Commissioning of a real time tumor tracking system using a gimbaled X-ray head

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INTRODUCTION

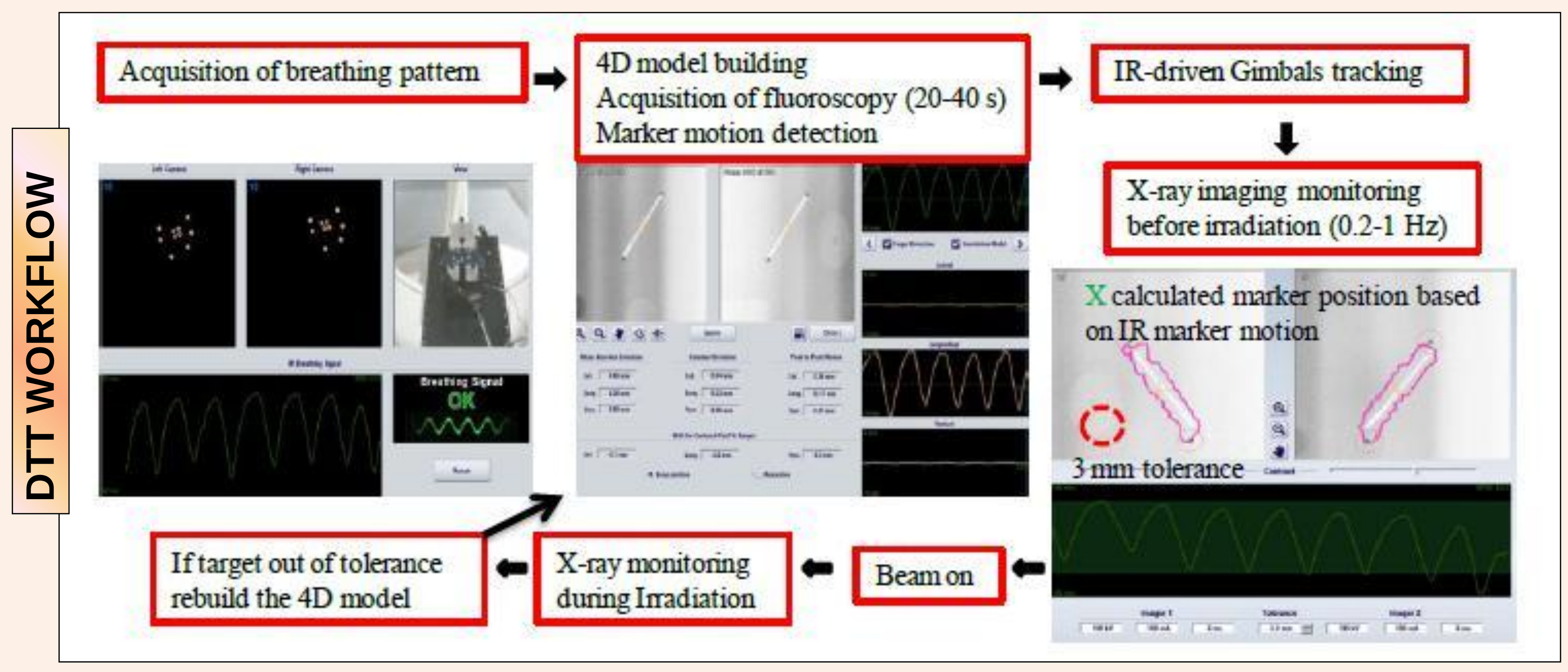
The VERO system (Mitsubishi Heavy Industries, Ltd., Japan and BrainLAB AG, Feldkirchen, Germany) is a novel platform for image-guided stereotactic body radiotherapy. Orthogonal gimbals hold the linac-MLC assembly allowing real-time tracking of moving tumors. This study aimed to determine the geometric and dosimetric accuracy of the **VERO Dynamic Tumor Tracking (DTT)** and to evaluate the imaging dose.

METHODS AND MATERIALS

Geometric accuracy of the DTT was evaluated for TILT and PAN direction and for gantry 0° and 90° in terms of: **prediction error** (**E_P**), difference between predicted and detected target positions during the 4D model; **mechanical error** (**E_M**), difference between tracked by the gimbaled head and predicted target positions; **tracking error** (**E_T**), difference between tracked and measured target positions. The latter were detected with the X-ray imaging system using a home-developed algorithm. Two moving phantoms were driven based on sinusoidal patterns with amplitudes of 10 and 20 mm, periods from 2 to 6 s and phase shift up to 1 s and on 3 patient patterns.

Dosimetric accuracy was evaluated with gafchromic EBT3films irradiated in the static as well as in the moving phantom with and without DTT.

