Radiation Absorbed Dose Estimation of 2-[F-18]Fluoro-2-Deoxy-D-Glucose Using Whole Body PET and Measured Organ Volume MRI

IV. 1. Radiation Absorbed Dose Estimation of 2-[F-18]Fluoro-2-Deoxy-D-Glucose Using Whole Body PET and Measured Organ Volume from MRI

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Introduction

To assess the radiation risk of administered radiopharmaceutical in PET study, two important parts are concerned; one is the total cumulated radioactivity in an organ and another is the absorbed dose estimation in the organ[1]. In both cases biokinetic information with human organ volumes and masses are essential. To estimate the cumulated activity and internal absorbed dose, the organ volumes from the MIRD phantom[2] for the Caucasian reference men and an another phantom for the Asian/Japanese reference men[3] are usually used[4]. Whatever the phantom is, in practice the deviation of organ size from the phantom may introduce an error in the cumulated activity and in the absorbed dose as well. Hence by using actual organ volumes of the individual in the whole body PET, a quantitative analysis of the organ cumulated activity and absorbed dose may give more accurate results than those with the MIRD phantom[2] and the Japanese reference man[3].

The purpose of this study was to establish an accurate measurement method of cumulated activity and absorbed dose of organs by using the whole body PET and MRI for the intake of 2-[F-18]Fluoro-2-Deoxy-D-Glucose (FDG). The following measurements has been done in this study:

1. Measurement of organ volumes as well as masses (source and target organs) of the individual by using whole body MR images.
2. Measurement of activity concentration of all source organs from the whole body PET image and estimation of total and cumulated activities of the source organs for the measured organ volumes.
3. Absorbed dose estimates of the individuals by using the measured target organ masses.
4. A comparison of the cumulated activities and internal absorbed doses by using individual organ information (volumes and masses) with MIRD phantom and Japanese reference man[2,3,4].

Materials and methods

The study consisted of 6 normal volunteers. All subjects gave their written consent and the study protocol was approved by the Ethics Committee for Clinical Research of Tohoku University. On each volunteer MRI and PET scans were performed[5] to measure the organ volumes and organ activity concentration.

The PET studies were done with a whole body PET scanner at CYRIC, Tohoku University.

The polynomial ROIs of each source organ on the transaxial PET images were defined by referring the MR image and the average activity concentration of an organ was measured[5].

All the data were corrected for physical decay. Cumulated activities of the source organs were calculated from the time activity curves[5]. To investigate the discrepancies of actual individual results against the phantom results, cumulated activities were also calculated with the MIRD phantom[2] and the Japanese reference man[3] by the following equation:

$$\tilde{A}_P = \tilde{A}_{MR} \times \frac{V_P}{V_{MR}} \qquad (1)$$

where $\tilde{A}_{MR}$ is the cumulated activity of the source organs using the measured individual volume V_{MR}, the cumulated activity $\tilde{A}_P$ is for the organ volume V_P, obtained either from the MIRD phantom (2) or from the Japanese reference man[3].

Absorbed Dose and Effective Dose Equivalent Calculations:

In the MIRD method (1) the mean absorbed dose to the k-th target organ is defined as:

$$D(r_k) = \sum_h \tilde{A}_h \, S(r_k \leftarrow r_h) \qquad (2)$$

where $S(r_k \leftarrow r_h)$ is the absorbed dose in the k-th target organ per unit cumulated activity of the h-th source organ, i.e. S-value, and $\tilde{A}_h$ the cumulated activity of the h-th source organ.

The absorbed doses in the 27 target organs were calculated for the three different sets of cumulated activities with the IDES code[6] based on the MIRD method[1]. A transformation method[7] was applied to the MIRD S-Tables[2] to obtain the S values of the measured individual organ weights and organ weights for the Japanese reference man[3]. In the case of major airway and nasal cavity wall, the S-values calculated by Deloar et al.[8] were used.

The effective dose equivalent of the target organs were calculated from the following relations:

$$H_E = \sum_h W_i H_i = \sum_h W_i D_i \quad Q = \sum_h W_i D_i \qquad (3)$$

where H_i is the dose equivalent of the i-th target organ, D_i is the absorbed dose of i-th target organ, Q is the quality factor (=1 for b and g-rays) and w_i tissue weighting factor given in ICRP 60[9].

Results and Discussion

The organs having the weighting factors according to the ICRP 60[9], were considered as the source organs and the volume of those organs were measured by MRI. The organ volumes of each individual were reported[5] with the organ volumes of MIRD phantom[10]. To obtain target organ masses from their volumes, the corresponding densities of those tissues in the MIRD phantom[10] were used[5].

