Calculation of beta absorbed fractions for iodine isotopes in ellipsoidal thyroid lobe

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ABSTRACT

Background: The thyroid gland absorbs nearly all the iodine in the blood, independently of its isotopic composition. When a large enough activity of radioactive iodine like ^{131}I, ^{132}I, ^{133}I is taken into the body, it can destroy the healthy thyroid gland cells as well as the cancer's cells. In fact, as it is well known, some isotopes of iodine are used not only for acquiring thyroid images but also for curing thyroid cancer or hyperthyroidism due to Graves' disease. Moreover, some of them are released in nuclear accidents. The aim of this work is to evaluate the absorbed fraction of beta rays from different iodine radioisotopes in thyroid lobe, using Monte Carlo method. ***Materials and Methods:*** We have applied the MCNPX code to calculate the beta absorbed fractions for the most important iodine radioisotopes in the thyroid lobes, supposed to have an ellipsoidal shape, with the volume varying from 1 ml to 25 ml and the material composition suggested by ICRP. The beta rays spectra of iodine isotopes have been taken from the LBNL website. ***Results:*** The result showed that the volume lobe variation had a significant effect on the absorbed fraction for beta rays in thyroid gland, up to 25% for ^{124}I. The absorbed fractions of beta rays were decreasing from ^{123}I to ^{131}I, ^{130}I, ^{126}I, ^{135}I, ^{133}I and ^{124}I respectively. ***Conclusions:*** Decreasing of the absorbed fraction might be related to the beta rays energy spectra of the isotopes. Moreover, for ^{131}I results obtained for beta absorbed fraction in spheres was in agreement with previously published results.

Keywords: *Thyroid gland; Beta absorbed fraction; Iodine isotopes; MCNPX code.*

INTRODUCTION

There are many different iodine isotopes (up to 37) and some of them have an important usage for medical applications (1-20). Radioactive iodine isotopes have the same physical properties as stable iodine-127 and thyroid gland cannot distinguish between radioactive and non-radioactive iodine. Iodine-131, with a gamma emission of 365keV and a physical half-life of 8.05 days, is readily available and has a low cost. Therefore, it is widely used for a number of nuclear medicine procedures, including monitoring and tracing the flow of thyroxin from the thyroid, imaging of thyroid, evaluation of the iodine uptake curve, therapy of thyroid benign diseases or cancer (1-4). Iodine-123 has a proper gamma emission (159 keV) for thyroid imaging by gamma camera with a physical half-life of 13.1 hours. Therefore, it is used for studies of thyroid metabolism and affords an excellent image quality. As well as, using ^{123}I for diagnostic purposes reduces the radiation risk, because of the short half-life, low intensity and low energy of Auger electron. Also, it hasn't the same stunning effect on functioning of thyroid tissue as ^{131}I, with an advantage for the subsequent radioiodine treatment [5, 6].

Iodine-124 can be used to identify mediastinal micro metastases in thyroid carcinoma by PET/CT imaging. Freudenberg *et al.* reported that Iodine-124 PET/CT imaging is a promising technique to improve treatment planning in thyroid cancer.[6-8] Iodine–125 is used in permanent low dose radiation brachytherapy, especially for localized prostate cancer [9, 10]. Farran had reported the use of ^{132}I in the diagnosis of patients undergoing treatment for thyroid disorders in 1969 [15] as well as, it had been used by Goolden *et al.* many years ago in studies of thyroid function [16].

Iodine neutron rich isotopes which are produced inside the reactors may be released in nuclear accidents, like Chernobyl in 1986, or disasters, as Fukushima in 2011 [17-19]. Therefore, the unwanted contamination of radioactive iodine can cause serious thyroid problems, the primary risk being thyroid cancer, with children more at risk than adults. Strand *et al.* published their study about the thyroid uptake not only of iodine-131 but also of iodine-133 in the population of southern Sweden from Chernobyl accident [17].

