

## **A PROJECT TO DESIGN A SOFTWARE PACKAGE FOR REPORTING MULTIDETECTOR CT (MDCT) DOSES**

**Aiping Ding<sup>1,2</sup>, Jianwei Gu<sup>1</sup>, Haikuan Liu<sup>1,3</sup>, Peter F. Caracappa<sup>1</sup>, George Xu<sup>1,\*</sup>**

1. Nuclear Engineering and Engineering Physics Program

Rensselaer Polytechnic Institute  
110 8<sup>th</sup> St, Troy, NY 12180 USA

[xug2@rpi.edu](mailto:xug2@rpi.edu)

2. Institute of Plasma Physics  
Chinese Academy of Sciences  
Hefei, Anhui, 230031 China

3. Institute of Radiation Medicine  
Fudan University  
Shanghai, 200032 China

### **ABSTRACT**

Computed tomography (CT) has established itself as one of the most significant diagnostic technologies. The advent of the multidetector CT (MDCT) has made it possible to capture images to create 4D motion images for cardiac and respiratory diseases. As its usage grows, more concerns about the potential radiation risk to patients associated with various CT scanning protocols have raised from the medical imaging community and patients. This paper describes the effort to develop a modern software package to estimate and report the organ dose and effective dose values for patients undergoing the CT examinations. Original dose data were derived from a large number of Monte Carlo (MC) simulations based both on the ICRP 60 and ICRP 103 tissue-weighting coefficient using MCNPX v2.5, involving detailed CT scanner models and anatomically realistic phantoms. Detailed CT scanner X-ray sources and protocols are considered in the Monte Carlo simulations. Several of CT scanner series and different operated tube voltage have been taken into consideration. The RPI Pregnant Women (RPI-P3, -P6 and -P9) and RPI Adult Male (RPI-AM) and Adult Female (RPI-AF) are utilized as the phantom models. The software is being developed using the Visual C#.NET platform with a graphical user interface (GUI) designed to allow a user to specify the patient type, body scan region, and scanner operating parameters. Using the object-oriented programming technology, 3D phantoms are displayed interactively to improve the user interaction with software functions. The organ dose and effective dose are rapidly archived and reported in the software according to the user-specified protocols.

*Key Words:* CT, organ dose, effective dose, phantom, report.

### **1. INTRODUCTION**

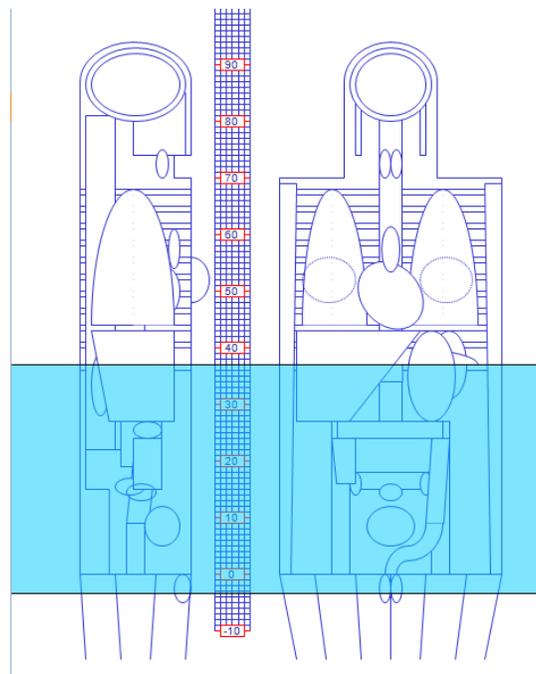
Computed tomography (CT) has experienced tremendous technological advances in recent years and has established itself as the most significant diagnostic imaging modality. The advent of the

