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Dosimetric comparison of lung stereotactic body radiotherapy treatment plans using averaged computed tomography and end-exhalation computed tomography images: Evaluation of the effect of different dose-calculation algorithms and prescription methods

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ABSTRACT

The purpose of this article is to quantitatively evaluate differences in dose distributions calculated using various computed tomography (CT) datasets, dose-calculation algorithms, and prescription methods in stereotactic body radiotherapy (SBRT) for patients with early-stage lung cancer. Data on 29 patients with early-stage lung cancer treated with SBRT were retrospectively analyzed. Averaged CT (Ave-CT) and expiratory CT (Ex-CT) images were reconstructed for each patient using 4-dimensional CT data. Dose distributions were initially calculated using the Ave-CT images and recalculated (in the same monitor units [MUs]) by employing Ex-CT images with the same beam arrangements. The dose-volume parameters, including D_{95}, D_{90}, D_{50}, and D_2 of the planning target volume (PTV), were compared between the 2 image sets. To explore the influence of dose-calculation algorithms and prescription methods on the differences in dose distributions evident between Ave-CT and Ex-CT images, we calculated dose distributions using the following 3 different algorithms: x-ray Voxel Monte Carlo (XVMC), Acuros XB (AXB), and the anisotropic analytical algorithm (AAA). We also used 2 different dose-prescription methods; the isocenter prescription and the PTV periphery prescription methods. All differences in PTV dose-volume parameters calculated using Ave-CT and Ex-CT data were within 3 percentage points (%pts) employing the isocenter prescription method, and within 1.5%pts using the PTV periphery prescription method, irrespective of which of the 3 algorithms (XVMC, AXB, and AAA) was employed. The frequencies of dose-volume parameters differing by >1%pt when the XVMC and AXB were used were greater than those associated with the use of the AAA, regardless of the dose-prescription method employed. All differences in PTV dose-volume parameters calculated using Ave-CT and Ex-CT data on patients who underwent lung SBRT were within 3%pts, regardless of the dose-calculation algorithm or the dose-prescription method employed.

Introduction

Lung cancer is the leading cause of cancer-related deaths worldwide, and the number of cases of early-stage lung cancer is expected to increase.[1] The standard of care for patients with early-stage lung cancer is surgical resection; however, some patients are medically unable to undergo any type of surgery because of advanced age or the presence of comorbidities.[2,3] Recently, stereotactic body radiotherapy (SBRT), which features delivery of hypofractionated radiotherapy using a stereotactic reference system, has come to play an increasingly important role as a nonsurgical treatment for early-stage lung cancer.[4] Several prospective multicenter clinical trials of SBRT have reported high control rates and favorable outcomes (comparable to those of surgery).[5,6] In multicenter clinical trials, it is wise to standardize treatment processes,

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including the dose-prescription method and the dose-calculation algorithm, among institutions.

Several studies have evaluated the effects of different dose-prescription methods and dose-calculation algorithms on radiation dose distributions and dose-volume histograms (DVHs).[7-9] However, few studies have explored the effects on DVHs of using different computed tomography (CT) images in dose calculations.[10,11] Free breathing (FB) expiratory phase CT (Ex-CT) and averaged CT (Ave-CT) images derived from 4-dimensional CT (4D-CT) data are commonly used in clinical practice to perform dose calculations, but the optimal image dataset for such work remains unclear. Both image sets have advantages and disadvantages. Ave-CT images embrace all respiratory phases. However, motion-blurring artifacts may influence the calculated dose distributions. Ex-CT images, on the contrary, restrict the acquisition of CT data to a single phase of breathing, thereby reducing motion artifacts. However, respiration-driven tumor motion is not taken into account.

We sought to quantitatively assess differences in dose distributions and DVH data obtained using Ave-CT and Ex-CT images for dose calculations, with the beam arrangements and monitor units (MUs) held constant. In addition, we evaluated the effects of different dose-calculation algorithms and dose-prescription methods on differences in dose distributions calculated using the 2 types of images.

Methods

Patients and tumor characteristics

Twenty-nine patients with solitary lung tumors who underwent SBRT were included in the analysis. Tumors were located in the upper lobe in 7 patients, in the middle lobe in 3, and in the lower lobe in 19. The respiration-driven amplitudes of tumor motion were fluoroscopically measured before treatment. The median amplitude was 15.1 mm (range: 3.5 to 46.1 mm). In 2 of the 29 cases, the motion amplitude was $>$ 40 mm.

