Physica Medica xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Physica Medica

journal homepage: http://www.physicamedica.com

Original paper

Identification of elemental weight fraction and mass density of humanoid tissue-equivalent materials using dual energy computed tomography

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A R T I C L E I N F O

Article history:
Received 29 September 2016
Received in Revised form 9 May 2017
Accepted 18 May 2017
Available online xxxx

Keywords:
Dual energy CT
Elemental weight fraction
Mass density
Monte Carlo simulation

A B S T R A C T

The purpose of this study was to obtain the fraction by weight of the elemental composition and mass density of a humanoid tissue phantom that includes lung tissue, soft tissue, and bone tissue, by using dual energy computed tomography (DECT). The fraction by weight and the mass density for tissue-equivalent materials were calculated by means of a least-squares method with a linear attenuation coefficient, using monochromatic photon energies of 10–140 keV, as obtained from DECT. The accuracy of calculated values for the fractions by weight of H (hydrogen), C (carbon), N (nitrogen), and O (oxygen) as verified by comparing the values with those that were analyzed using the combustion technique. The fraction by weight for other elements was confirmed by comparing with the analyzed values by means of energy dispersive photon spectroscopy. The calculated mass densities for each tissue were compared with those that were obtained by dividing the weight by volume. The calculated values of the fraction by weight that were obtained by means of DECT had differences of 1.9%, 9.2%, 6.6%, 7.8%, 0.8%, and 0.2% at a maximum for H, C, N, O, P (phosphorus), and Ca (calcium), respectively, from the reference values analyzed by the combustion technique and energy dispersive photon spectroscopy. The difference in the mass density for tissue was 0.011 g/cm^3 at a maximum. This study demonstrated the fraction by weight and the mass density of the humanoid tissue-equivalent materials that were calculated by means of DECT were expected high accuracy.

1. Introduction

The Monte Carlo method and Linear Boltzmann transport equation, based on theoretical concepts have been employed for current dose calculation algorithms in radiation therapy [1,2]. The calculational accuracy of these algorithms depends on uncertainties in the fraction by weight of the elemental composition and the mass density that are input as data for humanoid tissues [3,4], which are based on ICRU and ICRP reports [5,6]. The fraction by weight and the mass density are unambiguously determined by converting CT images to media maps and mass density, after which the fraction by weight for each tissue is constant for individual patients [1,2].

Recently, several studies have been conducted to calculate the fraction by weight and the mass density for humanoid tissues using dual energy computed tomography (DECT) [7,8]. DECT is capable of correcting image artifacts caused by scattered radiation and beam hardening from high atomic number materials such as bone tissue, by using projection data from water and iodine that have been scanned with DECT [9]. As the results indicate, DECT can determine a more accurate CT number compared to single energy CT (SECT), and this has been used to calculate the fraction by weight and the mass density for humanoid tissues [8,10].

Bazalova [8] reported the method of material extraction for solid water phantoms with 17 different tissue-equivalent materials, including air, lung, soft tissues, and bones, by analyzing the

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http://dx.doi.org/10.1016/j.ejmp.2017.05.060
1120-1797/

Please cite this article in press as: Shimomura K et al. Identification of elemental weight fraction and mass density of humanoid tissue-equivalent materials using dual energy computed tomography. Phys. Med. (2017), http://dx.doi.org/10.1016/j.ejmp.2017.05.060

effective atomic number and relative electron density for the tissue-equivalent materials by means of DECT. However, the elemental weight fraction is not presented in their study. Hünemohr [10] described a method of predicting elemental weight fractions for H (hydrogen), C (carbon), N (nitrogen), O (oxygen), P (phosphorus), and Ca (calcium) and mass density for 71 tissues, with the exception of lung tissue, by using a linear regression analysis from the effective atomic number and relative electron density obtained through DECT. The errors in predicted elemental weight fractions of C, O, and other elements were 10.2%, 12.1%, and less than 2.5%, respectively. Their method is more accurate and universal than that of Bazalova [8], but cannot predict the elemental weight fraction for the low electron density materials such as lung tissue, through the linear regression analysis.

Our present study calculated the elemental composition in fraction by weight and the mass density of a humanoid tissue phantom that includes lung tissue, soft tissue, and bone tissue, by using DECT. The elemental weight fraction and the mass density were calculated based on the least-squares method using a linear attenuation coefficient, and with monochromatic photon energies of 10–140 keV, as obtained from DECT.

