ORIGINAL ARTICLE

Radiation exposure and patient organ dose measurement from 18F-FDG in a PET/CT facility

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ABSTRACT

Background: 18F-fluorodeoxyglucose (FDG) is a radiopharmaceutical (radioactive tracer), generally used in the medical indicator on positron emission tomography/computerized tomography (PET/CT). PET/CT is an essential device for patients' diagnosis and their responses to treatment; it uses radioactive tracers for diagnosis. PET/CT is used with a special detector and worked with a computer to evaluate the sick organ and the functions of the tissues. PET/CT scanning is a special type of nuclear medicine indicator, highly used in clinics. In this study, we aimed to measure the level of radiation and its effectiveness in mentioned organs in PET/CT devices. In the basis of this study, we want to reveal the level of radiation in different age range of patient's absorbed organ 18F-FDG.

Methods: The absorbed organ's radiation level and the affected organ's radiation level were calculated in accordance with Monte Carlo (MC) methods.

Results: The results for the patient's target organs in the used phantoms showed variations in age stages when compared with those determined by the MC simulation. These variances result from the structural anatomical differences in the age studied and in significant changes in the relation to their activity rate.

Conclusion: The medical radiation which is exposed from PET/CT studies should be important in all the patients groups, furthermore, is more considerable in pediatric and adolescence patients. The As Low As Reasonably Achievable principle must be implemented in either by reducing the radiation dose on PET/CT or by considering alternative diagnostic imaging unit or device should be used.

Keywords: Positron emission tomography/computerized tomography (PET/CT), florodeoxyglucose (18F-FDG), radiation protection.

INTRODUCTION

The procedures in using positron emission tomography/computerized tomography (PET/CT) in hospitals and its obvious facilities have been increased in the recent years. PET/CT possesses a nuclear medicine scanning technique which is used in order to find out the diagnoses of the body. PET/CT is an effective method for locating the diagnosis. It also monitors the responses of the treatment and the specification of the malignancies [1,2]. PET/CT is a useful device which is used in cancer treatment in oncology as a combined remedial. By using a series of independent of CT transmission detectors, PET/CT enables useful information. At first, the patient's doses of PET and CT in PET/CT examination are calculated in different ways [3]. Most use of these diagnoses undoubtedly has benefit but there are others procedures for which the benefit is not clear or has not been quantified. It is the duty of the referring clinician and the nuclear medicine physician and others to assess the potential benefit-risk ratio for various procedures. In the last works, several different simulation codes have been developed to be used in nuclear medicine, such as Medical Internal Radiation Dose (MIRD) and VMC. Gómez-Ros et al. and Hunt et al. worked on Monte Carlo (MC) program with Visual MC (VMC) *in vivo* were used for the modeling. Lee et al. worked on the voxel phantoms for used in the VMC simulations. Fonseca et al. worked on MaMP and FeMP voxel phantoms.

MATERIALS AND METHODS

Clinical PET/CT studies performed with patients on different age classifications (Table 1). Patients absorbed organ doses and effective doses from [18F]-fluorodeoxyglucose (FDG) was estimated using the MC methods Internal Dosimetry Calculator [Vmc-International Commission on Radiological Protection (ICRP) 103] with patient specific scan parameters.

The purpose of this study is to find out the internal dosimetry (MC simulation) of the body where PET/CT protocols are used in patient's data and dose (absorbed organ and effective dose). The utility of such data value and evaluated of risks/benefits for PET scan and protocol optimization in its clinical usage and the results of patient activity dose values are calculated.

MC simulation was calculated in a series of phantoms, 5–74 years child, adolescent, young adult, middle aged, aged patients, and simulation geometry showed in

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Table 1. Age categories and life cycle groupings [4].

Growth stages	Age (years)	Patient number
Child	2–10	1
Adolescence	11–17	2
Young adult	18–40	3

