Journal of Cardiovascular Computed Tomography 10 (2016) 265–268

Contents lists available at ScienceDirect

Journal of Cardiovascular Computed Tomography

journal homepage: www.JournalofCardiovascularCT.com

Short communication

A pilot study of patient-specific cardiovascular MDCT dose maps and their utility in estimating patient-specific organ and effective doses in obese patients

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ARTICLE INFO

Article history:
Received 21 April 2015
Received in revised form
29 December 2015
Accepted 21 January 2016
Available online 22 January 2016

Keywords:
Monte Carlo
Organ dose
Effective dose
Dose-length product

ABSTRACT

Background: Estimates of effective dose (E) for cardiovascular CT are obtained from a scanner-provided dose metric, the dose-length product (DLP), and a conversion factor. These estimates may not adequately represent the risk of a specific scan to obese adults.
Objective: Our objective was to create dose maps sensitive to patient size and anatomy in the irradiated region from a patient's own CT images and compare measured E ($E_{DoseMap}$) to doses determined from standard DLP conversion (E_{DLP}) in obese adults.
Methods: 21 obese patients (mean body mass index, 39 kg/m^2) underwent CT of the pulmonary veins, thoracic aorta, or coronary arteries. DLP values were converted to E. A Monte Carlo tool was used to simulate X-ray photon interaction with virtual phantoms created from each patient's image set. Organ doses were determined from dose maps. $E_{DoseMap}$ was computed as a weighted sum of organ doses multiplied by tissue-weighting factors.
Results: E_{DLP} (mean ± SD, 5.7 ± 3.3 mSv) was larger than $E_{DoseMap}$ (3.4 ± 2.4 mSv) (difference = 2.3; $P < .001$).
Conclusion: Dose maps derived from patient CT images yielded lower effective doses than DLP conversion methods. Considering over all patient size, organ size, and tissue composition could lead to better dose metrics for obese patients.

1. Introduction

Concern about potential health risks of ionizing radiation-based medical imaging, particularly CT[1] have created demand for improved estimation, reporting, and recording of CT radiation dose. The effective dose (E), in units of millisieverts (mSv), is a dose descriptor that reflects the relative biological sensitivity of irradiated organs and tissues. E has traditionally been computed for CT using sophisticated Monte Carlo (MC) methods to simulate the transport of ionizing radiation through the body[2,3]. A 70-kg mathematical reference phantom with organs characterized as simple geometric shapes is typically used to represent all adults[4].

In the clinical setting, a practical method for estimating E uses scanner-provided dose-length product (DLP) values and published DLP conversion factors[5] for different body regions. Scanner-reported DLP values for adult scans are the product of the irradiated scan length and the volume CT dose index ($CTDI_{vol}$) obtained from a 32-cm diameter cylindrical polymethyl methacrylate phantom. The DLP conversion factors for adults are generated using the standard 70-kg mathematical reference phantom without regard for differences in sex, body habitus, and scanner type.[2]

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http://dx.doi.org/10.1016/j.jcct.2016.01.011
1934-5925/

Patient-specific 3D anatomical dose maps generated by performing MC simulations on virtual phantoms created from a patient's own CT data have the potential to better represent the population of obese adults and overcome some limitations of standard methods for estimating E. The primary aim of this study was to estimate organ and effective doses from patient-specific dose maps ($E_{DoseMap}$) and compare to doses determined from standard DLP conversion methods (E_{DLP}) in obese adults undergoing cardiovascular CT.

2. Technical methods

This retrospective study was approved by our institutional review board with waiver of informed consent. Twenty-one obese patients (24–73 years; 10 women) with body mass index (BMI) ranging from 30 to 61 kg/m^2 imaged for evaluation of the thoracic aorta (n = 9), pulmonary veins (n = 9), or coronary arteries (n = 3) were included in the study.

2.1. CT imaging

Data were acquired after contrast injection (75–90 mL, 370 mgI/mL [Ultravist 370, Berlex, Montville, NJ]) using prospectively electrocardiogram-triggered axial techniques with a gantry rotation time of 270 ms on a 256-slice CT scanner (Brilliance iCT, Philips Healthcare, Cleveland, OH). Tube potential (100 or 120 kVp) and tube current-time product (80–295 mAs) were selected depending on patient size and imaging target. Data acquisition was centered at 75% of the RR interval for aortic evaluation and at 40% for pulmonary vein evaluation. For the coronary arteries, data acquisition was centered at 75% RR and widened ± 5% to allow additional reconstructions from 70–80% RR. Images used for dose map creation were reconstructed with a 500-mm field-of-view. $CTDI_{vol}$ and DLP values were recorded.

