ISSN 1226-2854

S-value of Radioiodine(^{131}I) in Korean Reference Adult Male

— 한국 성인남성 표준인을 대상으로 한 방사성옥소(^{131}I)의 S-value 도출 —

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• Abstract

In order to better understand the effects of absorbed radioiodine upon Korean reference adult male, a mathematical phantom representation was contrived based on composite data of the physiology of Korean reference adult male. Using this, S-values of radioiodine(^{131}I) per each organ were calculated. The calculated S-values were compared to the existing data described in the TM-8381 report of ORNLcalculated on the basis of an ICRP-23 reference male. The results indicated that S-values were higher for the phantom based on Korean reference adult male. The results of this study illustrate that, while the bio-chemical constitution of each source and target organ of the torso are important, the relative location of the organs and characteristics of the radionuclides also exert important influences.

Key Words : Specific absorbed fractions, S-values, Absorbed doses

Ⅰ. Introduction

It is necessary to evaluate the absorbed doses of radiation to ensure optimal protection against radiation when radiation exposure occurs at a jobsite or when radiopharmaceuticals are orally administered or injected for diagnosis, treatment, or metabolic research purposes. The evaluation of radiation absorbed dose into the body is a result of handling the doses of radionuclides of radioisotopes distributed across organs and tissues in accordance to spatial and time parameters[1,2)]. The S-value is calculated by considering the various types and yields of radiation after deriving the specific absorbed fraction of each organ per radionuclide energy by using the characteristics of radiation within the source organs as well as the quantity of radioisotopes, characteristics of physical decay, types of radiation emitted upon decay, and energy. Through this, the radiation absorption into the body can be easily evaluated[3)]. The specific absorbed fractions and S-values in this study were calculated by using the MIRD-Type phantom a mathematical phantom based on the ICRP-23 reference man developed by Snyder, etc. in 1969. The specific absorbed fraction was derived in 1975 by using this phantom. In 1987, Cristy and Eckerman produced a mathematical phantom for several age groups of children and adults(classified into newborn, 1 year of age, 5 years of age, 10 years of age and 15

* 이 논문은 2007년 12월 18일 접수되어 2008년 3월 4일 채택 됨.
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years of age). In 1995, Stabin produced an anthropomorphic phantom of an adult female by using 15-year old children[4-6]. In Japan, the “Otoko” and “Onago” voxel phantoms using CT were developed in 2000. In Korea, the Korean reference man has been tentatively settled upon by the Radiation Health Research Institute of the Korea Hydro & Nuclear Power Co. However, this mathematical phantom is only in the stage of development. Currently, S-values and specific absorbed fractions calculated on the basis of the organs of the ICRP-23 Reference Man are used in Korea as the basic frame for internal radiation evaluation. Considering that the ICRP-23 Reference Man is based on Caucasians, when it is applied to Koreans or Asians with similar physical characteristics, an overestimation or underestimation error may be generated when deriving specific absorbed fractions or S-values because the weights or the shapes of organs are different. Therefore, a mathematical phantom was produced in this study by using the basic data of a composite of Korean reference adult male. 131I used for testing nuclear fuel(while a fuel rod is being replaced or for plant maintenance), examine the thyroid via oral administration or to treat cancer, may induce internal radioactivity exposure while a fuel rod is being replaced or for maintenance in a nuclear power plant. On the other hand, it is effectively used for thyroid diagnosis and cancer treatment in clinical research, but its negative effect is also reported to increase the absorbed dose of other organs.

Therefore, analysis of radionuclide within a human body will be beneficial for safeguarding people from radioactivity. In this Study, using the S-value of radioiodine(^{131}I) with 12 major organs as source organ was calculated after deriving the specific absorbed fraction for each organ.

Ⅱ. Materials and Methods

1. System of Medical Internal Radiation Dose(MIRD System)

The MIRD System refers to the calculation method of average radiation absorbed dose as suggested by the Medical Internal Radiation Dose Committee(Society of Nuclear Medicine, U.S.A.) in order to evaluate the radiation absorbed dose into human organs and tissues through the accumulation of radioactive materials into the human body. Calculating by way of the MIRD System requires an accurate measurement of radiopharmaceuticals dose, metabolic rate, distribution data in the body, physical properties of the nuclides and absorption characteristics in relation to the quality of beam radiation into the organs measured, et al. The MIRD System for radiation absorbed dose was formulated more systematically by Loevinger, etc. in 1988 as illustrated in eqn(1),