In a previous article, we reported the thyroid volume's influence on ^{131}I energy deposition evaluated using the Monte Carlo simulation method [20]. Recently, Amato *et al.* developed a Monte Carlo simulation in Geant4 to calculate the absorbed fractions for some beta rays emitter such as ^{199}Au, ^{177}Lu, ^{131}I, ^{153}Sm, ^{186}Re and ^{90}Y, uniformly distributed in ellipsoidal volumes of soft tissue [21]. In this study, we have calculated the beta absorbed fractions for main of iodine radioisotopes in the thyroid lobes, supposed to have an ellipsoidal shape and a volume varying from 1 ml to 25 ml.

Following the MIRD approach, the average beta dose to a target tissue can be calculated as:

$$D_\beta = \frac{\tilde{A}\,\Delta_\beta \phi_\beta}{m} \qquad (1)$$

Where ϕ_β is the beta absorbed fraction, $\tilde{A}$ is the cumulated activity, Δ_β is the average energy of beta spectrum and m is the mass of target region. The result of our study can be used for dose calculation of iodine isotopes in thyroid gland according to MIRD formula.

MATERIALS AND METHODS

For simulation of beta transport, we have applied the MCNPX code [22]. It is a general purpose, continuous and discrete energy, generalized-geometry, time-dependent code to simulate particles transport, based on Monte Carlo method. It contains flexible source and tally options and utilizes the last nuclear cross section libraries.

The code has been used to calculate the beta rays absorbed fractions of main radioactive iodine isotopes, with mass number ranging from 123 to 135, in a thyroid lobe of ellipsoidal shape, with the major axis two times of the minor axis. We must mention that Iodine-123 decays by electron capture, therefore its Auger electron spectrum is used for our simulation. The tissue density of thyroid gland has been considered of 1.05 g/cm^3 and the volume varying from 1 ml to 25 ml. Considering thyroid lobes to have an ellipsoidal shape, the mean distance of two lobes has been taken from the study of the experimental images of more than 50 patients. Figure 1 shows the scintigraphic image of a thyroid and the corresponding model of a thyroid lobe.

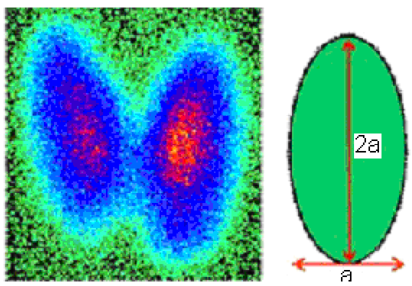

Figure 1. A real image of thyroid and the model of one thyroid lobe.

The beta rays spectra of the iodine isotopes have been taken from the LBNL Isotopes Project website (http://ie.lbl.gov/toi), whose last version 2.1 has been released in January 2004 by Firestone and Ekström (23).

To simulate the body, the adult 70 kg human MIRD5 phantom has been used, where the source organ was the thyroid gland with a uniform iodine radioisotope distribution (24). Also, the neck has been simulated with more detailed organs including skin, adipose layer under the skin, bone, spinal cord, thyroid lobes, and the remaining part as soft tissue. The soft tissue has been considered having 1.05 g/cm^3 density and the ICRP composition. We have used a dual core PC with 3GHz speed for running MCNPX code, 60 minutes per each running to reduce the error of the calculations.

RESULTS

Energy deposition of beta rays depends on size and geometry of the source region, distribution of the radioactive material, types of the radiations and energies emitted by the radionuclide. To obtain the absorbed fraction f_β, we have calculated the total absorbed energy per decay for beta rays of each iodine isotopes as shown in figure 2; then the absorbed fraction has been evaluated using the following equation:

$$\phi_\beta = \frac{\text{Beta's energy absorbed in the lobe}}{\text{mean energy of beta ray}} \qquad (2)$$

Figure 3 shows the beta absorbed fraction for 7 different iodine isotopes against the volume of thyroid lobe. The results show that the absorbed fraction of beta rays increases by volume for all the isotopes, and the variation is higher for ^{124}I than for other isotopes. It can be seen that the beta absorbed fraction for ^{124}I ranges from 0.75 for a small volume (1 ml) up to 0.91 for a high volume (25 ml). For ^{131}I the variation is from 0.95 till 0.98, and for ^{123}I it's around 1%, because of low energy Auger electron emitted from this radioisotope.

