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DETERMINATION OF CT-TO-DENSITY CONVERSION RELATIONSHIP FOR IMAGE-BASED TREATMENT PLANNING SYSTEMS

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Abstract—The implementation of tissue inhomogeneity correction in image-based treatment planning will improve the accuracy of radiation dose calculations for patients undergoing external-beam radiotherapy. Before the tissue inhomogeneity correction can be applied, the relationship between the computed tomography (CT) value and density must be established. This tissue characterization relationship allows the conversion of CT value in each voxel of the CT images into density for use in the dose calculations. This paper describes the proper procedure of establishing the CT value to density conversion relationship. A tissue characterization phantom with 17 inserts made of different materials was scanned using a GE Lightspeed Plus CT scanner (120 kVp). These images were then downloaded into the Eclipse and Pinnacle treatment planning systems. At the treatment planning workstation, the axial images were retrieved to determine the CT value of the inserts. A region of interest was drawn on the central portion of the insert and the mean CT value and its standard deviation were determined. The mean CT value was plotted against the density of the tissue inserts and fitted with bilinear equations. A new set of CT values vs. densities was generated from the bilinear equations and then entered into the treatment planning systems. The need to obtain CT values through the treatment planning system is very clear. The 2 treatment planning systems use different CT value ranges, one from −1024 to 3071 and the other from 0 to 4096. If the range is correct, it would result in inappropriate use of the conversion curve. In addition to the difference in the range of CT values, one treatment planning system uses physical density, while the other uses relative electron density.

Key Words: **CT scanning, Tissue characterization, Electron density, Treatment planning system, Tissue inhomogeneity.**

INTRODUCTION

Image-based treatment planning has become the standard of practice in radiotherapy.[1–7] Patient data are now acquired within a short time using the new generation fast helical computed tomography (CT) scanners. The CT images are then downloaded into a treatment planning system. At the treatment planning workstation, the CT image set is assigned as the primary set of patient data for treatment planning. Next, the tabletop is removed from the CT images and the external patient contours are extracted using edge-detection technique. In addition, the contours of the internal organs can be identified. Additional tools such as image fusion and co-registration are available to allow visualization of targets seen on other tomographic modalities superimposed onto the CT image set for delineation. Based on this information, a virtual patient can be constructed for 3-dimensional treatment planning. Inverse treatment planning for intensity-modulated radiation therapy can be implemented if the target volumes are drawn, and dose goal and dose constraint objectives are defined for these targets and organs at risk.

Tissue inhomogeneity correction should be applied to have accurate radiation dose calculations, in particular, to the lung. Studies have shown that uncorrected treatment plans can produce radiation dose errors exceeding 30% the prescribed dose.[8,9] The implementation of tissue inhomogeneity correction is facilitated by the availability of image-based treatment planning systems. Here, the tissue inhomogeneity is derived by converting the CT value in each voxel into radiological parameters such as relative electron density or physical density. The CT value and radiological parameter relationship is typically established empirically by scanning a tissue characterization phantom. This paper reports the proper procedure of relating CT values to radiological parameters and implementing them in the treatment planning systems.

METHODS AND MATERIALS

The physical features of the tissue characterization phantom, CIRS Model 062 (CIRS Tissue Simulation Technology, Norfolk, VA), are shown in Fig. 1. It is designed with a height of 270 mm and a width of 330 mm for an abdominal scan. However, it can be separated into a smaller size head phantom with a radius of 90 mm. The holes to accommodate the inserts are arranged in 2 concentric rings with radii of 60 mm and 115.3 mm. Each ring will have 8 holes equally spaced around the

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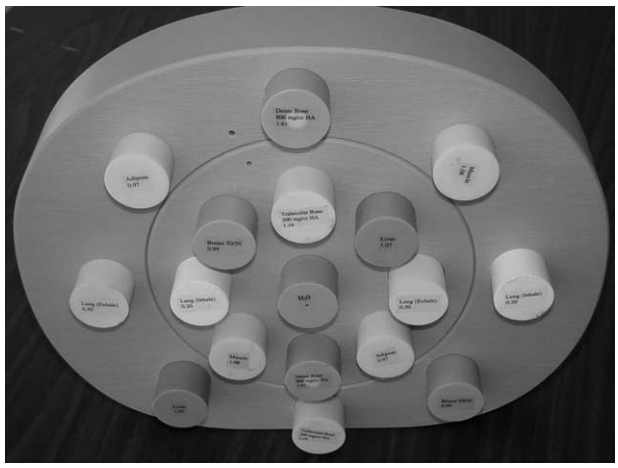

Fig. 1. Physical features of the tissue characterization phantom, CIRS Model 062, capable of adapting for head and body scans.