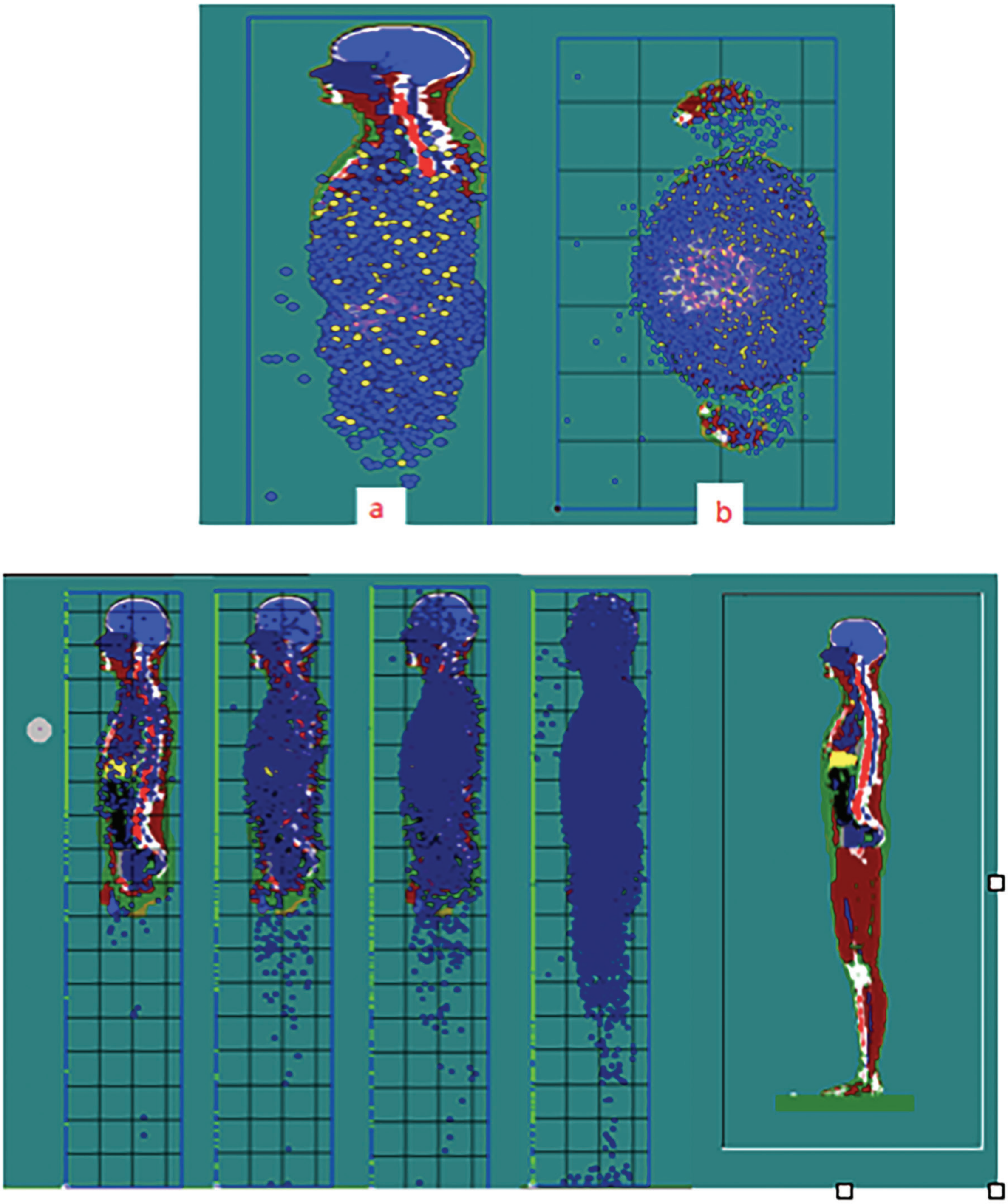

Figure 1. Simulation geometry. (a) in side view and (b) top view [(18F)-FDG] source.

Figure 1. Probable absorbed and affected organ doses of PET were calculated by using the MC software with specific [18F]-FDG doses. Simulation geometry in side view and top view VMC considered a "specialized" MC program as it is designed and the main geometry used is the voxel matrix. We used the activity of a [18F]-FDG deposited in a phantom body, through direct bioanalysis methods, we measured to calibrate the counting geometry. Estimated doses are arranged for patient's age, height, and weight in the concordance of the published values. MC simulation which we used is a code to measured absorbed dose prediction for radiopharmaceuticals used in nuclear medicine clinics. Simulation has data of phantom which estimates the evaluation of organ doses for the patients.

In this study, 5–74 years adult male models in phantom library were used to generate effective dose conversion factor. Absorbed dose, *D* ($J\ kg^{-1}$, special unit Gy), is an energy given dose which is created by ionizing radiation to a unit mass of matter. It is a physically measurable principle of the quantity. The mean of corporal weights of patients and its ICRP simulators are similar. They are used as ICRP dose conversion factors to calculate the organ's exposing rate.

D_T is the absorbed dose of the target organ, *T* is the accumulated radionuclide in a single source, *S* is the target organ of accumulated radionuclide (Equation 1).

$$D_T = A_S S(T \leftarrow S) \quad (1)$$

A is for the time united or accumulated activity. *A*, is the total number of disunited in the source organ. $S(T \leftarrow S)$ is the dose conversion factor (Table 1) and it is related with the amount of the radiation. It emits the energy disintegration and the mass of the target organ and geometry of the simulators [5].

Effective dose, *E* ($J\ kg^{-1}$, special unit Sv), is the total of equivalent dose in tissues or in organs. Each tissues or organs are multiplied by the eligible organ weighting factors which are also specified in the ICRP Publications cited.

E is the sum of all absorbed doses which are sized up by radiation evaluation and suitable organ evaluation factors of the whole body (Equation 2).

$$\text{Effective organ doses } W = \sum \times (T) \quad (2)$$

As for patients data were calculated in factors which are shown in Table 2, comparison of the tissue weighting factors are shown in Table 3.

MC code is a simulation which sets simulations to intended option for the absorbed radiation dose evaluation in complex situation [9-10-11]. The program MC (VMC) was specifically established in the Instituto de Radioprote Ção e Dosimetria in order to transfer photon though voxel phantoms. The program is established with Visual Basic and programmed to apply to internal and external dose calculations of photons [12]. Later, the program was spread to intended electron, proton, and alpha particle transport via voxel structures. VMC has been comprehensively used for validating contrasts of a number of bodily phantoms, and other MC programs are also used for international mutual comparison of corresponding parts [12,13]. VMC program is associated with voxel phantoms; VMC is an application which is used in three areas of radiation protection: calibration of *in vivo* measurement systems, dose calculations of external sources of radiation, and the calculation of

Table 2. Tissue weighting factor ICRP-103 [6].