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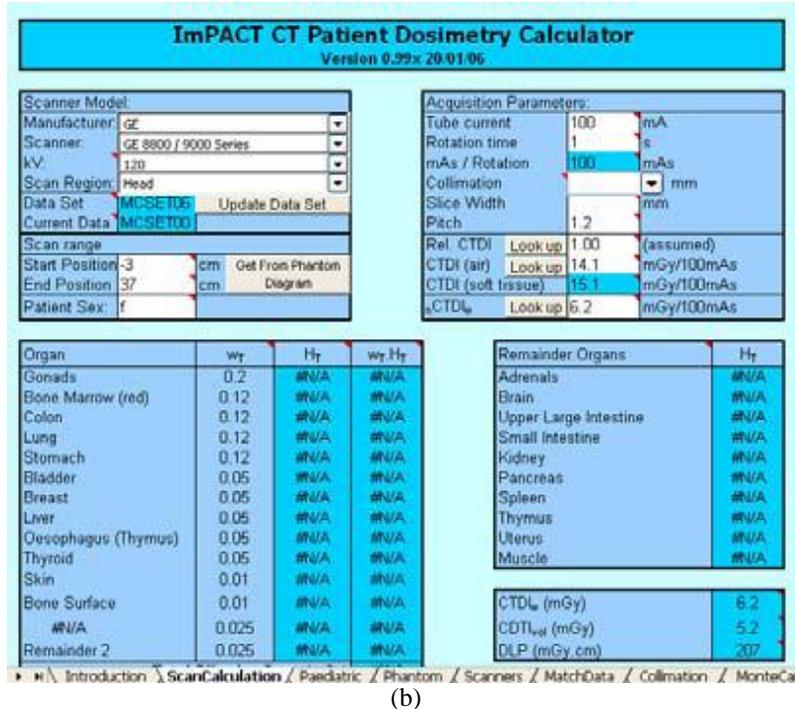
\* Corresponding author

multidetector CT (MDCT), in particular, has made it possible for the first time to capture images at a fast enough speed to create 4D motion images for cardiac and respiratory diseases [1]. However, MDCT scanning procedure delivers a relatively higher dose to the patients in comparison with standard radiographic procedures and older CT modalities. Although CT scans constitute only 4% of all medical examinations, it is estimated that CT doses contribute a remarkable 40% of the collective effective dose for all medical examinations [2]. Due to the increasingly frequent use of MDCT technology, more and more concerns about the radiation risk to patients from the radiation exposures associated with various CT scanning protocols have been raised from the medical imaging community and regulatory bodies [3, 4, and 5].

Therefore, an accurate and easy-to-use dose estimation and reporting software is a very useful tool for both the medical physics community and patients. Existing software packages for organ doses from CT examinations, such as ImpACT developed by ImpACT group [6], ImpactDose from VAMP [7], CT-Dose available in Denmark [8] and CT Expro [9] are all based on the stylized patient phantoms that contain overly simplified anatomies. Fig.1.a shows a screen shot of such simplified phantom. When compared with those voxel phantoms based on whole-body anatomical images, the stylized phantoms result in significantly different organ doses. Although some of these programs allow a user to generate the organ dose data, the effective dose calculations employed in these packages were based on the algorithms recommended in the ICRP 60 [2] which has been outdated after the recent release of the ICRP 103 [10]. Furthermore, some of these software packages do not include many latest MDCT scan machines and anatomical realistic patient phantoms and all were developed based on the old-fashioned programming features and even one package was entirely a spreadsheet based on the excel, as shown in Fig.1.b.



(a)



(b)

