Calculating organ doses of patients in spiral CT using EGS4 Monte-Carlo simulation of voxel phantom

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Abstract. According as the progress of medical technique, X-ray imaging systems have been progressed. Especially, X-ray CT imaging system have been improved and widely used as general diagnostic methods nowadays in Japan. However, the doses for patients of X-ray CT imaging are relatively higher than of other X-ray examinations. The dose estimations and optimizations on X-ray CT are very important for medical radiation protection, so that we estimated organ doses on spiral X-ray CT imaging by the method of Monte-Carlo simulations. A voxel phantom of a Japanese male developed in JAERI was used for the simulations. As Monte-Carlo simulation code, EGS4 was selected. The organ doses for X-ray CT imaging of lungs and liver have been calculated with the same conditions as the actual X-ray CT diagnoses in a hospital. For conventional CT imaging, the doses for each slice have also been estimated. They could be helpful for risk estimations of X-ray CT examinations.

1. Introduction

Since X-ray CT machine was invented in 1968, CT machines have been used for many medical fields as powerful and useful means for diagnoses. Until now, medical and electric technologies have been greatly improved including X-ray CT, and many types of CT have been developed. Recently, they have become to be general diagnostic methods, and been widely used in many hospitals and clinics. As generally using, the methods have applied for a lot of diagnoses, and begun to use combining other technique such as angiography. The number of patients has also been increasing.

On the other hand, the doses of patients on X-ray CT imaging are higher than other general X-ray diagnoses. On the viewpoint of radiation protection, the optimizations of X-ray CT imaging are very important. However, it is not easy to estimate patients’ doses by direct measurements using dosimeters. The CTDI method is used as the means of estimating diagnostic reference levels for the optimization of X-ray CT imaging [1]. It is actually practical, but not enough for the estimation of patients’ dose as equivalent or effective dose.

For the purpose of dose estimations, direct measurements on X-ray examinations have been performed using physical phantoms and dosimeters. Geometrically defined mathematical phantoms like MIRD type phantoms have also been used for Monte-Carlo simulations [2] with the progress of computer technologies. As the CT or MRI human image data have been accumulated, voxel type mathematical phantoms have been developing [3-6], and applying for estimations of medical exposure including CT imaging [7-9]. The simulations using voxel phantoms made possible for dose estimations to be considered organ sizes and shapes anatomically more accurate than other conventional type mathematical phantoms. We have calculated patients’ organ doses by using Monte-Carlo simulation method with a mathematical voxel phantom.

2. Materials and methods

The phantom used for dose calculation in this study was a voxel phantom, which has been developed in Japan Atomic Energy Research Institute [10]. It is based on the whole body pictures of X-ray CT imaging for one Japanese male, and constructed of about 6.63 million voxels of 0.98x0.98x10mm³ volume. As Monte-Carlo simulation code, EGS4 [11] for unix system was used. The geometry of phantom was included in the EGS4 user codes for simulations. The phantom was supposed to be in air without any peripherals of X-ray CT machine, because the influence of them
would be not so much for doses. The simulations have been done on PC Linux with g77 fortran compiler. The materials of the phantom were soft tissue, lungs and bone referred from ORNL data. The energy and number of X-ray photons were from Birch’s data [12].

As the conditions of X-ray CT imaging for simulations, lungs and liver scanning were selected. The voltage of X-ray was 120kV filtering with Al. The distance between X-ray tube focus and phantom was set as an actual CT machine using in a hospital. Both conventional and spiral scanning were simulated. The former has been set to be 7mm slice, and the latter has been set to be moved the same slice width per tube rotation. From the focus point of X-ray tube, photons were generated along with the spectra. The energy deposition of each organ dose was calculated.

3. Results

The absorbed energies per organ mass calculated for lungs and liver spiral X-ray CT imaging were shown in Figure 1 as relative organ doses for generated photon energy in the simulations. For example, organs of higher doses on lungs scanning were heart, lungs and stomach. On liver scanning, stomach, liver, kidneys etc. were organs of higher doses.

![Relative organ doses for slices of lungs and liver spiral scanning.](image)

For conventional lungs scanning, relative organ doses of each slice on lung scanning are shown in Figure 2. Y-axis is the scanning slice positions from the head of the phantom to foot direction. One slice per 4 slices is shown for simplifying graphics of the results, which can express the tendency enough. It shows a similar tendency as Figure 1. On head side scanning, heart, lungs, thyroid and spine are organs of higher doses because of the positions in the body. As scanning run to foot side, the doses of organs, such as stomach, small intestine, liver etc., increase. In Figure 3, organ doses of liver scanning are shown. Some slices are same as in Figure 2.
FIG. 2. Relative organ doses for slices of lungs scanning.

FIG. 3. Relative organ doses for slices of liver scanning.
4. Discussions

As expected, the doses of organs inside exposure area of CT scanning were higher than those of outside area as shown in Figure. 1. There is difference between doses of left and right lung. The dose of left lung is higher than right. It is supposed that it would be resulted by the geometry that the shapes, sizes and positions in the body. For both kidneys, the difference of the doses could be also explained by the cause.

The organ doses of each slice on conventional CT scanning shows the dependencies of X-ray entrance positions and energy depositions of organs. The organs of higher doses are changing as X-ray scanning run. The doses of outside area are very small compared to directly exposed organs, so that it is important to control exposure area when X-ray CT examinations are performed.

The Figures shown in results are relative organ doses, that is, the energy depositions divided by organ mass. When the whole organs are entirely inside exposure slice area, the organs are exposed uniformly. If not, the distributions of deposited energy in the organs are not uniform. Although the doses would be same in both situations, the risks of the organs are not biologically equivalent. In case of high dose exposure on CT examinations, the distribution of energy depositions in organs might be needed.

Many types of voxel phants have been developed and applied for many fields. Using them, dose estimations for patients have been done by using Monte-Carlo methods. There are reports on the effect of geometry for doses among mathematical phants of both MIRD type and voxels. The uncertainties originated in the phantom geometry could be studied quantitatively by them. Considering the variety of patients’ body, it is useful for dose estimation of each patient.

5. References