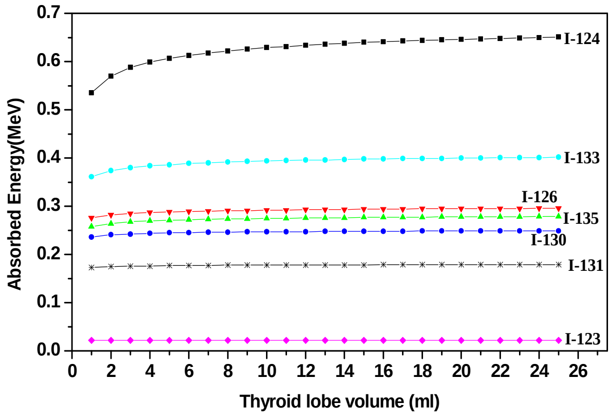

Figure 2. The absorbed energy of beta rays in ellipsoidal thyroid lobe against the lobe volume.

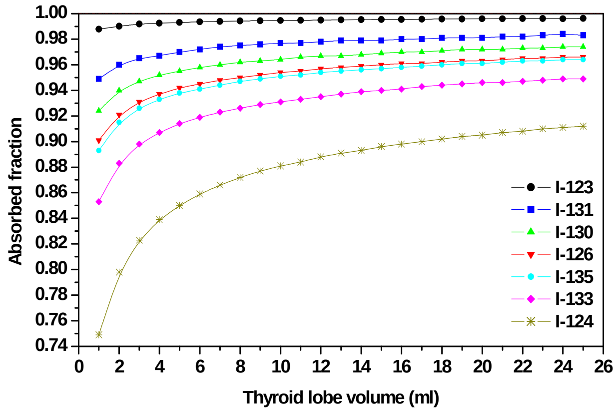

Figure 3. The variation of absorbed fraction of beta rays by thyroid lobe volume.

DISCUSSION

We have used a suitable analytical function which was introduced by Amato *et al.* (25) for the relationship between the absorbed fraction f_β and the generalized radius ρ, with 2 fit parameters ρ_0 and s:

$$\phi_\beta(\rho) = \left[1 + \frac{\rho_0}{\rho^s}\right]^{-1} \qquad (3)$$

The volume and surface area of an ellipsoid are given by:

$$\begin{cases} V = \dfrac{4}{3}\pi abc \\ S \cong 4\pi\left[\dfrac{(ab)^p + (bc)^p + (ac)^p}{3}\right]^{1/p} \quad ; \quad p = 1.6075. \end{cases} \qquad (4)$$

Based on the sphere radius, "Generalized Radius" for ellipsoid can be defined as three times of volume to surface ratio:

$$\rho = 3\frac{V}{S} \qquad (5)$$

Figure 4 shows the absorbed fraction of the beta ray variation against the generalized radius of ellipsoid. Also, in this figure it can be seen a good match of the fitted curves (drawn as continuous lines) to the obtained data. The fit parameters of the analytical function in equation 3 and the reduced chi-square (X^2/DoF) values for all of the iodine isotopes are listed in table 1. The obtained value of ρ_0 ranges from 0.1747 to 0.0068 (a variation of about 25.7 times!), while the s value is not varied too much and its value is around 1. These results show that the equation 3

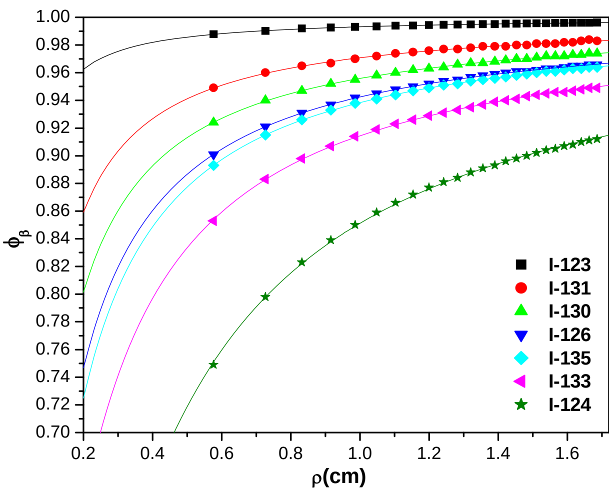

Figure 4. Absorbed fraction of the beta rays in ellipsoids variation against ρ, the generalized radius (lines curves are the fitted functions).

is correct and suitable in order to obtain the beta absorbed fraction as a function of the generalized radius.