**Figure1. A screen shot of the ImpACT Program: (a). Simplified phantom (b). the user interface**

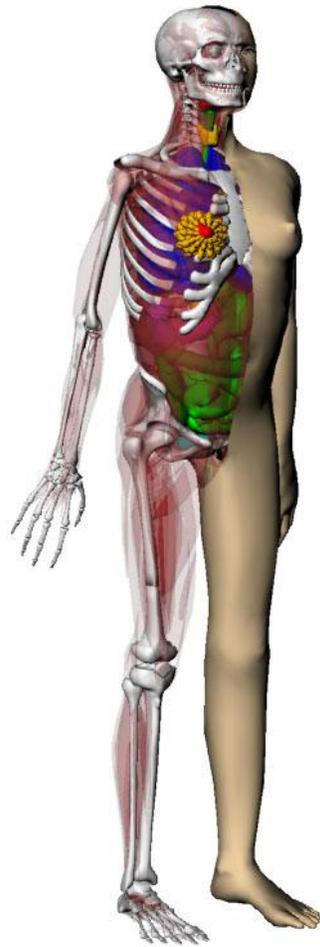
This paper describes a study that aims to develop a modern and easy-to-use software that estimates and reports the organ dose and effective dose values for patients who undergo the arbitrary MDCT examinations.

## 2. MATERIAL AND METHODS

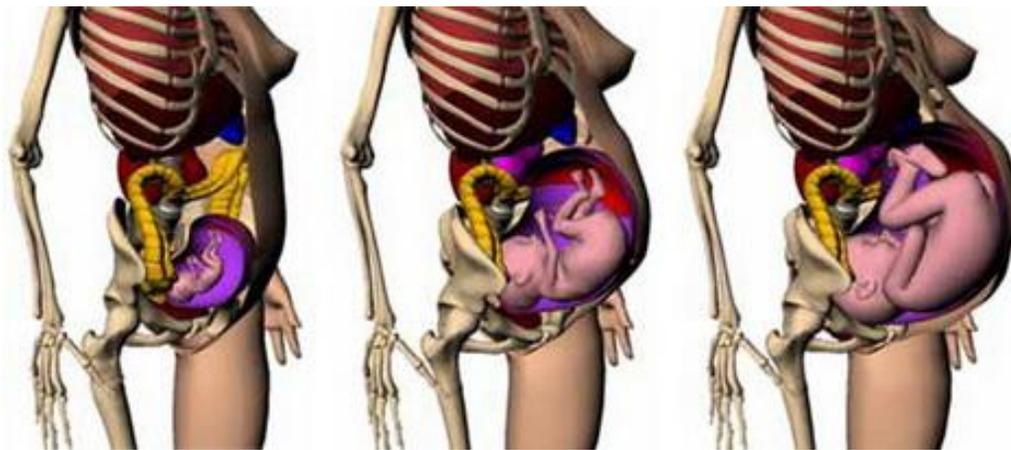
### 2.1. Phantom Models

In this study, the detailed distribution of radiation doses to different organ/tissues in the voxel phantoms are derived from a very large number of Monte Carlo (MC) simulations using the anatomical phantoms developed from medical images at RPI. Two types of realistic computational voxel phantoms were utilized in this study: 1).The RPI Pregnant Women (RPI-P3, -P6 and -P9) [11]; 2).RPI Adult Male (RPI-AM) and Adult Female (RPI-AF) [12]. Figure 2a shows these phantoms in 3D mode. All these phantom models are designed to match the ICRP anatomical references for average individuals and are more realistic approximation and provide more accurate results than stylized or mathematical models. Organ volumes and masses were carefully adjusted to agree with reference values recommended in the ICRP Publication 89 [13].A total of 28 materials were assigned to define the organs or tissues. The reference value of elemental organ or tissue compositions as well as mass densities was matched to ICRU Report 46[14].For the pregnant phantom model, the particular emphasis was placed on developing a realistic representation of fetus that consists of the skeleton (except for the 3-month phantom), brain, and soft tissue. All mesh-based phantoms, as shown in Fig.2.(a), were eventually converted to the voxel model with a resolution of 3 mm x 3 mm x 3 mm, and each phantom

contains a total of about 25 million voxels. The voxelized phantoms were finally implemented into MCNPX for organ dose calculations.



