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ARTICLE

External radiation exposure rate after ^{18}F-FDG PET/CT examination

K. Berberoglu[a,*]

Department of Nuclear Medicine, Anadolu Saglik Merkezi, Gebze, Kocaeli, Turkey.

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Abstract – ^{18}F fluorodeoxyglucose (FDG) is widely used for PET CT examinations; however, positron-emitting florin generates relatively high gamma radiation (511 keV) raising occupational as well as public safety concerns. This study aimed to measure the rate of radiation emitted from patients that underwent ^{18}FDG PET/CT examination for oncological conditions, approximately 2 hours after the procedure, before and after urination. A total of 100 patients who underwent ^{18}F-FDG PET/CT examination were included in this study. Following imaging, external radiation exposure rate was measured using proportional counter probe at 1-m distance, approximately 2 hours after the completion of imaging procedure, before and after urination. Factors effecting resulting exposure from patients were examined. The mean post-urination activity ranged between 0.2 and 6.3 μSv/h (median, 1.8 μSv/h). Presence of metastasis, tumor type and gender did not have any effect on mean post-urination activity ($P>0.05$ for all comparisons). Older age, greater BMI and higher administered dose were associated with higher post-urination activity ($P<0.05$ for all comparisons). Findings of this study showed that 2 hours after radionuclide injection, activity rate from patients is far below the recommended limits for general population and further decreases after urination. Discharging patients at 2 hours after urination would not seem to pose radiation health risk for relatives, public or other hospital staff.

Keywords: exposure, external / exposure, population / exposure, radiation / positron emission tomography (PET) / ^{18}F-FDG PET/CT examination

1 Introduction

Positron emission tomography (PET) provides functional metabolic information about the tissues since it gives an accurate idea on the distribution of a positron emitting radiopharmaceutical involved in cellular metabolism. Since metabolism of tumor cells significantly differ from healthy cells, currently PET represents one of the most important methods in the diagnosis of cancer. PET/CT examination on the other hand has the ability to combine functional and structural information obtained by PET examination and CT examination, respectively. This resulted in a rapid expansion of its indications and clinical use in a number of oncological and non-oncological conditions (The Royal College of Radiologists, 2016) since its introduction to clinical practice. In oncology, it is currently used for the initial diagnosis, treatment planning, response evaluation and follow-up purposes in a wide range of tumor types (The Royal College of Radiologists, 2016).

^{18}F fluorodeoxyglucose (FDG) is the most widely used radiopharmaceutical agent for clinical PET applications in general and oncology in particular (Rohren *et al.*, 2004; Królicki *et al.*, 2011). It is a molecule similar to glucose labeled with a short physical half-life radionuclide (^{18}F, 110 min). Unlike glucose, it is excreted mainly in the urine. On the other hand, positron-emitting florin generates 511 keV annihilation photons raising occupational as well as public safety concerns. To date, a number of studies have examined the occupational safety of this imaging modality (Nakamura *et al.*, 2006; Seierstad *et al.*, 2007; Andersen *et al.*, 2008; Zanzonico *et al.*, 2008; Vargas Castrillon and Cutanda Henriquez, 2011; Kumar *et al.*, 2012; Wrzesien and Napolska, 2015; Wrzesien and Albiniak, 2016; Tulik *et al.*, 2017; Zargan *et al.*, 2017; Mithun *et al.*, 2018); however, information regarding environmental and public exposure following patient discharge is scarce (Al-Haj *et al.*, 2011; Demir *et al.*, 2011). Such lack of information results in hesitations on the timing of safe patient discharge or safe referral to other hospital units.

In nuclear medicine practice, as low as reasonably achievable exposure (ALARA) is a widely accepted principle.

*Corresponding author: kezbanberberoglu@hotmail.com
[a] Present address: Postane Mahallesi, Atasev Sokak, Oguzhan Sitesi, No. 7, Tuzla, 34940 Istanbul, Turkey.