2. Materials and methods

In this study, the fraction by weight for the elemental composition and mass density of a humanoid tissue phantom that includes lung tissue, soft tissue, and bone tissue were obtained by using

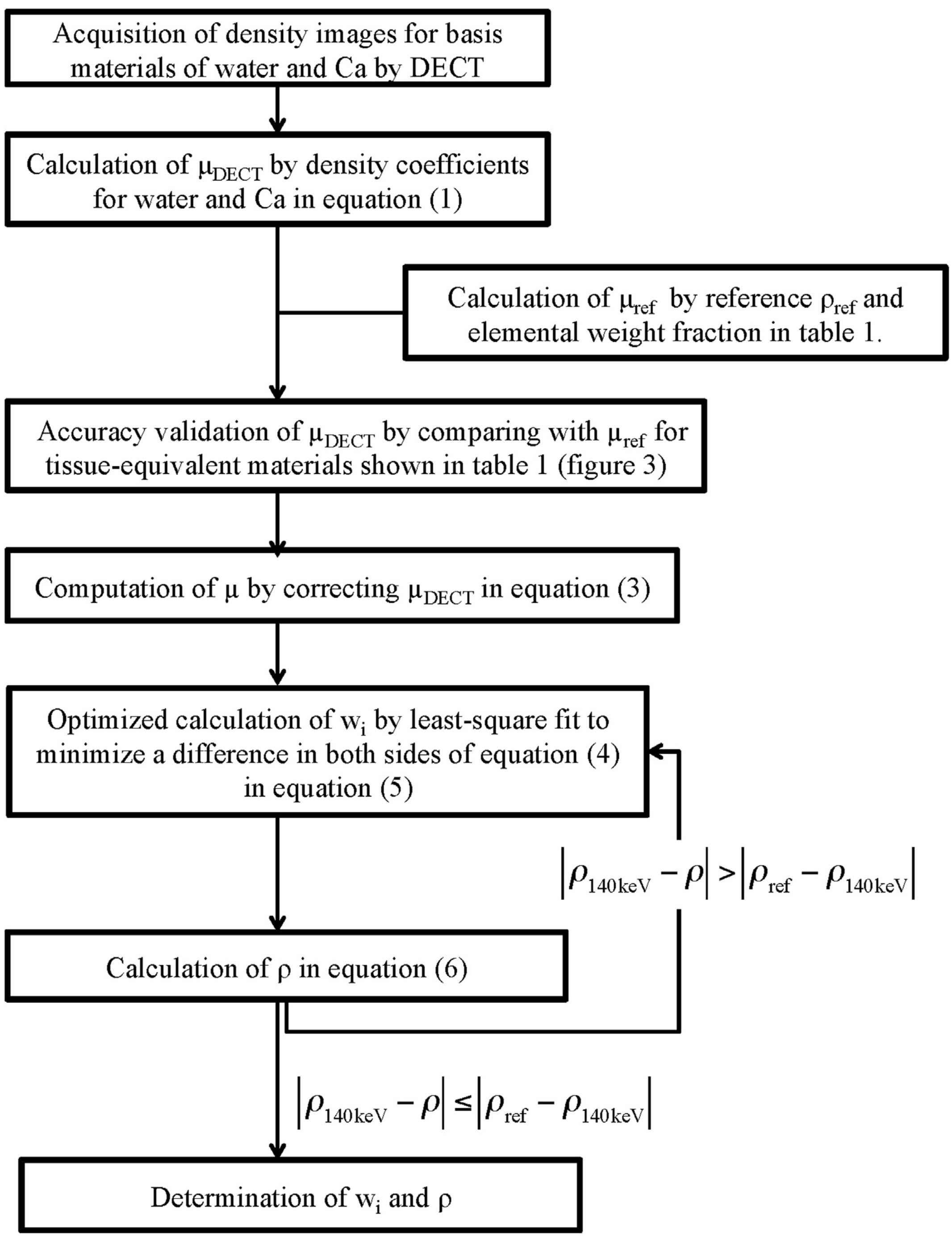

Fig. 1. Flowchart to obtain the fraction by weight and mass density for tissue-equivalent materials.