(a)



(b)

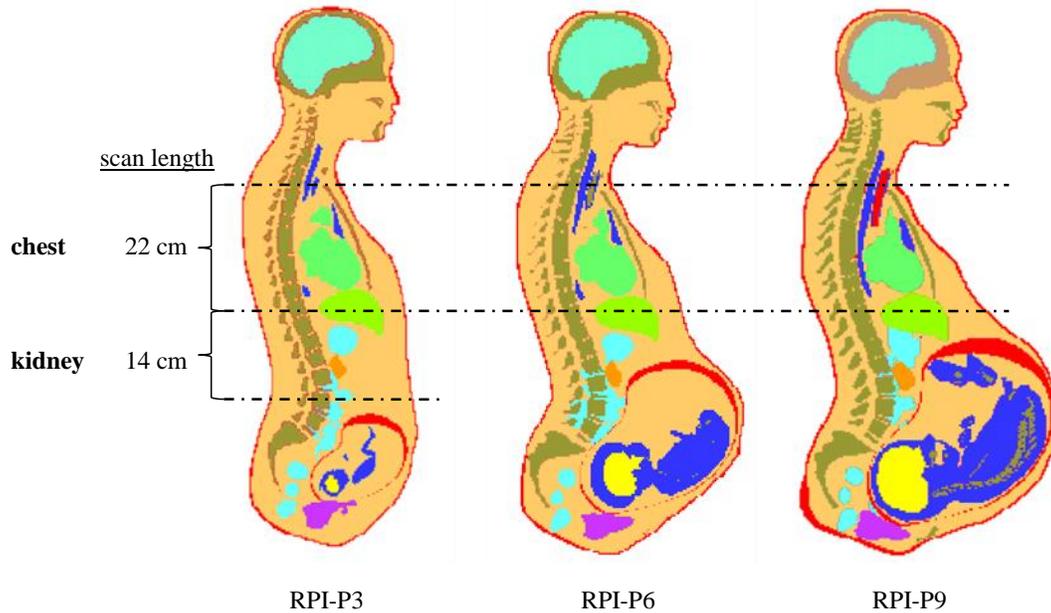
**Figure2. Illustration of the difference between (a) mesh-based RPI Adult male phantom and (b) mesh-based RPI-P3, RPI-P6 and RPI-P9 phantoms at the end of three gestational periods of 3, 6 and 9 months**

## 2.2. CT Scanner

The detailed CT scanner involving x-ray sources and scanning protocols are considered in the Monte Carlo simulations. A MDCT scanner (LightSpeed 16, General Electric Healthcare Corporation, Waukesha, WI) has been modeled with the detailed description of the source geometry and movement, the energy spectrum, the bow-tie filter as well as the beam shape [15]. Different operating tube including 80kVp, 100kVp, 120kVp and 140kVp, were also taken into consideration. The distance from the source to isocenter is 54cm, the fan angle of beam is  $55^\circ$ , and the nominal beam width at the isocenter is 20mm. The filter is aluminum. For the other scanners, made by GE, Philips, Siemens, and Toshiba, a matching parameter, named the ImPACT Factor (ImF), is used. ImF is a ratio of measured values determined by a particular CT scanner and kVp [16]. Good correlation was shown between effective dose (normalized to on-axis, free-in-air dose) and ImF. The relative difference between measurement and ImF data was normally within  $\pm 10\%$ . Therefore, ImF can be used as a correction factor of different scanners, allowing the calculation of the organ dose and effective dose of any new CT scanner. Scanner technical parameters (mAs, pitch, and collimation) that affect the calculation of patient radiation doses are also considered in this software.

## 2.3. Organ Dose Calculations

The organ dose data set was established by Monte Carlo (MC) simulations using CT scanner and anatomical phantoms. As an example, Fig.3 illustrates the selections of two types of scanning range for simulations. The chest scan was performed for RPI-P3,-P6 and -P9 phantoms, and the kidney scan was performed for RPI-P3. The MCNPX 2.5 code was adopted as the simulation tool [17]; a series of simulations were performed to calculate organ dose to adult female and male phantoms, as well as a set of pregnant patient phantoms. For each of the CT exam simulations, a total of 10 million initial photons were run to ensure statistical uncertainties less than 5% for the organs in the field of view. The organ or tissues doses were calculated using the track-length cell energy deposition tally (F6: p).



