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Research article

Evaluating radiation exposure risks from patient urine in a PET-CT center: should concerns arise?

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Abstract: Introduction and Objectives: Fluorine-18 fluorodeoxyglucose (^{18}F-FDG) is used to stage various malignancies, with approximately 30% of non-metabolized ^{18}F-FDG being excreted through urine. Patients are advised to drink 500 mL–1 L of water to increase urine production so that they can empty their bladder whilst still at the facility to reduce the radiation dose to the bladder wall; this makes their urine radioactive. This study aims to assess the radiation dose rates from a toilet at a positron emission tomography/computed tomography (PET/CT) center. **Methods:** Radiation dose measurements were conducted using a portable digital rate meter (6150AD-6 Automess) with a measuring range of 1 μSv/h to 10 mSv/h (energy range 60 keV to 1.2 MeV). The measurements were carried out over a 5-day period. The background radiation was recorded between 8:00–8:30 am. Dose rate measurements were taken daily at 9 am at several places in the toilet: on the seat, on the cistern lid, and approximately 1 m to the left and right of the chamber. Additional daily measurements carried out at 10 am, 11 am, and 12 pm. The annual cumulative dose was estimated based on a five-day working week for 42 working weeks, 8 hours per day. **Results:** The measured weekly dose rate from the toilet was 14.40 ± 0.020 μSv/h. The approximate annual dose over 42 working weeks was 0.63 ± 0.001 mSv/year. **Conclusions:** The estimated annual radiation dose from the toilet (0.63 mSv/year) is well below the recommended dose limits for members of the public (1 mSv/year) and radiation workers (20 mSv/year) by the International Commission on Radiological Protection (ICRP). Therefore, there is no significant concern regarding an exposure from patient urine in this setting.

Keywords: radioactive urine; radiation; cumulative dose; fluorine-18 fluorodeoxyglucose; photons

1. Introduction

The term nuclear often generates fear among the public, as the first thing that comes into their minds are nuclear weapons [1]. However, with developments in computer software, radiopharmacy, and instrumentation, there has been an increased awareness of the significant role played by nuclear medicine (NM) in diagnoses as well as the treatment of various disorders and diseases [2]. NM involves the use of diverse radioactive tracers for either diagnostic or therapeutic purposes for various ailments [3]. The radioactive tracers are combined with biological molecules commonly referred to as pharmaceuticals to form NM drugs known as radiopharmaceuticals [4,5].

Radiopharmaceuticals can target specific organs, tissues, or cells within the human body [4,5]. The pharmaceutical component is fabricated such that the targeted organ or tissue preferably absorbs it. Once administered into the body, it targets the desired organ and delivers radioactivity to the target. The radiation emitted by the decaying radioisotope inside the targeted organ is detectable outside the body by an imaging system [6]. A positron emission tomography (PET) scanner is one such imaging modality used in NM in many hospitals [7]. Among the notable roles of PET imaging are the assessment of primary tumors and metastases, prognosis, treatment planning, monitoring of therapies, and the inclusive detection of recurrent tumors [8]. Unlike other radiological modalities, PET scanners can show the desired whole-body information in a single scan [9].

The mostly commonly used radiopharmaceutical in PET imaging to visualize glucose metabolism in vivo is fluorine-18 fluorodeoxyglucose (^{18}F-FDG). ^{18}F-FDG is an analogue of glucose [8,10] and it accumulates in the tumors. F-18 undergoes beta decay by emitting a positron and a neutrino. The positron travels a short distance in the tissue before losing its kinetic energy and annihilating with an electron, which results in the emission of two gamma photons of energy 511 keV that move in opposite directions. F-18 has a half-life of approximately 110 minutes [11]. After ^{18}F-FDG has been administered to a patient, a PET scanner forms two-dimensional or three-dimensional images of the distribution of ^{18}F-FDG within the body. The amount of administered activity for ^{18}F-FDG studies depends, to some extent, on the mass of the patient, the length of the uptake time, and the acquisition mode. Adults typically receive 370–740 MBq of ^{18}F-FDG, while pediatric patients receive approximately 4–5 MBq/kg [12]. Once administered into the body, ^{18}F-DG spreads in the whole body within minutes. Within 33 minutes after injection, 3.9% of non-metabolized ^{18}F-FDG accumulates in the bladder, and 20.6% of non-metabolized ^{18}F-FDG is collected 2 hours later [8]. The patients are usually encouraged to drink large amounts of water (500 mL–1 L) to increase urine production [13]. The flow of urine aids the excretion of the non-metabolized radionuclide for the purpose of reducing the radiation dose to the bladder [13]. Before leaving the NM Center, the NM patient would have eliminated much of the radiation by both a physical and biological decay of the radionuclide. Approximately 30% of the non-metabolized ^{18}F-FDG is excreted within the urine [11].

