Determination of Tumor Size and Hounsfield Unit/Electron Density Values in Three Different CT Scans for Lung SBRT Planning

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ABSTRACT

The success of Radiotherapy treatment depends on the accurate calculation of dose distributions. The calculation algorithms calculate the dose distributions according to the physical properties of the materials in which the radiation interacts. In our study, the effects of different CT scanning techniques for tumor and healthy organ's physical properties were investigated in lung SBRT treatments. We performed Normal-CT, Deep Insprium Breath Hold-CT (DIBH-CT) and Average-CT scans for 18 lung SBRT patients. Eighteen patients were scanned by each technique; Gross Tumor Volumes (GTV) were examined. Hounsfield Unit (HU) and Electron Density (ED) values, the most important parameters in dose calculation, were compared for three scan techniques. HU and ED values were examined for a spherical area of 10 cm diameter around of GTV and 1 cm outer of GTV. According to DIBH-CT, GTV was determined 18.4% (p< 0.001) greater in Normal-CT and 31.8% (p< 0.001) greater in Average-CT. Density of GTV decreased in Normal-CT and Average-CT, but healthy lung tissue's density around GTV increased. The biggest differences for HU, ED and GTV volume were obtained in the Average-CT. Distortion and artefacts caused by respiratory motion were minimized with DIBH-CT. The ED/HU values were determined more accurately without respiratory motion with DIBH-CT. Thus, GTV can be determined in real dimensions with sharp limits and dose distributions can be calculated more accurately.

Keywords: Lung SBRT, Breath Hold,SGRT, Hounsfield Unit, Electron Density

INTRODUCTION

Lung Stereotactic Body Radiotherapy (SBRT) is a treatment method in which high radiation doses are implemented in several fractions (usually for the lung 48-60 Gy in 3-6 fractions). Although the total dose implemented to the patient is the same as in conventional radiotherapy (RT) (usually 50-66 Gy in 25-33 fractions), the high radiation doses planned per fraction in SBRT are equivalent to biologically much larger radiation doses. For this reason, the biological effective dose (BED) is greater compared to conventional RT (≥ 100 Gy versus 50-66 Gy).[1] There are two major problems in lung SBRT. One of them is the respiratory motion and the other is tissue inhomogeneity. There are uncertainties in the calculation of dose distribution of inhomogeneous mediums. These are attenuation of absorption in the lung medium, increased lateral range, charged particle equilibrium effected and re-build up effects. The uncertainties and difficulties arising from these two problems increase even more in small fields. Respiratory motion leads to the possibility of missing the target, and also causes a different calculation of the electron density (ED) and Hounsfield Unit (HU) values.[2]

According to the European Cancer Research and Treatment Organization (EORTC), it is recommended that tumor movement to be determined in three dimensions in lung planning and implementation. Considering the motion for lung RT; it is suggested that computer tomography (CT) can be scanned in slow mode, holding breathe or diaphragm compression can be performed, or finally CT can be scanned at any phase of respiration and treatment can be implemented.[3]

RT treatment planning is based on geometric and density information obtained from tomography scans. It is known that the breathing motion during scan changes the patient's anatomy, position and intensity. Depending on respiration, tumors, healthy tissues and organs can move to great extent. The amount of this motion can vary according to the anatomical and physiological condition of the patient. The tumor can also make large movements in three axes (coronal, sagittal and transverse). This movement can lead to significant differences between the planned and implemented dose distributions. Due to the uncertainties in tumor and organ movement, planned target volume (PTV) was developed in conformal planning according to report 62 of the International Commission on Radiological Units (ICRU).[3] PTV involves internal organ movements due to physiological reasons such as respiration or heartbeat, patient movements that can occur during treatment, and uncertainties due to patient positioning errors.[4] In our study, we have investigated the effect of respiratory motion on tumor size, ED and HU values in lung SBRT treatment.

