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I-131 Radyoizotop Aktivitelerinin Nükleer Tıpta Kullanılan Organ Dozu Üzerine Etkisi

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Anahtar kelimeler
Nükleer Tıp;
Radyasyon;
Doz;
NCINM

Öz

Hayatta radyasyona maruz kalmanın birçok yolu vardır. Özellikle tıbbi uygulamalar, şiddetli maruziyetin en önemli sebebidir. Tıbbi uygulamalarda Bilgisayarlı Tomografi (BT) taramaları ilk sırada yer alırken, nükleer tıp ikinci sırada yer almaktadır. Tabii ki, maruz kalan doku ve dolayısıyla organlar tarafından emilen doz, sağlığa yönelik risklerle doğru orantılıdır. Nükleer tıpta tedavi amaçlı vücuda yerleştirilen radyoizotoplar nedeniyle sadece tümörün bulunduğu organ ve/veya dokulara değil, çevredeki diğer organ ve dokular az miktarda olsa da doz absorbe eder. Bu çalışmada erişkin fantomların (erkek ve dişi) tiroid bezine yerleştirilen iyot radyoizotop I-131'in aktivitelerine göre tiroid bezi, timüs ve lenf bezlerinin aldığı dozlardaki değişim Monte Carlo-tabanlı NCINM kodu ile araştırılmıştır.

Effect of I-131 Radioisotope Activities on Organ Dose Used in Nuclear Medicine

Keywords
Nuclear Medicine;
Radiation;
Dose;
NCINM

Abstract

There are many ways to be exposed to radiation in life. Medical applications, in particular, are the most important form of severe exposure. In medical applications, Computed Tomography (CT) scans are in the first place, while nuclear medicine is in the second place. Of course, the dose absorbed by the exposed tissue and therefore the organs is directly proportional to the risks to health. In nuclear medicine, due to the radioisotopes placed in the body for therapeutic purposes, some doses are not given only to the organ and/or tissues where the tumor is placed, but also to other surrounding organ and tissues. In this study, the change in the doses received by the thyroid gland, thymus, and lymph nodes according to the activities of the iodine radioisotope I-131 placed in the thyroid gland of adult phantoms (both male and female) were investigated with the Monte Carlo-based code.

1. Introduction

Nuclear medicine is the use of radioisotopes placed in the body of patients for the purposes of diagnosis or treatment of diseases. Recently, functional imaging is performed in diseases related to almost every organ system in universities, state hospitals, and nuclear medicine departments serving in some private centers in our country. The diagnostic tests performed in all these centers mentioned above are scintigraphic imaging of the many organs and diseases, as well as the treatment of some tumors, especially thyroid diseases.

The nuclear medicine history goes back to the introduction of the atomic theory by John Dalton in the early 1800s, the discovery of X-rays by Wilhelm Konrad Roentgen in 1895, and the creation of the cyclotron by Ernest Lawrence in 1928. The most important step is the discovery of artificial radioactivity by Marie Curie in 1934, which is accepted as a milestone. However, many historians accept as the true beginning of nuclear medicine is the usage of radioactive iodine to treat toxic goiter in the 1940s.

Technetium radioisotope, which is still the most frequently used in nuclear medicine imaging, was produced artificially in 1937 and its commercial production, distribution and use started after 1965. In the following years, nuclear medicine started to develop rapidly with the discovery of agents used in liver-spleen and brain imaging.

In nuclear medicine, which was used only for diagnostic imaging in the beginning, but also for therapeutic purposes, it is very important to determine which organs will be affected by the radiation of the radiopharmaceutical used as an internal radiation source and the total radiation risk for the patient (Toohey *et al.* 2000). Because it is desired that the dose of radiation to be given should not cause the slightest damage to other healthy tissues and organs. The radiation dose to the body and organs cannot be determined by clinical measurements but is calculated using body-like models called phantoms created in the computer environment. These phantoms can be mathematical models developed in the 1970s in which organ and tissue volumes are represented by the simplest geometric shapes (rectangular prism, cylinder, etc.), as well as they may be tomographic models developed towards the end of the 1990s, which are very similar to real body images.

