

Nuclear medicine staff exposure to ionising radiation in ^{18}F -FDG PET/CT practice: a preliminary retrospective study

Bojan Pavičar^{1,4}, Jasna Davidović^{2,6}, Biljana Petrović³, Goran Vuleta², Saša Trivić²,
Vlatko Šajinović², Nataša Egeljić-Mihailović², Nataša Todorović⁴, and Branko Predojević⁵

¹ Center for Radiation Therapy, International Medical Centers, Affidea, Banja Luka, Bosnia and Herzegovina

² University Clinical Centre of the Republic of Srpska, Department of Nuclear Medicine and Thyroid Disorders, Banja Luka, Bosnia and Herzegovina

³ Public Health Institute of the Republic of Srpska, Banja Luka, Bosnia and Herzegovina

⁴ University of Novi Sad Faculty of Sciences, Novi Sad, Serbia

⁵ University of Banja Luka Faculty of Natural Sciences, Banja Luka, Bosnia and Herzegovina

⁶ University of Belgrade School of Electrical Engineering, Belgrade, Serbia

[Received in December 2020; Similarity Check in December 2020; Accepted in September 2021]

This retrospective study provides an insight into the levels of radiation exposure of six nuclear medicine (NM) staff (four technologists and two nurses) performing routine diagnostic ^{18}F -fluorodeoxyglucose (^{18}F -FDG) positron emission tomography-computed tomography (PET/CT) at the University Clinical Centre of the Republic of Srpska, Department of Nuclear Medicine and Thyroid Disorders, Banja Luka, Bosnia and Herzegovina. Data analysis included monthly staff exposure measured with personal thermoluminescent dosimeters (TLD) between June and December 2018, quantified in terms of normalised dose for the whole body [Hp(10)] and dominant hand [Hp(0.07)] and their comparison between each staff member and between the two groups (technologists and nurses). The study goal was to establish how our Department compared with reports from other PET/CT centres worldwide in terms of annual number of procedures and exposure limits and whether there could be room for further improvements in radiation protection. The number of procedures rose considerably from 208 in 2016 to 876 in 2019 and was 423 in the observed seven-month period. Mean individual whole-body exposure dose per GBq of injected ^{18}F -FDG activity, [Hp(10)/A] was 18.55 $\mu\text{Sv}/\text{GBq}$ for the four technologists and 15.61 $\mu\text{Sv}/\text{GBq}$ for the two nurses. Mean dominant-hand exposure dose per GBq of injected ^{18}F -FDG activity [Hp(0.07)/A] was 16.99 $\mu\text{Sv}/\text{GBq}$ and 25.44 $\mu\text{Sv}/\text{GBq}$ for the two groups, respectively. The average annual cumulative dose for all staff was (1.06 \pm 0.29) mSv for Hp(10) and (1.15 \pm 0.32) mSv for Hp(0.07). These results are comparable with those of similar studies. Staff doses were well below the annual limits. Nurses received slightly higher extremity doses than technologists. In view of the increasing trends in the number of PET/CT procedures, dose monitoring should be continued to identify exposure hotspots and maintain doses as low as possible.

KEY WORDS: ^{18}F -fluorodeoxyglucose; ALARA principle; automated dispensing systems; occupational dose; positron emission tomography-computed tomography; thermoluminescent dosimeters; TLD

Positron emission tomography with computed tomography (PET/CT) is a non-invasive, nuclear medicine imaging technique that provides valuable diagnostic information on the function of internal organs, their anatomy, and morphological changes. PET uses imaging agents, mostly ^{18}F -fluorodeoxyglucose (^{18}F -FDG) to trace glucose metabolism (1). Fluorine-18 has a 109-minute half-life and a positron emission of 630 keV. Its physical characteristics make it suitable for external detection of 511 keV annihilation photons but not very suitable for use by nuclear medicine (NM) staff. PET/CT procedures

include many tasks contributing significantly to their occupational radiation exposure (2). In addition to the working procedures already in place, many other factors contribute to the occupational dose, such as staff experience and training, workload, the health status of a patient, type of PET/CT scanner, administered activity, and CT protocols. All this requires continuous efforts by all staff to implement correctly the ALARA principle and the International Commission on Radiological Protection (ICRP) recommendations (3).