National and international regulatory bodies have set radioactivity levels at which patients can be discharged safely after radionuclide scan examinations. One of the most conservative guidelines recommend that the ambient dose equivalent rate at 1 m from a patient who underwent treatment with radioactive substance should not exceed 25 μSv/hour at the time of discharge (ARPANSA Radiation protection series No. 4, 2002). The corresponding figure for the national guideline is 30 μSv/hour (TAEA, 2000).

This study aimed to measure the rate of radiation emitted from patients that underwent ^{18}FDG PET/CT examination for oncological conditions, approximately two hours after the procedure.

2 Patients and methods

2.1 Patients

A total of 100 patients (57 females, 43 males, mean age 51.8 ± 14.5 years) who were diagnosed with a malignant disease and underwent ^{18}F-FDG PET/CT examination were included in this study. Following imaging, external radiation exposure rate was measured at 1-m distance, shortly after the completion of imaging procedure before and after urination.

2.2 ^{18}F-FDG PET/CT examination

^{18}F-FDG studies were performed using a PET/CT scanner (Discovery 690; GE Healthcare, Milwaukee, WI, USA). European Association of Nuclear Medicine (EANM) procedure guidelines for tumor imaging (version 2) was followed for patient preparation and imaging. Each patient received ^{18}F-FDG (18flour-fluorodeoxyglucose) intravenously through an intravenous catheter and imaging was done after an hour of rest. The mean administered dose was 260.3 ± 55.5 MBq (range, 136.9–421.8).

2.3 Metabolic tumor volume measurements

Metabolic tumor volumes were estimated using PET/CT images. SUVs calculated from the volumes of interest (VOIs) that were placed over the regions of abnormal ^{18}F-FDG uptake were used for quantitative assessment of ^{18}F-FDG uptake. The boundaries of each VOI were checked by comparison with fused CT to exclude adjacent ^{18}F-FDG avid structures. The maximum SUV (SUV_{max}) within the VOI was recorded for the primary tumor. Metabolic tumor volume (MTV) was defined as the total tumor volume segmented via the threshold SUV. The threshold of the mediastinal blood pool activity was used to define the lesions.

2.4 Measurement of external radiation exposure rate

Immediately following the completion of imaging procedure, the external radiation exposure rate was measured in each patient in another room with low background activity using proportional counter probe (NEB.211), which was calibrated by the Cekmece National Atomic Energy Agency, Istanbul, Turkey. Then, the patient was asked to urinate after which post-urination measurements were made. Measurement ranges for the probe were as follows: radiation dose intensity, 0.1 μSv/h − 19.9 mSv/h; automatic level transition radiation dose, 0–19.9 mSv, energy dependence, +25/−15%, between 50 keV and 1.25 MeV, according to Cs-137 661 keV. Measurements were made at 1-m distance and from midthoracic level. All measurements were corrected for background activity.

2.5 Statistical analyses

Statistical Package for Social Sciences (SPSS) version 21 was used for the analysis of data. Descriptive data are presented as mean ± standard deviation, median (range) or frequency (percentage), where appropriate. Hypothesis tests and graphical methods were used to test the normality of distribution. Wilcoxon Signed Rank test was used for the comparison of measurements before and after urination. Mann-Whitney U test or Kruskal Wallis test was used to compare continuous variables between groups. Correlations between continuous variables were tested using Spearman's test. A p-value smaller than 0.05 was considered an indication of statistical significance.

3 Results

Table 1 shows patient characteristics. Breast cancer was the most common type of malignancy (26%) followed by colorectal cancer (15%) and lung cancer (13%). Almost half of the patients had distant metastasis. The mean duration between radionuclide injection and pre-urination measurement was 99.6 ± 23.1 minutes (median: 98; range: 57–156) and the mean duration between pre- and post-urination measurements was 4.4 ± 3.4 minutes (median: 4; range: 1–33).

