Evaluations of the dose discrepancies calculated on CT and cone-beam CT using pencil beam convolution and analytical anisotropic algorithms

Introduction: The integration of kV on-board imager with the radiotherapy treatment machines is emerging a vital clinical tool [1] that provides diagnostic quality radiographic, fluoroscopic and computed tomography images. Mostly, these images are used in image-guided radiation therapy (IGRT) to setup patients accurately using internal anatomy before each treatment session. Further, the volumetric CBCT images might be useful for treatment planning and dose calculation as image quality is improved where accurate electron density can be obtained from CBCT numbers. The CBCT provides updated images of patient anatomy just prior to dose delivery. This anatomical information is useful for accurate IGRT and ability to perform adaptive radiation therapy. However, CBCT image quality is inferior to that from conventional CT. Image artifacts present in clinical CBCT images include scattered radiation, couch attenuation, streaking, beam hardening, mechanical instabilities, cupping and patient motion. The purpose of this study is to investigate the differences in dose calculated using kV cone-beam CT (CBCT) and conventional simulation CT (CT) using pencil beam convolution (PBC) and analytical anisotropic algorithms (AAA).

Methods: A kV on-board imaging system that is integrated on a Varian Trilogy linear accelerator was used to acquire CBCT images for patient setup and tumor localization. The clinical plans calculated on conventional CT using the PBC and AAA in Eclipse treatment planning system were imported on CBCT images. The structures, beams and leaf sequences from the initial clinical plan were preserved and transferred to CBCT. Treatment plans for 8 lungs, 1 lumbar spine, and 1 liver cancer patients was used in this study. Each patient has one CT and 3 to 5 CBCT scans. Dose differences from two-dimensional distribution on axial, coronal and sagittal CT and CBCT slices were calculated using PBC and AAA. The gamma index was used to analyze the dose distributions with dose difference and distance-to-agreement tolerance criteria of 2%/2mm, 3%/3mm, and 5%/5 mm.

Results: Figure 1(a) shows the overlay of the dose distribution, Fig. 1(b) represents % dose difference map, and Fig. 1(c) percentage dose difference histogram for a lung patient (#5). The data (Table 1) show that nearly 67% and 90% of the patients had an average dose calculated on CBCT higher than that calculated on CT using PBC and AAA, respectively. The overall average of the mean percentage dose difference (MPDD) between CT and CBCT from all patients in the different planes was 0.5% and 1.8% using PBC and AAA algorithms, respectively. The MPDD ranged from -13.2% to 7.9% using PBC and from -13.9% to 9.9% using AAA. Additionally, the standard deviations for individual patient average MPDD show that the MPDD values are within nearly 6.7%. The gamma analysis with tolerance criteria of (3%,3mm) using AAA had lower or equal passing rates (84% of 139 cases) than PBC when comparing dose distributions in axial, coronal and sagittal planes calculated on CBCT and CT.

Conclusion: The dose calculated on CBCT was generally higher on CBCT than CT. The AAA dose showed larger deviations of CBCT dose calculations from CT. The AAA seems to accounts for image artifacts inherent to CBCT than PBC. The discrepancies in dose between CBCT and CT were the largest in lung patients because of large variations in CBCT and CT numbers. Further, anatomical changes such as tumor deformation and shrinkage during the treatment course might affect the discrepancies in dose calculated on CBCT and CT.
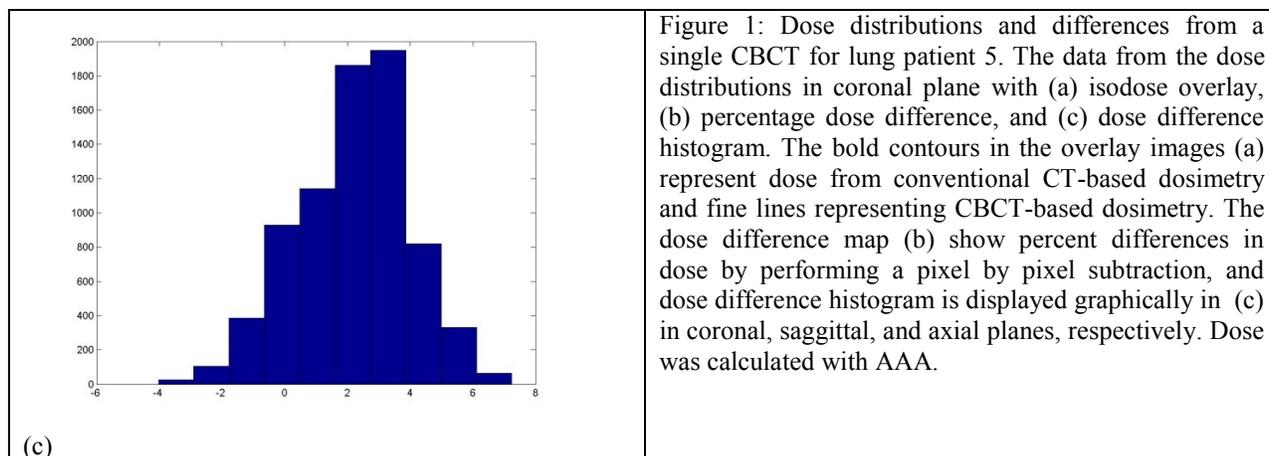

