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Validation of moving target doses using ArcCHECK Planned Dose Perturbation Algorithm.

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ABSTRACT

The aim of the study is to use Planned Dose Perturbation (PDP™) measurement-guided reconstruction method to estimate dynamic 4D (4 dimensional) dose and evaluate both 3D dose and DVH (Dose Volume Histogram)changes caused by target motion resulting from respiration. Five patients of Carcinoma lung were selected for the study. Target and Organ at risks were (OARs) delineated on 4 dimensional Computed Tomography (4DCT) data set of each patient. Dose of moving target vs. stationary target were simulated and compared for OARs and target by analyzing 3D dose and DVH.There was almost 3.5% higher target maximum doses measured with moving target after applying the target motion trajectory data as compared to the stationary target whereas OARs doses were comparable. The results, clinically signifies the importance of motion management in lung tumors.

KEYWORDS

4DCT; ArcCHECK; Respiratory Motion Sim; 3DVH

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INTRODUCTION

Respiration affects the instantaneous position of almost all thoracic and abdominal structures such as lung, breast, liver, pancreas posing significant problems in the radiotherapy of tumors located at these sites. All respiratory techniques fundamentally require a synchronization of the radiation beam with the patient's respiratory cycle[1,2].There are several methods developed in the literature for accurately targeting the tumor movement like breathhold technique, gating[3,4].The exact treatment delivery needs to be verified with appropriate Quality Assurance (QA) programs.

In IMRT (Intensity Modulated Radiotherapy) QA approach the connection between the individual field analysis and the patient dose distribution might be affected due to the combined planning and delivery imperfections , methods or algorithms to compare measurement-derived[5].Therefore, estimated DVHs against planned DVHs would perhaps be the greatest step towards establishing clinically relevant IMRT QA standards. The passing rates themselves are not absolute and are subject to statistical confidence intervals based on sampling density. Of particular importance in these and other publications is the 3%, 3mm criteria that has been proven to yield high rates of "false negatives" (high passing rates even when there were clinically relevant errors), a significant finding regarding the status quo.[6,7]

3DVH offers advantages over alternative methods to estimate DVH from measurement. This introduces the possibility for false positives (if the QA dose engine is less accurate than the Treatment planning system(TPS)) or false negatives (if both engines share similar errors), both distinct possibilities. With 3DVH's PDP (Planned Dose Perturbation) algorithm, the measured differences perturb the predicted system, ensuring that differences analyzed are derived from differences that were actually measured [8].

The ArcCHECK 4D dose data and the 4D CT motion trajectory enable a new feature in 3DVH version 3.0 called "Respiratory Motion Sim ™". This new feature estimates target dose and DVH changes caused by a target moving within a dynamic dose delivery. Because it's virtual, there are no limits on motion modeling and there is no additional setup or hardware [9]

This Respiratory Motion Sim ™ from Sun Nuclear extends the 3DVH® 4D dose perturbation methodology and allows the physicist to define motion trajectories and quantitatively evaluate the impact of organ motion on dose distribution without the use of any moving phantom. It quantifies and visualises the effects of structure motion on the estimated patient dose distribution, including DVH. [10]

It uses Planned Dose Perturbation (PDP™) measurement-guided reconstruction method to estimate dynamic 4D dose and Evaluate both 3D dose and DVH changes caused by motion to determine if motion management is necessary ,and to QA motion management plans . It Assures the Internal Target Volume (ITV) is of adequate size and shape. It determines if the target dose degrades due to Interplay and if neighboring critical organs are overdosed.

MATERIALS AND METHODS

Five patients of Ca lung were selected for the study. 4DCT scan was taken for all five patients in 10 respiratory phases (0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%). GTVs (gross tumor volume) were created in each respiratory phase. ITV (Internal target volume) or GTV 4D was generated with combining GTVs in all 10 respiratory phases. PTV 4D (Planning target volume) is the volume generated from GTV 4D with 5 mm margin. The prescription dose to the PTV 4D was 60 Gy in 30 fractions. OARs (Organ at risk) like Right lung, Left lung, Heart, Spine, Esophagus were delineated in all patients. Patients were planned with 7 beams IMRT using 6 MV beam in Varian Trilogy with HD (High Definition MLC). For dose validation patient plan was delivered on an ArcCHECK phantom.