The **imaging dose** was assessed using the Unfors RaySafe X_2 R/F sensor and gafchromic XR-QA2 films in terms of Entrance Surface Dose (ESD).



RESULTS AND DISCUSSION

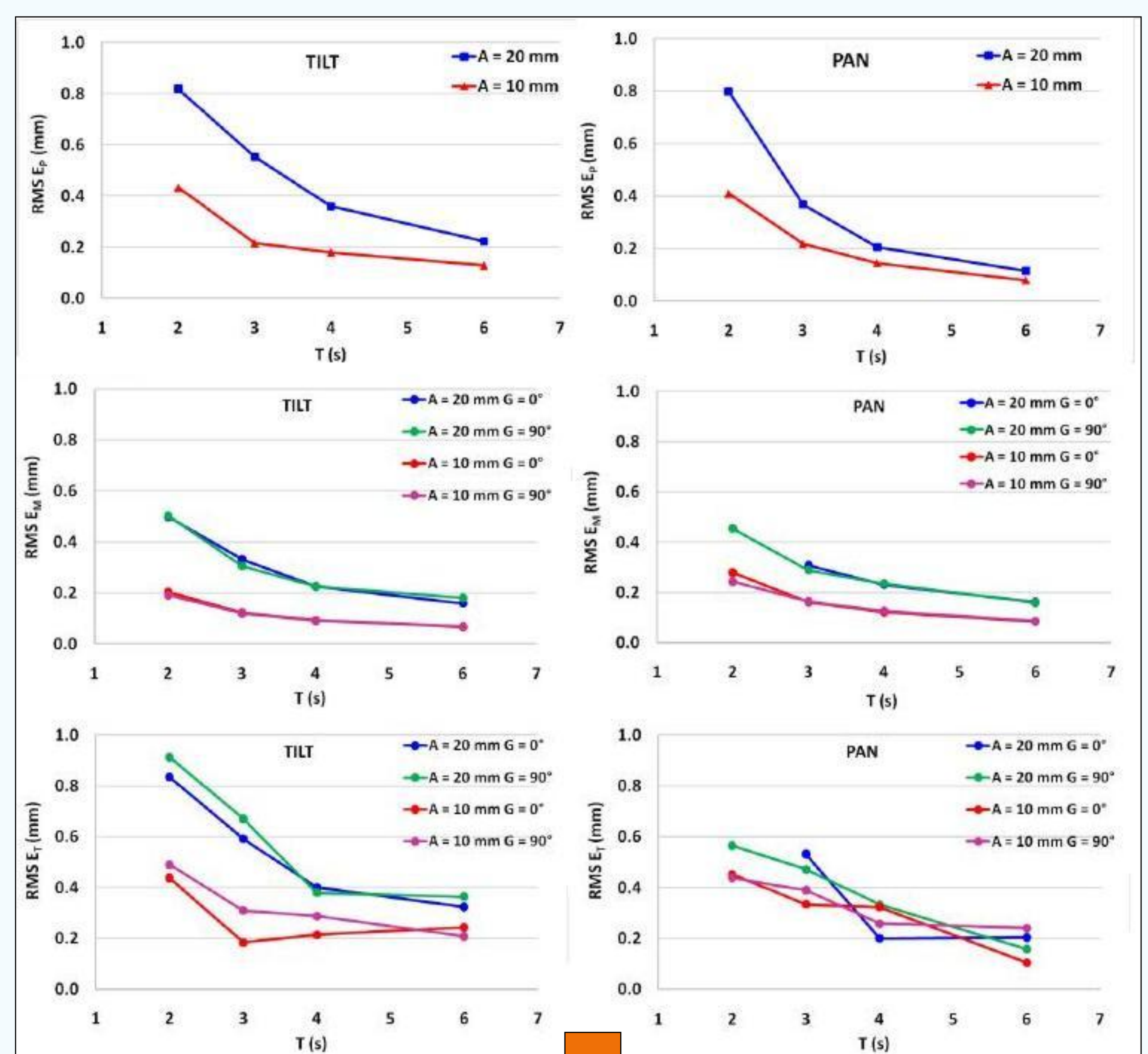
GEOMETRIC ACCURACY

A total of 165 logfiles were analyzed in combination with the X-ray imaging evaluation to calculate E_P, E_M, and E_T. The mean correlation coefficient between predicted and detected target position was 0.997. **The RMSs of E_P, E_M, and E_T were up to 0.8, 0.5 and 0.9 mm, for all non phase-shifted profiles.** The correlation coefficients between E_P and E_T were 0.990 and 0.900 for the TILT and PAN direction.