Annual dose limits for the whole body [effective dose, Hp(10)] and extremities [equivalent dose; Hp(0.07)] are 20 mSv and 500 mSv, respectively (4). So far, clinical experience worldwide has demonstrated that these levels are unlikely to be exceeded in the clinical settings based on automated dispensing systems, given the observed trends

Corresponding author: Jasna Davidović, University Clinical Centre of the Republic of Srpska, Department of Nuclear Medicine and Thyroid Disorders, Dvanaest beba bb, 78 000 Banja Luka, Bosnia and Herzegovina, E-mail: jasna.davidovic@kc-bl.com



in NM staff doses over the years (5–7). On the other hand, Hp(0.07) doses to operating staff working in facilities using semi-automated or manual dispensing systems may be significantly higher and even surpass the annual limits (4, 5, 8, 9).

Increasing trends in the number of PET/CT examinations and plans to introduce some novel radiopharmaceuticals for an ever wider spectrum of clinical indications raise concern over increased staff radiation exposure in the imminent future. Therefore, it is essential to analyse and estimate their risk of exposure in the years to come, taking into account current data on the number and type of PET/CT procedures used, the number of employees involved, workload allocation among staff members, and radiation protection measures implemented.

The primary aim of our study was to get an insight into radiation exposure of PET/CT staff using an automated system at the Department of Nuclear Medicine and Thyroid Disorders of the University Clinical Centre of the Republic of Srpska, Bosnia and Herzegovina, in terms of Hp(10) and Hp(0.07). In addition, we wanted to see whether these doses comply with the European Association of Nuclear Medicine (EANM) guidelines (10) and dose limit regulations (4, 11) and how they compare with reports from similar PET/CT facilities worldwide in order to see if and which improvements in radiation protection are needed.

PARTICIPANTS AND METHODS

This retrospective study analysed staff irradiation from June to December 2018 recorded on thermoluminescent dosimeters (TLDs) resulting from exposure during routine diagnostic procedures with a Discovery 610 PET/CT scanner (General Electric, Chicago, IL, USA) and MEDRAD⁷ Intego PET Infusion System for automatic dispensing and injection of radiopharmaceuticals (Bayer HealthCare LLC, Whippany, NJ, USA). MEDRAD[®] Intego can deliver ¹⁸F-FDG within ±10 % of the prescribed dose and within ±2 % of the measured dose (12). The only radiopharmaceutical in use during the observed period was ¹⁸F-FDG. It was delivered to the NM Department in a transport container in the form of single doses of fixed activity (3.70 GBq or, less frequently, 5.55 GBq each).

We followed six staff members, four of whom were certified radiological technologists (T1, T2, T3, T4) and two certified nurses (N1, N2). Typically, they were organised in shifts of two technologists and one nurse.

The age of the technologists was 38 (T1), 42 (T2), 37 (T3), and 31 years (T4) and of the nurses 37 (N1) and 42 years (N2). These six staff members were also occasionally involved in other nuclear medicine practices. However, from June to December 2018, they worked only on PET/CT and performed 423 procedures (1–3 per week) in patients with an average weight of 80 kg (range 31–160 kg) and age 60 years (range 6–86 years). The number of

procedures performed differed between staff members: T1 (142), T2 (53), T3 (102), T4 (126), N1 (189), and N2 (234).

Dosimetry

The NM staff was equipped with two passive TLDs each, one for the whole body and one for the hands (ring dosimeter). The whole-body TLD is worn on the chest, whereas the ring dosimeter is worn on the base of the index finger of the operator's dominant hand (Figure 1).

Both whole-body and ring TLD readouts corresponded to one month of cumulative dose measurements, as stipulated by country regulation (11). TLDs are read by the Personal Dosimetry Laboratory at the Public Health Institute of the Republic of Srpska. The Laboratory holds an accreditation according to ISO/IEC 117025 standard for measurements. The TLDs used in this study are of the MTS-N (LiF, Ti) type and are read by a semi-automatic RADOS RE-200 TLD reader. The detection limit for this TLD type is 26 µSv for one-month measurements, and measurement uncertainties for the whole body and ring TLDs are 28 % and 33 %, respectively (4).

Personal dosimeters are routinely calibrated for Hp(10) and Hp(0.07) at the Secondary Standard Dosimetry Laboratory (SSDL) of Vinča Institute of Nuclear Sciences, Belgrade, Serbia, which has metrological traceability to the primary standard at the International Bureau of Weights and Measures (BIPM) through the International Atomic Energy Agency (IAEA) Dosimetry Laboratory. Furthermore, SSDL is accredited to the ISO/IEC 17025 standard.

