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An EGS4 User Code with Voxel Geometry and a Voxel Phantom Generation System

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Abstract

An EGS4 user code with voxel geometry (the UCPIXEL code) has been developed in order to make accurate dose evaluation by using human voxel phantoms. The voxel data have a format devised by GSF. This format can compress so large amount of high-resolution voxel data that required memory for computation is greatly reduced. UCPIXEL can treat 8 basic irradiation geometries (AP, PA, RLAT, LLAT, ROT, ISO, AB, BA) and cylindrical pseudo-environmental radiation source with arbitrary size, energy and directional distribution. In addition, UCPIXEL can model contaminated soil with arbitrary area and depth under a phantom and radiation from the soil. By using a post-processor, effective dose equivalent, effective dose and organ doses can be evaluated from the output of UCPIXEL. Preliminary results of effective dose calculated by using UCPIXEL for a Japanese voxel phantom are demonstrated and compared with the previous results for MIRD-type phantoms. We have also developed an intelligent system which automatically constructs a voxel phantom from CT data. We introduce this system and preliminary results are shown.

1 Introduction

Fluence to effective dose equivalent or effective dose conversion coefficients for photons or electrons have been evaluated by some researchers[1-5]. In these studies, dose calculations have generally been performed using MIRD-type anthropomorphic phantoms or other simplified phantoms.

While the MIRD-type phantoms have been widely used, voxel phantoms derived from image data have been developed and used for dose analysis[6-8]. Veit et al. developed 8 week old baby and 7 year old child voxel phantom[6], and organ doses and SAF were evaluated[7,8]. The voxel phantoms were based on CT scans of real persons, while MIRD-type phantoms describe the geometry of human body and its organs by simple mathematical equations based on anatomical data of a reference man. By using the voxel phantom construction technique developed by Zankl et al., Saito et al. has recently developed a Japanese male voxel phantom [9]. Hunt et al. have also developed a voxel phantom called NORMAN from a whole-body magnetic resonance image (MRI). [10]

We have developed an EGS4 user code (the UCPIXEL code) which can treat voxel geometry in order to make precise dose analysis and evaluate dose difference between races and individuals by using the voxel phantoms. Also, electron dose conversion coefficients for the Japanese male voxel phantom have been calculated by the UCPIXEL code. In this paper, preliminary results of the calculation are presented and compared with the previous results for MIRD-type phantoms[3].

Though dose calculations by using voxel phantoms would open up a new field for radiation protection dosimetry or radiation therapy, the problem is that voxel phantom construction is very time-consuming work. It usually takes more than 2 to 3 months to develop a complete human voxel phantom. Especially in the radiation therapy, such long time makes treatment planning impossible. To reduce the labor of the human body modeling, a prototype of an intelligent system which automatically constructs a voxel phantom from CT data has been developed. The outline of the system and preliminary results are shown.

2 The Voxel Phantom

A voxel phantom is a human body model defined by a three dimensional rectangular grid. The Japanese male phantom developed by Saito et al.[9] was derived from whole-body CT scan with contiguous 179 slices with 1cm intervals. Each slice consists of 512 $\times$ 512 pixels. Figure 1 shows the whole body of the Japanese male phantom. The voxel size is 0.98 mm $\times$ 0.98 mm $\times$ 1 cm. The height is 170 cm and the mass is 65 kg. The voxel phantom consists of 5 materials: skin, lung, soft, bone, and bone marrow tissues.

Figure 2 shows original CT images on the left side and the corresponding Japanese male phantom on the right side. From Figure 2, we can see that the voxel phantom realistically simulates the organ and tissue shapes and allows local structure modeling. The total number of voxels is $512 \times 512 \times 179 \sim 4.7 \times 10^7$. If each voxel has 4 byte data, the total data amount to about 188 Mbytes. Since voxel data are rather memory-expensive and higher resolution requires more memory, the Japanese male voxel phantom have a specific data format which can efficiently compress the data. This format is the same as that used for the voxel phantoms developed by Veit et al.[6]. We call the format "GSF format". By using the GSF format, the total amount of voxel phantom data is reduced to about 10 Mbytes.