The Monte Carlo technique is used as a random numbers technique and was used in the design of atomic weapons in the 1940s. It is considered to be a very successful tool, especially for applications where the interaction of radiation with material environments is examined (Andreo *et al.* 1991) It is a modeling technique that is commonly used in situations where physical measurements are either very difficult or impossible or in the planning phase of a very large physical experiment, generally trying to describe an event or experiment numerically using statistical random numbers. In modeling the interactions of radiation in the material environment, it determines the physical properties and parameters of the particles carrying the radiation energy, such as energy, position, flight direction, and flight distance, by using random numbers and appropriate probability distributions within the geometry you have created. Then, the types of physical interactions that the particles moving in the medium will undergo, the amount of energy to be lost in each interaction, the scattering angles, etc. tries to calculate. As a result, the radiation dose amounts left in the predefined geometries are calculated.

The use of radioactive iodine is a method that is successfully applied in the treatment of goiter diseases, which are defined as hyperthyroidism and cause thyroid gland hormone elevation in the blood. In some cancers of the thyroid gland, radioactive iodine therapy is also used for the destruction of thyroid gland residues left behind after thyroid gland surgery and for the treatment of the spread of thyroid cancers in the body. Radioactive iodine, injected into the body in different ways, is absorbed from the digestive system and collected in the thyroid gland cells. Due to the radiation, it emits, the growth and activity of thyroid cells stop, the function of the overactive thyroid gland returns to normal, or the unwanted thyroid tissues are destroyed. The rest of the radioactive iodine is excreted from the body mostly through the urine, and some of it is excreted with saliva, sweat, and feces, and there is no more radioisotope in your body between 10 days and 1 month. The dose of radioactive iodine varies according to the nature of thyroid cancer.

In this study, Monte Carlo simulation studies were performed by placing I-131 radioisotope in the thyroid in adult female and male phantoms. The doses received by the thyroid gland, thymus, and lymph nodes were calculated via NCINM code.

2. Material and Method

The dose absorbed by the organ is a baseline dose amount defined by the International Commission on Radiation Protection (ICRP) as the average energy delivered to the mass substance (ICRP 1991, ICRP 2007). The dose absorbed by the organ is not directly measurable but can be obtained from measurable quantities such as air kerma or particle flux via dose conversion coefficients.

Dose conversion coefficients are calculated by modeling the radiation field of the exposure event and scoring the energy deposition for the tissues and organs involved in a human phantom, a representative model of human anatomy. The solution of the radiation transport problem is accomplished by well-characterized Monte Carlo methods. Computational human phantoms have developed very rapidly due to the need in the industry. In the 1980s, first-generation phantoms, known as stylized phantoms, modeled body and organ contours with mathematical equations and thus geometric shapes (Cristy 1980). These phantoms lacked anatomical realism but could be easily modified by changing parameters in mathematical equations. New generation phantoms, also known as voxel phantoms, have anatomical realism as they are developed using datasets obtained from tomographic images (Caon 2004). However, voxel phantoms are rigid and cannot be easily manipulated to account for anthropometric variations in populations. Hybrid phantoms, the third and newest generation of phantoms, have been developed to offer the flexibility of first-generation mathematical phantoms as well as the anatomical realism of voxel phantoms (Xu 2014). This flexibility of hybrid phantoms allows body sizes to be adjusted to develop phantoms with different body morphologies (Ding *et al.* 2012, Geyer *et al.* 2014).

NCINM code is based on the widely accepted MIRD formalism (ICRP 2008). This code was developed in three steps:

- First, calculations of a comprehensive library of specific absorbed fractions (SAFs) for multiple combinations of source and target sites in a set of computational phantoms (both pediatric and adult) combined with a MCNP code.
- Second, derivation of a S values library from SAFs and nuclear decay data from ICRP report (ICRP 1991).
- Finally, a GUI-based user-friendly code was compiled to facilitate the dosimetry process.

The code will give following outputs:

i. Absorbed doses and absorbed doses: Absorbed doses and absorbed doses per unit administered activity are calculated for all target regions in terms of mGy and mGy/MBq, respectively. Absorbed does per unit administered activity to target region r_T, which is also called absorbed dose coefficients, $\frac{D(r_T)}{A_0}$, is calculated using:

$$\frac{D(r_T)}{A_0} = \sum_{r_s} \frac{\tilde{A}(r_s)}{A_0} S(r_T \leftarrow r_s)$$

where first term is the cumulated activity per unit administered activity in source tissue r_s and second term is the S value for regions r_s (source) and r_T .

ii. Two effective doses: Effective doses is calculated based on ICRP 60 (1991) and 103 (2007) in terms of S_v.

iii. Target region mass

iv. S values: S values are calculated in terms of mGy/MBq.s for selected regions r_s (source) and r_T (target), selected phantom, and also selected radionuclide. Besides S values are displayed on screen and could be taken as a file in text format.