4D-CT and target delineation

The details of the SBRT planning and treatment processes used in our institution have been described previously.[12,13] Each 4D-CT scan was obtained using a Varian Real Time Position Management Respiratory Gating System (ver. 1.7; Varian Medical Systems, Palo Alto, CA, USA) and a LightSpeed 16 RT CT Scanner with 16 rows of detectors (General Electric Medical Systems, Waukesha, WI, USA); the slice thickness was 2.5 mm in the axial cine mode. The tube voltage and current were set to 120 kV and 100 mA, respectively. The scan length was that of the entire lung. The gantry rotation time was 0.7 s. An interscan delay of 2 s was selected to prevent marker vibration caused by couch movement. Next, 4D-CT slice and respiratory motion data were transferred to an Advantage 4D Workstation (General Electric Medical Systems) and imported to an iPlan RT Image System (Brainlab AG, Feldkirchen, Germany). The 4D-CT datasets were reconstructed by reference to the respiratory phase and then binned into 10 respiratory cycle phases (0% to 90%, with 0% representing maximum inspiration). Ex-CT images were defined as images taken at the midpoints between consecutive inhalation peaks. Ave-CT images were generated by averaging 10-phase CT datasets.

Each internal target volume (ITV) was determined using maximum intensity projection (MIP) datasets derived from 4D-CT images with reference to a 10-phase CT image dataset. When the delineated ITV did not adequately embrace the extent of tumor motion (as revealed fluoroscopically), the ITV was manually expanded based on x-ray fluoroscopy evaluation.[12] Each PTV was determined by adding a uniform margin of 5 mm to the ITV, to allow for setup uncertainties and errors in mechanical accuracy. The tumor characteristics of the PTVs are shown in Table 1. The Ave-CT values of, and the PTVs derived using, Ave-CT data were lower than those obtained when Ex-CT data were employed in 26 patients.

Field setup, dose prescription, and dose-calculation algorithms

We used 6 to 8 noncoplanar static x-ray beams of 6 MV. All plans were calculated using 2 different dose-prescription methods: isocenter and PTV periphery prescription. When employing the isocenter prescription method, we added a leaf margin of 5 mm to the PTV. When using the PTV periphery prescription method, each leaf margin was arranged to fit the 70% isodose line to the 90% level of the PTV (the acceptance criterion was 88% to 92%), and the dose received by 2% of the PTV was required to be $<$ 107%.

Dose distributions were calculated using 3 different algorithms. The first was the XVMC running iPlan RT Dose (ver. 4.5.3; Brainlab AG) and featuring heterogeneity correction. The grid size and the mean variance were set to 2.3 $\times$ 2.3 $\times$ 2.5 mm^3 and 2%, respectively. The second was the Acuros XB (AXB), and the third the anisotropic analytical algorithm (AAA) with a grid size of 2.5 $\times$ 2.5 $\times$ 2.5 mm^3; both algorithms are implemented in the software of the Eclipse treatment planning system (ver. 11.0.31; Varian Medical Systems). Dose distributions were initially calculated using Ave-CT images employing the 2 prescription methods and all of the XVMC, AXB, and AAA (thus, 6 calculations for each case). Next, dose distributions were recalculated using Ex-CT data, the same target volumes, the same beam arrangements, and the same fields and MUs.

Dose-volume histogram evaluation

The differences in PTV dose distribution and DVH data evident when Ave-CT and Ex-CT data were used were measured in each case. The D_{XX} indicates the dose received by XX% of the PTV (thus, D_{95}, D_{90}, D_{50}, and D_2). We also evaluated the effects of tumor size, motion amplitude, and CT target value on differences in dose distributions by calculating Pearson's product-moment correlation coefficients. Differences in dose-volume parameters were compared via analysis of variance.

Results

We calculated the differences in PTV dose-volume parameters (D_{95}, D_{90}, D_{50}, and D_2) by subtracting the parameters derived using Ave-CT data from those obtained employing Ex-CT data collected

Table 1
Tumor characteristics. Data are shown as medians (with ranges) or as numbers of patients

	Median	Number or (range)
Tumor location (upper/middle/lower)		7/3/19
Amplitude (mm)	15.1	(3.5 to 46.1)
PTV		
Volume (cm^3)	64.7	(15.6 to 115.7)
CT value		
Ave-CT image (HU)	−521	(−777 to −228)
Ex-CT image (HU)	−506	(−768 to −166)

Ave-CT image = image generated by averaging 10 computed tomography images; Ex-CT image = image taken at the midpoint between consecutive inhalation peaks; HU = Hounsfield unit.