3 The UCPIXEL Code

3.1 Code description

The UCPIXEL code is an EGS4 user code with voxel geometry. In order to save memory, the UCPIXEL code reads and memorizes voxel data with the GSF format. The voxel size and the resolution (the number of slices and pixels) can be set arbitrarily. The UCPIXEL code can treat 8 basic irradiation geometries (AP, PA, RLAT, LLAT, ISO, ROT, AB, BA). Furthermore, the UCPIXEL code can model environmental radiation and radiation from contaminated soil and air. The environmental radiation source is modeled by a pseudo-cylindrical surface or volume source.

3.2 Method of calculation

Preliminary calculations were carried out using the UCPIXEL code and effective dose was evaluated. Calculations were performed for a whole body irradiation of the Japanese male voxel phantom, placed in a vacuum, with the geometries of AP, PA, ISO. For the calculations, 13 discrete electron energies ranging from 1 MeV to 10 GeV were considered. Note that effective dose was evaluated for a male phantom with no breast and ovaries.

3.3 Results and discussion

The results of the calculations are shown in Figure 3 to 5. Figure 3 to 5 show effective dose respectively for AP, PA, ISO irradiation geometries. The results of this work are also compared with those given by Ferrari et al. for hermaphrodite MIRD-type phantom [3]. The agreement of both results is good, but at relatively high energies (E>100 MeV), our results are generally a little smaller than those given by Ferrari et al. This is due to the lack of breast and ovaries in the Japanese male phantom.

Figure 6 to 8 show organ doses at the electron energy of 10 MeV and 10 GeV respectively for AP, PA, ISO. The results are also compared with those given by Ferrari et al. [3]. At the energy of 10 GeV, the agreement of both results are good since at such a high energy, electrons are highly relativistic and energy is almost uniformly deposited in the phantoms. On the other hand, at the energy of 10 MeV, some organ doses for the Japanese male phantom are significantly different from those for the MIRD-type phantom. This is mainly due to the difference in the positions and structures of the organs and tissues.

From the results described above, we confirmed that the UCPIXEL code works well and that voxel phantoms are indispensable in precise dose estimation for irradiation of electrons with relatively low energies like internal exposure analysis and dose evaluation for environmental electron radiation.

4 The Voxel Phantom Generation System

A prototype of an intelligent system which automatically constructs a voxel phantom from CT data has been developed. To form a voxel phantom from a given CT images, we read each image in, colorize the grey CT value, identify and segment the organs/tissues, and enumerate the segments. It is very laborious work to this procedures manually. The voxel phantom generation system reduces this labor and makes human body modeling efficient.

4.1 Outline of the system

The system reads normalized CT data and constucts a voxel phantom which consists of 4 regions: skin, lung, bone, and the other region inside the body (we call this remainder region "soft tissure" here). The input CT data must be normalized as $0 < \mathrm{CT\ value} < 4095$. The outline of this system is shown in Figure 9. This system consists of a master module and 4 submodules: skin, lung, bone, soft tissue indentifiers. Each submodule is optimized to identify one specific part of a human body assigned by the master (for instance, skin identifier identifies only skin) and sends back the identification results to the master. The master combines the results to fom the corresponding voxel phantom. The optimization is done by giving the following knowledge and rules about human anatomy to each indentifier.