Data analysis

We analysed normalised whole-body and dominant-hand exposure doses per GBq of injected ¹⁸F-FDG activity [Hp(10)/A and Hp(0.07)/A, respectively] per month, cumulative Hp(10) and Hp(0.07) doses (µSv), total administered activities for each team member, cumulative doses Hp(10) and Hp(0.07) per procedure, and total

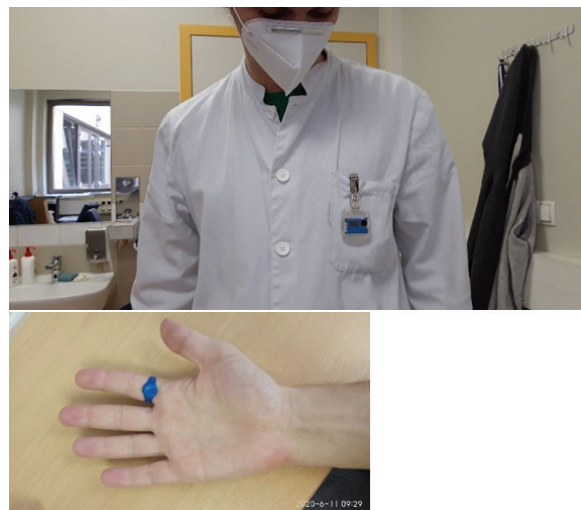


Figure 1 Correct placement for the whole-body and a ring dosimeter

normalised $\text{Hp}(10)/\text{A}$ and $\text{Hp}(0.07)/\text{A}$ for technologists and nurses over the seven months.

In order to determine the strength and direction of linear correlation, we calculated Pearson's correlation coefficient between $\text{Hp}(10)/\text{A}$ and $\text{Hp}(0.07)/\text{A}$ for technologists, $\text{Hp}(10)/\text{A}$ and $\text{Hp}(0.07)/\text{A}$ for nurses, and $\text{Hp}(10)/\text{A}$ $\text{Hp}(0.07)/\text{A}$ for all. Strong correlation (r) was considered the one between 0.5 and 1, and weak correlation between 0.1 and 0.29 (13). Mean values of the above pairs of normalised doses were compared using the independent sample t -test. Data were analysed with software packages OriginPro 9.0 (OriginLab Corporation, Northampton, MA, USA) and SPSS Statistics 23.0 (IBM, Armonk, NY, USA).

RADIATION PROTECTION MEASURES AND WORKFLOW

NM department had in place all appropriate radiation protection procedures for PET/CT imaging. Lead-shielded transportation containers were used for the transport of the radiopharmaceutical according to international standards and national legislation on ionising radiation protection, which included 10 cm thick lead bricks (occasionally used as an additional tool to shield the radiopharmaceutical during its transport from the manufacturing facility to the NM Department). The NM staff also used 30 cm long grasping forceps for safer radiopharmaceutical manipulation and the MEDRAD® Intego PET infusion system with the following radiation shielding profile: dose rates of 0.26 mSv/h up to 2.3 mSv/h for the vial shield, peak rate ≤ 0.014 mSv/h at 30.5 cm distance from any surface of the cart with 27.75 GBq in the vial, and peak rate < 0.001 mSv/h at 30.5 cm distance from the surface in the operator position

with 27.75 GBq in the vial (12). The injector itself is equipped with tungsten and lead shielding.

Personal protective garments such as lead aprons, gloves, and thyroid shields were also available, but not routinely used when handling ^{18}F -FDG, as they have been found no to provide significant protection (14). Nonetheless, individual preferences whether to use them or not were always respected. Wearing protective garments may help to reduce exposure in rare cases of contamination with liquid spills. It is also worth mentioning that the whole-body dosimeter, worn at the chest level, may have occasionally been covered by the lead apron.

Latex gloves were routinely used for all types of operations. They do not protect against beta or gamma radiation but provide a physical barrier between the radiopharmaceutical and operator's skin in case of a spill.

Shielding barriers also included walls, doors, and lead glazing of the PET/CT scanning and adjacent rooms. PET/CT scans were performed from the control room shielded to block all X-ray and most of gamma radiation. This means that the positron-emitting radionuclide was the major contributor to the radiation dose to which the technologists and nurses were exposed.