The increased use of diagnostic imaging and therapeutic studies involving the use of ionizing radiation raises concerns about the risk of exposure to the personnel, patients, and members of the public who visit the PET center. Exposure can be internal or external as a result of using unsealed radiation sources [11]. The personnel are exposed during the handling, preparation, and administration of radiopharmaceuticals. To protect the personnel, radiation protection measures that emphasize minimizing the duration of exposure and maximizing the distance from the source have been implemented as alongside an effective use of shielding [14]. Additional preventative measures, such as monitoring the radiation dose to the staff, have also been implemented with the aim of reducing the deterministic and stochastic effects of radiation [15,16]. Several researchers have conducted dose surveys and dealt, in detail, on the importance of radiation protection in NM [8,9,11,15–17].

Despite the success of previous radiation protection programs, this is the first radiation protection study at our center that specifically focuses on the exposure from radioactive urine and the estimation of potential cancer risk, which served as the motivation for this study.

Several media reports have emerged which described the increased cancer risk associated with medical imaging examinations. According to a National Council on Radiation Protection and Measurements report released in March 2009, medical imaging contributed to approximately 15% of total radiation doses in the United States in the 1980s, as compared to approximately 50% in 2006 [17]. The wide dispersion of information on radiation and its effects has caused anxiety among both members of the public and personnel working in radiation environments. A concerned clinical worker posted the following to Health Physics news: “I work in a hospital and learned that after eight months of work, my employee bathroom is also used by PET scan patients to empty their bladders, and they have radioactive urine. How much exposure was this? Why doesn’t the hospital have to put up a sign about the radiation? It really scares me [18].” This study answers concerns of this nature. Only dose survey results can convince both the public and personnel whether they are at an increased risk of cancer induction from radioactive urine.

This study investigates the radiation levels from the toilets of patients with the aim of determining the likelihood of an exposure risk posed by “radioactive urine” to patients and care givers who accompany them to the toilet as well as staff who work in the PET/CT center.

2. Materials and methods

2.1. Study design and methods

A portable dose rate meter (6150AD-6 Automess, Germany) with an internal probe and a measuring range of 0.1 µSv/h to 10 mSv/h (energy range 60 keV to 1.3 MeV) was used to measure the gamma dose rates in a toilet used by radiation workers (staff), care givers, and patients (both males and females) administered with ^{18}F-FDG over a period of 5 days. The portable dose rate meter was calibrated by the South African Nuclear Energy Corporation (NECSA) for 511 keV photons.

The background radiation was measured between 8:00 and 8:30 am daily throughout the 5-day study period. Five background radiation measurements were recorded each day, and the mean value was calculated for each day. The measured values excluded contamination from the previous day based on the assumption that it was negligible on grounds that the last patient was administered with ^{18}F-FDG at 12 pm. Based on this given time frame (20 hours), namely from the last time of attending the last patient at 12 pm to the next day when measuring the background radiation at 8 am, we have 10.9 half–lives of F-18. The half-life of F-18 is 110 minutes, which approximates to 1.83 hours.

Furthermore, precautions were taken to avoid contamination during the next day of measurements, which included storing used syringes and gloves in shielded containers. Additionally, the floors and equipment were wiped on a daily basis after the attendance of the last patient at 12 pm to eliminate the possibility of any persistent contamination.

Each patient was advised to drink 500 mL–1 L of water to aid in urine production [13]. Furthermore, the patients were advised to flush the toilet twice after use.

The gamma dose rate measurements were performed at 9:00 am, which was immediately after the first patient administered with ^{18}F-FDG had used the toilet. The dose rate measurements were taken with the dose rate meter placed 1 m above the points 1, 2, and 3 marked with an X and adjacent to the water closet (WC) at points 4 and 5 marked with an X (Figure 1).

Reading 1 was measured on the cistern cover marked with an X. However, the marking cannot be seen due to the open toilet seat cover (Figure 1). Lastly, measurements were taken every day at the same times (8 am, 9 am, 10 am, 11 am, and 12 pm) for the next 4 consecutive days. Five consecutive readings were taken at each of the marked points (1, 2, 3, 4, and 5) for 1 minute, which is a duration that accounted for statistical fluctuations meant to guarantee a stable reading.

