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Continuous On-Beam Computor Tomographic Image Reconstruction at the Moment of Treatment by Amplitude/phase Scaling of Deformation Vector Fields

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INTRODUCTION

A potential difference in patient's anatomy between the time of treatment and the time of planning CT is an ever-present challenge in radiation therapy. To address this challenging problem, our current study aimed at developing a new method for the generation of the continuous CT images (cCT) that represents patient anatomy at the moment of irradiation.

AIM

To reconstruct three-dimensional cine-computor tomographic(cCT) images that represent the moments of therapeutic beam irradiation from planning four-dimensional (p4D) CT images.

METHOD

- Reference 4DCT images were generated using an anthropomorphic digital phantom with two significantly-different respiratory traces in their shapes and tumor motion extents in three different tumor positions (close to diaphragm(DP), close to chest wall(AP), and close to the center of lung(CN)). One CT images are considered as p4DCT and the other as treatment 4DCT (t4DCT).
- DVFs were acquired by image registration between a pivot phase (the end of exhale) and other phases of the p4DCT images. Projection images for all phases were calculated through the p4DCT and the t4DCT images (we denote the projection images as p4DCT-P and t4DCT-P, respectively).
- On each projection image set, the motion amplitude of the visible tumor was quantified as the displacement of its center-of-mass coordinate at each phase from the coordinate at the pivot phase. The ratio of the amplitude on the t4DCT-P set to that on the p4DCT-P set was obtained for each phase and was converted to the scaling factor using a predetermined lookup-table between amplitude ratios and DVF ratios (considering nonlinearity between the two ratios).
- The scaled DVFs were then multipled to the DVFs, resampling the p4DCT images, and generating images at the time of beam irradiation (b4DCT). The b4DCT images were compared with the t4DCT images.

RESULTS

The reconstructed b4DCT images showed good agreement with the reference t4DCT with <1.5 mm error for 3-cm tumor and 1.9 mm for 1-cm tumor close to diaphragm at the center of mass for the significant variation of the respiratory trace we have adopted in this study. The disagreement at the tumors close to chest well and center of lung was less than 1.0 mm and 0.5 mm, respectively. Table 1 quantified the agreement of b4DCT to t4DCT at the COM of the tumor in its positional difference for each phase of the four cases. Significant improvement was achieved by using this: from 9.72 mm to 1.94 mm in the maximum difference of the COM and 53% to 84% in the DICE coefficient. Although the amplitude of the input trace for t4DCT, showed the largest difference from that for p4DCT at the 5^{th} phase, the agreement was found to be worst at the 8^{th} phase from the case of DP with 1cm tumor.

*Table 1. Quantified agreement in the positional difference (mm) at the COM of the tumors before and after applying this method. *largest disagreement*

	DP_1cm		DP_3cm		AP_1cm		CN_1cm	
Phase	before	after	before	after	before	after	before	after
2	0.70	0.96	0.71	0.07	0.48	0.23	0.22	0.05
3	2.81	1.73	2.42	0.42	1.49	0.72	0.56	0.08
4	6.80	0.92	5.75	1.46	3.19	1.03*	1.28	0.21
5	9.72*	0.76	8.77*	1.48*	4.40*	0.99	1.75*	0.31
6	8.97	0.95	8.30	1.35	4.18	0.61	1.63	0.17
7	7.72	1.34	6.75	1.35	3.41	1.03	1.32	0.38
8	4.85	1.94*	4.25	0.82	2.38	0.89	0.98	0.47*
9	3.12	0.33	2.75	0.21	1.73	0.35	0.65	0.08
10	1.87	0.49	1.76	0.24	1.20	0.51	0.46	0.03

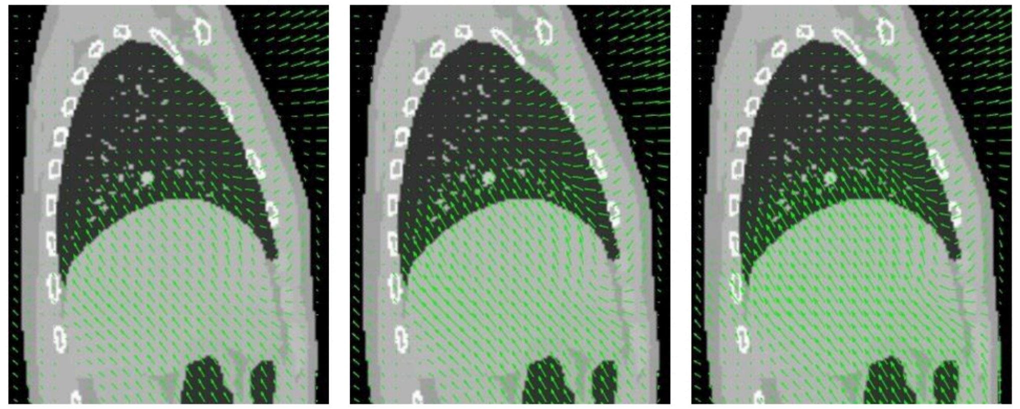

Figure 1. Deformation vectors fields for the modelled tumor near diaphragm, DVF(r, phase1→8) from the p4DCT images (A), DVF(r, 1→8) from the t4DCT images (B), DVF(r, 1→8) for the b4DCT images (C). At phase 8, the error of the proposed method was greatest.

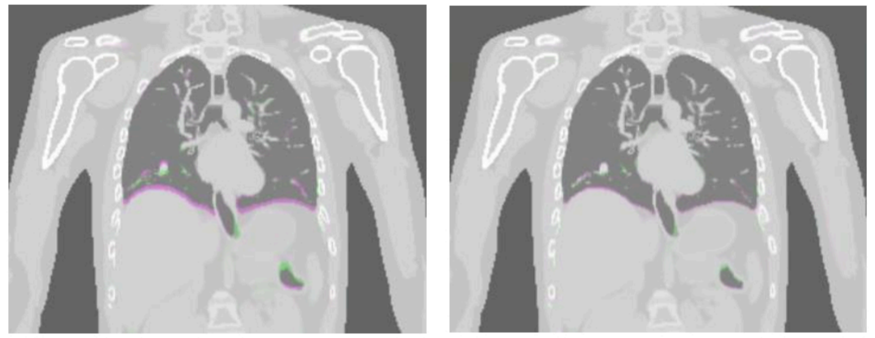

Figure 2. Overlaid coronal images of the t4DCT image with the p4DCT at the phase 8 (A) and those of the b4DCT image with the t4DCT (B). In (A), if different from the other, t4DCT images is in green and p4DCT images is in purple. In (B), if different from the other, b4DCT images is in green and t4DCT images is in purple. In both (A) and (B), if two image sets agree to each other, then they are in black and white.

CONCLUSIONS

The method of amplitude scaling could reconstruct the cCT images from p4DCT images accurately. We attempted to achieve the aim by utilizing motion amplitude differences between the time of p4DCT and that of treatment beam irradiation, as visible in target projection images, and the DVFs of the p4DCT. Not only the idea of using the amplitude difference, but also the usage of the target image, not the entire projection image, were new. We have verified our method against the case of the most irregular respiration change among the respiration data we have and also at the tumor locations that experiences most deformation (at chest wall and diaphragm). This large change was not tried before.

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