Tissue	Tissue weighting factor wT	ΣwT
Bone-marrow (red), colon, lung, stomach, breast, remaining tissues (adrenals, extrathoracic region, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate, small intestine, spleen, thymus, uterus/cervix)	0.12	0.72
Gonads	0.08	0.08
Bladder, oesophagus, liver, thyroid	0.04	0.16
Bone surface, brain, salivary glands, skin	0.01	0.04
Total		1.00

Table 3. Comparison of the tissue weighting factors form ICRP publications 26, 60, and 103 [6, 7, 8].

Organs	Tissued weighting factors		
	ICRP 26	ICRP 60	ICRP 103
Gonads	0.25	0.2	0.08
Bone marrow	0.12	0.12	0.12
Lung	0.12	0.12	0.12
Breast	0.15	0.05	0.12
Thyroid	0.03	0.05	0.04
Bone Surfaces	0.03	0.01	0.01
Remainder	0.3	0.05	0.12
Colon	-	0.12	0.12
Stomach	-	0.12	0.12
Bladder	-	0.05	0.04
Liver	-	0.05	0.04
Esophagus	-	0.05	0.04
Skin	-	0.01	0.01
Salivary glands	-	-	0.01
Brain	-	-	0.01

Table 4. Patient 1 the absorbed organ doses and effective doses (for 1–10 hours).

Organ doses D(T)in mGy										
Estimated organs	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours	8 hours	9 hours	10 hours
Bone marrow	0.82	1.64	6.92	9.3	11.6	13.84	16.28	18.46	20.93	23.28
Colon	0.84	1.67	8.17	10.97	13.66	16.37	19.19	21.82	24.67	27.28
Lung	12.8	25.47	0.24	0.32	0.39	0.47	0.57	0.62	0.73	0.78
Stomach	3.47	6.81	0.73	0.92	1.17	1.44	1.63	1.92	2.09	2.32
Breast	0	0	0	0	0	0	0	0	0	0
Remainder	5.08	10.16	2.2	2.91	3.65	4.44	5.08	5.92	6.53	7.26
Gonads	0.02	0.04	10.32	13.96	17.1	20.81	24.05	27.75	30.93	34.64
Bladder	0.09	0.17	213.71	287.11	356.03	427.96	501.45	570.62	644.72	713.27
Oesophagus	7.59	15.51	0.31	0.32	0.52	0.58	0.63	0.77	0.81	0.9
Liver	3.15	6.26	0.76	1.01	1.26	1.51	1.78	2.01	2.28	2.52
Thyroid	3.6	6.72	0.06	0.19	0.03	0.12	0.29	0.16	0.38	0.12
Bone surface	1.48	2.95	3.13	4.17	5.19	6.27	7.29	8.35	9.38	10.39
Brain	0.11	0.22	0	0.01	0.01	0.01	0.01	0.01	0.01	0.02
Salivary glands	3.85	7.87	0.16	0.16	0.26	0.29	0.32	0.39	0.41	0.46
Skin	0.4	0.8	1.26	1.68	2.12	2.52	2.95	3.36	3.79	4.22
Adrenals	2.77	5.83	1.4	1.42	1.76	2.97	2.49	3.95	3.2	2.96
Extrathor airways	7.59	15.51	0.31	0.32	0.52	0.58	0.63	0.77	0.81	0.9
Gall bladder	3.47	6.81	0.73	0.92	1.17	1.44	1.63	1.92	2.09	2.32
Heart	18.8	37.41	0.36	0.47	0.58	0.68	0.83	0.91	1.07	1.15
Kidneys	1.59	3.19	1.36	1.78	2.26	2.78	3.08	3.7	3.96	4.49
Lymphatic nodes	18.8	37.41	0.36	0.47	0.58	0.68	0.83	0.91	1.07	1.15
Muscle	0.79	1.57	2.72	3.63	4.53	5.44	6.35	7.25	8.16	9.07
Oral mucosa	0.11	0.22	0	0.01	0.01	0.01	0.01	0.01	0.01	0.02
Pancreas	2.46	4.76	1.1	1.5	2.03	2.27	2.66	3.03	3.41	4
Prostate	0.02	0.04	10.32	13.96	17.1	20.81	24.05	27.75	30.93	34.64
Small intestine	0.84	1.69	7.2	9.71	12.19	14.41	16.93	19.21	21.77	24.41
Spleen	3.75	7.51	0.58	0.8	1.01	1.17	1.41	1.56	1.82	1.98
Thymus	0	0	0	0	0	0	0	0	0	0
Eye lens	0.18	0.38	0.02	0	0	0.01	0.03	0.01	0.04	0
Effective Dose(mSv)	3.74	7.43	12.82	17.22	21.36	25.68	30.06	34.25	38.64	42.79

absorbed and affected doses which are explained in this study.

The simulation of photon transports via a voxel phantom needed adapted voxel geometries in MC program. VMC is written in visual Basic®, Microsoft Windows related program. It is easy to be used and it has a comprehensive graphic output. The voxel phantoms were improved by the National Radiological Protection Board and Yale University. VMC simulation also does the effective dose calculations and they are performed during the usage of the internal dose computer program IDAC 2.0. Affected dose presented by ICRP is calculated with the tissue sizing up factors from ICRP publication 60. The computer program uses the tissue sizing up factors from ICRP publication 103 to estimate the effective dose.