MATERIALS AND METHODS

Three of the 18 patients were female and fifteen were male. Median age is 67. Five of the patients included in the study had primary lung cancer, and 13 patients had single lung metastasis. According to tumor location, 2 Right Lower Lobe (RLL), 2 Left Upper Lobe (LUL), 5 Left Medium Lobe (LML), 4 Right Lower Lobe (RLL), 1 Right Medium Lobe (RML), 4 Right Upper Lobe (RUL) were classified. Tumor localization and gross tumor volumes (GTV) for each patient are detailed in Table 1.

Computed tomography and scanning protocol; CT scans via the X-ray tube and the synchronized movement of the detectors rotating around the patient. It is basically an imaging system that obtains a slice view of the region to be examined using X-ray. These slice images are constructed to form a three-dimensional image. Furthermore, it is avoided that images consisting of two-dimensional (X-ray) images are superimposed with the slice view. However, thanks to the collimation, photon scattering is reduced to the minimum, making the tissue density differences more visible. The images are obtained by gathering the linear attenuation coefficients at each point along ray passing through the region to be examined. The resulting slice images are the numerical distribution of the linear attenuation coefficients. All attenuation coefficients cannot be determined by a single measurement of transmittance. Because in the fractional transmittance equation, μ_{tissue} is not exactly certain. However, the multiple X-ray transmittance obtained from the different orientations of the X-ray source and the detector allows calculation of all attenuation coefficients.[5,6] The calculated attenuation coefficients are represented by the HU number. The HU scale is between –1024 and +3071. Bone structures have a HU value of around +1000 while air equivalent mediums have a HU value of around –1000. Hounsfield Unit:

$$HU_{(x,y,z)} = 1000 \frac{(\mu_{tissue}(x,y,z) - \mu_{water}}{\mu_{water}}$$

Where x, y, z are the coordinates of a voxel and μ is the linear attenuation coefficient. The HU number is transformed into a grayscale[5-8]; thus the image is obtained.

CT data are used for RT treatment planning. In treatment planning, the dose distribution at the site to be treated is calculated according to ED. The ED values are used to calculate the dose distribution. These ED values are obtained by calibrating to HU values on CT images. In this calibration, the HU-ED curve is obtained. The accuracy of calibrating to the ED of the HU is a key component for dose calculations in an inhomogeneous mediums.[9-12]

CT data were acquired on a Simens Biograph mCT 20 PET / CT (Knoxville, TN, USA) scanner

Table 1. Tumor volumes (GTV) and localizations for 18 patients

Patient No	Tumor Localization	DIBH-CT Volume (mL)	Average-CT Volume (mL)	Normal-CT Volume (mL)
1	RLL	0.31	0.66	0.52
2	LML	0.82	1.99	0.86
3	LUL	1.03	1.42	1.30
4	LML	1.22	1.60	1.29
5	LLL	1.38	1.78	1.50
6	LML	1.32	1.74	1.60
7	RLL	1.44	1.78	1.73
8	RUL	1.63	2.22	1.78
9	RUL	2.51	3.11	2.77
10	RLL	4.18	5.46	4.44
11	LLL	3.60	6.96	4.05
12	LML	5.73	6.31	5.90
13	LML	9.15	13.35	9.52
14	RUL	15.38	20.17	17.19
15	LUL	16.30	20.30	17.32
16	RUL	18.21	19.79	19.67
17	RML	45.15	59.49	48.40
18	RLL	110.75	148.39	144.45
Mean		13.34	17.58	15.79
STD		25.93	34.59	33.24