The cumulated activities of 18 source organs for three sets of organ volumes were calculated[5]. Those mean cumulated activities are shown in Table 1 with the standard deviations and compared with the other result[4]. Among the cumulated activities of the source organs in our study, the brain, bladder and liver showed the highest values in this descending order. The results except for bladder, lung, liver and pancreas showed good agreement among these three calculations. The discrepancies of the results for those organs are due to the differences of organ volumes in between measurements and in the MIRD phantom and Japanese reference man[2,3]. The cumulated activity of the bladder for measured volume is very close to the result of Mejia et al.[4], but differences arise in phantom studies[2,3] due to the assumption of constant bladder volume. The cumulated activity of the kidney in this study was around 7 times higher than the result of Mejia et al.[4]. This large values with wide dispersion may be due to the difference of the renal function of the individuals and in this study all the subjects were relatively younger (average age 30 yrs) than the Mejia et al.[4]. The cumulated activities of the liver and pancreas are very close to those of Mejia et al[4], but those in the lung shows 4 times difference. The brain cumulated activities under this work are consistent among these three cases but 4 times differ from the result of Mejia et al. [4]. The heart cumulated activity is around a factor 2 times lower than the result of Mejia et al. [4]. In the remainder of the body, variation of cumulated activities among three cases is due to the difference of organ sizes in individual measurement and two phantoms[2,3]. The cumulated activity in the remainder of the body calculated by Mejia et al. [4], 1964 kBq-h/MBq, which is around 14% higher than this study. The reason is, in the study of Mejia et al. only seven source organs are considered and other organs were the part of the remainder body.

The mean absorbed doses of 27 target organs with their standard deviations for three different types of cumulated activities are summarized in Table 2 and compared with the other result[4].

The mean absorbed doses in Table 2 show good agreement among three cases (for individual, MIRD phantom and Japanese reference man) except the doses of bladder wall, stomach wall, colon (LLI+ULI) and testes due to the difference of volumes, which affected the cumulated activities of those organs. Although the mean effective dose equivalent calculated from Eq. 3, for the measured organ volumes of average body weight 64 kg and the MIRD phantom of 70 kg body weight are almost equal together, the effective dose equivalent for the Japanese reference man of 60 kg is 25% lower than the former two results. In the comparative study with other results[4] in Table 2, the absorbed doses in bladder for measured

mass and MIRD phantom[2] are 4 times and those in lung and brain are around 2.5 times higher than other results[4].

In conclusion, a coupled use of the whole body PET for the organ activity concentration measurement and MRI for the organ volume measurement can greatly improve the accuracy of the cumulated activities and absorbed doses of the organs.

References

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Table 1. Comparison of Average Cumulated Activity (kBq-h/MBq) (mean ± standard deviation) of the Source Organs Using the organ volumes from the Measurment (MRI), MIRD Phantom (2), Japanees reference man (3) and Other Result.

Source Organs	This Work			
	Average Cumulated Activity Using the Measured Volume by MRI	Average Cumulated Activity Using MIRD Phantom (2)	Average Cumulated Activity Using the Organs Volume of the Japaness reference man (3)	Cumulated Activity by Mejia et.al. (4)
Adrenal	1.1 ± 0.6	1.4 ± 0.6	1.1 ± 0.5	
Major Airway (Wall)	4.2 ± 1.6	5.3 ± 3.0	4.9 ± 2.3	
Nasal Cavity (Wall)	3.7 ± 1.6	5.1 ± 3.5	4.3 ± 2.8	
Bladder Content	176.4 ± 122.2	262.5 ± 228.9	86.7 ± 76.8	162
Stomach Content	15.8 ± 9.1	11.7 ± 6.2	6.4 ± 3.2	
Small Intestine	52.1 ± 30.0	68.8 ± 41.4	55.8 ± 34.2	
ULI Content	19.0 ± 11.9	14.6 ± 6.9	13.0 ± 6.2	
LLI Content	13.3 ± 5.4	10.3 ± 5.7	9.2 ± 5.2	
Kidney	57.5 ± 26.0	58.2 ± 26.1	61.8 ± 20.8	8.1
Liver	132.4 ± 25.1	189.0 ± 48.0	158.3 ± 40.2	112
Left Lung	44.2 ± 13.6	70.8 ± 18.3	71.5 ± 18.9	*23.2
Right Lung	45.8 ± 12.4	54.2 ± 7.5	63.5 ± 10.1	
Pancreas	6.2 ± 3.3	15.3 ± 19.7	21.2 ± 3.3	10.3
Spleen	13.2 ± 3.8	12.8 ± 4.3	10.0 ± 3.3	34.1
Testes	4.0 ± 1.6	2.5 ± 0.9	2.3 ± 0.8	
Thymus	4.5 ± 10.2	4.7 ± 7.7	5.9 ± 13.7	
Thyroid	1.1 ± 0.8	1.5 ± 0.7	1.3 ± 0.6	
Brain	444.3 ± 73.8	414.0 ± 56.8	428.0 ± 62.8	178
Heart (Left Ventricle)	41.6 ± 14.7	29.7 ± 18.1	31.9 ± 11.6	85.1
Remainder Body	1559.7 ± 157.6	1407.6 ± 263. 9	1603.0 ± 151.6	1964.2

* Both Left and Right Lung

Table 2. Average Absorbed Dose Estimates (mGy/MBq) (mean ± standard deviation) to the Target Organs in This work and Comaprision with Other Results.

