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Original article

Determination of Organ Doses in Radioiodine Therapy using Monte Carlo Simulation

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Abstract

Radioactive iodine treatment is a type of internal radiotherapy that has been used effectively for the treatment of differentiated thyroid cancer after thyroidectomy. The limit of this method is its affects on critical organs, and hence dosimetry is necessary to consider the risk of this treatment. Scope of this work is the measurement of absorbed doses of critical organs by Monte Carlo simulation and comparing the results with other methods of dosimetry such as direct dosimetry and Medical Internal Radiation Dose (MIRD) method. To calculate absorbed doses of vital organs (thyroid, sternum and cervical vertebrae) via Monte Carlo, a mathematical phantom was used. Since iodine 131 (^{131}I) emmits photon and beta particle, *F8 tallies, which give results in MeV were applied and the results were later converted to cGy by dividing by the mass within the cell and multiplying by 1.6E-8. The absorbed dose obtained by Monte Carlo simulations for 100, 150 and 175 mCi administered ^{131}I was found to be 388.0, 427.9 and 444.8 cGy for thyroid, 208.7, 230.1 and 239.3 cGy for sternum and 272.1, 299.9 and 312.1 cGy for cervical vertebrae. The results of Monte Carlo simulation method had no significant difference with the results obtained via direct dosimetry using thermoluminescent dosimeter-100 and MIRD method. Hence, Monte Carlo is a suitable method for dosimetry in radioiodine therapy.

Keywords: Absorbed dose, Monte Carlo simulation, phantom, radioiodine therapy, thyroid cancer

Introduction

Radioactive iodine therapy (RIT) is a type of internal radiotherapy. The treatment uses a radioactive form of iodine called iodine 131 (^{131}I). The radioactive iodine circulates throughout the body in the bloodstream.[1-5] Thyroid cancer cells pick up the iodine wherever they are in the body. The radiation in the iodine then kills the cancer cells. RIT affects other vital organs. Therefore, it is important to properly assess the benefits and risks to a patient from this procedure. One factor, that strongly influences the intensity or probability of radiation effects, is the energy absorbed by the tissue (absorbed dose), this assessment can be performed only if one knows the radiation dose that will be delivered to other organs by RIT.

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In nuclear medicine procedures, it is almost impossible to measure the radiation dose directly using any kind of radiation detector. Instead, this has to be calculated by using a variety of physical and biological data and mathematical equations specially developed for this purpose. The use of a well-supported radiation transport code such as Monte Carlo N-Particles (MCNP) with the knowledge of patient anatomy will result in a significant improvement in the accuracy of dose calculations.[5-8]

The scope of this study was to obtain absorbed dose of organs using MCNP simulation method and then comparing the results with Medical Internal Radiation Dose (MIRD) method and experimental method thermoluminescent dosimeter (TLD).

Materials and Methods

For the theoretical simulations of the thyroid, sternum and cervical vertebrae MIRD mathematical phantom which, described in previous work, have been used.[2] The mathematical phantom is a representation of the human body. In these phantoms, all organs are represented with

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geometrical bodies (such as cylinders, ellipsoids, tori, etc.), which are described with suitable mathematical equations. A corresponding chemical constitution for various types of organ tissues is also defined.[8] The density of the sternum and cervical vertebra is noted to be 1.4 g/cm^3 and the density of thyroid is noted to be 1.04 g/cm^3.

To simulate the problem with MCNP, an input file that describes the geometry of the problem, specifies the materials and the source, and defines the desired result from the simulation, must be prepared.

The desired result for this study is absorbed doses of vital organs (thyroid, sternum and cervical vertebra). To calculate absorbed dose using Monte Carlo simulation, either F6 tallies or *F8 tallies can be used but since ^{131}I emits both photons and beta particles and F6 tallies were not defined for beta particles, for this reason, *F8 tallies were used for calculating the absorbed doses in this study. However, we calculated the absorbed doses of photons emitted by ^{131}I by both *F8 and F6 tallies to compare the results of these two tallies with each other. The *F8 tallies, which give results in MeV, were later converted to Gy by dividing by the mass within the cell and multiplying by 1.6E-10 to convert the units from MeV/g to J/kg^1 (Gy) or 1.6E-8 to convert the units to cGy. The mass within the cell was determined by multiplying the density of the material in the cell by the volume of the cell. The F6 tallies, which give results in MeV/g^1, were converted to Gray (Gy) with the tally multiplier card (FM card). The simulation was done for 10^6 particles and relative error was decreased by using variance reduction techniques to <0.001 for each organ.

Since MCNP gives the results per disintegration, so to calculate the absorbed dose of administrated activity, it is necessary to multiply the result by accumulated activity in source organ (thyroid). The accumulated activity was estimated in the previous work.[4] Briefly, in the place of two lobes of thyroid two bottles of 5 mCi of ^{131}I were used, and TLDs were placed on the surface of the thyroid phantom for 24 h. Subsequently, dose measurement on patients and phantom were compared. Because the amount of activity in phantom was known, the amount of iodine in patient thyroid could be estimated.[4,5]

Results

The results are divided into three groups of 100, 150 and 175 mCi that is based on the therapeutic dose administrated to patients. Table 1 summarizes the results of absorbed doses of photons, calculated by F6 and *F8 tallies. Table 2 summarizes the results of absorbed doses of photons and beta particles, calculated by *F8 tallies. Note that Tables 1 and 2 are the rare results of MCNP and some calculations have done to get the absorbed doses of organs for the administrated activity to patients.