ArcCHECK is of 21 cm diameter and 36 cm length which contains 1386 diodes in a helical geometry. The spacing between two diodes is 1 cm. All five patient's IMRT plans were created on an ArcCHECK phantom, in Varian Eclipse TPS, which was scanned in CT.

The TPS calculated 3D fluence on an ArcCHECK phantom was compared with ArcCHECK measured fluence using SNC patient software and the gamma pass rate was more than 98% with 3mm Distance to Agreement (DTA) , 3% Dose Difference (DD) criteria. As we already discussed above that this analysis is not enough, we used 3DVH software (Sun Nuclear Corp) which calculates the delivered dose distribution in patient by perturbing the calculated dose using error detected in fluence or planar dose measurement. The 3DVH analysis used the dose differences derived from comparing the measured dose with calculated doses from the TPS, to perturb the initial TPS-calculated dose. The 3DVH then overlays the resultant dose on the patient's structures using the resultant PDP algorithm. Measured dose distributions were compared with the calculated ones using the gamma index (GI) method and acceptance criteria of 3mm DTA, 3% DD.

We created the 4DCT motion trajectory path for each patient manually from motion kernels delineated from 4D CT studies in the form of x, y and z co ordinates. (Table 1).The motion path was checked and verified over many cycles to quantify the shifts. [11]

The ArcCHECK 4D dose data and the 4D CT motion trajectory data estimates target dose and DVH changes caused by a moving target within a dynamic dose delivery. Dose of moving target vs. stationary target were simulated and compared for OARs and target by analyzing 3D dose and DVH (Table 2) using Respiratory Motion Sim ™ software.

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RESULTS

Dose-volume histogram (DVH) analysis for patient plans revealed small differences between moving target plan and static target plan for OARs whereas PTV 4D and GTV 4D global maximum doses of the moving target plans were higher than that of the stationary target (Table2). There was found almost 3.5% higher doses measured with moving target after applying the target motion trajectory data as compared to the stationary target whereas OARs doses were comparable. Single tailed paired Student's t test has been applied between 'Doses in Static Plan' and 'Doses in Dynamic Plan' (Table 2), to check the statistical significance between the two Plans. The difference in GTV 4D Static vs Dynamic and PTV 4D Static vs Dynamic were not statistically significant (>0.05).The results, clinically signifies the importance of motion management in lung tumors.

DISCUSSION

The Respiratory Motion Sim ™ uses the 4D dose perturbation methodology and allows defining motion trajectories and quantitatively structure motion on the estimated patient dose distribution, including DVH .Moreover, clinically relevant differences increased with increasing QA passing rate, indicating that some of the largest dose differences occurred in the cases of high QA passing rates, which may be called "false negatives." The clinical importance of any disagreement between the measured and the calculated dose is often difficult to interpret; however, beam errors (either in delivery or in TPS calculation) can affect the effectiveness of the patient dose. [12]

For motion perturbation, each target voxel is still analyzed, but the static patient dose voxels are now modified for motion errors/differences derived from the phantom doses. With patient per voxel doses now approximated for a moving target, all voxels may be binned to create the estimated DVH to the moving target. This "Moving target DVH" can directly compared to the "Stationary target DVH" in order to quantify the impact of interplay, in particular to assess if the target dose coverage is robust (or fragile) with respect to the patient-specific target motion. "Moving target DVHs" can be readily compared to the "Stationary target DVH". [13]

The absolute doses of IMRT fields measured under the stationary condition served as a reference for comparison to the other conditions. Our results showed a small (upto 3.5%) dose variation between the static and moving conditions using IMRT which was not significant statistically.

So far only the theoretical framework of the 4D dose perturbation algorithm has been presented. The next necessary step is to verify this formalism empirically. In its most obvious form, such verification would involve measuring the cumulative dose per fraction with any integrating dosimeter in a moving phantom representing a patient, and comparing the results with the planned dose perturbation dose grid derived from the measurement in the stationary cylindrical phantom.

CONCLUSION

Respiratory MotionSim (RMS) allows the clinician to simulate the dosimetric impact of target motion with proven accuracy. This software allows the physicist to define motion trajectories and quantitatively evaluate the impact of organ motion on dose distribution.RMS is an important tool for clinicians committed to evidence-based decision making and quality assurance of highly modulated radiation therapy treatments where organ motion is a concern. Further research is needed to determinate the role of a PDP-type algorithm to accurately estimate patient dose effect.