The code is not taken into account in biokinetic models. It was originally written for vocational exposed workers, the code has been used in radionuclides in nuclear medicine procedures. That is why the residence time in the main source organs is related with that. F-18 is the main radionuclide in FDG; Hayes et al. used this as a kinetic pattern [10].

RESULTS AND DISCUSSION

All the mean estimated absorbed organ doses for 1–10 hours to the relevant organs are listed in Tables 4–6. All the mean estimated effective doses for 1–10 hours to the relevant organs are listed in Tables 4–6. The background radiation dose was subtracted before D_T was estimated in each measuring sessions.

Table 5. Patient 2 the absorbed organ doses and effective doses (for 1–10 hours).

Organ doses D(T)in mGy										
Estimated organs	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours	8 hours	9 hours	10 hours
Bone marrow	2.12	4.27	6.41	8.48	10.64	12.72	14.9	16.96	19.04	21.13
Colon	2.5	5.03	7.51	10.06	12.5	15.02	17.48	19.94	22.54	25.03
Lung	0.07	0.15	0.21	0.3	0.37	0.45	0.5	0.59	0.65	0.73
Stomach	0.22	0.43	0.64	0.83	1.1	1.32	1.52	1.68	1.91	2.22
Breast	0	0	0	0	0	0	0	0	0	0
Remainder	0.68	1.33	2	2.67	3.35	4.03	4.6	5.34	6.01	6.58
Gonads	3.18	6.31	9.54	12.5	15.74	19.14	21.77	25.45	28.36	30.65
Bladder	65.45	131.46	196.35	262.3	327.22	391.12	456.73	521.86	587.31	652.25
Oesophagus	0.09	0.16	0.25	0.34	0.43	0.53	0.51	0.74	0.83	0.87
Liver	0.23	0.47	0.69	0.93	1.18	1.42	1.65	1.88	2.07	2.35
Thyroid	0.02	0.08	0.03	0.02	0.11	0.04	0.16	0.22	0.22	0.14
Bone surface	0.96	1.91	2.86	3.82	4.8	5.72	6.7	7.66	8.62	9.61
Brain	0	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.02
Salivary glands	0.05	0.08	0.13	0.17	0.22	0.27	0.26	0.38	0.42	0.45
Skin	0.39	0.77	1.16	1.55	1.93	2.33	2.7	3.09	3.45	3.89
Adrenals	0.45	0.65	0.82	1.45	1.84	1.82	2.07	2.29	2.9	2.82
Extrathor airways	0.09	0.16	0.25	0.34	0.43	0.53	0.51	0.74	0.83	0.87
Gall bladder	0.22	0.43	0.64	0.83	1.1	1.32	1.52	1.68	1.91	2.22
Heart	0.1	0.22	0.32	0.44	0.54	0.66	0.74	0.87	0.95	1.08
Kidneys	0.42	0.81	1.24	1.68	2.08	2.54	2.81	3.31	3.77	4.11
Lymphatic nodes	0.1	0.22	0.32	0.44	0.54	0.66	0.74	0.87	0.95	1.08
Muscle	0.83	1.66	2.5	3.33	4.16	4.99	5.82	6.67	7.48	8.33
Oral mucosa	0	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.02
Pancreas	0.35	0.7	1.1	1.38	1.76	2.1	2.37	2.85	3.35	3.66
Prostate	3.18	6.31	9.54	12.5	15.74	19.14	21.77	25.45	28.36	30.65
Small intestine	2.2	4.44	6.72	8.91	11.12	13.42	15.57	17.92	19.91	22.24
Spleen	0.18	0.37	0.55	0.76	0.89	1.12	1.32	1.42	1.7	1.88
Thymus	0	0	0	0	0	0	0	0	0	0
Eye lens	0	0.01	0	0.02	0	0.08	0	0.01	0	0.25
Effective Dose(mSv)	3.93	7.88	11.78	15.71	19.63	23.5	27.37	31.32	35.23	39.05

Estimated absorbed organ, effective dose by unit activity administered in age 5, height 110, weight 19, (mg/dl) 113, and activity dose (mci) 4.6 are listed in Tables 4 and 7. Estimated absorbed organ an effective dose per unit activity administered in age 5, height 110, weight 19, (mg/dl) 113, and activity dose (mci) 4.6 are listed in Tables 4 and 7. Estimated absorbed organ, effective dose by unit activity administered in age 16, height 162, weight 58, (mg/dl) 88, and activity dose (mci) 9.13 are listed in Tables 8 and 9. Estimated absorbed organ, effective dose by unit activity administered in age 33, height 180, weight 115, (mg/dl) 115, and activity dose (mCi) 10.12 are listed in Tables 6 and 9.

In addition to this, to relate the dose estimating, the effective dose of ^{18}F-FDG, ^{18}F-fluoride which are also given in Table 10, overlaps the corresponding dose published for the radiopharmaceuticals by ICRP.

For patient 1, the estimated absorbed organ doses per unit activity administered shown in Figure 2 and estimated effective applied doses per unit activity shown in Figure 3. For patient 2, the estimated absorbed organ per unit applied doses shown in Figure 4, the estimated effective applied doses per unit activity shown in Figure 5. For patient 3, the estimated absorbed organ per unit applied doses activity shown in Figure 6, the estimated affected applied doses per unit activity shown in Figure 7. For patient 1, patient 2, and patient 3, the estimated absorbed organ doses per unit activity administered shown in Figures 2, 4, and 6, respectively. For patient 1, patient 2, and patient 3,

Table 6. The absorbed organ doses and affected doses of patient 3 (for 1–10 hours).