equipped with Catalyst™ (C-RAD, AB, Sweden) surface guide system. Imaging parameters were: tube voltage 120 kV, tube current 75 mAs, field of view 78 cm on a 512 x 512 pixel grid, slice thickness 1 mm. The patients were positioned with WingSTEP ™ (Elekta Ltd, Stockholm, Sweden) with their arms up. Three different CT scans were performed for each patient during normal breathing, in the range containing all phases of respiration, and in deep breath. CT images were grouped as right-left and upper-middle-lower lobes according to localization. The Normal-CT scans were made in the slow mode of the tomography device to be 0.13 seconds per slice. Average-CT images were obtained from four-dimensional scans containing the entire respiratory cycle. In the Deep Inspirium Breath Hold-CT (DIBH-CT) scanning technique, the patient inhaled deeply until the specified phase interval and breathing for the patient was restricted in this phase interval. With the Catalyst™ surface scan system, tomography scan is performed while respiration is at the specified phase interval. The patient takes a deep breath to the specified phase interval, and CT scan or treatment is performed in this range.

The Catalyst™ optical surface scanning system consists of two components: The light emitting diode and the charge coupled device camera system. It is mounted on the foot side of the treatment couch on the ceiling. To scan the patient's skin, the light that is reflected from the patient's skin is collected by the camera after sending an electromagnetic wave to the nearby visible region. The position of the patient is determined by calculation of the light collected by the camera using optical triangulation logic. The frequency of the Catalyst™ surface scan system is 47-63 Hz, the wavelength of the scan light is 405 nm (blue), 528 nm (green), 624 nm (red). The dimensions of the scanned area are 800 mm x 1300 mm x 700 mm (X, Y, Z). The measurement repeatability is 0.2 mm. Position accuracy is less than 1 mm.[13,14]

In three CT scans of each patient, GTVs were consecutively determined by a physician to minimize systematic uncertainties. GTVs in three different tomographies of 18 patients were contoured in the Monaco V5.11.02 (Elekta Ltd, Missouri, USA) treatment planning system. ED and HU values were calculated in the treatment planning system for GTV contoured separately for all three CT scan

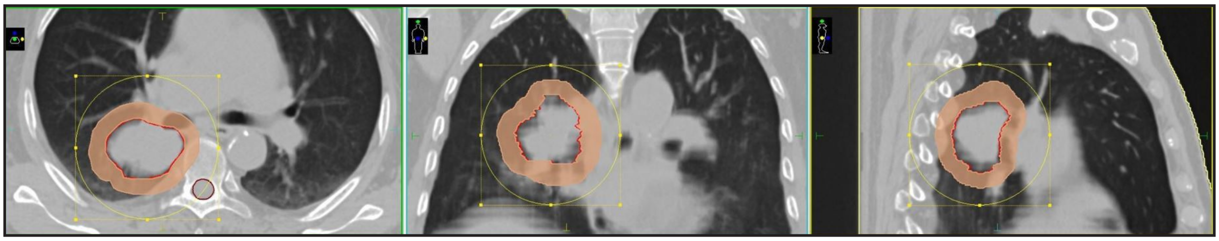

Figure 1. The volume of the spherical area of 10 cm in diameter and the volume of the ring area covering 1 cm outer of GTV

techniques. To detect differences in the ED and HU values around the GTV and the surrounding area, a 10 cm diameter spherical area centered on the GTV and a ring area covering 1 cm outside of the GTV were created. ED and HU values of these areas were calculated for three CT techniques. Figure 1 shows a 10 cm diameter spherical area and a 1 cm ring area around the GTV. Statistical analysis was performed with the Friedman test after comparisons with DIBH-CT, Average-CT, and Normal-CT.

RESULTS

The mean GTV values for 18 patients were calculated as 13.34 mL with DIBH-CT, 17.58 mL with Average-CT and 15.79 mL with Normal-CT. Since respiratory movement was restricted with DIBH-CT, GTVs with more solid and sharper limits were obtained. If the DIBH-CT reference is accepted, the average GTV dimensions in 18 patients increase by 18.4% in Normal-CT and 31.8% in Average-CT. Table 1 shows the GTV sizes of 18 patients. According to Friedman statistical analysis, the differences between tumor volumes in three CT techniques were statistically significant ($p< 0.001$).