1. CT values:
   - Skin, lung, and bone have characteristic CT values.
   - Skin has CT values greater than 500.
   - Lungs have CT values between 80 and 839.
   - Bone has CT values greater than 1139.
2. Volume of regions:
   - Small regions are removed as noise.
3. Postion in a image:
   - The center of mass, maximum and minimum coordinates of the organ/tissue.
4. Distribution:
   - Standard deviation of the organ/tissue distribution
5. Symmetry:
   - A Left and right lung

4.2 Results and discussion

The function of the voxel phantom generation system was examined using CT data from which the Japanese male phantom was developed by Saito et al.[9]. Figure 10 shows some slices thorough the Japanese voxel phantom manually developed by Saito et al.[9] and the corresponding phantom automatically constructed by the voxel phantom generation system. Automatically constructed voxel phantom is quite simple compared with that developed by Saito et al because it consists of only 4 regions, but the voxel phantom generation system worked quite well and succeed to identify human body, lungs, bones, soft tissues. We examined that this system works well in the region containing lungs.

5 Summary and Future Work

An EGS4 user code with voxel geometry (UCPIXEL code) has been developed. Using the UCPIXEL code, effective dose for electrons of the Japanese male voxel phantom was evaluated. Voxel phantom exhibited quite different organ dose characteristics for low-energy electrons in comparison with MIRD-type phantoms. Detailed dose analysis using the Japanese male and female voxel phantom is still underway.

A prototype of an intelligent system which automatically constructs a voxel phantom from CT images has also been developed. Given a set of CT data, the prototype system generates voxel phantoms defined by skin, lungs, bones, and soft tissues. We have examined that the system works well in indentifying organs and tissues, although the generality of the knowledge and rules of the identifiers has to be examined thoroughly by using more data sets. In addition, identifiers for other organs may also be incorporated to the system

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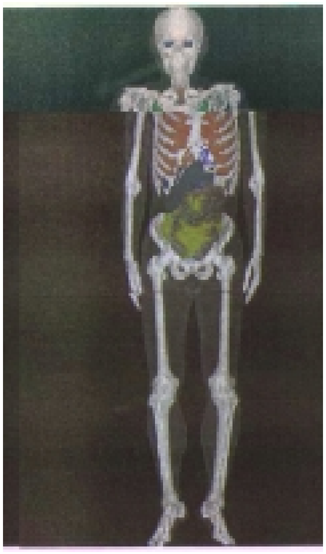

Figure 1: The Japanese male phantom developed by Saito et al.[9]

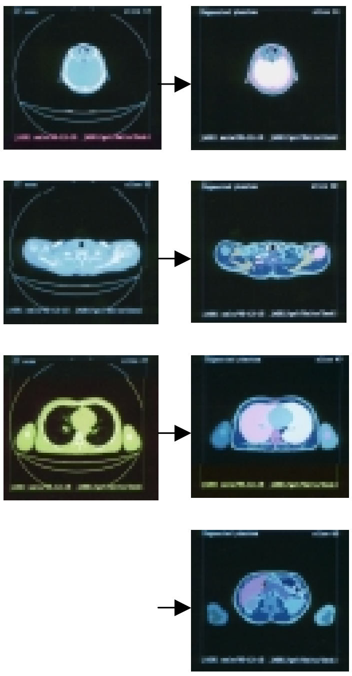

Figure 2: Original CT images (the left) and the corresponding Japanese male phantom (the right) in 4 slices.

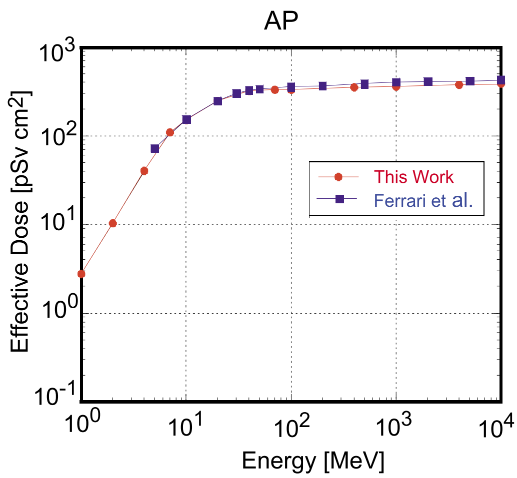

Figure 3. Effective dose per unit fluece as a function of electron energies for AP irradiation geometry of the Japanese male phantom, placed in a vacuum.

