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DOSE ESTIMATION OF PATIENTS FROM DIAGNOSTIC X-RAY BASED ON CT-VOXEL PHANTOM

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1 Introduction

For dose estimation on medical exposure, not only measurements using dosimeters for physical phantoms but also calculations for mathematical phantoms have been applied. MIRD-5 mathematical phantoms, those are constructed of simple geometric shapes, have principally used for dose calculations, because it have been difficult to define organs anatomically accurate on making phantoms. As computer technology progress, voxel phantoms have been developed based on CT or MRI diagnostic images. These voxel phantoms have advantages that the shapes of organs and body are relatively accurate as anthropomorphic phantoms. They are applied for many academic and technological fields as alternatives of human bodies. It is also possible to use for medical dose estimations, so that we used a voxel phantom (Figure 1.), which was developed in JAERI (Japan Atomic Energy Research Institute) based on CT-images[1], for estimation of patients' dose on general X-ray diagnoses. Doses of organs were calculated by EGS4 Monte Carlo simulation code[2], and compared to data calculated by MIRD-5 phantom in NRPB-R186.

2 Methods

The voxel phantom developed by JAERI is a collective of about 6.63 million voxels. The size of each voxel is about 1*1*10cm, and defined based on CT-images of a Japanese man who has almost mean body size in Japan. The height and weight are 172cm and 62kg respectively. The body is divided for more than 100 regions, and the voxel data of region kinds and coordinates are included in text files.

As general diagnoses, chest X-ray examinations were selected for dose calculations, those were for chest PA and AP. Comparing to MIRD-5 phantoms, the same conditions of examinations in NRPB-R186 were selected. The X-ray tube voltages were 100, 120 and 140kV with Al 2.0 - 3.0mm, and FSDs were 150 and 160cm. Exposure field was 32*40cm for each examinations. In actual examinations, some peripheral equipments such as table or stand are near or connected with patients. However, the effectiveness of their scatterings for calculations were ignored for efficiencies of simulations, and the phantom was assumed to be alone in free air. The absorbed doses in tables of NRPB-R186 are normalized to unit entrance surface dose of the MIRD-5 phantom, so that voxels in 5*6cm near center of exposure field were selected and calculated absorbed dose as the value of denominator for normalized doses.

The materials of the phantom used for simulations were assumed to be same as MIRD-5. They are three kinds of materials based on ORNL data, i.e. soft tissue, lung and bone. X-ray spectra were referred to data by Birch et al.[3] The doses of organs in CT-voxel phantom were calculated by egs4unix_3.2. The machine used was a VT-Alpha 600 (Red Hat Linux 6.1) computer which has a 64bit Alpha CPU. The FORTRAN compiler was g77 (egcs-2.91.66, g77-0.5.24). The history of these Monte-Carlo simulations was 5 million for each examination.

3 Results

On chest PA examination, the calculated organ doses are shown in Figure 2. There are differences between the doses of CT-voxel phantom and MIRD-5, especially lungs, kidneys, stomach and thyroid, those are organs inside the exposure field. The doses of CT-voxel phantom are higher than MIRD-5. Small differences were found for brain and pancreas. The relative absorbed energy fractions among organs of CT-voxel phantom were similar to MIRD-5.

In Figure 3, similar to the result of chest PA simulation, all organ doses of CT-voxel phantom calculated on chest AP examinations are higher than MIRD-5. There are large differences for lungs, kidneys and thyroid comparing to MIRD-5. The doses of liver, which is an organ located in the exposure field, is also different.

The calculated absorbed doses are shown in Figure 4. which displays absorbed dose levels by gray scales in the cross section of phantom chest. Darker region means higher absorbed doses, and doses of lungs are high as shown in Figure 4.

4 Discussions

In order to compare to data of MIRD-5 phantom calculations in NRPB-R186, the estimated doses of CT-voxel phantom were translated to normalized absorbed doses by dividing entrance surface doses which were calculated as absorbed doses in some voxels of exposure field center. Hence, organ doses calculated are sensitive to the accuracy of the center voxels' doses strongly depending on simulation history. Although history numbers were not small, the probability of energy deposition in center voxels were not enough for simulations because of their small sizes as targets of exposures. Accordingly, the differences in the result between doses of each phantom will arise from the insufficient history calculations, and this can explain higher doses. Effects of organ volumes on calculations of absorbed doses are not negligible, however, the differences of doses which were also caused by their shapes and sizes are included in the results.