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Table 1: Average values of Target (GTV) motion trajectory data for all patients

Phase	X (cm)	Y (cm)	Z (cm)	T (s)
1(max exhalation)	0.0	0.0	0.0	0.0
2	-0.02	-0.46	0.02	0.52
3	0.28	-1.46	0.03	0.85
4	0.89	-1.78	0.02	1.14
5	1.24	-2.15	0.25	1.78
6 (max inhalation)	1.59	-2.95	0.15	2.10
7	1.47	-2.05	0.08	2.55
8	1.05	-1.78	0.07	2.99
9	0.45	-1.10	0.15	3.58
10	-0.04	-0.52	0.18	4.25
1(max exhalation)	0.0	0.0	0.0	4.95

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Table 2: Variation in target and OAR Doses in Static and moving target for all five patients

	ROIs	Rt Lung		Lt Lung		Heart		Spine	Esophagus		GTV 4D		PTV 4D	
Patient 1	Volume in cc	3458.4		1852.2		393.9		40.3	47.5		131.7		627.7	
	Statistics	Mean	Max	Mean	Max	Mean	Max	Max	Mean	Max	Mean	Max	Mean	Max
	Doses in Static plan (Gy)	7.36	59.6	21.54	60.47	8.65	59.89	38.42	29.45	60.06	60.51	62.4	58.18	62.78
	Doses in Dynamic Plan (Gy)	7.38	59.09	21.84	60.02	8.81	61.19	39.03	29.97	59.91	61.75	61.77	59.15	62.79
	% Difference	-0.27	0.86	-1.39	0.74	-1.85	-2.17	-1.59	-1.77	0.25	-2.05	1.01	-1.67	-0.02
Patient 2	Volume in cc	1376.8		1929.9		487.6		36.1	21.1		396.3		914.6	
	Statistics	Mean	Max	Mean	Max	Mean	Max	Max	Mean	Max	Mean	Max	Mean	Max
	Doses in Static plan (Gy)	34.2	63.95	6.51	62.81	17.12	63.02	42.28	35.5	64.19	62.87	65.43	62.07	66.57
	Doses in Dynamic Plan (Gy)	34.66	64.96	6.6	64.26	17.91	64.15	43.29	35.95	66.14	64.11	66.74	63.26	68.93
	% Difference	-1.3	-1.6	-1.4	-2.3	-4.6	-1.8	-2.4	-1.3	-3.0	-2.0	-2.0	-1.9	-3.5
Patient 3	Volume in cc	2327.7		2493.5		505.9		29.3	46.7		184.9		495.7	
	Statistics	Mean	Max	Mean	Max	Mean	Max	Max	Mean	Max	Mean	Max	Mean	Max
	Doses in Static plan (Gy)	23.36	67.32	4.01	36.04	18.49	67.18	50.15	11.67	57.56	62.22	66.09	61.13	68.67
	Doses in Dynamic Plan (Gy)	23.93	69.09	4.03	35.52	18.81	68.82	51.92	11.74	58.8	64.13	67.91	62.91	69.95
	% Difference	-2.44	-2.63	-0.50	1.44	-1.73	-2.44	-3.53	-0.60	-2.15	-3.07	-2.75	-2.91	-1.86
Patient 4	Volume in cc	1031.2		852.9		465.7		39.7	30		27.3		66.7	
	Quick Stat	Mean	Max	Mean	Max	Mean	Max	Max	Mean	Max	Mean	Max	Mean	Max
	Doses in Static plan (Gy)	7.54	65.92	2.19	20.32	4.21	29.25	31.11	6.37	30.96	64.31	66.91	63.47	67.64
	Doses in Dynamic Plan (Gy)	7.72	68.04	2.21	20.86	4.23	29.13	31.63	6.44	31.82	66.06	69.07	65.53	69.47
	% Difference	-2.39	-3.22	-0.91	-2.66	-0.48	0.41	-1.67	-1.10	-2.78	-2.72	-3.23	-3.25	-2.71
Patient 5	Volume in cc	1488.5		875.6		261.9		47.6	25.5		163		291.3	
	Quick Stat	Mean	Max	Mean	Max	Mean	Max	Max	Mean	Max	Mean	Max	Mean	Max
	Doses in Static plan (Gy)	6.16	33.41	20.79	60.03	0.74	2.71	35.22	31.6	63.41	60.97	64.99	59.89	65.39
	Doses in Dynamic Plan (Gy)	5.99	33.95	20.56	59.39	0.73	2.8	34.23	31.88	62.95	61.21	64.23	58.87	66.13
	% Difference	2.76	-1.62	1.11	1.07	1.35	-3.32	2.81	-0.89	0.73	-0.39	1.17	1.70	-1.13