**Figure3. RPI-P3, RPI-P6 and RPI-P9 phantoms at the end of three gestational periods of 3, 6 and 9 months, respectively. The anatomic coverage of the chest scan ranged from just above the clavicle bone down to below the diaphragm (around the middle of the liver). The anatomic coverage of the kidney scan was performed only for the RPI-P3 phantom and was ranged from above the middle of the liver to below the bottom of the left kidney.**

#### 2.4. Design of Software Framework

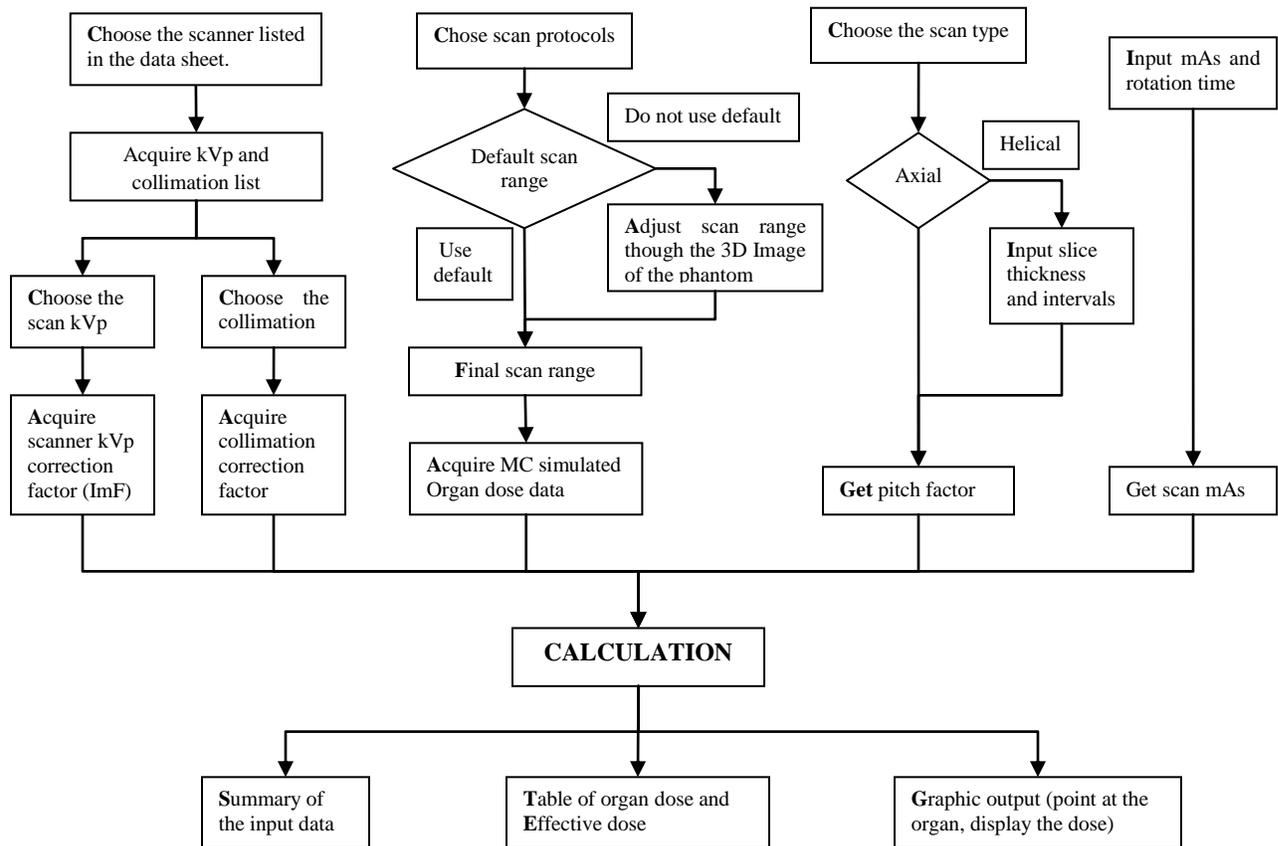
The software package is designed to estimate and report the organ dose and effective dose easily and accurately. All the related organ doses are incorporated into a dose database, which was compiled using Microsoft SQL server 2005[18] based on multiple sets of organ dose data derived from Monte Carlo simulations. Combined with the additional knowledge of the scanner parameters, such as the axial scan range, the scan pitch, the tube current and scanning time in milliamp-seconds (mAs), the tube, the software package embedded with this database was designed to be a user-friendly tool for evaluating the radiation risk to the patient.