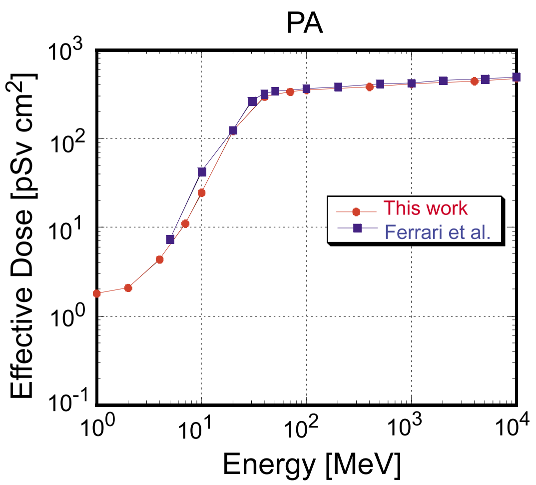

Figure 4. Effective dose per unit fluece as a function of electron energies for PA irradiation geometry of the Japanese male phantom, placed in a vacuum.

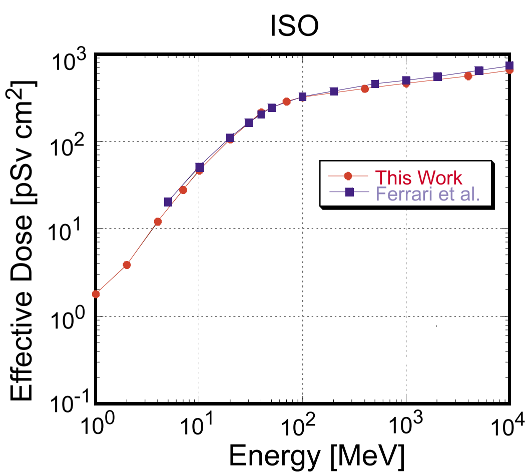

Figure 5. Effective dose per unit fluece as a function of electron energies for ISO irradiation geometry of the Japanese male phantom, placed in a vacuum.

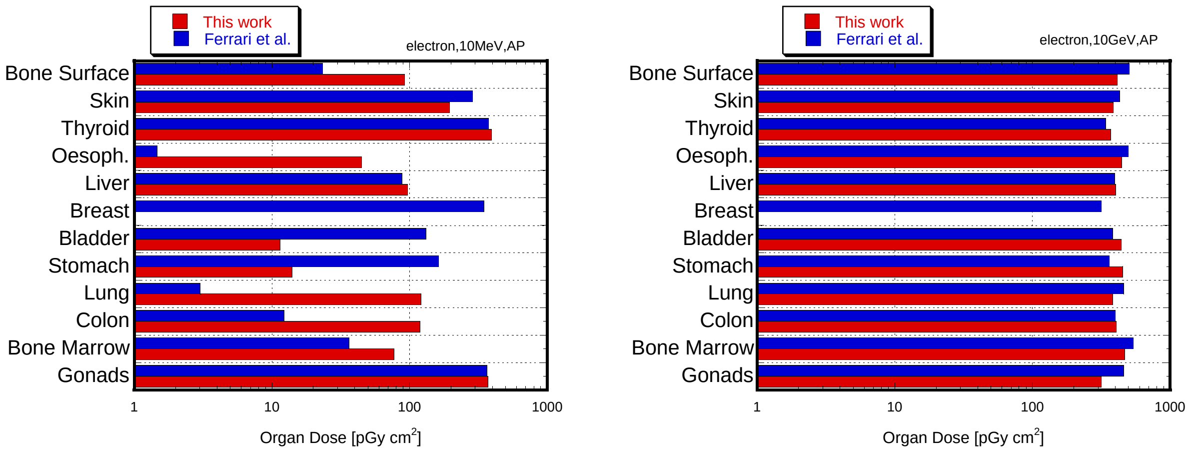

Figure 6: Organ dose for AP irradiation geometry at the electron energy of 10 MeV on the left side and 10 GeV on the right side of the Japanese mail phantom