Amato *et al.* (21) have reported the ^{131}I beta absorbed fractions for ellipsoidal shape with different ratio of axes and various masses of thyroid. Our results are in good agreement with the result of Amato *el al.* considering the beta absorbed fractions for spheres (listed in table 2).

Table 2. Comparison of our result for beta absorbed fractions in spheres with the result of Amato *el al.* (21)

V (cm^3)	φ_1 This work	φ_2 Amato *et al.*	$\sigma = \varphi_1 - \varphi_2$
1	0.899	0.90	-0.001
0.5	0.940	0.94	0
1	0.953	0.96	-0.007
2	0.963	0.97	-0.007
10	0.978	0.98	-0.002
20	0.983	0.98	0.003

CONCLUSION

The results show that considering the lobe volume variation has a significant effect on the absorbed fraction for beta rays. It can be due to the short range of beta rays and to increasing surface to volume ratio of ellipsoidal lobe, which causes some beta particles near the surface to deposit a fraction of their energy outside of the lobe. Moreover, our results for beta absorbed fraction in spheres are in good agreement with the result of Amato *el al.* (21) for ^{131}I.

Table 1. Fit parameters and reduced chi-square values for all of the iodine isotopes.

Radioisotope	ρ_0	s	X^2/DoF
For ^{124}I	0.1747 ± 2.8E-4	1.1617 ± 4.72E-3	7.322E-7
For ^{133}I	0.0935 ± 1.4E-4	1.0934 ± 4.37E-3	2.532E-7
For ^{135}I	0.0656 ± 7E-5	1.0908 ± 3.12E-3	7.169E-8
For ^{126}I	0.061 ± 7E-5	1.0664 ± 3.3E-3	7.067E-8
For ^{130}I	0.0461 ± 8E-5	1.0447 ± 5.1E-3	1.033E-7
For ^{131}I	0.0301 ± 1.2E-4	1.0538 ± 1.13E-2	2.331E-7
For ^{123}I	0.0068 ± 2E-5	1.0835 ± 9.04E-5	8.619E-9