$$D = \widetilde{A}\, S \quad (1)$$

Here, the cumulated radioactivity is(curie-hour or becquerel-second). The cumulated radioactivity in a single organ is proportional to the total number of disintegrations in the organ. S is the radiation dose in the target region at the time of unit integration of a radioisotope in source regions. The MIRD Committee designated this value as the ‘S-value’. The S-value can be expressed in more detail as shown in eqn(2),

$$S = \frac{k \sum_i n_i E_i \phi_i}{m} \quad (2)$$

Where S-value is the mean absorbed dose to a target organ per unit cumulated activity in the source organ, n_i is the number of particles of type-i radiation emitted per nuclear transition, E_i is the mean energy per particle of type-i radiation, ϕ_i is the absorbed fraction per unit mass of the target organ, m is the Target organ.

When applying the classical unit to the constant number of k, the value of 2.13 is produced. The Radiation absorbed dose is expressed as *rad*, which is the radioactivity of μCi, mass of g and energy of MeV. Currently, SI units are being used. If the classical units are converted to SI units, rad can be converted to Gy and μCi to Bq. The absorbed fraction(ϕ_i) is determined by the types of radiation and energy, sizes, shapes, and constitution of source/target organs, distance between the source organs and target organs and the composition of tissues between the organs. In fact, the internal radiation evaluation varies in accordance with the radioactivity accumulated in a single organ and the energy absorption rate in many of the target organs. Therefore, radiation absorbed dose can be evaluated simply with only the cumulated radioactivity if the S-values per radionuclide are calculated as in eqn(2)[1,2,4].

2. Configuration of the Anthropomorphic Phantom

In this study, a mathematical phantom to represent the organs of a Korean reference male was contrived by applying modifications and reinforcements to the basic mathematical phantom of the MIRD-type anthropomorphic phantom on the basis of the Korean reference man as suggested by the Radiation Health Research Institute of the Korea Hydro & Nuclear Power Co., Ltd[7]. The MIRD-type phantom was configured with the body being erect and each of the organs represented in suitable shape such as an ellipse, cone, plane, cylinder, etc. A 3-dimensional(in centimeters) diagram on an orthogonal grid was produced using a quadratic equation. The z-axis is directed vertically through the head, the x-axis across the chest starting from the right shoulder to the phantom's left, and the y-axis from the anterior to the posterior of the phantom. The general equation of the mathematical phantom is as of eqn(3),

$$\left(\frac{x}{A_T}\right)^2+\left(\frac{y}{B_T}\right)^2 \le 1{,}0 \le Z \le C_T \quad \cdots\cdots (3)$$

Here, A_T, B_T and C_T respectively indicate the maximum values of the X, Y and Z axes of the cylinder[8-10]. To suit the trunk of Koreans, this can be expressed as in eqn(4),

$$\left(\frac{x}{17.25}\right)^2+\left(\frac{y}{9.8}\right)^2 \le 1{,}0 \le Z \le 64.135 \quad \cdots\cdots (4)$$

Although heights and weights of Korean show trend of increasing in couple of past decades, The average heights/weights were evaluated as 172 cm/68 kg for male, whole body MR/CT images for collection of anatomical data were obtained from 54 healthy adults male of near-average heights and weights[7].

The mathematical phantom for optimal organ modeling must be as close as possible to the actual organs. To ensure this, none of the organs can overlap. When administering the Monte Carlo calculation by computer, overlapping parts cause errors, thus negating the values. In order to prevent this, optimal organ modeling was arrived at using a Korean reference adult male with a height of 170 cm and weight of 68 kg, rather than the actual average height of approximately 172.4 cm. Also, for the external shape of each organ, the same method as for the MIRD-type mathematical phantom was applied to depict them as relatively simple spatial diagrams such a sphere, cylinder, ellipse, etc. Thus, after deriving a specific absorbed fraction, an S-value of ^{131}I was calculated. In Table 1, organs of the Reference Korean Male, the Reference Japanese Male and the ICRP-23 Reference Man based on Caucasians are compared. Also, the mathematical phantom of the Korean man was calculated by using organs of the Korean Adult Male suggested in Table 1.

