Absorbed dose evaluation for the normal neighboring organs against thyroid gland of hyperthyroidism for iodine-131 radionuclide therapy using the Monte-Carlo based PHITS code combined with voxel phantom data

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The purpose of this paper is to report the implementation of absorbed dose calculations of the Monte-Carlo based PHITS code combined with voxel phantom data using the Marinelli-Quimby in clinical use. The developed method of this work has allow us to know simply absorbed dose evaluation for the normal neighboring organs against thyroid gland of hyperthyroidism for ^{131}I radionuclide therapy including the targeted organ of thyroid gland with Basedow disease.

I. INTRODUCTION

In radionuclide therapy with the radiopharmaceuticals in the field of nuclear medicine, several beta emitters are generally used well until now. Those beta emitters as iodine-131 (^{131}I), strontium-89 (^{89}Sr), and yttrium-90 (^{90}Y) have been utilized for the treatments of pain palliations of thyroid cancer and bone metastases and of the non-Hodgkin's lymphoma on the radionuclide therapy so far. Today by the clinical fulfillment involved in advances in the alpha targeted delivery of radionuclides and radionuclide conjugation chemistry techniques as well as the increased availability of α emitters appropriate for clinical use, we have led the alpha radionuclide therapy to the treatments and patient trails of radiopharmaceuticals labeled with α-particle emitters (1) such as ^{223}Ra, ^{217}At, and so on. Really in late several years the clinical treatments for the bone metastasis patients of castration resistivity prostate cancer become performed in the radionuclide therapy of ^{223}Ra α-emitter for the first time from June, 2016 in Japan. It is necessary to control the absorbed doses appropriately to normal tissues (risk organs) to each minimum level while maximizing the radiation damage and the advantages of high potency and localized energy deposition to targeted tumors and immunodeficiency organs in the radionuclide therapy during such a tidal current relative to the radiation therapy, and the adequacy of the absorbed dose evaluation involved in their radiation properties of β- and α-emitters become more important in future (2) . Today to simplify the implementation of absorbed dose calculations using voxel phantom data, the research group for radiation transport analysis in JAEA have promoted to develop the Monte-Carlo based PHITS (Particle Heavy Ion Transport code System) code (3) and to establish the code becoming one of the standarded calculation codes for risk assessment and research field of medical physics. We have collaborated with the PHITS research group to work on the pertinent improvement of the PHITS code which is specialized for medical physics in clinical use. There is, this study will be dedicated to the absorbed dose calculated upon the maximum equal dose distribution at a targeted thyroid gland with Basedow disease in radionuclide therapy of ^{131}I as a $\beta(\gamma)$ emitter by PHITS in conjunction with the voxel phantom date of an adult male, and with based on the normalization of the obtained absorbed dose, we have developed a new method becoming possible to simplify the implementation of the absorbed dose calculations for the neighboring risk organs using the formula of Marinelli-Quimby generally in clinical use for the targeted organ of thyroid gland.

II. METHODS

The latest version of PHITS code already released on september 2016 is 2.88 and it becomes available for us to perform the implementations of absorbed dose evaluation of targeted thyroids of I-131 $\beta(\gamma)$ nuclides delivered on radiopharmaceuticals in radionuclide therapy. In geometrical modeling of a complex structure such as human body the PHITS code can provide valuable insight and assistance for dosimetry of organs of interest including thyroid gland in this work. This original voxel modeling in PHITS virtual space described based on Universe and Lattice functions and easily exchanging to initial input data as formed a binary format for PHITS using the software named dicom2phits make possible numerical voxel data of adult male licensed under ICRP publication 110 in which the content provides shapes of organs and elemental composition in a general adult male. The unit size of the voxel phantom on the adulte male in PHITS space is a rectangular of $2 \times 2 \times 8$ mm^3. For the source modeling of beta particle originated from β-decay of I-131, the beta energy spectrum is available by referring to the MIRD Decay Schemes 2nd Edition (4) . On the course of the present PHITS calculations of the absorbed dose for the targeted thyroid gland with Basedow disease, the preliminary results will reveal the absorbed dose and the dose distribution obtained from the total number of history of 1E+7 that is the details are 2E+6 per one batch by 5 batch. All the calculation processes were executed by the openMPI-based parallel calculation of PHITS using our workstations of MacPro (3.5 GHz 6 core Intel Xeon E5, this machine score is about 141 GFlops) and NIVIDA Tesla K20 (3.6 GHz core Intel Xenon, its score is about 120 GFlops). Our focused Marinelli-Quimby's formula of ^{131}I in clinical use is expressed as follows,

$$\text{absorbed dose of thyroid gland (Gy)} = \frac{135 \times A \times U \times T_{eff}}{3.7 \times W \times 8 \times 3.7 \times 100},$$

where A (MBq) is a prescription radioactivity of ^{131}I, U (%) is an uptake rate on 24 hours, T_{eff} (day) is an effective half-life of ^{131}I, and W is the targeted thyroid gland of ^{131}I. The simplified suggested method in this study enables us to deduce the absorbed doses the neighboring risk organs with based on the normalization of the obtained absorbed dose of thyroid gland by the formula.

III. RESULTS

Figure 1 shows an example output of the absorbed dose distribution on the coronal cross section which was calculated by the PHITS code through the total number of history of 1E+7. This figure presents the absorbed dose of thyroid gland becomes obviously highest in comparison with that of the neighboring organs because its calculation has reproduced that the radiopharmaceutical labeled with $\beta(\gamma)$ emitter of ^{131}I is accumulated into the targeted organ by radionuclide therapy of Basedow disease. From all the calculated results with based on the normalization by the Marinelli-Quimby's formula, we can find that the absorbed doses of thyroid gland as a targeted organ is determined to be 334.6 Gy and esophagus, skin, spinal marrow and salivary gland as risk organs are simply obtained to be 2.54, 0.19, 1.27, and 0.02 Gy.

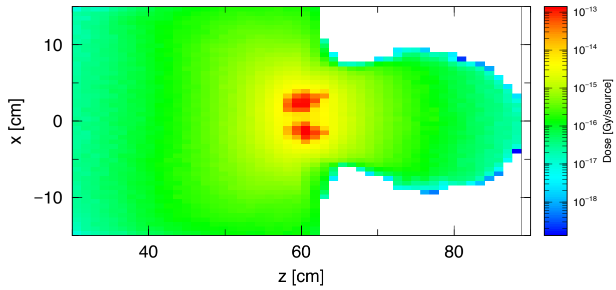

Fig. 1 Absorbed dose distribution on the coronal cross section of the upper half of voxel phantom

IV. CONCLUSION

In this study, from the implementation of the absorbed dose calculations for the combined with the PHITS code and Marinelli-Quimby's formula in genrally clinical use, it can be concluded that our developed method will be validated to obtain the absorbed doses of not only targeted organ of thyroid gland with Basedow disease, but also the normal neighboring risk organs including esophagus, skin, spinal marrow and salivary gland.

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