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REFERENCES

1. Vini L and Harmer C (2000) Radioiodine treatment for differentiated thyroid cancer. *Clin Oncl (Rcoll Radiol),* ***12:*** *365-72.*
2. Matheoud R, Canzi C, Reschini E, Zito F, Voltini F, Gerundini P (2003) Tissue-specific dosimetry for radioiodine therapy of the autonomous thyroid nodule. *Med Phys,* ***30:*** *791-8.*
3. Kim WG, Ryu JS, Kim EY, Lee JH, Baek JH, Yoon JH, Hong SH, Kim ES, Kim TY, Kim WB, Shong YK (2010) Empiric high-dose 131-Iodine therapy lacks efficacy for treated papillary thyroid cancer patients with detectable serum thyroglobulin, but negative cervical sonography and ^{18}F-fluorodeoxyglucose positron emission tomography scan. *J Clin Endocrinol Metab,* ***95:*** *1169-1173.*
4. Sgouros G, Hobbs RF, Atkins FB, Nostrand DV, Ladenson PW, Wahl RL (2011) Three-dimensional radiobiological dosimetry (3D-RD) with ^{124}I PET for ^{131}I therapy of thyroid cancer. *Eur J Nucl Med Mol Imaging,* ***38 :*** *S41–S47.*
5. Urhan M, Dadparvar S, Mavi A, Houseni M, Chamroonrat W, Alavi A, Mandel SJ (2007) Iodine-123 as a diagnostic imaging agent in differentiated thyroid carcinoma: a comparison with iodine-131 posttreatment scanning and serum thyroglobulin measurement. *Eur J Nucl Med Mol Imaging*, ***34:*** *1012–1017.*
6. Barwick T, Murray I, Megadmi H, Drake WM, Plowman PN, Akker SA, Chew SL, Grossman AB, Avril N (2010) Single photon emission computed tomography (SPECT)/computed tomography using Iodine-123 in patients with differentiated thyroid cancer: additional value over whole body planar imaging and SPECT. *Eur J Endocrinol,* ***162:*** *1131–1139.*
7. Sundram FX (2006) Clinical use of PET/CT in thyroid cancer diagnosis and management. *Biomedical Imaging and Intervention Journal,* ***2:*** *1-5.*
8. Eschmann SM, Reischl G, Bilger K, Kupferschläger J, *et al.* (2002) Evaluation of dosimetry of radioiodine therapy in benign and malignant thyroid disorders by means of iodine-124 and PET. *Euro J Nuclear Med,* ***29:*** *760-767.*
9. Grimm PD, Blasko JC, Sylvester JE, Meier RM, Cavanagh W (2001) 10-year biochemical (prostate-specific antigen) control of prostate cancer with 125I brachytherapy. Int J Radiation *Oncology Biol Phys,* ***51:*** *31–40.*
10. Stock RG, Stone NN (2010) Current topics in the treatment of prostate cancer with low-dose-rate brachytherapy. *Urol Clin North Am,* ***37:*** *83-96.*
11. AllahAbadia A, Daykin J, Sheppard MC, Gough CSCL, Franklyn JA (2001) Radiological treatment of hyperthyroidism-progonostic factors for outcome. *J Clin Endocrinol Metab,* ***86:*** *3611-3617.*
12. Cooper DS, Doherty GM, Haugen BR, Kloos RT, *et al.* (2006) Management guidelines for patients with thyroid nodules and differentiated thyroid cancer. *Thyroid*, ***16:*** *109-141.*
13. Traino AC, di Martino F, Lazzeri M. Stabin MG (2000) Influence of thyroid volume reduction on calculated dose in radioiodine therapy of Graves' hyperthyroidism. *Phys Med Biol,* ***45:*** *121–129.*
14. Wildman JC, Powsner ER, Plato PA (1980) Absorbed fractions for photons of ^{125}I and ^{129}I in the thyroid. *Int J Appl Radiat Isot,* ***31:*** *421-423.*
15. Farran HE (1969) The use of ^{132}I in the diagnosis of patients undergoing treatment for thyroid disorders. *Br J Radiol,* ***42:*** *235.*
16. Goolden AW, Mallard JR (1958) The use of iodine 132 in studies of thyroid function. *Br J Radiol,* ***31:*** *589-95.*
17. Strand SE, Erlandsson K, Löwenhielm P (1988) Thyroid uptake of iodine-131 and iodine-133 from Chernobyl in the population of southern Sweden. *J Nucl Med,* ***29:*** *1719-2.*
18. Tagami K and Uchida S (2011) Can we remove iodine -131 from tap water in Japan by boiling? – Experimental testing in response to the Fukushima Daiichi Nuclear Power Plant accident. *Chemosphere,* ***84:*** *1282-4.*
19. Jaworowski Z and Kownacka L (1988) Tropospheric and stratospheric distributions of radioactive iodine and cesium after the Chernobyl accident. *J Environ Radioact,* ***6:*** *145-150.*
20. Mowlavi AA, Fornasier MR, de Denaro M (2011) Thyroid volume's influence on energy deposition from ^{131}I calculated by Monte Carlo (MC) simulation. *Radiol Oncol,* ***45:*** *143-146.*
21. Amato E, Lizio D, Baldari S (2009) Absorbed fractions in ellipsoidal volumes for β^- radionuclides employed in internal radiotherapy. *Phys Med Biol*, ***54:*** *4171-4180.*

22. Waters LS (ed), (2002) "MCNPX User's Manual, version 2.3.0", LA-UR-02-2607, Los Alamos, NM, USA.
23. Firestone RB and Ekström LP (1999) LBNL Isotopes Project - LUNDS University, Table of Radioactive Isotopes. Version 2.1. The website: http://ie.lbl.gov/toi/nuclide.asp?iZA=530131
24. Snyder W, Ford M, Warner G (1969) Estimates of absorbed fractions for monoenergetic photon sources uniformly distributed in various organs of a heterogeneous phantom: MIRD pamphlet no. 5. *J Nucl Med,* ***10:*** *5–52.*
25. Amato E, Lizio D, Baldari S (2011) Absorbed fractions for electrons in ellipsoidal volumes. *Phys Med Biol*, ***56:*** *357–365.*