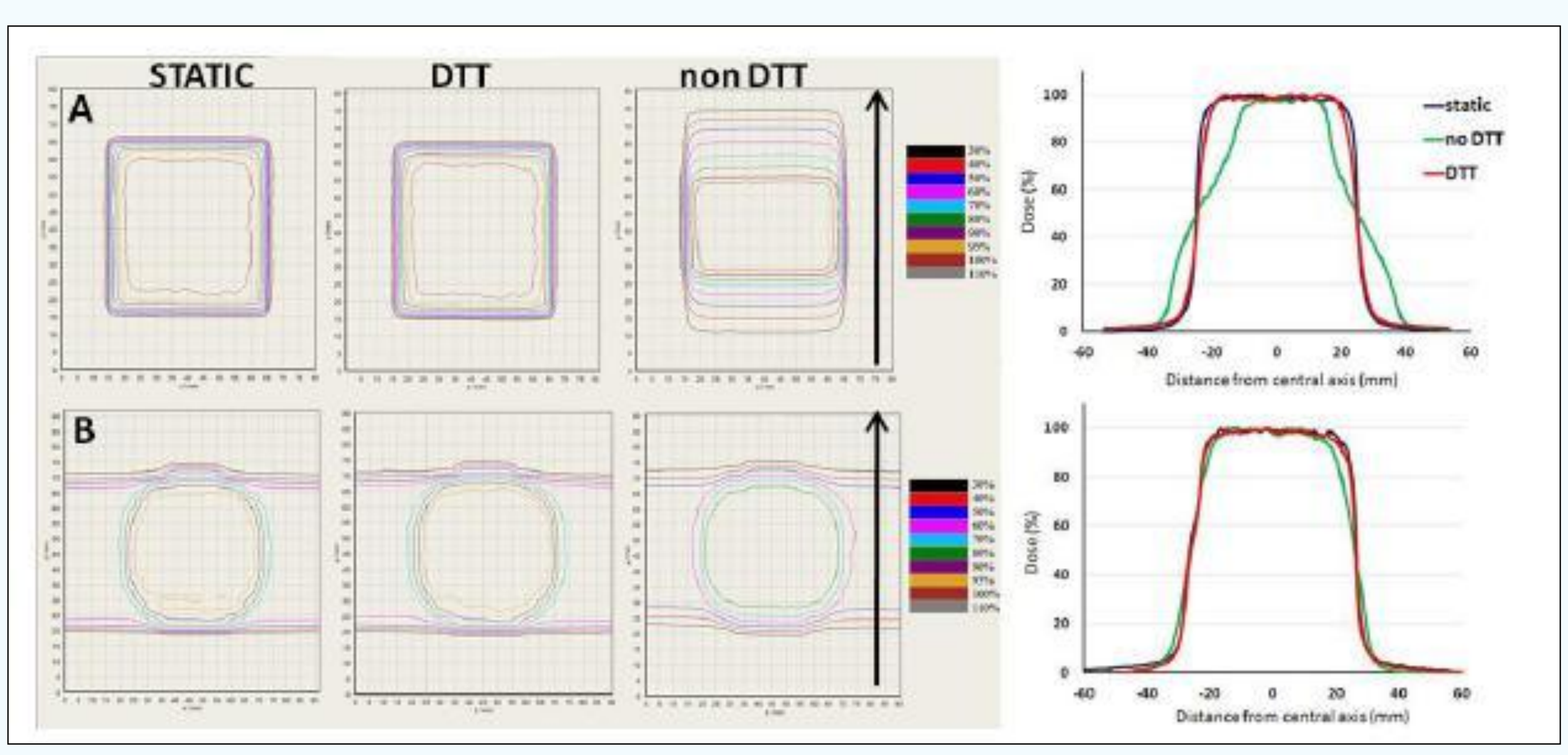
The gantry angle does not have any influence in tracking accuracy. The high correlation coefficient between E_P and E_T reveal that E_T could be well estimated from E_P, being E_M almost negligible. This finding confirms that the accuracy of the 4D model in terms of predicting the internal target position from the surrogate measurements is a key issue in IR tracking. For this reason we suggest to update the 4D model several time during the treatment to assure high intra-fraction tracking accuracy.