Organ doses D(T)in mGy										
Estimated organs	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours	8 hours	9 hours	10 hours
Bone marrow	0.83	1.68	2.52	3.37	4.24	5.04	5.84	6.76	7.51	8.33
Colon	0.85	1.71	2.54	3.39	4.18	5.09	5.9	6.78	7.53	8.55
Lung	12.94	25.92	38.92	51.98	64.89	77.78	90.77	103.89	117.01	130.05
Stomach	3.48	6.97	10.49	13.86	17.54	20.95	24.21	28.04	31.11	34.75
Breast	0	0	0	0	0	0	0	0	0	0
Remainder	5.17	10.36	15.51	20.7	25.79	31.08	36.2	41.09	46.78	51.49
Gonads	0.02	0.03	0.05	0.06	0.08	0.11	0.14	0.09	0.14	0.19
Bladder	0.09	0.17	0.27	0.33	0.46	0.49	0.6	0.67	0.74	0.85
Oesophagus	7.99	15.66	23.38	31.83	39.3	48.53	55.25	62.63	71.89	77.69
Liver	3.18	6.36	9.55	12.75	15.92	19.13	22.22	25.63	28.74	31.98
Thyroid	3.27	7.24	10.97	14.72	18.16	22.22	24.35	27.1	32.04	37.95
Bone surface	1.5	3.01	4.49	6	7.51	9	10.5	12.01	13.49	15.07
Brain	0.11	0.23	0.33	0.44	0.56	0.67	0.78	0.88	0.98	1.14
Salivary glands	4.05	7.94	11.85	16.13	19.93	24.6	28.01	31.76	36.43	39.42
Skin	0.4	0.81	1.22	1.63	2.03	2.43	2.85	3.24	3.65	4.07
Adrenals	2.93	5.97	8.96	11.06	13.17	16.77	20.26	19.37	27.51	26.21
Extrathor airways	7.99	15.66	23.38	31.83	39.3	48.53	55.25	62.63	71.89	77.69
Gall bladder	3.48	6.97	10.49	13.86	17.54	20.95	24.21	28.04	31.11	34.75
Heart	19	38.07	57.17	76.36	95.32	114.25	133.34	152.6	171.88	191.04
Kidneys	1.62	3.28	4.92	6.58	8.2	9.62	11.51	13.08	14.49	16.27
Lymphatic nodes	19	38.07	57.17	76.36	95.32	114.25	133.34	152.6	171.88	191.04
Muscle	0.8	1.6	2.4	3.2	4	4.79	5.6	6.4	7.2	7.98
Oral mucosa	0.11	0.23	0.33	0.44	0.56	0.67	0.78	0.88	0.98	1.14
Pancreas	2.43	5.1	7.27	10.02	12.59	15	17.19	19.55	22.53	24.81
Prostate	0.02	0.03	0.05	0.06	0.08	0.11	0.14	0.09	0.14	0.19
Small intestine	0.86	1.71	2.58	3.46	4.33	5.15	6	6.82	7.77	8.53
Spleen	3.82	7.6	11.43	15.21	19.04	22.83	26.75	31.01	34.02	38.28
Thymus	0	0	0	0	0	0	0	0	0	0
Eye lens	0.24	0.33	0.89	1.31	1.31	1.56	2.12	3.02	1.96	3.33
Effective Dose(mSv)	3.78	7.58	11.38	15.21	18.98	22.86	26.49	30.27	34.2	37.99

estimated effective applied doses per unit activity shown in Figures 3, 5, and 7, respectively. The affected effective doses for patient 1, patient 2, and patient 3, in 1–10 hours were found range of 3.74–42.79 mSv, 3.93–39.05 mSv, 3.78–37.99 mSv, respectively.

The radiation exposure from source 18F-FDG in PET/CT studies can be specifically considered, for those patients who exposed to regular follow-up examinations. According to several performed PET/CT studies, radiation doses are remarkably changes. The other known risk is the potential which has been caused due to extended period effects of the medical treatment of patient and these are substantial manifold pediatric malignancies. It is known that Stochastic effects (radiation included) cause neoplasm and heritable genetic effects. There is no known threshold for stochastic effects and their severity has no relation with dose. Patient who takes chemotherapy drugs and medical ionizing radiation for their treatment regimens are in certain risk and this can be caused to other secondary malignancies. Recently in clinics, the rising use of PET/CT in the executive of patient malignancies increase the state of being radiation exposure in children. Organ doses uncertainty raises a significant number of issues when creating a treatment plan for a doctor or medical staff, patient homecoming, or patient in hospital. Those radiopharmaceutical inputs are defined by the user and have a considerable impact on the results of MC simulation.

Table 7. Patient (child) coefficients for the relationship between body [weight, height, age, blood glucose level (mg/dl), and activity dose].

Patient Number	Age	Height (cm)	Weight (kg)	DM(mg/dl)	Activity (mCi)
1	5	110	19	113	4.6

Table 8. Patient 2 coefficients for the relationship between body [weight, height, age, blood glucose level (mg/dl), and activity dose].

Patient number	Age	Height (cm)	Weight (kg)	DM (mg/dl)	Acivity (mCi)
2	16	162	58	88	9.13

Table 9. Patient 3 coefficients for the relationship between body [weight, height, age, blood glucose level (mg/dl), and activity dose].