Organs of the Korean Adult Male were compared to the organs of the ICRP-23 Reference Man, MIRD Phantom and Japanese Man. The result indicates that the weight of the organs of the Korean Adult Male was at the medium level of the weight of organs of the ICRP-23 Reference Man and Japanese Male. That is, there is a possibility of overestimation

Table 1. Masses of Organs and Tissues [Unit : g]

Organ	Reference Korean (Male)	ICRP-23 Reference (Man)	Reference Japanese (Male)	MIRD Phantom
Adrenal glands(2)	10**	14	14	15.5
Brain	1370	1400	1462	1451
Breast	26	26	-	350.48‡
Esophagus	40*	40	-	46.49
Gall Bladder	11*	10	8	10.5
Heart	340	-	360	595.2
Kidneys	260	310	320	284.2
Liver	1800	1800	1600	1809
Lung	1000	1000**	1100	999.2
Pancreas	60	100	130	60.27
Skeleton	10000*	10000	8300	10470
Spleen	200	180	140	173.6
Stomach	150	150	140	150
Testes	32	35	37	37.08
Thymus	20*	20	33	24.80
Thyroid	20	20	19	19.63
Urinary Bladder	45	45	40	45.13
Height (cm)	172±4.3	174.5±6.6	170±6	174
Weight(kg)	68.6±5.8	71.7±10	64±9	69.88

* ICRP-23 values are used due to lack of data. **plus arterial and venous blood. ‡ mass (both)

or underestimation when deriving S-values based on the organs of the ICRP-23 Reference Man and Japanese Reference Man as well as when applying them to the internal radiation evaluation of Koreans.

3. Calculation by monte carlo method

For the internal organs of the mathematical phantom used in this study, the masses and physical builds were determined and modeled on the basis of data from the Korean reference adult male as shown in(Fig. 1). Also considered were the substances of each organ, the constituting substances suggested in TM-8381, and the report of the Oak Ridge National Laboratory(ORNL). It is presumed that the lungs, bones(or skeleton) and other tissues are comprised of soft tissue. The densities were respectively given the values of 0.296 g/cm^3, 1.40 g/cm^3 and 1.04 g/cm^3.

The Monte Carlo particle transport code(MCNP4C-code) was used in calculating the photon transport and the quantity of energy given. For comparison against existing data, 12 organs were set as source and target organs. Photon energy was classified into 10 levels(0.02, 0.03, 0.05, 0.1, 0.2, 0.5, 1.0, 1.5, 2.0, 4.0 MeV) to derive a specific absorbed fraction per each organ. The S-value of radioiodine (^{131}I) was calculated after deriving specific absorbed fractions per each organ.

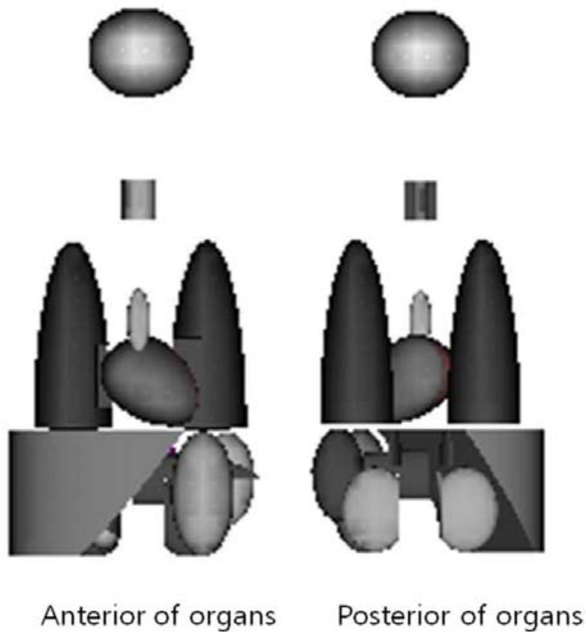

Fig. 1. Anatomical position and constitution of the phantom

Ⅲ. Results and Discussion

A mathematical phantom was contrived using composite data of a Korean reference adult male. Using this, the S-value of radioiodine(^{131}I) with 12 organs as source regions was calculated after deriving the specific absorbed fraction as shown in Table 2. The ICRP-38 database was used for information related to the decay chain of radioiodines (^{131}I) to calculate S-values. The calculated S-values were compared to the existing data described in the TM-8381 report of ORNL and examined accordingly as shown in Table 2. The result indicated that the