The average dose rate for each of the five marked points was calculated using the following formula:

$$\text{Average dose rate} = \frac{\sum_{ii}^{nn} DD_{ii}}{nn} \quad (1)$$

where DD_{ii}, is the dose rate at instant i (at each point marked X) measured in μSv/h, and n is the number of measurements conducted at each point mark with an X.

Additional daily measurements were conducted at 10 am, 11 am, and 12 pm, when the use of the toilet was at its peak. The toilet that was used is a normal WC similar to one used within many homes (Figure 1).

Figure 1. WC showing positions where dose rates were measured.

The total dose rate measured in a day attributed to radioactive urine was calculated as the sum of the mean dose rates measured at 9 am, 10 am, 11 am, and 12 pm in the toilet and background. For the entire study day, the ambient dose rate was calculated using the following formula:

$$\text{Daily ambient dose} = 4 \times \text{background dose} + \text{Cumulate toilet dose from 9 am to 12 pm} \quad (2)$$

Factor 4 in Eq 2 accounts for the 4 hours in which the radiation worker remains in their working environment and is exposed to background radiation (1 hour before the first patient is attended to at 9 am and three (3) hours after the last patient is attended to at 12 noon). However, the background radiation for the remaining working hours up to 4 pm is not factored in Eq 2 since they spend their time on an upper floor in non-controlled administrative stations.

The weekly dose rate was calculated using the following formula:

$$\text{Weekly cumulative dose rate} = \sum_{1}^{nn} DD_{xx} \quad (3)$$

where DD_{xx} is the ambient dose rate measured on day x, and n is the number of study days the ambient dose rate is measured.

The annual cumulative dose rate was calculated using the following formula:

$$\text{Annual cumulative dose} = 42 \times \sum_{1}^{nn} DD_{xx} \quad (4)$$

where 42 represents the number of working weeks for the personnel, n represents the number of days the ambient dose rates were measured, and DD_{xx} represents the ambient dose rate measured in one day. The calculated value was compared with limits for the radiation workers and members of the public proposed by the International Commission of Radiological Protection (ICRP) [20].

3. Results

3.1. Patient demographics and dose rate measurements

A total of 45 patients (20 males and 25 females) administered with ^{18}F-FDG used the toilet during the five-day study period. Table 1 presents a summary of the demographics of the patients and the quantity of administered ^{18}F-FDG.

Table 1. Patient demographics and amount of ^{18}F-FDG activity administered.

	Males	Females
Gender	20	25
Age range (years)	36–65	35–75
Mean age	45	34
Administered activity (MBq)	141.441–354.687	143.07–404.262
Mean administered activity ± SD (MBq)	253.641 ± 66.233	274.495 ± 86.219

Note: SD: Standard deviation.

A total of 25 background radiation measurements were conducted alongside 125 radiation dose rates measurements from the toilet. Table 2 presents the dose rate measurements, the weekly dose rates, and the calculated annual cumulative dose.

Table 2. Background and PET/CT toilet ambient dose rate measurements over a five-day period.

Measurement µSv/h	Time (am)																								
	Day 1					Day 2					Day 3					Day 4					Day 5				
	8 am	9 am	10 am	11 am	12 pm	8 am	9 am	10 am	11 am	12 pm	8 am	9 am	10 am	11 am	12 pm	8 am	9 am	10 am	11 am	12 pm	8 am	9 am	10 am	11 am	12 pm
1	0.17	1.09	0.25	0.20	0.14	0.16	0.97	0.27	0.21	0.22	0.14	1.18	0.19	0.18	0.19	0.14	1.41	0.23	0.25	0.37	0.11	0.64	0.32	0.17	0.28
2	0.15	1.11	0.59	0.28	0.80	0.14	1.36	0.41	0.25	0.27	0.12	1.33	0.29	0.23	0.94	0.16	1.15	0.53	0.29	0.68	0.12	1.18	0.45	0.26	0.72
3	0.12	1.61	0.56	0.61	0.49	0.09	1.71	0.43	0.23	0.42	0.11	1.41	0.34	0.19	0.97	0.12	1.48	0.62	0.23	0.53	0.12	1.85	0.51	0.34	0.65
4	0.16	1.65	0.53	0.36	0.36	0.12	1.17	0.23	0.27	0.12	0.14	1.38	0.25	0.29	0.64	0.11	1.41	0.22	0.31	0.52	0.13	1.19	0.47	0.32	0.93
5	0.17	1.21	0.37	0.22	0.62	0.12	1.28	0.26	0.18	0.21	0.13	1.25	0.23	0.21	0.78	0.13	1.17	0.29	0.16	0.46	0.12	1.31	0.33	0.24	0.71
Average dose rate	0.15	1.33	0.46	0.33	0.48	0.13	1.30	0.32	0.23	0.25	0.13	1.31	0.26	0.22	0.70	0.13	1.32	0.38	0.25	0.51	0.12	1.23	0.42	0.27	0.67
Daily dose (µSv)	3.20					2.62					3.01					2.98					2.59				
Total weekly dose (µSv)	14.40 ± 0.02																								
Annual exposure	625.9 ± 0.27 µSv ~ 0.63 ± 0.001 mSv																								

Note: 8 am measurements are background dose rates; Columns 9 am–12 pm represents dose rates measured in the toilet at the indicated hours.

