1st International & 28th National Conference on Nuclear Science & Technology 2022 (ICNST22)
Nuclear Science & Technology Research Institute

Calculation of one-year-old child absorbed dose in ^{18}F-DOPA and ^{68}Ga-EDTA PET imaging using reference voxel phantom and GATE code

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Abstract
Evaluation of the absorbed dose in children is essential to prevent irreversible damage because children's organs are more sensitive to radiation than adults due to their high growth rate. Therefore, in this study, the absorbed dose of organs in a one-year-old male was evaluated for the two radiopharmaceuticals ^{18}F-DOPA and ^{68}Ga-EDTA used in PET imaging. The one-year-old child reference voxel phantom and the Monte Carlo GATE code were used to accomplishing this. Among the tissues studied, the urinary bladder wall, kidneys and prostate have the highest absorbed dose. Comparing the choice of this phantom with the stylized phantoms of a one-year-old child, due to the precise structure of this phantom from the anatomy of the body, can provide more accurate values of the absorbed dose of the organs.
Keywords: Absorbed dose, Pediatric voxel phantom, Monte Carlo simulation.

Introduction
The ^{18}F-DOPA and ^{68}Ga-EDTA are diagnostic radiopharmaceuticals in PET imaging of adults and children [1,2]. Calculation of dosimetric parameters is one of the important factors in assessing radiation damage to the tissue [3]. Children are highly sensitive to radiation and are prone to irreversible damage [4]. Therefore, accurate evaluation of the absorbed dose in children is very important to prevent the side effects of PET imaging [5]. Dosimetric calculations have been performed by Monte Carlo simulations and stylized phantoms by different groups [6,7]. According to ICRP recommendations, the use of voxel phantoms is more accurate than stylized phantoms [8]. Zankl et al. Calculated the absorbed dose of three diagnostic radiopharmaceuticals including ^{68}Ga-EDTA in adult reference voxel phantoms [9]. Xie et al. Evaluated the absorbed dose of four PET diagnostic radiopharmaceuticals including ^{18}F-L-DOPA in a 5-year hybrid phantom [10]. Due to the importance of pediatric radiation, in this study, the absorbed dose of two diagnostic radiopharmaceuticals ^{18}F-DOPA and ^{68}Ga-EDTA in the one-year-old child was evaluated. For this purpose, the latest reference voxel phantom of a one-year-old child [11] and the GATE Monte Carlo simulation was used.

Material and methods
Absorbed dose to patients was calculated using MIRD formalism. For this purpose, ICRP128 biokinetic data were used to calculate the cumulated activity of ^{18}F-DOPA and ^{68}Ga-EDTA [12]. In this study, the GATE v.8.2 code was used to calculate the S values of body organs. In the first step, the reference adult male voxel phantom was used to validate the simulation [13]. In the second step, the image of a one-year-old male reference phantom with a pixel count of 393×248×543 was used as both voxelized phantom and source [11]. The image of the phantoms is shown in Figure 1. For each part of the phantom (134 ID and 57 Medium), the ingredients of different body parts were defined according to the ICRP143 report [11]. The simulations were performed with the positron-emitting radionuclides ^{18}F and ^{68}Ga that they're widely distributed in the organ tissue of the source. The energy spectrum of positron emitters to define the source and the Penelope electromagnetic physics package in all simulations was used. DoseActor output was used to calculate the absorbed dose. Each simulation was performed with 100 million particles and dose values were obtained per particle unit. In all simulations, statistical uncertainty for S values of organs was obtained below 3%.

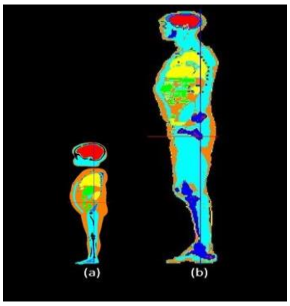

Figure 1. The image of reference voxel phantom a) One-year-old male and b) Adult male.

Results and discussion
For validation, the results of the absorbed dose of ^{68}Ga-EDTA in the adult male voxel phantom were compared with the results of the study by Zankl et al. [9]. This comparison shows that the results of this simulation are in good agreement with the previous study. The absorbed doses of different body organs in the one-year-old voxel phantom were calculated for ^{18}F-DOPA and ^{68}Ga-EDTA and the results of these values are presented in Table 1. In ICRP reports, the absorbed doses of radiopharmaceuticals in children have been calculated using stylized phantoms. Therefore, the absorbed dose values obtained in this study were compared with the

absorbed dose values reported in ICRP128 for the one-year-old child [12].