	Breathing pattern			Gantry = 0°			Gantry = 90°		
		A (mm)	T (s)	RMS (mm)			RMS (mm)		
				E_P	E_M	E_T	E_P	E_M	E_T
TILT	P1	6.4 ± 3.3	3.7 ± 1.3	0.2	0.2	0.2	0.2	0.2	0.2
	P2	8.4 ± 2.7	3.0 ± 0.4	0.2	0.2	0.3	0.2	0.2	0.3
	P3	13.2 ± 1.7	2.8 ± 0.3	0.3	0.2	0.3	0.3	0.2	0.4
PAN	P1	6.4 ± 3.3	3.7 ± 1.3	0.2	0.2	0.2			
	P2	8.4 ± 2.7	3.0 ± 0.4	0.5	0.3	0.5			
	P3	13.2 ± 1.7	2.8 ± 0.3				0.4	0.3	0.4
2D vector	sine 3D	10 (LL, CC), 20 (AP)	6	0.1	0.1	0.3	0.1	0.2	0.3
	sine 3D	10 (LL, CC), 20 (AP)	4	0.2	0.2	0.3	0.2	0.2	0.4
	sine 3D	10 (LL, CC), 20 (AP)	3	0.4	0.2	0.3	0.4	0.4	0.4

High accuracy even in case of aperiodic patterns and for 3D breathing profiles



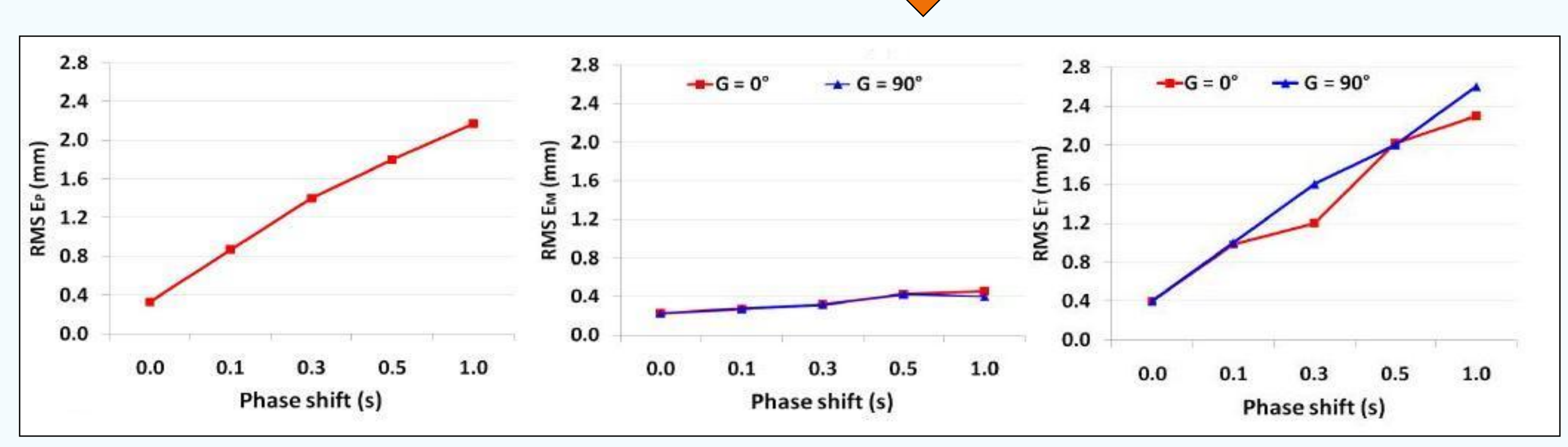
DOSIMETRIC ACCURACY



A consistent reduction of the high dose regions and a widening of the low dose regions were observed when irradiating the moving phantom without DTT compensation, in comparison with the static condition. With DTT compensation such differences were less than 4.7 mm for the high dose and 2.9 mm for the penumbra region obtained with the 0.5 s phase-shifted breathing profile.

The agreement between static and DTT dose distributions in terms of gamma analysis (2% - 2mm) was very high, always greater than 97%, while in case of non DTT such agreement was significantly reduced between 68% and 90%.

PHASE SHIFT STUDY



There is an **important effect of the phase shift** on tracking accuracy. As the absolute correlation coefficient between IR and target motion decreases from 1 to 0.23 (1 s phase shift), E_P and E_T increase linearly from 0.3 mm to 2.2 mm and from 0.4 mm to 2.6 mm, while the variation of E_M was negligible.

IMAGING DOSE

For an X-ray beam of 100 kVp and 1 mAs, typically used for the patients, the **ESD per portal** was **16.6 mGy** (0.07 mGy per image) while the one due to 1 minute treatment verification at a frequency of 1 Hz was 4.2 mGy.

Imaging dose depends mainly on the level of image quality required to automatically detect the implanted marker, therefore it depends on patient characteristics. A method to reduce the ESD, beside optimized imaging parameters and small X-ray field sizes, is to choose different portals, if multiple 4D models are required, to spread the skin dose over a larger surface.

CONCLUSIONS

The performance of the VERO DTT system was investigated for geometric and dosimetric accuracy and for the extra dose due to the imaging procedure. The DTT system tracked the target in real time with **high accuracy** even for very fast and phase-shifted motion patterns, regardless of the gantry angles investigated, leading to **dose distributions very similar to the static condition**. The hybrid approach guarantees an **acceptable level of imaging dose.**