Average dose rate = $\frac{\sum_{ii}^{nn} DD_{ii}}{nn}$ is the dose rate at instant i measured in µSv/h, n is the number of measurements at the given instant.

Daily dose rate = 4 × background dose rate + dose rates measured in the toilet × 1 hour each;
4 represents hours in which one remains exposed to background radiation that is one hour before the patient is administered with ^{18}F-FDG and three hours from the time the last patient was attended to the time the personnel dismiss from work at 4 pm.

4. Discussion

Patients administered with ^{18}F-FDG for PET studies in our PET/CT center were requested to drink 500 mL–1 L of water, in accordance with the European Association of Nuclear Medicine EANM guidelines [13], to promote urine production. Prior to discharge, the patients emptied their bladder, thus releasing radioactive urine that contains metabolites of ^{18}F-FDG, hence the need of rigorous environmental radiation monitoring, particularly in shared spaces such as toilets.

Our study evaluated radiation exposure within a PET/CT center, and revealed an annual accumulative dose 0.63 mSv. This estimated value (0.63 mSv/year) is well below the annual public dose limit of 1 mSv and the occupational exposure limit of 20 mSv, as recommended by the ICRP [19]. Therefore, the radiation exposure within our PET/CT center does not pose significant cancer risks to the staff, patients, or the general public.

The maximum dose rate recorded in the toilet was 3.20 µSv/h substantially lower than the 5 µSv/h limit established for restricted areas [20]. This finding is comparable to that of Akinlade and Kelani [20], who reported occupational doses ranging from 0.20 mSv to 0.86 mSv for radiation workers over a standard 8-hour workday, 5 days a week, across 50 weeks annually. Their dose range includes our value of 0.63 mSv and similarly remains within the ICRP recommended limits [20].

In contrast, Ejeh et al. [21] recorded higher dose rates (21.73 µSv/h in female toiles and 5.62 µSv/h in male toilets) for patients who were administered with ^{99m}Tc labeled radiopharmaceuticals. While these results were within the prescribed limit of the 1 mSv/year threshold, they were notably higher than the 3.20 mSv/hr measurement established in our facility. These elevated rates, attributed to infrequent patient flushing and a larger cohort of patients (142 females and 60 males), highlight critical protocol differences. In our facility, the adherence to a mandatory double-flush protocol likely minimized the radioactive residue, thus contributing to the lower dose rate of 3.20 µSv/h. Such measures reduce the environmental contamination, thus aligning with ICRP's principle of optimizing radiation protection [19]. Furthermore, the exclusion of catheterized males who did not use the toilet in the patient numbers (n = 45) also contributed to a lower dose rate in this study.

5. Conclusions

Radiation levels in the toilets used by patients administered with ^{18}F-FDG for PET studies alongside radiation workers and members of the public in this study were found to be very low (0.63 mSv per year), with measured values less than 1mSv per year and 20 mSv per year, as prescribed for members of the public and occupational workers, respectively, by the ICRP [19]. This may be attributed to several factors including low numbers of patients who underwent PET/CT studies per day and an adherence by patients to the instruction of flushing the toilet twice as per the instructions, which was visible on the toilet door. Although the radiation levels were found to be low for this particular study, it is recommended that radiation workers and patients should have their own separate toilets, as well as the designation of male and female patients having separate toilets.

Author contributions

All authors participated in varying degrees in the conceptualization, methodology, validation, and composition of this work and they all consented to this published version.

Use of AI tools declaration

The authors declare they have not used artificial intelligence (AI) tools in the creation of this article.

Ethical approval of the research and informed consent

The study was approved by the Research Ethics Committee of a Health Sciences University under clearance (SMUREC/M/184/2021: PG). No direct patients' data was used in this study. Only demographic information (age and gender) was used gathered from patient records kept confidential by the researchers in line with the act on protection of personal information.

Conflict of interest

The authors declare no conflict of interest.

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