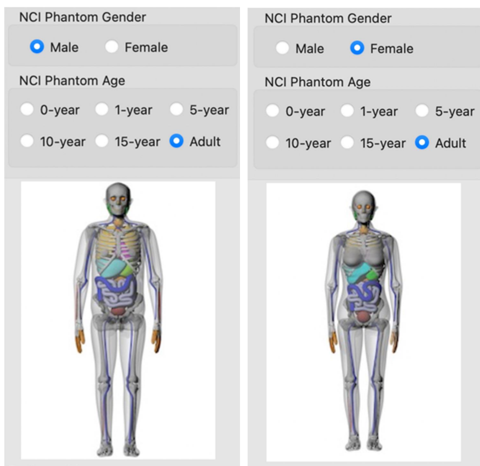

Figure 1. Adult female and male phantoms.

3. Results

In this study, Monte Carlo-based NCINM code developed by NCI was used. The I-131 radioisotope with different activity was placed in the thyroid gland of adult female and male phantoms for half an hour. These selected activities are both for Hyperthyroid treatment (9, 12, 15 and 18 mCi) and for Differentiated thyroid cancer treatments (50, 100, 150 and 200 mCi) are in the used range. The doses taken by the thyroid gland, thymus, and lymph nodes were calculated and compared with each other. In addition, the specific activity obtained in accordance with the ICRP-60 and ICRP-103 reports was also given. Fig. 1 shows the images of adult phantoms used in the calculations.

In Table 1, the doses taken by the Thyroid gland, Thymus, and Lymph nodes according to the activity for the I-131 radioisotope placed in the thyroid for both adult male and female phantoms at the end of the simulation are given in mGy. In addition, in the same table, the effective dose received by the phantom is given in mSv in accordance with the ICRP-60 and ICRP-103 reports.

Table 1. Doses of adult man and woman phantoms according to activity.

	Male					Female				
Activitiy (MBq)	Organ Doses (mGy)			Effective Doses (mSv)		Organ Doses (mGy)			Effective Doses (mSv)	
	Thyroid gland	Thymus	Lymph nodes	ICRP60	ICRP103	Thyroid gland	Thymus	Lymph nodes	ICRP60	ICRP103
333	798.5	4.416	4.518	40.17	32.27	952.3	4.414	3.127	48.01	38.55
444	1065	5.888	6.024	53.57	43.03	1270	5.885	4.17	64.01	51.4
555	1331	7.36	7.53	66.96	53.79	1587	7.357	5.212	80.01	64.26
666	1597	8.831	9.035	80.35	64.55	1905	8.828	6.255	96.01	77.11
1850	4436	24.53	25.1	223.2	179.3	5291	24.52	17.37	266.7	214.2
3700	8872	49.06	50.2	446.4	358.6	10580	49.05	34.75	533.4	428.4
5550	13310	73.6	75.3	669.6	537.9	15870	73.57	52.12	800.1	642.6
7400	17740	98.13	100.4	892.8	717.2	21160	98.09	69.5	1067	856.7

The change in the dose taken by the thyroid gland according to the values given in Table 1 is given graphically in Fig. 2 according to both adult male and female phantoms. Similarly, the doses received by the Thymus and lymph node are given in Figs. 3 and 4, respectively.

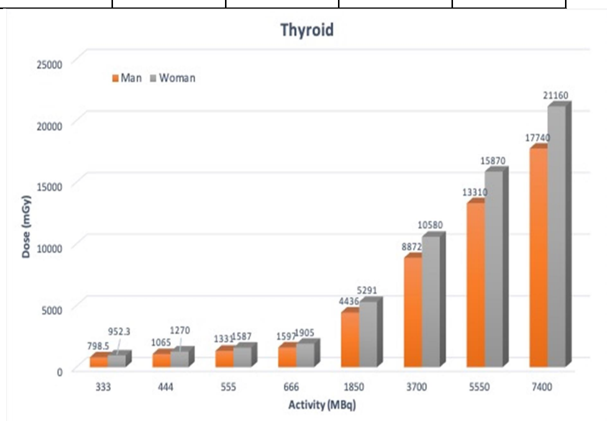

Figure 2. The change of the dose received by the thyroid gland according to the activity.