Mean pre-urination activity ranged between 0.9 and 8.2 μSv/h (median: 3.0 μSv/h). Activity significantly decreased after urination (2.2 ± 1.4 vs. 3.4 ± 1.8 μSv/h, $P < 0.001$), with a mean difference of 1.2 ± 0.9 μSv/h. The mean post-urination activity ranged between 0.2 and 6.3 μSv/h (median: 1.8 μSv/h). Presence of metastasis, tumor type and gender did not have any effect on mean post-urination activity ($P > 0.05$ for all comparisons) (Tab. 2). Post-urination activity positively but weakly correlated with age ($r = 0.202$, $P = 0.044$), BMI ($r = 0.211$, $P = 0.035$) and administered dose ($r = 0.234$, $P = 0.019$); however, no correlation was found with tumor volume ($r = 0.025$, $P = 0.805$). Older age, greater BMI and higher administered dose were associated with higher post-urination activity ($P < 0.05$ for all comparisons) (Tab. 2).

4 Discussion

This study examined the radiation exposure rate to the environment at 1-m distance after approximately two hours post-injection of ^{18}F-FDG. The resulting exposure is well below regulatory limits and is further decreased after urination. This study is among few studies which measured environmental exposure rather than occupational exposure after ^{18}F-FDG PET/CT setting.

Previous data supports that PET/CT may be associated with relatively high external radiation exposure from the patient. An earlier study identified higher radiation exposure to a nuclear medicine technician during PET scanning when

Table 1. Patients characteristics.

Characteristic	$n = 100$
Age, y (mean ± SD)	51.8 ± 14.5
Body mass index, kg/m^2 (mean ± SD)	26.3 ± 5.8
Diagnosis	
Breast cancer	26 (26%)
Colorectal cancer	15 (15%)
Lung cancer	13 (13%)
Gynecological cancer	10 (10%)
Hematological malignancies	9 (9%)
Gastroesophageal cancer	6 (6%)
Melanoma	5 (5%)
Others	16 (16%)
Tumor volume, cm^3 (mean ± SD)	40.8 ± 75.6
Metastasis present	46 (46%)
Dose administered, MBq (mean ± SD)	260.3 ± 55.5

Unless otherwise stated, data presented in n (%).

Table 2. Comparison of subgroups with regard to final activity rate.

Subgroups	Final activity rate, μSv/h	P for difference
Age		
> median (> 53 y)	2.6 ± 1.6	0.020
≤ median (≤ 53 y)	1.8 ± 1.0	
Gender		
Male	2.2 ± 1.3	0.972
Female	2.2 ± 1.4	
Tumor type		
Breast cancer	2.2 ± 1.3	0.679
Colorectal cancer	2.5 ± 1.5	
Lung cancer	2.4 ± 1.6	
Gynecological cancer	2.0 ± 1.6	
Hematological malignancies	1.9 ± 0.9	
Gastroesophageal cancer	2.1 ± 1.3	
Melanoma	3.0 ± 2.1	
Others	1.7 ± 0.9	
Metastasis		
Present	2.3 ± 1.6	0.844
Absent	2.1 ± 1.2	
BMI		
> median (> 25.1 kg/m^2)	2.6 ± 1.5	0.007
≤ median (≤ 25.1 kg/m^2)	1.7 ± 1.0	
Administered dose		
> median (> 248 MBq)	2.6 ± 1.6	0.007
≤ median (≤ 248 MBq)	1.7 ± 0.9	
Tumor volume		
> median (> 12 cm^3)	2.4 ± 1.6	0.371
≤ median (≤ 12 cm^3)	2.0 ± 1.1	

Data presented as mean ± standard deviation.

compared to other nuclear medicine procedures (Chiesa *et al.*, 1997). This seems partly due to the higher specific gamma constant of ^{18}F, and partly to the extra time needed for patient positioning during which staff is in relatively close contact. Nevertheless, staff exposures can be maintained below regulatory limits (Benatar *et al.*, 2000; Zanzonico *et al.*, 2008; Kumar *et al.*, 2012; Zargan *et al.*, 2017). A technician dose of 20–25 nSv per injected MBq of ^{18}F is common across centers and usually dose limits are reached after 3000 patient procedures (Seierstad *et al.*, 2007). It is of not to mention that there is still room for reducing staff exposure and procedural advances has such potential. For example, using a shielded automatic infusion device resulted in 10-fold decrease in staff extremity and body doses during ^{18}F-labeled radiopharmaceutical administration (Schleipman and Gerbaudo, 2012).