As mentioned above, the estimated doses of simulations using a mathematical phantom depend on the definitions of organ shapes and sizes. Similar to other voxel phantoms, organs of CT-voxel phantom are anatomically accurate. For Japanese patients, CT-voxel phantom is more appropriate for dose estimations compared to conventional phantom, because this has constructed based on CT images of a Japanese man who has mean size body. Strictly speaking, these calculated doses, however, are appropriate only for mean size patients. The methods to modify the phantom are needed for patients who have different body sizes on estimating each medical exposure.

In addition to the organ shapes, relative positions of organs are also important as factors for the accuracy of estimating organ doses in medicine. On X-ray diagnoses, organs having higher doses are inside exposure field, and the doses of organs outside are relatively very low. When an organ is out of the field on a phantom simulation and inside in actual examinaiton, the estimated doses are quite different between them. The difference of the small intestine doses of the chest AP simulation is considered to be caused by that small intestine is not inside the field at the examination in NRPB-R186.

Even though the sensitivity of biological effects for radiation exposure is not uniform in one organ, mean absorbed doses have been adopted for the quantities to estimate radiation risks. For considering the randomicity of sensitivities, more than one regions are needed for calculations as ROI. It is not easy for conventional mathematical phantoms to divide one organ into many small regions. On the other hand, organs can be divided for voxel phantoms by changing definition of voxels into other region number on simulations. The possibility of analysis in detail can be expected so that distribution of energy depositions in organs can be shown like Figure 4.

References

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2) W. R. Nelson, H. Hirayama and D. W. O. Rogers, "The EGS4 Code System", *SLAC-Report-265*, 1985.

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Figure 1: CT-voxel phantom.