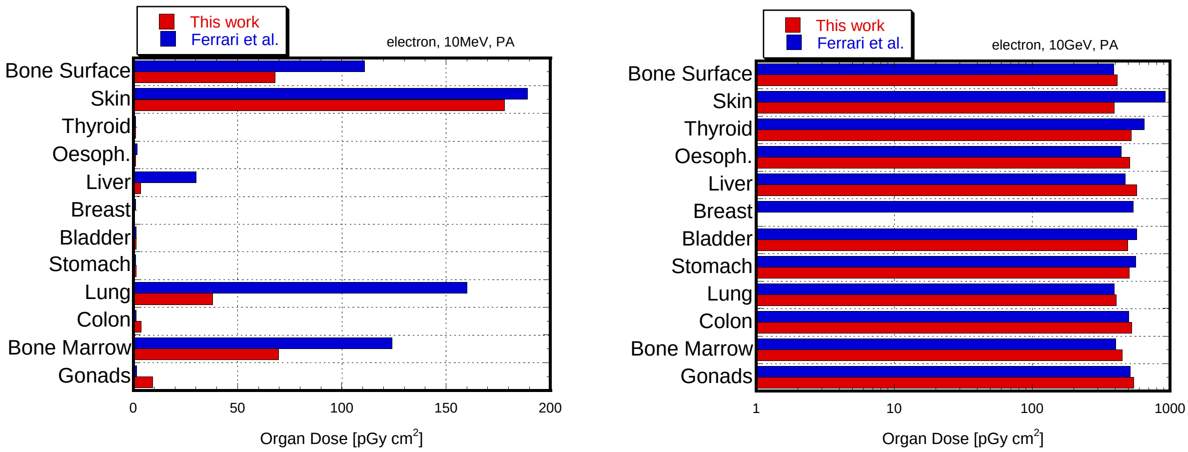

Figure 7: Organ dose for PA irradiation geometry at the electron energy of 10 MeV on the left side and 10 GeV on the right side of the Japanese mail phantom

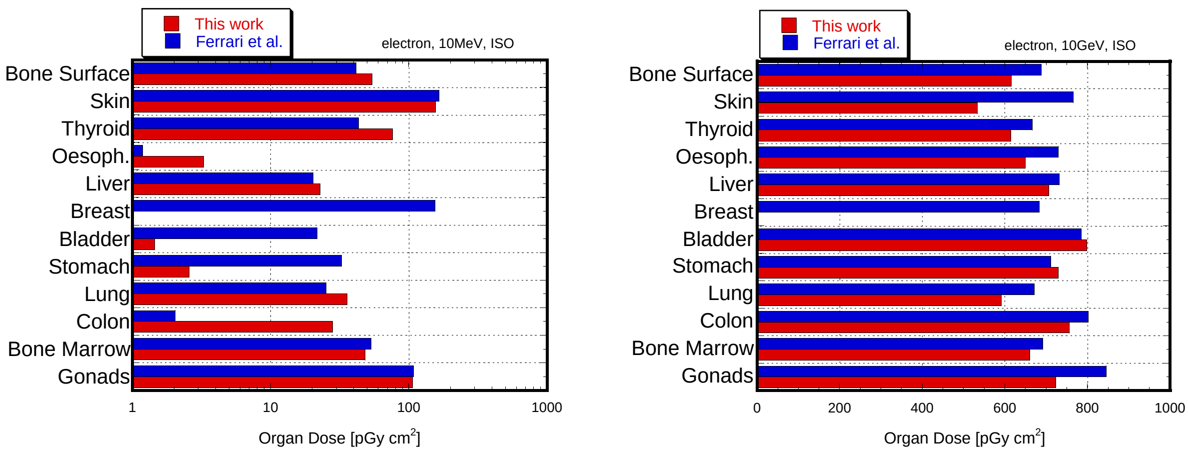

Figure 8: Organ dose for ISO irradiation geometry at the electron energy of 10 MeV on the left side and 10 GeV on the right side of the Japanese mail phantom