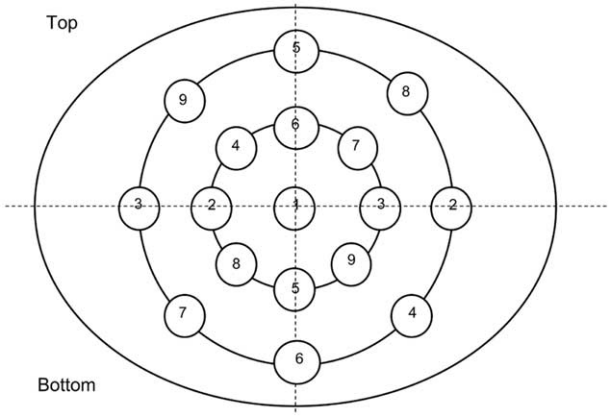

Fig. 2. Arrangement of tissue inserts within the tissue characterization phantom.

ring. There is also a hole at the center of the phantom; hence, it can accommodate a total of 17 inserts.

The commercially available tissue characterization phantom comes with 17 inserts and a titanium insert as an option as listed in Table 1. The relative electron density ranges from 0.190 to 1.512 or correspondingly from 0.195 g/ml to 1.609 g/ml for physical density. Inserts that can accommodate thermoluminescence dosimeters (TLDs) or films are also available upon request. The arrangement of the insert materials is shown in Fig. 2.

The GE Lightspeed Plus scanner is a third-generation (the tube and detector array are attached to the same rotating frame and move simultaneously) multislice scanner with a 70-cm bore size aperture and 496.9-mm scanning field of view (SFOV). It has a 16-row detector system and an 8-row data acquisition system (DAS) to allow for simultaneous acquisition at different longitudinal locations as opposed to single-row detector array of conventional single-slice CT scanners.[10–12] With this system, the scanner provides 8 data rows of output, allowing for simultaneous acquisition of as many as 8 axial images per gantry rotation. The 16-row detector is segmented into 16 physically separated cells in the longitudinal direction to provide post-patient collimation of the x-ray beam. The actual detector cell size is 2.19 mm in the longitudinal direction. The effective cell size is 1.25 mm in the longitudinal direction at the isocenter. These cells in the longitudinal direction can be summed into a "macro-cell" giving the thickness of 1.25 mm (1 cell), 2.50 mm (2 cells), 3.75 mm (3 cells), and 5.0 mm (4 cells). The number of macro-cell in the longitudinal direction forms the macro-row. The maximum scanned width for a 16-row detector would be 20 mm (4 × 5.0 mm). The scanner has a shorter focal spot to imaging isocenter distance of 541 mm compared to 630 mm in a single-slice scanner. The focal spot to detector distance is 949 mm. The system is equipped with large and small focal spots with dimensions of 1.2 × 1.2 mm and 0.9 mm × 0.7 mm, respectively.

Table 1. Tissue descriptions and densities

Materials	Location in Figure 2	Physical Density (g/ml)	Relative Electron Density
Syringe water	1	1.000	1.000
Lung (inhale)	2	0.195	0.190
Lung (exhale)	3	0.495	0.489
Breast (50/50)	4	0.991	0.976
Dense bone 800 mg/ml HA	5	1.609	1.512
Trabecular bone	6	1.161	1.117
Liver	7	1.071	1.052
Muscle	8	1.062	1.043
Adipose	9	0.967	0.952
Titanium		4.507	3.735

The scanner has the ability to generate images of various thickness, made possible with the helical scanning mode. However, the image thickness is dependent on the pitch, which is defined as the ratio of the table travel per gantry revolution to the beam collimation and number of detectors in a macro-row. For example, if a scanning of 4 slices is obtained using 4 detector macro-row × 2 pitches, then reconstruction of images of thickness from 1× to 4× the detector macro-cell size is possible.

Before performing the CT scan, the tissue characterization phantom was set up such that the laser passed through the center of the phantom. Next, the scanning table was arranged such that the internal CT laser passed through the center of the phantom; the CT scanner was then set to zero. A typical scanning parameter of 120 kVp used in standard scanning protocols with 5-mm slice thickness was used. After the scan, CT images of the tissue characterization phantom were downloaded into the network and forwarded to the Varian Eclipse and the Philip Pinnacle treatment planning systems.

At each treatment planning system, these CT images were converted into treatment planning images. The