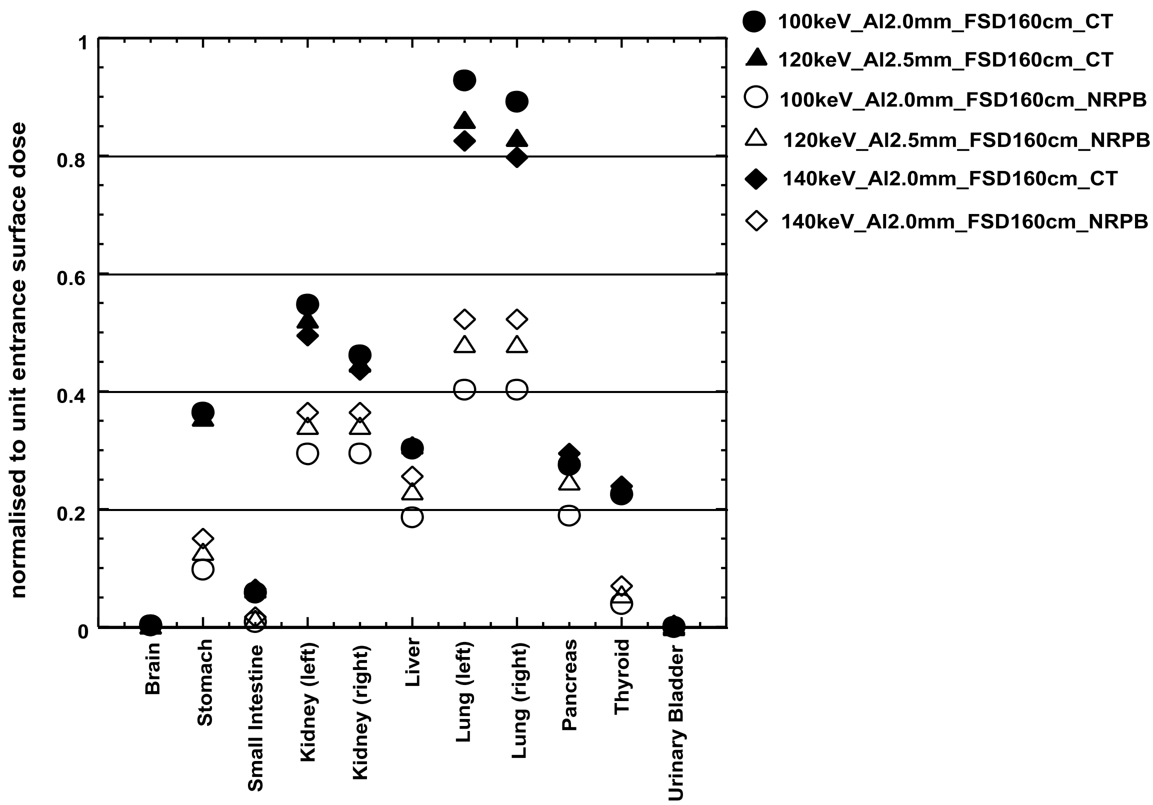

Figure 2: Normalized to unit entrance surface dose on chest PA X-ray examination.

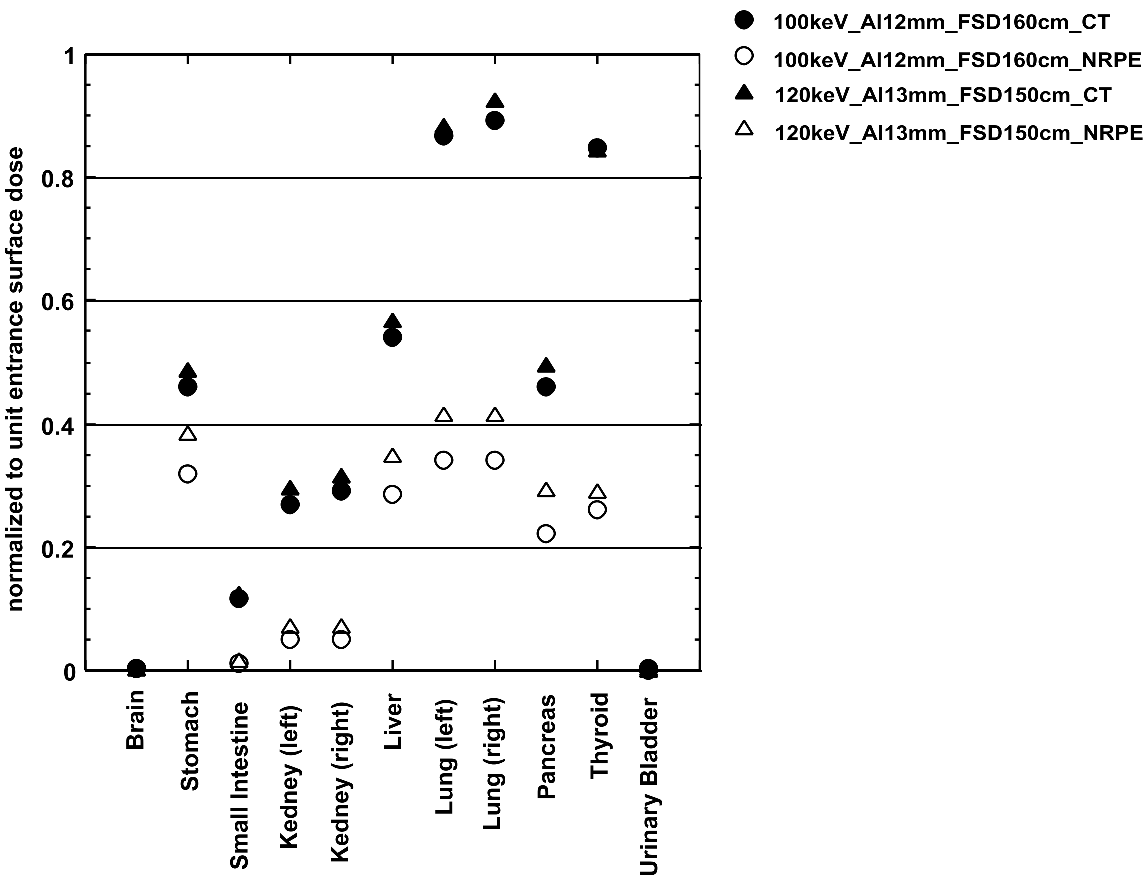

Figure 3: Normalized to unit entrance surface dose on chest AP X-ray examination.

Figure 4: Absorbed doses of organs on cross section of CT-voxel phantom on chest AP examination.