HU; The mean values for GTV were calculated as –165 for DIBH-CT, –211 for Normal-CT and –233 for Average-CT ($p< 0.001$). Mean values for the 10 cm sphere centering on GTV were calculated as –536 for DIBH-CT, –439 for Normal-CT and –438 for Average-CT ($p< 0.001$). Mean values for 1 cm ring area around GTV were calculated as –658 for DIBH-CT, -561 for Normal-CT and –557 for Average-CT ($p< 0.001$).

ED; The mean values for GTV were calculated as 0.85 for DIBH-CT, 0.82 for Normal-CT and 0.80 for Average-CT ($p= 0.179$). Mean values for the 10 cm diameter sphere centered on the target volume were calculated as 0.48 for DIBH-CT, 0.59 for Normal-CT, 0.59 for Average-CT ($p= 0.001$). Mean values for the ring area covering 1 cm outer of GTV were calculated as 0.37 for DIBH-CT, 0.47 for Normal-CT and 0.46 for Average-CT ($p< 0.001$) (Table 2).

DISCUSSION

Respiratory motion is a major problem in lung RT. This problem can lead to much greater uncertainties and errors, especially in lung SBRT. In order to minimize these uncertainties and possible errors, the target volume should be accurately defined and the physical properties of the medium should be determined accurately for the dose distribution calculation. The calculation of the dose distribution is done by converting HU values, which are the num-

Table 2. Average HU and ED values for 18 patients

	GTV-Mean			10 cm sphere volume-Mean			1 cm outer ring volume-Mean		
	BHCT	AvCT	nCT	BHCT	AvCT	nCT	BHCT	AvCT	nCT
HU Mean	-165.67	-233.33	-211.11	-536.72	-438.78	-439.67	-658.00	-557.83	-561.44
HU STD	106.60	115.98	77.87	186.40	182.27	191.10	171.82	210.62	192.76
ED Mean	0.85	0.80	0.82	0.48	0.59	0.59	0.37	0.46	0.47
ED STD	0.10	0.11	0.07	0.18	0.18	0.19	0.17	0.17	0.19

ber of CT, to ED values. Uncertainties in the values of HU or ED directly affect dose distributions in the treatment plan. These uncertainties should be reduced both in the target and in the surrounding healthy tissue (especially in the high dose area). Since respiratory movement is restricted with DIBH-CT, these uncertainties are minimized. With DIBH-CT, the ED and HU values were close to the water equivalent of GTV (for water, approximate ED: 1.0 g/cm^3, HU: 0) and close to the lungs except for the GTV (for lung, approximate ED: 0.3-0.6 g/cm^3, HU: –400/–600). The biggest differences in GTV size, HU and ED values were found in tumors located in the lower lobe. In tumors located close to the mediastinum and apex, differences were less between the three techniques.

RT is a treatment for the purpose of protecting the surrounding healthy tissue and organs at the maximum level while the target is irradiated with the optimum dose. For this purpose, the accuracy of the ED and HU values of each point where the radiation interacts is important in order to calculate the dose distribution of the target and its surroundings correctly during the planning. In order for dose calculation algorithms to be able to process correctly, the physical properties of all tissues and organs which the radiation interacts with, that are in the field of view of the radiation, must be correctly identified and uncertainties should be reduced. For this reason, the spherical area of 10 cm in diameter centered on the target volume and the ring area covering 1 cm outer of GTV were formed in our study. ED and HU values for these areas were examined for three different CT imaging. HU and ED values are expected to be low because 1 cm ring area contains more lung tissue. In our study, the lowest HU values were obtained at DIBH-CT. Higher values were obtained in Average-CT and Normal-CT. When the lungs were filled with air with DIBH-CT scans, the ED and HU values were the closest to the lungs. In addition, as a result of their study, Josipovic et al. stated that lung volume increase in DIBH resulted in 6% decreased lung density for stage I and 12% for stage III, and these values are coherent with our results.[15] When the ED and HU values of the GTV and the surroundings are examined with a sphere of 10 cm diameter, it is similar to the results of the ring area formed around 1 cm of the GTV.