2.2. Dose map creation

Patient-specific dose maps displaying pixels with values representing the absorbed dose of corresponding tissue voxels were created from patient datasets using a previously validated MC simulation tool (Diagnostic Photon Simulation [DiPhoS], Philips Research, Eindhoven, Netherlands). The MC simulations modeled the entire imaging chain including the generation of x-rays, modification of x-rays through processes such as beam shaping and filtering, and the propagation of x-ray photons through the body.

A patient-specific virtual phantom was created by voxelizing each patient's image set. Each voxel was classified as 1 of 6 material types based on fixed Hounsfield unit (HU) thresholds: air (−1000 HU), lung (−930 HU), adipose tissue (−200 HU), soft tissue (+5 HU), skeletal muscle (+40 HU), cortical bone (+400 HU). Stoichiometry was used to compute the mass attenuation coefficient for each material type and applied x-ray spectrum. Each voxel was assigned a mass density estimate based on its measured HU value and calculated mass attenuation coefficient[6]. The mass of tissue within a given voxel was then computed from the mass density and voxel size. For each virtual phantom, the paths of individual x-ray photons through irradiated tissue were modeled with MC methods based on known physical interactions (Rayleigh scattering, Compton effect, photoelectric effect) specified by probability distributions, which described the photon's interaction, transport, and energy deposition. The energy (Joules) deposited in each voxel was tallied in a corresponding voxelized grid and divided by the mass (kg) of irradiated tissue to determine the $CTDI_{vol}$-normalized absorbed dose per voxel. Normalized absorbed dose was multiplied by the scanner-provided $CTDI_{vol}$ (mGy) to obtain absorbed dose (mGy).

2.3. Organ segmentation

Radiosensitive organs in the scan range (skin, lungs, breasts, stomach, liver, esophagus) were manually segmented from dose maps by 2 consulting observers (C.T., K.Y.) to determine the average absorbed dose for each organ. For partially exposed organs (eg, stomach and liver), dose to the portion of the organ within the scan range was based on measurement from dose maps and dose to the portion outside the scan range was estimated using an extrapolation model.

2.4. Effective dose calculation

E_{DLP} was determined by multiplying the clinically accepted standard conversion factor (k) for the chest[5], 0.014 mSv × mGy^{-1} × cm^{-1}, by the scanner-provided DLP: E_{DLP} = DLP × k. For comparison, $E_{DoseMap}$ was determined by multiplying individual organ doses (OD) measured from dose maps by the appropriate tissue-weighting factor (w)[7] and summing over all organs(i): $E_{DoseMap} = \Sigma OD_i \times w_i$.

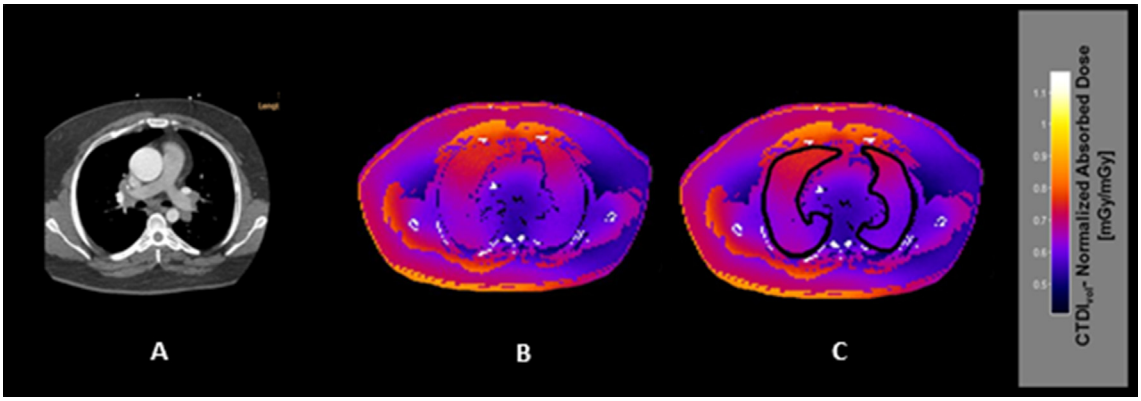

Fig. 1. An example of an axial CT attenuation image (A), the corresponding dose map displaying volume CT dose index ($CTDI_{vol}$)-normalized absorbed dose values (mGy/mGy) (B), and dose map with lung segmentation indicated by black contours (C) for a male patient with a body mass index of 45 kg/m^2. The patient was imaged with a prospective electrocardiogram-triggered axial technique at a tube potential of 120 kVp for evaluation of the thoracic aorta. The dose map shows nonuniformity (more dose accumulation on the patient's left side) because at this slice position, the x-ray tube was positioned such that x-rays entered that portion of the patient twice during the 400° rotation required for data acquisition.