Table 2. S-value comparison per each organ

Target organ \ Source organ	Phantom	Brain	Thyroid	Thymus	Lung	Heart	Adrenals
Brain	Korean	1.82E-01	1.17E-06	2.00E-07	3.56E-07	8.60E-08	5.95E-08
	ORNL	1.82E-01	1.17E-06	2.19E-07	2.09E-07	9.70E-08	2.13E-08
Thyroid	Korean	4.02E-06	1.82E-01	3.50E-06	2.97E-06	1.09E-06	4.93E-07
	ORNL	2.62E-06	1.82E-01	2.75E-06	1.41E-06	8.36E-07	1.97E-07
Thymus	Korean	7.12E-07	5.39E-06	1.83E-01	1.63E-05	2.15E-05	3.28E-06
	ORNL	2.19E-07	2.74E-06	1.83E-01	0.00E+00	1.23E-05	1.15E-06
Lungs	Korean	5.45E-07	2.24E-06	7.50E-06	3.64E-01	1.14E-05	1.40E-05
	ORNL	2.09E-07	1.57E-06	4.99E-06	1.82E-01	7.46E-06	4.13E-06
Heart	Korean	4.00E-07	2.02E-06	2.42E-05	4.10E-05	1.82E-01	1.76E-05
	ORNL	9.70E-08	8.36E-07	1.23E-05	7.45E-06	1.82E-01	4.92E-06
Adrenals	Korean	8.79E-08	2.93E-07	1.48E-06	1.90E-05	5.40E-06	3.68E-01
	ORNL	2.13E-08	1.97E-07	1.15E-06	4.13E-06	4.92E-06	1.83E-01
Kidneys	Korean	4.20E-08	1.23E-07	4.92E-07	1.94E-06	1.57E-06	5.38E-05
	ORNL	9.16E-09	1.21E-07	4.24E-07	1.23E-06	1.41E-06	8.59E-05
Liver	Korean	7.76E-08	2.39E-07	1.19E-06	5.25E-06	3.91E-06	1.46E-05
	ORNL	3.35E-08	2.18E-07	1.11E-06	3.41E-06	4.02E-06	7.45E-06
Pancreas	Korean	8.47E-08	2.87E-07	1.52E-06	7.03E-06	6.23E-06	4.70E-05
	ORNL	2.59E-08	2.00E-07	1.08E-06	2.95E-06	5.78E-06	1.80E-05
Spleen	Korean	6.56E-08	1.64E-07	5.82E-07	3.77E-06	1.72E-06	1.40E-05
	ORNL	3.47E-08	1.95E-07	6.54E-07	2.82E-06	2.72E-06	7.86E-06
Stomach	Korean	6.10E-08	1.87E-07	1.05E-06	9.41E-06	3.46E-06	2.42E-05
	ORNL	1.67E-08	1.34E-07	7.98E-07	2.02E-06	4.39E-06	4.54E-06
Urinary Bladder	Korean	1.91E-08	4.05E-08	1.91E-07	7.04E-07	4.79E-07	2.49E-06
	ORNL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Target organ \ Source organ	Phantom	Kidney	Liver	Pancreas	Spleen	Stomach	Urinary Bladder
Brain	Korean	3.20E-08	4.37E-08	2.72E-08	4.43E-08	1.55E-08	1.38E-09
	ORNL	9.16E-09	3.35E-08	2.59E-08	3.47E-08	2.19E-08	0.00E+00
Thyroid	Korean	1.87E-07	3.44E-07	2.13E-07	2.22E-07	1.55E-07	1.16E-08
	ORNL	1.21E-07	2.19E-07	2.01E-07	1.95E-07	9.81E-08	0.00E+00
Thymus	Korean	1.29E-06	1.48E-06	1.87E-06	1.17E-06	1.39E-06	5.34E-08
	ORNL	4.24E-07	1.11E-06	1.08E-06	6.54E-07	8.21E-07	0.00E+00
Lungs	Korean	5.07E-06	4.99E-06	4.70E-06	3.97E-06	2.87E-06	1.17E-07
	ORNL	1.23E-06	0.00E+00	2.95E-06	2.83E-06	1.91E-06	0.00E+00
Heart	Korean	5.86E-06	6.80E-06	1.13E-05	5.15E-06	6.55E-06	2.08E-07
	ORNL	1.41E-06	4.02E-06	5.78E-06	2.72E-06	4.06E-06	0.00E+00
Adrenals	Korean	9.02E-05	1.00E-05	2.66E-05	1.19E-05	6.14E-06	3.30E-07
	ORNL	1.27E-05	7.45E-06	1.78E-05	7.86E-06	5.02E-06	0.00E+00
Kidneys	Korean	1.82E-01	6.66E-06	1.07E-05	1.33E-05	5.20E-06	6.26E-07
	ORNL	1.82E-01	5.02E-06	8.66E-06	1.15E-05	4.48E-06	0.00E+00
Liver	Korean	1.60E-05	1.82E-01	5.57E-06	1.59E-06	2.90E-06	3.50E-07
	ORNL	5.02E-06	1.82E-01	6.33E-06	1.34E-06	2.54E-06	0.00E+00
Pancreas	Korean	2.73E-05	9.28E-06	1.82E-01	2.23E-05	2.77E-05	5.17E-07
	ORNL	8.66E-06	6.33E-06	1.82E-01	2.23E-05	2.06E-05	0.00E+00
Spleen	Korean	1.84E-05	1.21E-06	1.24E-05	1.82E-01	1.01E-05	2.29E-07
	ORNL	1.15E-05	1.34E-06	2.23E-05	1.82E-01	1.29E-05	0.00E+00
Stomach	Korean	2.32E-05	3.12E-06	2.76E-05	1.06E-05	1.82E-01	6.66E-07
	ORNL	4.37E-06	2.64E-06	2.13E-05	1.27E-05	1.82E-01	0.00E+00
Urinary Bladder	Korean	5.32E-06	1.92E-06	2.25E-06	1.71E-06	2.59E-06	1.83E-01
	ORNL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.82E-01