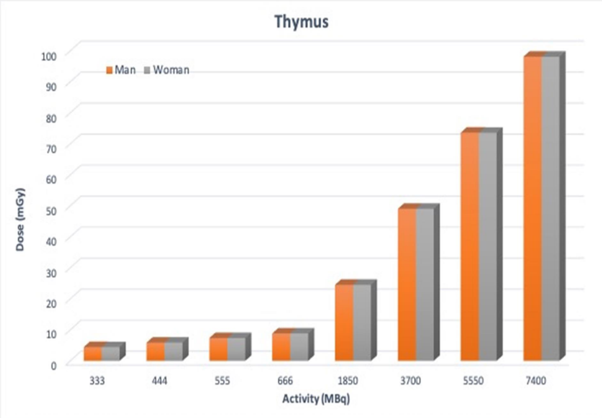

Figure 3. The change of the dose received by the thymus according to the activity.

The effective dose calculated in both male and female phantoms according to the ICRP-60 and ICRP-103 references is given according to the varying activity in Figs. 5 and 6, respectively.

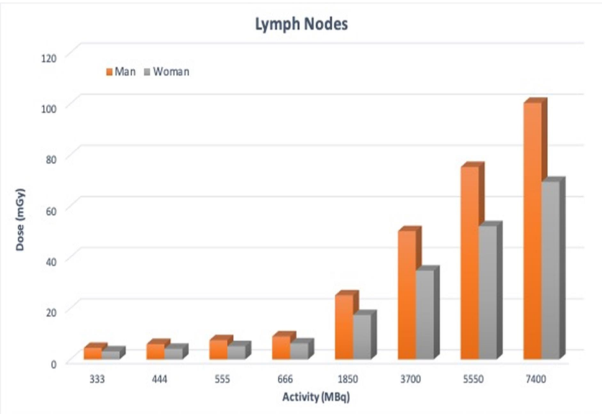

Figure 4. The change of the dose received by the lymph node according to the activity.

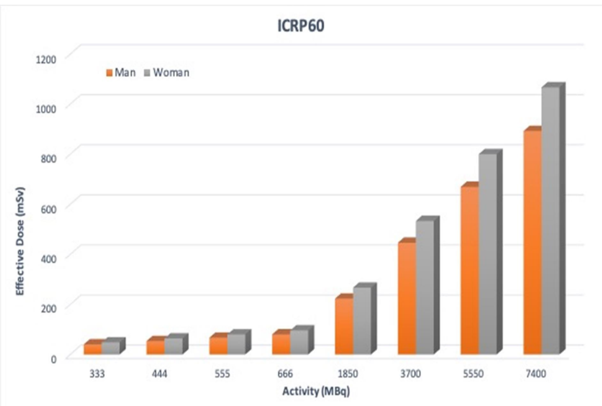

Figure 5. Variation of effective dose with activity according to ICRP-60 reference.

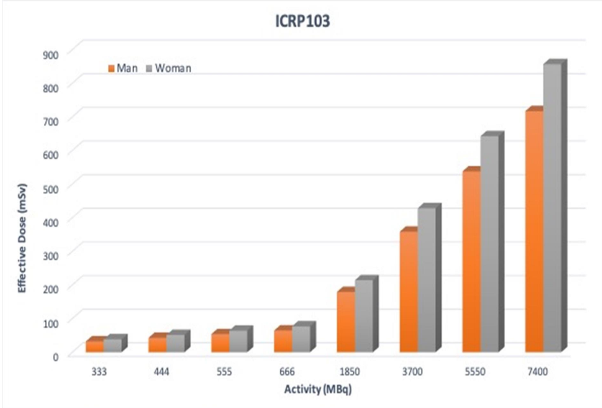

Figure 6. Variation of effective dose with activity according to ICRP-103 reference.

4. Conclusion

The doses of the thyroid, thymus, and lymph nodes were calculated with the help of the Monte Carlo-based NCINM code, using the reference adult male and female phantoms available in the NCINM code developed by NCI. Organ dose coefficients for the radioisotope I-131 with a different activity, which was placed in the thyroid for half an hour, and effective doses were calculated according to the ICRP-60 and ICRP-103 references for both adult male and female phantoms (given in Fig. 1). While activities of 333, 444, 555, and 666 MBq used in this study are used in the treatment of hyperthyroidism, activities of 1850, 3700, 5550, and 7400 MBq are used in differentiated thyroid cancer. As can be seen from the graphics, it shows that more doses are taken in women in treatments with the same activity. As expected, the irradiation geometry plays an important role in the dependence of the organ doses on the body structure and then on the effective dose. The data obtained will be useful to other users using ICRP reference phantoms for Monte Carlo dose calculation to compare the calculation process.

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