Patient number	Age	Height (cm)	Weight (kg)	DM (mg/dl)	Acivity (mCi)
3	33	180	108	115	10.12

Table 10. The estimated affected dose activity per unit administered in this study and ICRP.

Effective dose (mSv/MBq)	ICRP Publication 106	This work; estimated effective dose	Age classification
18F-FDG	1.9E-02	1.7E-03	Adult male
18F-fluoride	1.7E-02	9.2E-03	Adult male

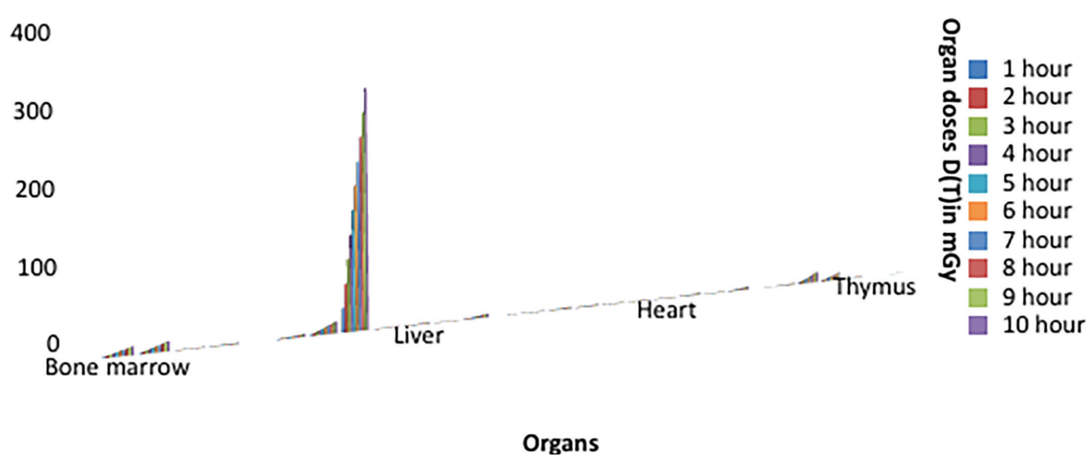

Figure 2. Patient 1 averaged absorbed organ dose per unit activity administered on 1–10 hours.

In this study, we particularly focused the increased risk of developing secondary malignancies of radiation exposure in adolescence, in young adult, in adult, and elderly. The conclusion is radiation exposure comes from PET/CT to all the patients, but especially in pediatric patients, this should be adhered to the As Low As Reasonably Achievable (ALARA) principle and with pediatric protocols in order to obtain diagnostic information. Other effects of radiation human radiation cataracts take from months to more than year to appear, and dose cannot simply explain such difference thus further studies are required to address whether different mechanisms work for early and late occurring cataracts and how individual differences in radiosensitivity affect cataracts in the latency period.

For all age categories and life cycle groupings patients, who have received medical radiotherapy as a part of their treatment, the radiation exposure of serial PET/CT studies are unimportant; however, the incremental radiation dose is substantial in patients who do not take radiation therapy. Besides, for the patient's growth stages categories, who receive ionizing radiation, should not take radiation to especially the sensitively region, so the absorbed organ doses such are important. Picking over the ALARA principle and the other radiologic diagnostic imaging without sacrificing diagnostic info in the radiation exposure of PET/CT are essential.

Additionally, using of PET/CT in patients may be done in clinic with

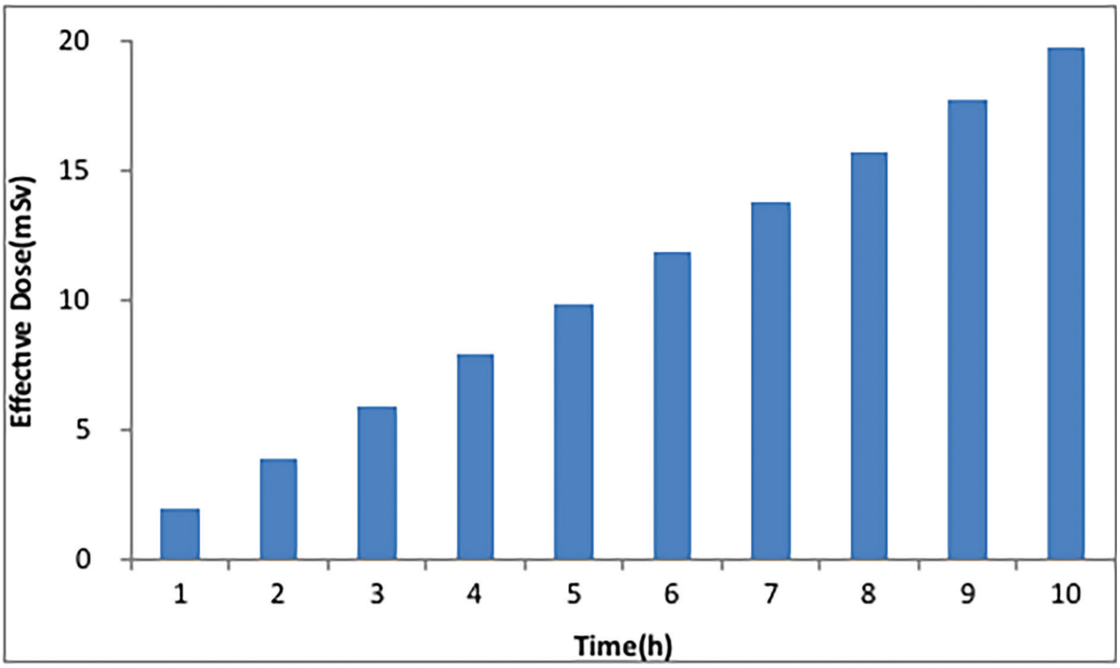

Figure 3. Patient 1 averaged effective dose per unit activity administered on 1–10 hours.