Cf: Korean = Korean reference adult malt, ORNL=TM-8381 report of ORNL

S-values derived from the Korean reference adult male were consistently higher than those of Oak Ridge and TM-8381 data. This was due to the difference in the mass of the organs, distance between the source and target organs, composition of the organs and types as well as range of radiation in source organs. When the weight of a body and organ is low, the absorbed fraction will be low. On the other hand, S-values calculated to consider the specific absorbed fractions by dividing the absorbed fraction with the weight of the organ, types of radionuclides and yields indicated relatively higher results. Having compared the two data, the S-values were found to be similar. However, there was a tendency that the values derived on the basis of the Korean reference adult male in most of the energy regions were in the higher level. In addition, organs located relatively closer to the source organs produced higher S-values. Accordingly, organs located farther away from the source organs produced lower S-values.

Ⅳ. Conclusions

In this study, a mathematical phantom was contrived to generate a qualitative evaluation of the radiation absorbed dose in a Korean reference adult male. Using this, S-values of ^{131}I with 12 organs as target organs were calculated after deriving specific absorbed fractions per each organ.

The calculated S-values were compared to the existing data described in the TM-8381 report of ORNL. As a result, S-values were found to be higher in the phantom based on the Korean Reference Adult Male in most organs. This is considered to be because of the differences in body size and masses of organs comprising the phantom, radioactive characteristics of source organs, quantity of radioisotopes contained within the source organs, physical characteristics of disintegration and the types as well as energy of radiation emitted at the time of disintegration. Secondly, organs located closer to source organs displayed a greater tendency for energy penetration than the organs located farther away. Therefore, S-values indicated differences per each organ in accordance with the space in which it is located.

Thirdly, when kidneys, which are separated into two parts although of the same physiological function, are set as the source organ, higher S-values were displayed in the pancreas and stomach located relatively at the center of the trunk than the liver and spleen, which are located to the left and right sides of the kidneys. As illustrated in the results of this study, the positions of organs situated within a confined space must be considered as very important. It was found that, for source organs and target organs located inside a specific part of the trunk, not only the composition, but also their positions exert important influences.

The calculated S-value in the study can be utilized as the basic data for evaluating internal absorbed doses of Koreans as well as other Asians whose body shapes are similar to those of Koreans.

Acknowledgements

This work was supported by the SRC/ERC program of MOST/KOSEF and was financially supported by MOCIE through IERC program.

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• Abstract

한국 성인남성 표준인을 대상으로 한 방사성옥소(^{131}I)의 S-value 도출

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한국 성인 남성 표준인(Korean Reference Adult Male)의 기초 자료를 이용하여 수학적 모의 피폭체(Mathematical Phantom)를 제작하였다. 또한 이를 이용하여 방사성옥소(^{131}I)의 각 장기별 S-value를 산출 하였다. 산출된 S-value는 기존 ICRP-23표준인에 근거하여 산출한 MIRD 5, 및 ORNL-TM 8381자료와 비교해 보았다. 그 결과 S-value는 한국 성인 남성 표준인에 기초한 모의 피폭체가 높은 값을 나타냈다. 이는 몸통이라는 특수한 공간에 위치하게 되는 선원장기(source organ) 및 표적장기(target organ)가 함유하고 있는 구성물질도 중요하지만 그에 못지않게 이들이 차지하고 있는 위치 및 방사성핵종의 특성 또한 중요하게 작용한다는 것을 알 수 있었다.

중심 단어 : 비흡수분획, S-value, 흡수선량, 모의피폭체