To date, few studies examined exposure to the surrounding people after PET/CT examination, including other hospital staff and relatives. A Japanese study measured the radiation exposure of a driver that transports patients injected with FDG for PET examination using a pocket dosimeter (Nakamura *et al.*, 2006). A single trip was 15 kms long and the mean measured doses ranged 7.31 microSv and 2.26 microSv depending on the distance of the patient (1.1 or 1.9 m, respectively). Based on these measurements, maximum radiation exposure per year ranged between 3.02 mSv (1.1 m) and 0.92 mSv (1.9 m). If a driver is assumed to be a non-radiation worker, although the dose exposed per hour seems below limits, the cumulative dose seems to be a somewhat higher than the population limit of 1 mSv at 1-m distance; therefore, keeping at least 2-m distance would be safer to avoid a marginally high cumulative dose in such workers, in addition to exposure surveillance. However, activity rate measured in that study is similar to the levels found in the present study and if a single patient is concerned, these figures are well below for environmental recommendation.

A recent study from Poland estimated staff radiation exposure in a nuclear medicine facility after administration of 18F-FDG for the purpose of PET/CT examination in a dynamic way (Tulik *et al.*, 2017). Staff exposure caused by a patient walking through the department was instantaneously measured through the path on several locations and average exposures were calculated. Estimated annual exposure values ranged between 0.2 mSv/year in the physician's room and 0.6 mSv/year in the PET/CT scanner control room. Average exposure near patient registration desk was 0.4 mSv/year. Nevertheless, these values were much less than the annual limit.

In this study, higher administered dose was associated with higher post-urination activity rate at 1 m. This is in line with the findings of a study comparing recommended ^{18}F-FDG dose (7–8 MBq/kg body weight) with half the recommended dose (3–4 MBq/kg body weight) (Mithun *et al.*, 2018). In that study, the exposure rates from the patients at 100-cm distance were 0.021 ± 0.011 vs. 0.011 ± 0.0028 mSv/h at 1 h post-injection, in the high versus low dose group, respectively. Activity seems to be halved by dose reduction; however, authors did not mention on statistical difference.

To the best of our knowledge, only a single study focused particularly on exposures at certain distances from patients at the time of discharge after ^{18}F-FDG PET/CT examination. At approximately 2 hours after 550-MBq ^{18}F-FDG injection, dose rates at 0.1, 0.2, 0.5, 1.0 and 2.0 m were 345, 220, 140, 50 and 15 μSv per hour, respectively. In this study, we found 1.8 μSv/h rate at 1 m after a mean post-injection duration of 104 mins,

which is lower than the values measured in the study by Demir *et al.* (2011). This discrepancy may be due to the lower dose used in the present study.

Since radioactivity exposure from patients that received ^{18}F-FDG PET/CT is thought to be somewhat higher based on the nature of the investigation and the radionuclide itself, potential radiation from such patients raises concerns regarding radiation risks. Other departments may refuse close contact with such patients due to this possibly exaggerated risk, which may cause delays in routine medical care of the patients. However, findings of this study showed that 2-hour after radionuclide injection, activity rate from patients is far below the recommended limits for general population. These values further decrease after urination.

5 Conclusion

Findings of this study suggest that discharging patients 2 hours after injection and instructing them to urinate before leaving the nuclear medicine department would be a safe practice and activity would not pose radiation health risk for relatives or other hospital staff.

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