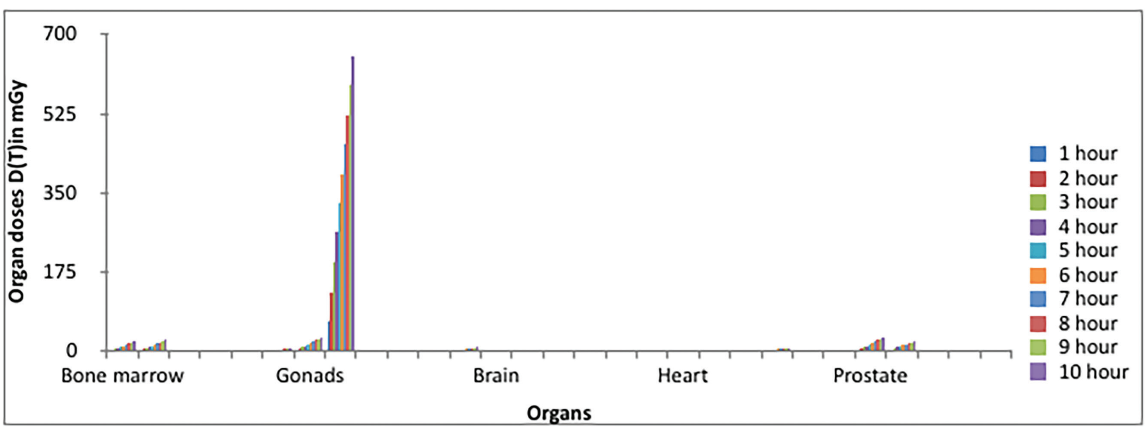

Figure 4. Patient 2 averaged absorbed organ dose per unit activity administered on 1–10 hours.

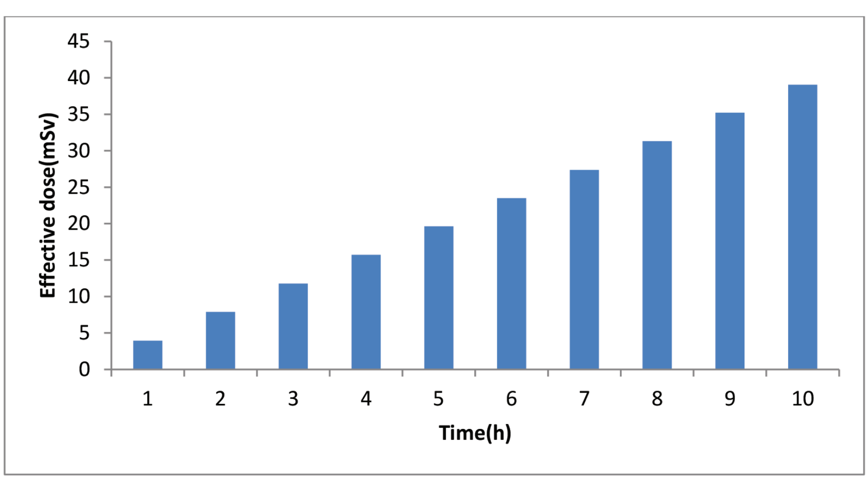

Figure 5. Patient 2 averaged effective dose per unit activity administered on 1–10 hours.