(a)

(b)

(c)
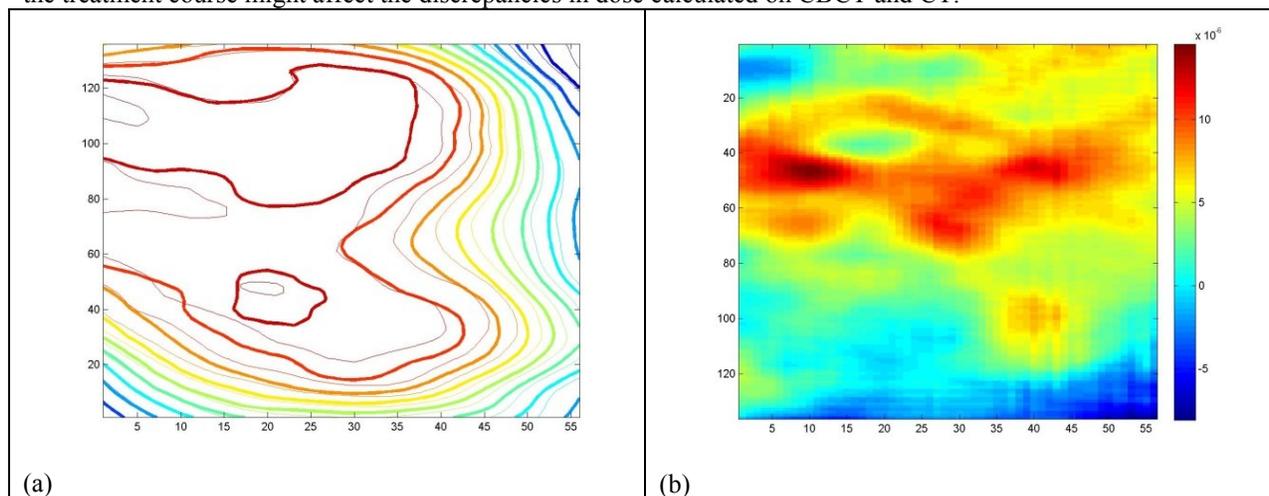
Figure 1: Dose distributions and differences from a single CBCT for lung patient 5. The data from the dose distributions in coronal plane with (a) isodose overlay, (b) percentage dose difference, and (c) dose difference histogram. The bold contours in the overlay images (a) represent dose from conventional CT-based dosimetry and fine lines representing CBCT-based dosimetry. The dose difference map (b) show percent differences in dose by performing a pixel by pixel subtraction, and dose difference histogram is displayed graphically in (c) in coronal, saggittal, and axial planes, respectively. Dose was calculated with AAA.

Table 1: Mean and standard deviation of the percentage dose difference between CBCT and CT calculated using PBC and AAA dose calculation algorithms

| | PENCIL BEAM CONVOLUTION (PBC) | | | | | | ANALYTICAL ANISOTROPIC ALGORITHM (AAA) | | | | | |
| | Axial | | Coronal | | Sagittal | | Axial | | Coronal | | Sagittal | |
	Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD
Patient 1 /Lung	-2.79	10.72	12.27	9.44	-6.22	7.55	7.12	4.11	9.90	5.66	5.99	4.09
Patient 2 /Spine	3.48	0.91	2.23	1.57	13.22	35.88	3.45	0.82	2.56	1.59	13.86	35.69
Patient 3 /Lung	4.91	1.81	5.81	1.53	5.94	1.71	1.90	1.95	1.27	2.67	-0.33	2.92
Patient 4 /Lung	0.88	0.73	1.04	1.26	1.12	1.62	0.74	0.90	0.66	1.40	0.62	1.55
Patient 5 /Lung	1.77	0.38	1.75	0.72	1.86	0.60	1.55	1.99	1.89	2.09	2.11	2.12
Patient 6 /Lung	-1.95	2.99	-1.35	1.73	-3.11	2.59	2.08	2.93	2.52	3.60	3.92	3.04
Patient 7 /Lung	1.49	1.05	1.89	1.03	1.59	0.83	1.04	1.30	1.46	1.26	1.03	1.38
Patient 8 /Lung	-0.13	0.78	0.00	1.80	0.33	0.88	0.02	0.78	-0.30	2.42	0.50	1.24
Patient 9 /Lung	-0.03	0.55	0.05	0.63	0.07	0.62	1.14	1.41	2.31	2.43	2.05	2.49
Patient 10 /Liver	5.90	9.10	7.91	4.21	6.25	4.57	2.80	2.94	4.41	2.50	3.97	2.76

[1] D. A. Jaffray and J.H. Siewerdsen, *Cone-beam computed tomography with a flat panel imager: initial performance characterization.* Med. Phys., 2000. **27**: p. 1311–1323.