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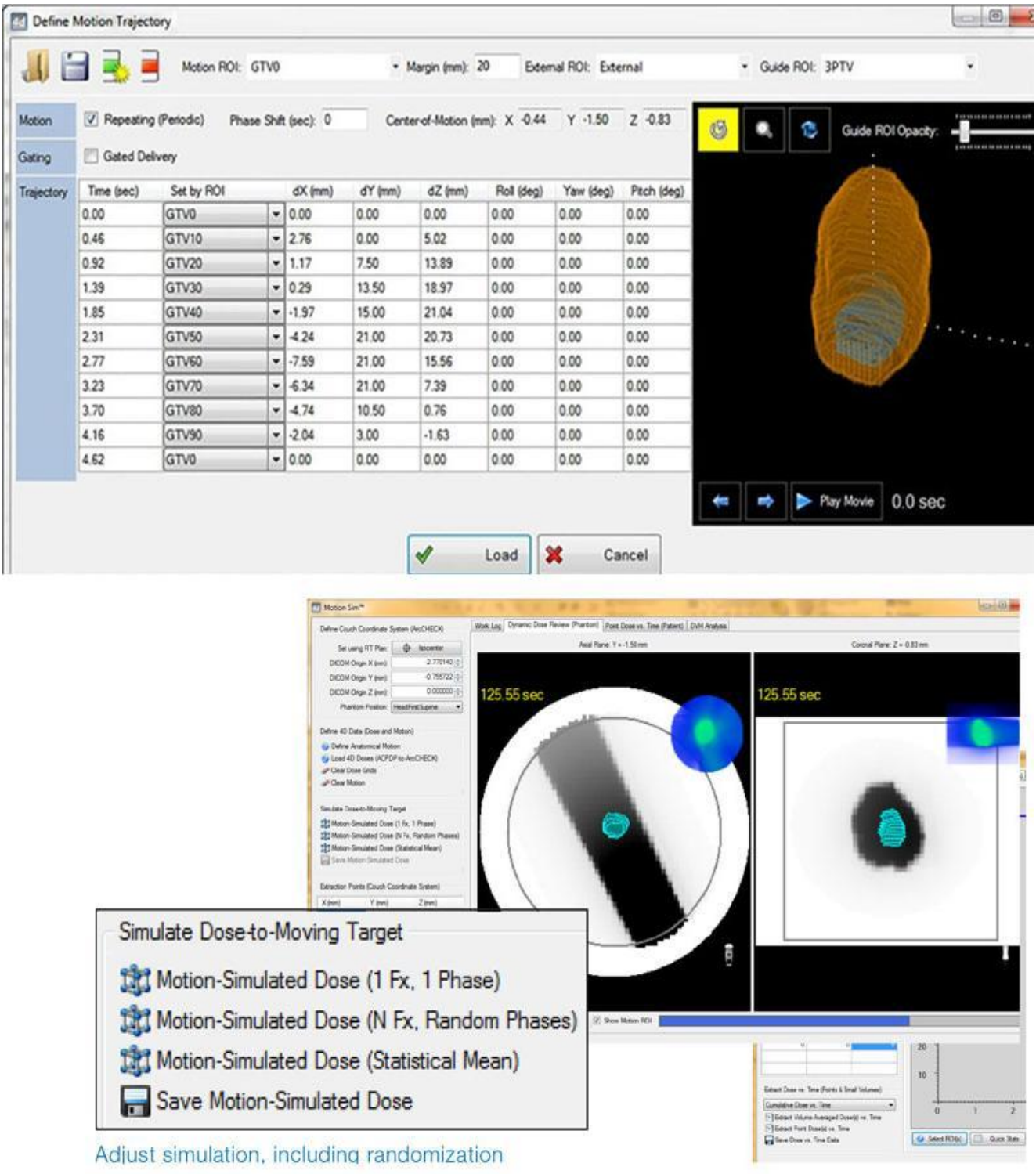