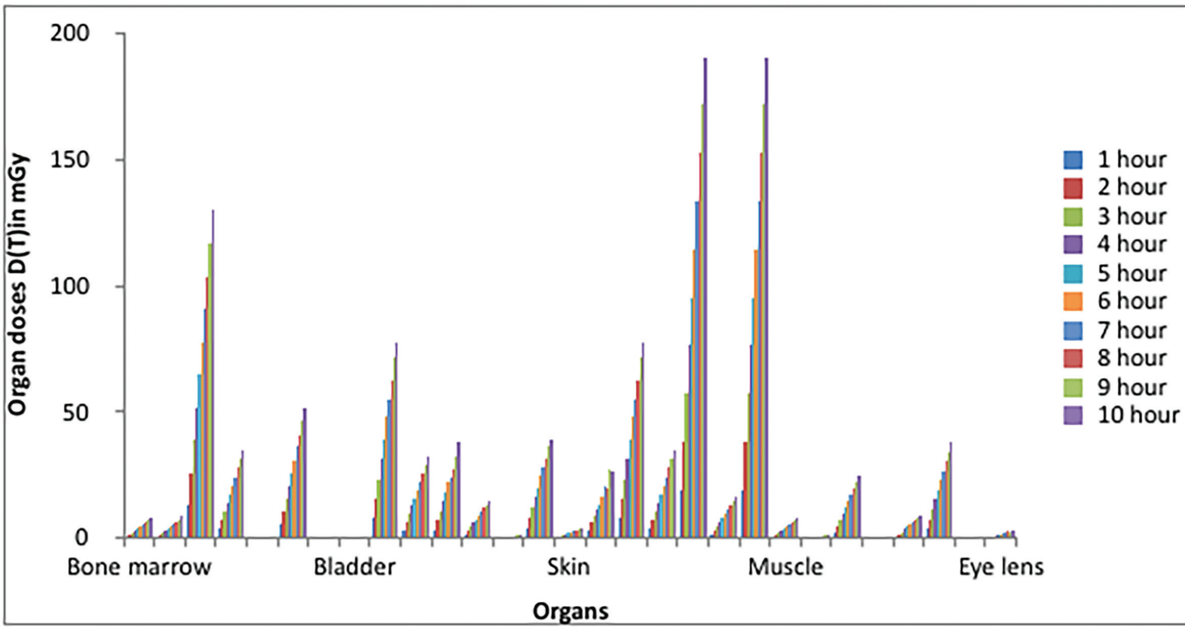

Figure 6. Patient 3 averaged absorbed organ dose per unit activity administered on 1–10 hours.

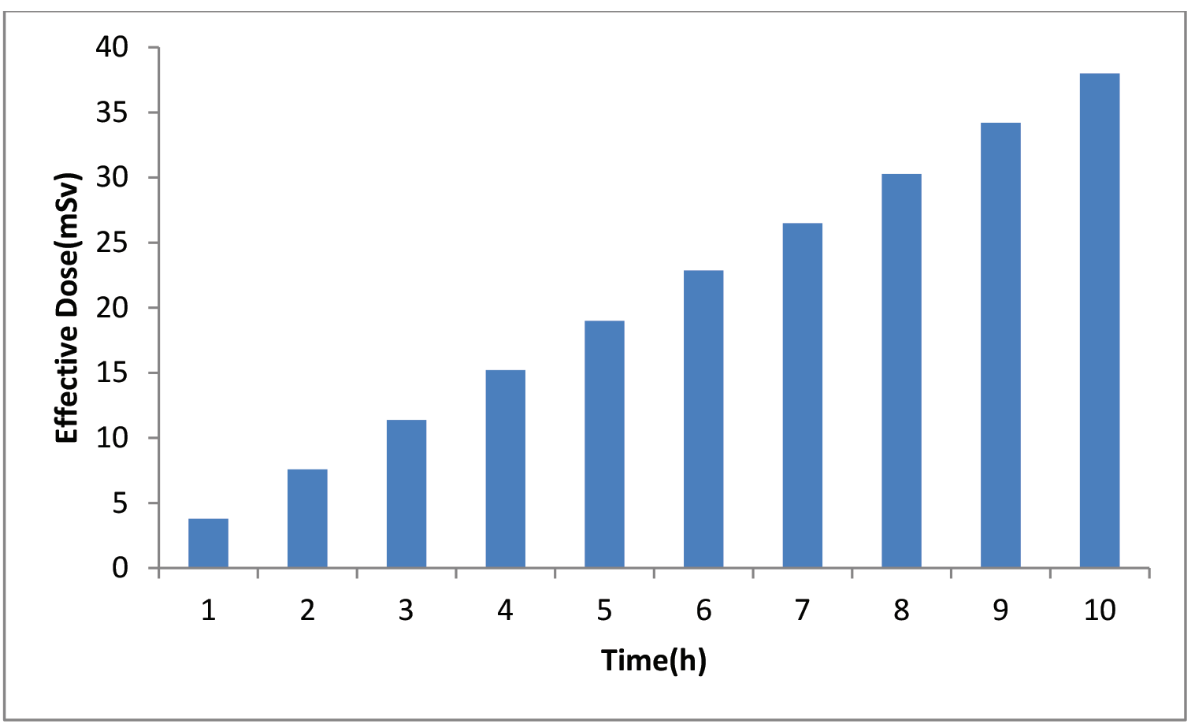

Figure 7. Patient 3 averaged effective dose per unit activity administered on 1–10 hours (weight, height, age, DM, and activity dose).

particular point on the risk factor and with the benefit and effective radiation dose to the especially sensitive patients. The PET/CT technician should be used protocols mentioned above useful for patients. Especially, the PET/CT technician should be used protocols mentioned above useful for patients.

CONCLUSIONS

The results for the patients target organs in the used phantoms showed variations in age stages when compared with those determined by the MC simulation. These variances result from the structural anatomical differences in the age studied and in significant changes in the relation to their acivity (mCi) rate.

The medical radiation which is exposured from PET/CT studies should be important in all the patients groups, furthermore, is more considerable in pediatric and adolescence patients, which we showed in our work patient number 1 and 2. The ALARA principle must be implemented in either by reducing the radiation dose on PET/CT or by considering alternative diagnostic imaging unit or device should be used.

The measurement of the absorbed dose to organs of the body from radiopharmaceuticals most estimates depend on MC simulation techniques. Like the ALARA, the MIRD is the most important in nuclear medicine. This study was intended for cognize the absorbed organ doses and efficient radiation doses in PET/CT draw attention to doses. In short, more studies on radiogenic non-cancer effects are evident necessary.

List of Abbreviations

CT	Computerized tomography
MC	Monte Carlo
MIRD	Medical Internal Radiation Dose
PET	Positron emission tomography
VMC	Visual Monte Carlo

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The authors declare that there is no conflict of interest regarding the publication of this article.

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