Table 3 shows the amount of ^{131}I in thyroid obtained by comparison of absorbed dose in patients and phantom which was estimated in the previous study.[4]

Table 4 shows the results of MCNP simulation after applying the necessary calculation on results of Table 2.

Table 5 also summarizes the result of calculating methods of MCNP simulation compared to MIRD method[5] and experimental methods (TLD).[4]

Discussion

Internal radiation dosimetry of radiopharmaceuticals is an important aspect of nuclear medicine to weigh risk versus benefit considerations. However, since implantation of many dosimeters in the human body is undesirable (or impossible), the doses of internal organs are not measurable and some dose calculation has to be applied.[5] Monte Carlo techniques have been used

Table 1: Absorbed doses of photons

Organ	F6 tally result (cGy)	SD (±)	**F8/m tally result (cGy)	SD (±)
Thyroid	5.8808E-01	0.00032	5.8760E-01	0.00011
Sternum	1.9142E-03	0.00001	1.9084E-03	0.00008
Cervical vertebra	1.5996E-04	0.00025	1.6840E-04	0.00027

SD: Standard deviation

Table 2: Absorbed doses of photons and beta particles calculated by *F8

Organ	*F8/m tally result For photons (cGy)	SD (±)	*F8/m tally result For beta particles (cGy)	SD (±)
Thyroid	5.8760E-01	0.00011	5.5941E-01	0.00023
Sternum	1.9084E-03	0.00008	1.5996E-06	0.00091
Cervical vertebra	1.6840E-04	0.00027	3.2437E-07	0.00021

SD: Standard deviation

Table 3: The activity obtained by use of phantom

Administrated activity (mci)	10	100	150	175
Absorbed dose (cGy)	33.3±0.4	315.6±0.7	348.3±0.3	361.9±0.2
Activity (mCi)	10.0±6	94.9±0.4	104.6±0.3	108.8±0.3

Table 4: Results of MCNP simulation (cGy)

Organ	Group 1 (100 mci)	Group 2 (150 mci)	Group 3 (175 mci)
Thyroid	388.0±0.4	427.9±0.7	444.8±0.6
Sternum	208.7±0.3	230.1±0.6	239.3±0.5
Cervical vertebra	272.1±0.5	299.9±0.4	312.1±0.2

MCNP: Monte Carlo N-Particles

Table 5: Results of three different methods of dosimetry

mCi	Organ	Calculated dose in MCNP (cGy)	Calculated dose in MIRD (cGy)	Obtained dose from TLD (cGy)
100	Thyroid	388.0	419.9	315.6
150	Thyroid	427.9	463.2	348.2
175	Thyroid	448.8	481.5	361.9
100	Sternum	208.7	228.9	201.5
150	Sternum	230.1	252.4	275.2
175	Sternum	239.3	252.4	242.6
100	Cervical vertebra	272.1	228.9	311.5
150	Cervical vertebra	299.9	252.4	184.1
175	Cervical vertebra	312.1	252.4	325.9

MCNP: Monte Carlo N-Particles, MIRD: Medical Internal Radiation Dose, TLD: Thermoluminescent dosimeter

extensively in Medical Physics applications and offer the most powerful tool for modeling radiation transport in different media.[3,4]

Comparing the results of absorbed doses of organs obtained by F6 and *F8 tallies for photon, it's obvious that there's no significant difference between the results of these two different tallies but since F6 is not defined for beta particles and ^{131}I emits beta particles as well as photons, *F8 is used for the purpose of calculating of absorbed doses of organs in this study.

The beta rays emitted from ^{131}I travel a maximum distance of 3 mm in tissue and as it's shown in Table 2, the results of *F8 tallies for beta particles in sternum and cervical vertebrae are quite negligible. The thyroid has the greatest amount of absorbed dose. Absorbed doses in studied organs will be decrease as the administrated activity decreases.

As shown in Table 5, the results of three different methods of dosimetry are in a good agreement. However, the results of MCNP simulation and MIRD calculation are closer to each other than TLD measurement and that could be due to the fact that both of these method are based on the phantom of reference human data and on the other hand because of inability of TLD in measuring the absorbed dose of beta rays emitted from ^{131}I because as it's said before the maximum distance that the beta rays emitted from ^{131}I travel in tissue is 3 mm, and they do not contribute to measured dose by TLDs.

Although MCNP simulation is an effective, fast and cost-effective method in dosimetry of internal organs, but it also has its own limitations. For example, it's based on reference human data, and this could be a source of error in estimation of absorbed doses of different patients. However, estimating the mass of every patient's thyroid via scanning decreases this error.[8] On the other hand, the accuracy of absorbed dose of internally distributed radiopharmaceuticals estimated by the MCNP method depends on the cumulated activity of the source organs and their mass. The usual methods for obtaining the cumulated activity are, positron emission tomography, single photon emission computed tomography, extrapolation from animal data, calculations based on the mathematical biokinetic model and use of TLD.[9,10] In this study, the source activity was estimated by using TLD dosimetry, which means that the source of error in TLD dosimetry affect the results of the simulation.

Conclusions

Monte Carlo simulation is a suitable and cost-effective method for dosimetry in radioiodine therapy and since the results of MCNP simulation, MIRD calculations, and experimental dosimetry are in good agreement with each other, it's possible to use any of these methods instead of each other by the clinician.

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