Table 1. The absorbed dose of different body organs for ^{18}F-DOPA and ^{68}Ga-EDTA in one-year-old child voxel phantom and ICRP128 report values in one-year-old child stylized phantom [12].

Target Organ (T)	Absorbed dose per unit activity administered (mGy/ MBq)			
	^{18}F-DOPA		^{68}Ga-EDTA	
	1 year M voxel phantom	ICRP128	1 year M voxel phantom	ICRP128
Adrenals	5.08E-02	5.50E-02	5.90E-02	6.20E-02
Brain	4.15E-02	4.40E-02	5.06E-02	5.50E-02
Breasts	4.07E-02	3.90E-02	5.00E-02	5.20E-02
Colon	8.30E-02	6.30E-02	8.44E-02	7.00E-02
ET region	4.13E-02	-	4.92E-02	-
Gallbladder Wall	4.88E-02	5.00E-02	4.62E-02	6.00E-02
Heart Wall	4.94E-02	5.00E-02	5.61E-02	5.80E-02
Kidneys	9.64E-02	1.40E-01	2.01E-01	2.50E-01
Lens of eyes	3.35E-02	-	3.95E-02	-
Liver	5.02E-02	5.20E-02	5.65E-02	6.00E-02
Lungs	8.16E-02	4.60E-02	1.07E-01	5.60E-02
Lymph Nodes	5.24E-02	-	6.15E-02	-
Muscle	4.21E-02	5.10E-02	5.15E-02	6.10E-02
Oesophagus	4.82E-02	4.70E-02	5.62E-02	5.70E-02
Oral Mucosa	3.79E-02	-	4.69E-02	-
Pancreas	5.37E-02	5.60E-02	6.11E-02	6.30E-02
Prostate	1.65E-01	-	1.72E-01	-
Salivary Glands	4.35E-02	-	5.18E-02	-
Skin	3.28E-02	4.00E-02	3.49E-02	5.30E-02
Small Intestine wall	6.55E-02	6.50E-02	6.67E-02	7.00E-02
Spleen	4.67E-02	5.30E-02	5.46E-02	6.10E-02
Stomach Wall	4.93E-02	5.00E-02	5.05E-02	5.90E-02
Testes	5.94E-02	7.00E-02	6.84E-02	7.70E-02
Thymus	4.89E-02	4.70E-02	5.58E-02	5.70E-02
Thyroid	4.73E-02	5.00E-02	5.55E-02	5.80E-02
Urinary Bladder Wall	5.46E-01	1.00	2.26	2.40

The results show that for the one-year-old child, the urinary bladder wall, prostate and kidneys have the highest absorbed dose values for ^{18}F-DOPA, respectively. The highest absorbed dose values for ^{68}Ga-EDTA are urinary bladder wall, kidneys, prostate and lungs, respectively. Comparison of absorbed dose values in one-year-old voxel phantoms with stylized phantom [12] shows significant differences in the urinary bladder wall, kidneys and lungs for ^{18}F-DOPA and skin, lung for ^{68}Ga-EDTA. This difference may be due to the structural differences between voxel phantom and stylized phantom. The voxel phantom has a more accurate description of the shape, volume, and location of the organs [11], and the absorbed dose depends heavily on the distances between the organs. The organ absorbed dose reported in ICRP128 for the stylized phantom does not include respiratory tract regions, lymph nodes, oral mucosa, prostate, salivary glands, and lens of eyes. Due to the importance of these organs in new approaches to effective dose calculation, in this study, the absorbed dose of radiopharmaceuticals in the organs mentioned for the voxel phantom was calculated.

Conclusions

The absorbed dose for the one-year-old male child model was calculated in ^{18}F-DOPA and ^{68}Ga-EDTA PET imaging. The results show that the highest absorbed dose of organs was related to the use of ^{68}Ga-EDTA. The urinary bladder wall, kidneys and adjacent organs have a higher absorbed dose due to the distribution and residence time of these radiopharmaceuticals in the body. The urinary bladder contents are an important source region for all radiopharmaceuticals and the absorbed dose to the bladder wall is often among the doses limiting the amount of activity that can be administered. Hence, this finding may prove to be important for radiopharmaceutical dosage. New pediatric voxel phantoms due to their precise structure of body anatomy can be a good alternative to children's stylized phantoms in dosimetric calculations.

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