The software framework was developed using Microsoft .NET platform [19]. Microsoft .NET is based on object-oriented paradigm and provides powerful ability to integrate different Microsoft development integrated development environment (IDE) together and share the code among others development tools. The Microsoft Visual Studio 2005 is an efficient and advanced object-oriented development tool. As part of the Visual Studio 2005, the Visual C#.NET [20] was used as the major programming language in the development of the graphical user interface (GUI).

In this work, the 3D phantoms are displayed in real-time in the main window using resources from the Visualization Toolkit (VTK), an open-source toolkit for performing image processing, and visualization [21].The GUI is designed to allow a user to specify the patient type, body scanning region, and various scanner operating parameters. Using the object-oriented

programming technology and VTK, 3D phantoms are displayed interactively to improve the user interaction with the software functions.

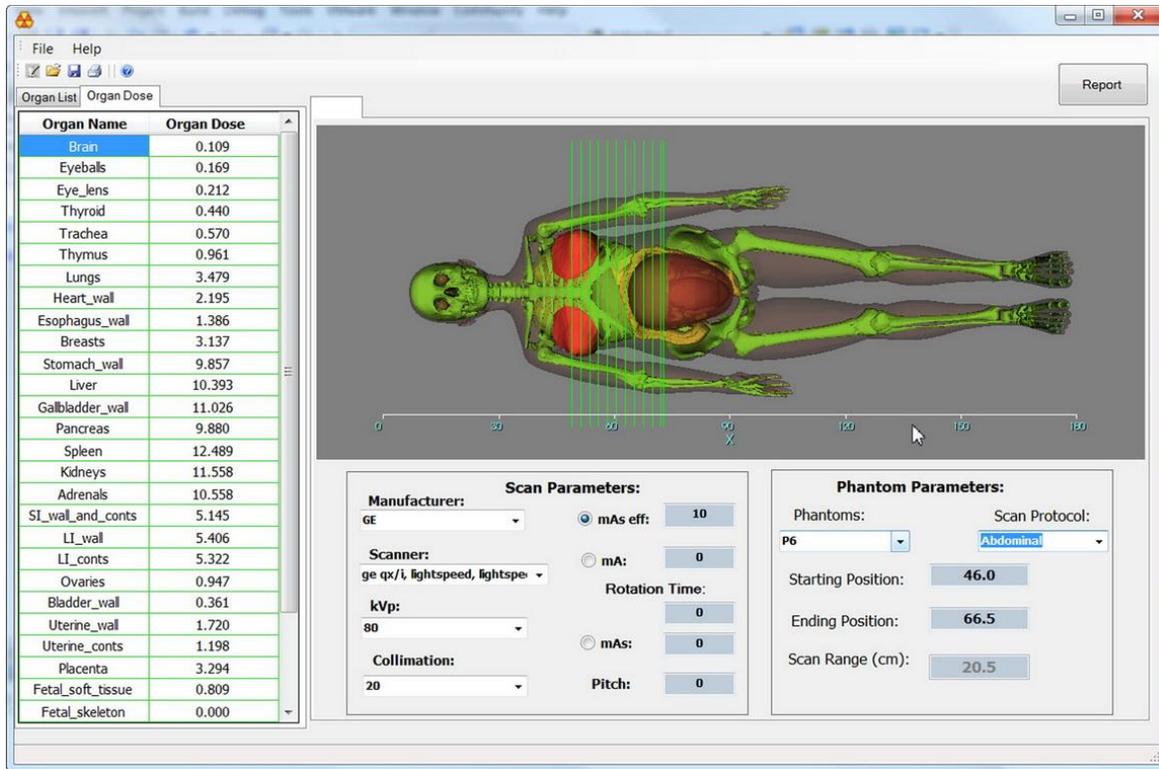
According to the user-specified scanning protocols and parameters, the organ doses and effective doses are rapidly archived reported on the GUI. The flowchart of the MDCT dose reporting software design is illustrated in Fig.4.



