulated doses showed good agreement with a mean absolute dose difference of 2.9%, for all PSDs (Table 1). Particularly for PSDs 1 and 6 the effect of dose accumulation is clearly visible. Here, the measured dose shows an agreement with the accumulated dose within positioning uncertainty. As expected, measured and planned doses differed due to the effect of motion.

Table 1. Dose differences [%] including positional uncertainty

PSD	Measured vs accumulated		Measured vs planned	
1	0.3%	[-17.2%, 19.3%]	102.9%	[89.2%, 107.8%]
2	1.4%	[0.5%, 2.1%]	0.9%	[0.4%, 1.5%]
3	1.6%	[0.6%, 2.4%]	-2.0%	[-4.5%, 0.5%]
4	1.3%	[0.4%, 1.7%]	1.7%	[0.8%, 2.1%]
5	0.4%	[-3.2%, 3.3%]	-1.8%	[-6.0%, 2.3%]
6	-12.6%	[-40.3%, 25.4%]	-59.5%	[-67.1%, -38.8%]

During MLC tracking experiments, PSDs 1 and 6 at the edges of the GTV were strongly affected by the sinusoidal motion. For these PSDs, translational and deformable tracking [C and D] achieved the smallest total dose differences compared to the static scenario [A] (Figure 2). The in-field PSDs 2-5 measured similar doses for scenarios B, C, and D.

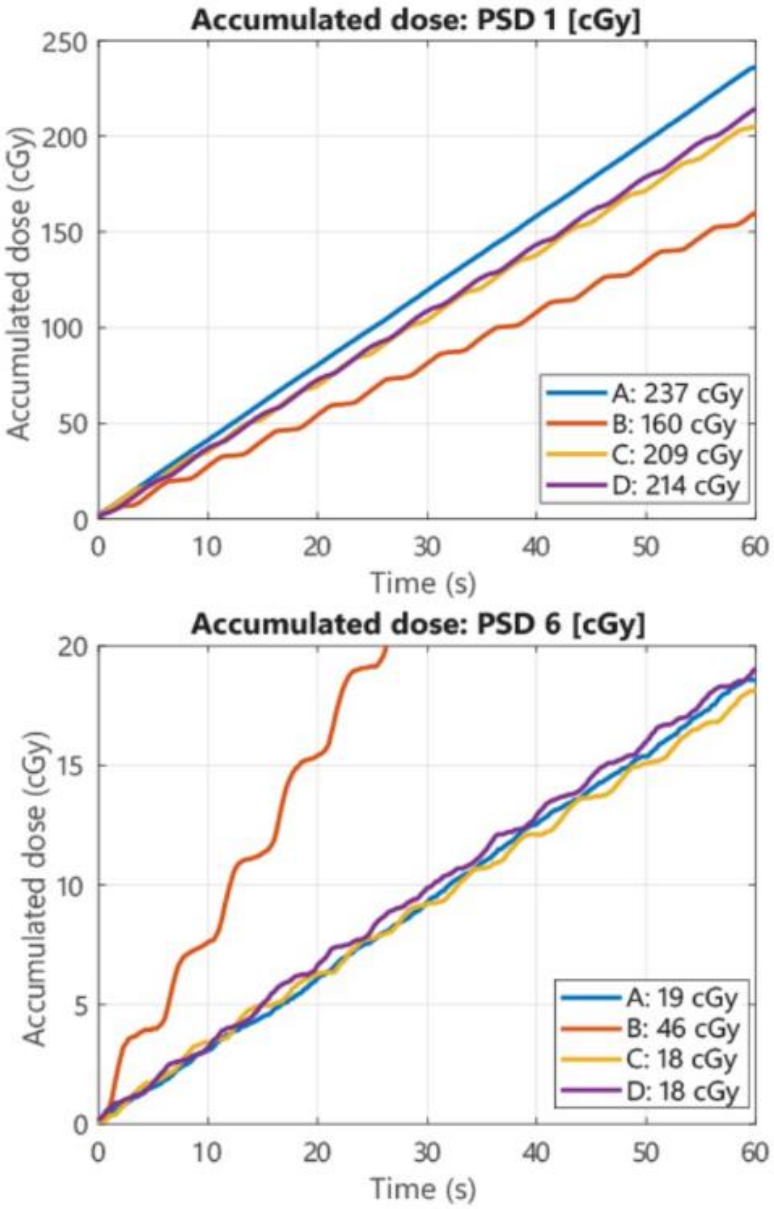

Figure 2. Accumulated dose of PSD 1 and PSD 6, acquired during the following scenarios: [A] Static Delivery – no motion. [B] Static Delivery – with motion. [C] Translational MLC tracking. [D] Deformable MLC tracking. The plotted doses in the legend were averaged over two measurements.

Conclusion:

This study demonstrates the vast potential of a novel prototype deformable phantom with six integrated PSDs for real-time dosimetry measurements on an MR-linac. In the future, the (positioning and fibre routing of the) PSDs in the phantom could be improved, to reduce uncertainties on the measurements. The deformable phantom showed the first feasibility to validate deformable MLC tracking and dose accumulation.

Keywords: Deformable dosimetry, Tracking, Dose accumulation

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