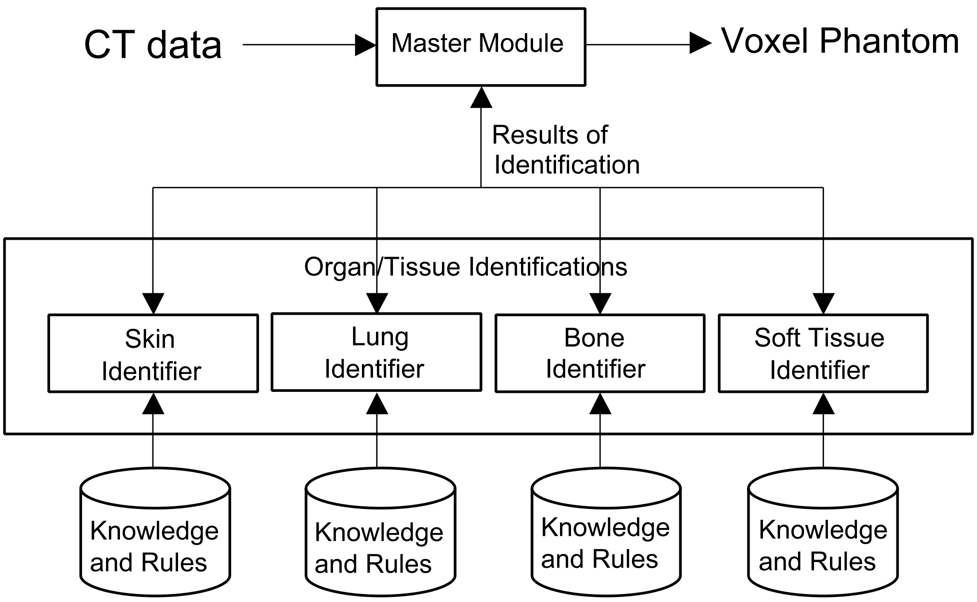

Figure 9. Outline of voxel phantom generation system

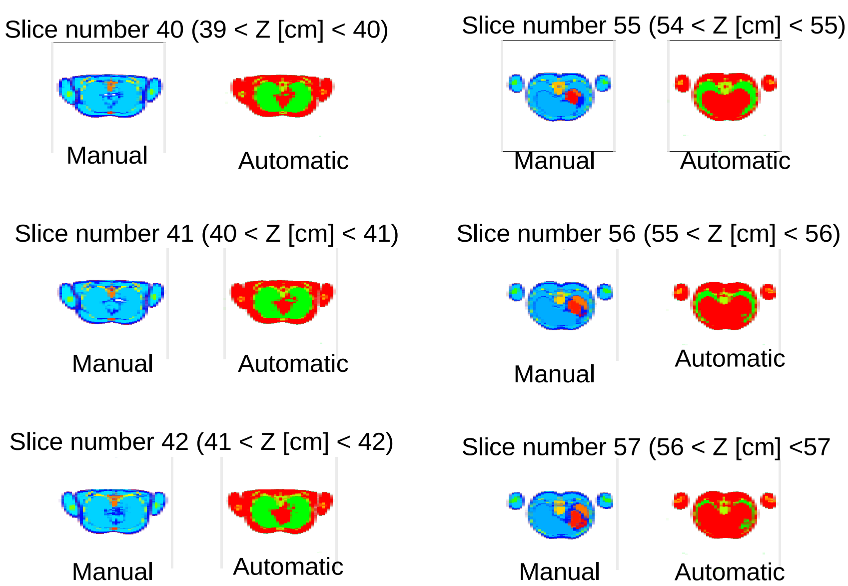

Figure 10. The Japanese male voxel phantom manually developed by Saito et al.[9] and the Japanese male voxel phantom automatically generated by the voxel phantom generation system. Z is the distance from the top of the head.