**Figure 4. The design flowchart of MDCT dose reporting software.**

### 3. RESULTS

A software package for CT dose reporting is developed in this study and offers a user-friendly graphical interface, as shown in the Fig. 5, on which a phantom is chosen by user and is displayed in a 3D rendering mode.



**Figure 5. Screen shot of the GUI showing the pregnant patient in 3D. The scanning range can be specified by the user selecting protocols from a pull-down menu or by drawing directly on the phantom. Organ doses are displayed instantly on the left panel of the screen.**

The software includes the following features:

1) User Input Parameters:

- CT Manufacturer
- type of scanner listed in the GUI
- scan type (Axial or Helical)
- kVp for the scanner.
- collimation for the scanner
- mAs and rotation time
- phantom type
- pitch factor (for axial canner slice thickness and intervals are required)
- scanning range on the 3D patient phantoms displayed on the GUI directly
- scanning protocols from a drop-down Combo box

2) Software Report:

- Summary of the input parameters data

- Tabulated results of the organ dose and tissue weighting factors, as well as the effective dose
- Graphic output illustrating organ and associated effective dose

The GUI design and features of this software improves upon existing tools by considering the latest CT scanners, new ICRP recommendations and anatomically realistic patient phantoms. A user can also initialize the scanner type and scan parameters, like mAs, pitch and collimation in the interface. The scan range can be defined interactively by user using mouse to draw the scanning lines above the 3D phantom or be specified automatically by choosing the protocols from a protocols list menu. The following scan protocols are available now in the GUI: head, neck, chest, abdominal, kidney and pelvis. The organ dose and effective dose are rapidly archived and tabulated on the data grid panel embedded on the GUI. Effective dose values are calculated based both on the ICRP 60 and ICRP 103 tissue-weighting coefficients, respectively. After calculation, the software will automatically summarize the input data with the selected scan parameters in the interface and output a table covering the organ doses and effective dose in Microsoft Word documentation (.doc) format. The reporting results suggest that the organ dose estimates can be different by a ratio as great as 0.77 to 1.24 for the organ or tissue covered in the scan range, and 0.13 for the organ out of the scan region between our calculations using the RPI series of voxel phantoms and those derived from the stylized MIRD-type phantoms.

#### **4. CONCLUSIONS**

MDCT is expected to increase the overall radiation exposure to the patient population in the future. The increasing concerns about the radiation risk require a tool for estimating and reporting dose that includes the latest MDCT machines and anatomically realistic patient phantoms. This paper has described our efforts to develop an easy-to-use software program to accomplish this. Models of various MDCT scanners and adult male/female, as well as pregnant patients were used to perform a large number of Monte Carlo calculations. Also used were models of the x-ray sources in the MDCT scanners, as well as models of the scan procedure. The methods employed in this software improve upon existing software in two aspects: it considers the latest MDCT scanners and the patient anatomy represented by anatomically realistic phantoms. Object-oriented programming allows a user to interactively and visually select a number of parameters. The dose reporting features, which are refined, are expected to facilitate dose documentation, dose analysis and expected to improve both the accuracy and usability in reporting CT doses in the future.

#### **ACKNOWLEDGMENTS**

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