Target Organs	This work			Mejia et al. (4)
	Absorbed dose for measured mass (by MRI) of 64 kg average body weight	Absorbed dose for MIRD Phantom (2) of 70 kg body weight	Absorbed dose for Japanees reference man (3) of 60 kg body weight	
Adrenal	2.1E-02 ± 4.5E-03	2.1E-02 ± 5.3E-03	2.4E-02 ± 6.0E-03	1.8E-02
Major Airway (Wall)	2.5E-02 ± 4.1E-03	2.3E-02 ± 6.8E-03	2.9E-02 ± 7.3E-03	
Nasal Cavity (Wall)	3.1E-02 ± 5.0E-03	2.7E-02 ± 3.6E-03	3.4E-02 ± 4.6E-03	
Bladder wall	4.0E-01 ± 3.2E-01	4.1E-01 ± 3.4E-02	1.8E-01 ± 1.5E-01	1.2E-01
Stomach wall	1.4E-02 ± 1.5E-03	1.4E-02 ± 3.3E-03	1.4E-02 ± 2.2E-03	1.5E-02
Small Intestine	1.6E-02 ± 2.8E-03	1.6E-02 ± 4.0E-03	1.8E-02 ± 4.1E-03	1.7E-02
ULI wall	1.7E-02 ± 3.4E-03	1.6E-02 ± 3.9E-03	1.9E-02 ± 4.3E-03	1.7E-02
LLI wall	1.5E-02 ± 2.7E-03	1.5E-02 ± 3.2E-03	1.7E-02 ± 3.6E-03	1.8E-02
Kidney	4.0E-02 ± 1.4E-03	4.1E-02 ± 1.6E-02	4.6E-02 ± 1.8E-02	3.0E-02
Liver	2.6E-02 ± 6.7E-03	2.7E-02 ± 5.6E-03	2.8E-02 ± 5.7E-03	2.3E-02
Lung	2.6E-02 ± 2.8E-03	2.6E-02 ± 4.1E-03	3.1E-02 ± 4.4E-03	1.1E-02
Ovary	1.5E-02 ± 1.9E-03	1.4E-02 ± 1.9E-03	1.5E-02 ± 1.2E-03	
Pancreas	3.3E-02 ± 2.1E-03	3.6E-02 ± 3.4E-02	3.7E-02 ± 3.5E-03	2.0E-02
Spleen	2.0E-02 ± 3.6E-03	1.9E-02 ± 4.6E-03	2.1E-02 ± 4.9E-03	2.2E-02
Testes	1.8E-02 ± 2.9E-03	1.7E-02 ± 3.7E-03	1.7E-02 ± 3.6E-03	1.5E-02
Thymus	1.1E-02 ± 1.5E-03	9.5E-03 ± 1.4E-03	1.3E-02 ± 8.0E-04	
Thyroid	1.8E-02 ± 4.8E-03	1.7E-02 ± 5.2E-03	1.9E-02 ± 5.0E-03	1.3E-02
Uterus	1.8E-02 ± 2.6E-03	1.8E-02 ± 5.5E-03	1.7E-02 ± 2.3E-03	1.9E-02
Breast	8.7E-03 ± 1.1E-03	7.6E-03 ± 1.1E-03	1.0E-02 ± 7.0E-03	1.0E-02
Ribs	9.7E-03 ± 1.2E-03	8.6E-03 ± 1.1E-03	1.2E-02 ± 6.0E-04	
Skull	3.0E-02 ± 6.3E-03	2.4E-02 ± 2.0E-03	3.1E-02 ± 2.4E-03	
Spine	1.3E-02 ± 1.6E-03	1.1E-02 ± 1.3E-03	1.5E-02 ± 7.0E-04	
Pelvis	1.2E-02 ± 1.4E-03	1.1E-02 ± 5.0E-03	1.3E-02 ± 6.0E-04	
Brain	6.9E-02 ± 6.9E-03	6.8E-02 ± 6.7E-03	9.0E-02 ± 8.9E-03	2.9E-02
Heart Wall	2.3E-02 ± 1.0E-02	2.3E-02 ± 9.9E-03	3.1E-02 ± 1.3E-02	3.0E-02
Red Marrow	7.2E-03 ± 1.2E-03	6.1E-03 ± 4.0E-04	7.7E-03 ± 3.0E-03	1.2E-02
Bone Surface	8.7E-03 ± 1.3E-03	7.4E-03 ± 6.0E-04	9.5E-03 ± 0.0003	1.5E-02
Effective Dose Equivalent (mSv/MBq)	3.6E-02 ± 1.6E-02	3.6E-02 ± 1.8E-03	2.7E-02 ±7.3E-03	2.4E-02