Hanley et al., evaluated the dosimetric benefits and feasibility of DIBH-CT technique in the treatment of lung tumors. They examined 4 different CT scan techniques for 5 lung patients. They emphasized two distinct features of the deep breathing technique: deep breathing, which reduces lung density, and holding breath, which stops the motion of lung tumors. Thus, they suggested that PTV margins could be further reduced by this technique. They emphasized that more accurate and more precise treatment could be performed with CT, which was determined in a smaller volume and lung density was lower than other techniques.[16]

Aarup et al., compared dose distributions at 6 MV and 18 MV energies of different dose calculation algorithms at different lung densities in virtual lung phantom. At the center of the lung lobe, a tumor 2 cm in diameter was formed and the lung density was calculated as 0.01, 0.1, 0.2, 0.4 g/cm^3. They were obtained that the target dose for 6MV in the Monte Carlo algorithm ranged from 89.2% to 74.9% and for 18 MV ranged between 83.3% and 61.6% when they were changed the lung density from 0.1 to 0.4 g/cm^3. They were obtained no significant difference in the Pencil Beam algorithm with lung density change.[17]

Fredberg et al. compared tumor volume (GTV) sizes in 3D-CT, 4D-CT and BH-CT scans of patients with lung tumors. A total of 36 patients with 46 tumors referred for SBRT of lung tumors were included in the study. PET / CT, 4D-CT and BH-CT scans were performed in all patients. The GTV size from the BH-CT was considered the closest to true tumor volume and was chosen as the reference. The reference GTV size was compared to GTV sizes in 3D-CT, at mid-ventilation (MidV), at end-inspiration (Insp), and at end-expiration (Exp) bins from the 4D-CT scan. The median BH-CT GTV size was 4.9 cm^3 (0.1 - 53.3 cm^3). Median deviation between 3D-CT and BH-CT GTV size was 0.3 cm3, between MidV and BH-CT size was 0.2 cm3, between Insp and BH-CT size was 0.3 cm^3, and between Exp and BH-CT size was 0.3 cm^3. The 3D-CT, MidV, Insp, and Exp median GTV sizes were all significantly larger than the BH-CT median GTV size.[18]

As a result, distortion and artefacts due to respiratory motion are minimized by DIBH-CT. With DIBH-CT, ED and HU values can be calculated more accurately without being affected by the respiratory motion. According to DIBH-CT, lung density increases in Normal-CT and Average-CT and thus affects the calculation of the dose of healthy lung.[19] The difference in density in healthy lung between Normal-CT and Average-CT is very small, ED and HU values were similar. The closest results were obtained with DIBH-CT, and the biggest difference was obtained with Average-CT according to water equivalent analysis in ED and HU values in GTV. With reference to DIBH-CT, target volume was calculated as 18.4% in Normal-CT and 31.8% in Average-CT.[19-22] It was observed that the differences between the three techniques increased, especially in GTVs located in the lower lobe of the lung. Respiratory-induced differences and uncertainties are always greater in the lower lobe of the lung.[18-22]

The biggest problems of DIBH-CT technique compared to other techniques are that each patient is unable to hold breathing and treatment times are longer. Because DIBH-CT restricts the respiratory motion, we are able to detect GTV in real size. We can identify much smaller target volumes than other CT scanning techniques. Even if Average-CT reduces the chance of missing the target to a minimum, much more healthy tissue protection is achieved with the DIBH-CT technique, which is applied with an accurate and precise technique. With DIBH-CT, we determine the HU / ED values of GTV and healthy tissues more accurately. So we can do more accurate calculations. DIBH-CT increases lung volume and can potentially reduce treatment-related toxicity in locally advanced lung cancer.[23]

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