Fig 1: Motion trajectory window in "Respiratory Motion Sim" software together with simulation of dose to moving target

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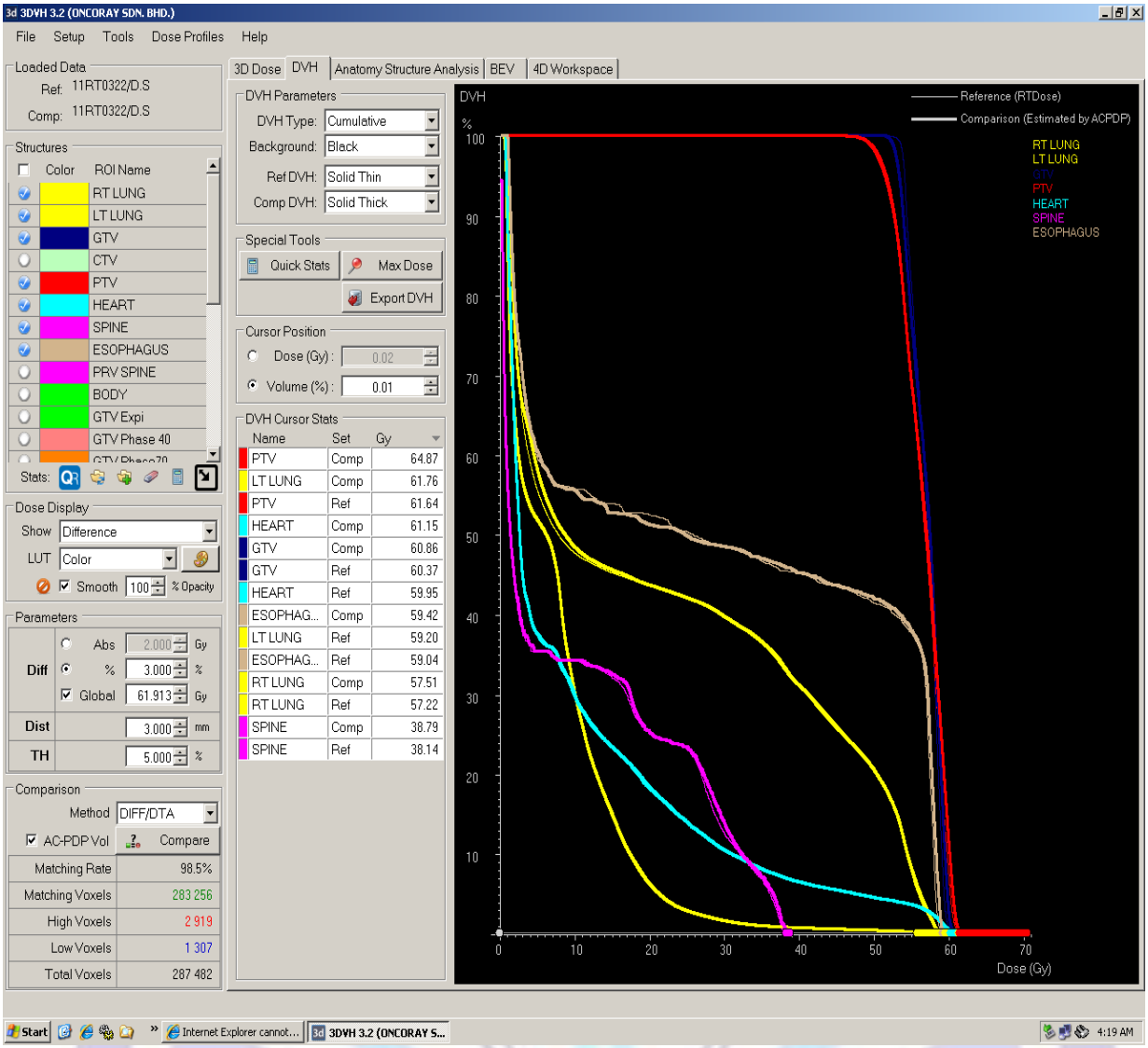

Fig 2: Comparison of moving (estimated by ACPDP) and stationary(Reference) target doses

Dotted thin line: Stationary target dose(Reference) ; Solid thick line: Moving target dose(Comparison)