In addition to these protective measures, the PET/CT facility was designed to ensure a smooth workflow (see subsection below) to avoid loss of radionuclide activity due to lag times and to minimise time spent in proximity of an injected patient. The negative pressure ventilation system was independent of the rest of the hospital to limit the circulation of radioactive particles (gasses and aerosols) and expel radioactive particles. The personnel had also received manufacturer-specific, hands-on training to work with the GE Discovery 610 PET/CT unit and the MEDRAD®

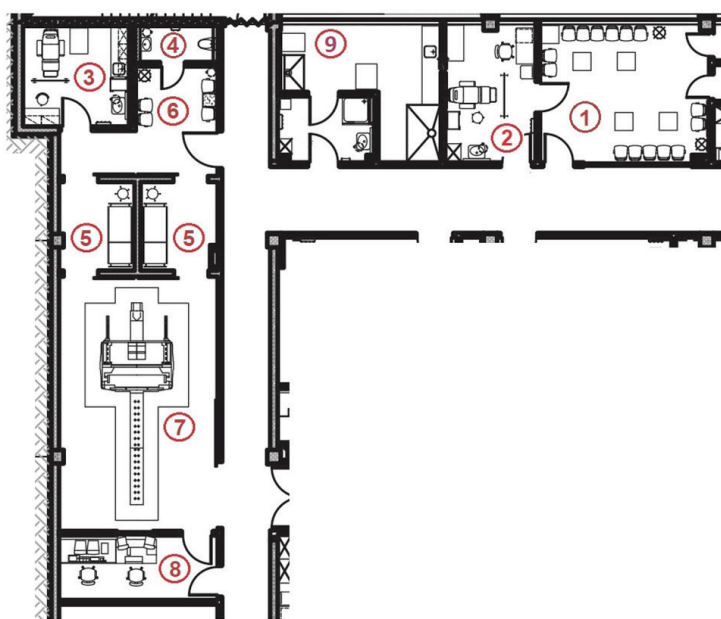


Figure 2 PET/CT facility floor plan design. 1 – waiting room 1; 2 – patient prep room; 3 – ^{18}F -FDG injection room; 4 – patient bathroom; 5 – patient uptake rooms; 6 – waiting room 2; 7 – PET/CT scanning room; 8 – PET/CT control room; 9 – hot laboratory

Intego PET infusion system ever since the PET/CT system was installed in March 2016.

Workflow

Figure 2 shows the floor plan design of the PET/CT facility. The technologists and nurses had separate responsibilities for the entire duration of patient scanning. Other professionals involved in PET/CT procedures (such as NM physicians) did not routinely perform any of the activities that might have resulted in measurable exposure to ionising radiation from radiopharmaceuticals used in PET/CT procedures. The workflow could roughly be divided into two phases: the first carried out by a nurse and the second by a technologist.

In phase 1, the nurse receives the container with ¹⁸F-FDG and places it into the automatic dispensing system. The system then calculates ¹⁸F-FDG activity to be dispensed and injected according to the EANM guidelines (10). Before ¹⁸F-FDG injection, all the scheduled patients are identified and registered. The nurse takes the patient from waiting room 1 to the patient prep room, where the patient's blood glucose levels are measured and an intravenous cannula placed. If blood glucose levels do not fall within the reference interval even after a second measurement, the procedure is postponed to another day. Otherwise, the nurse takes the patient to the ¹⁸F-FDG injection room. The

automated injection process takes about 30 seconds, and during that time, the nurse waits outside the injection room to avoid exposure. After injection, the patient is instructed to rest on the bed in one of the two patient uptake rooms for 60 minutes, covered with a quilt or two blankets.

In phase 2, at the end of the uptake time, the technologist sitting in the PET/CT control room instructs the patient via speakerphone to go to the patient bathroom to empty her/his bladder, and escorts her/him to the scanning room, positions the patient on the scanner bench, and makes the scan. Scanning takes between 20 and 45 minutes, depending on the size of the region scanned and the protocol used (usually 'whole body' or 'total body'). Whenever the total body scanning protocol is performed, the technologist must re-enter the scanning room and reposition the patient, which results in increased exposure. Then the technologist escorts the patient to waiting room 2, where the patient waits for the physician and/or radiologist to review the obtained PET/CT images. If the images are good, the patient is released from the Department. Otherwise, the patient is immediately asked to do another round of imaging. The same procedure is repeated until all the scheduled patients are processed.

RESULTS AND DISCUSSION

From 2016 to 2019, the annual number of PET/CT procedures at the NM Department increased from 208 to

Table 1 Period under consideration, number of PET/CT workdays, number of PET/CT procedures and total injected activity

Observed period (month) in 2018	Number of PET/CT workdays	Number of PET/CT procedures	Total injected ¹⁸ F-FDG activity (GBq)
June	6	44	11.7
July	7	53	14.2
August	8	62	15.7
September	7	47	12.3
October	10	76	19.5
November	11	85	21.3
December	8	56	14.3
Total:	57	423	109.0

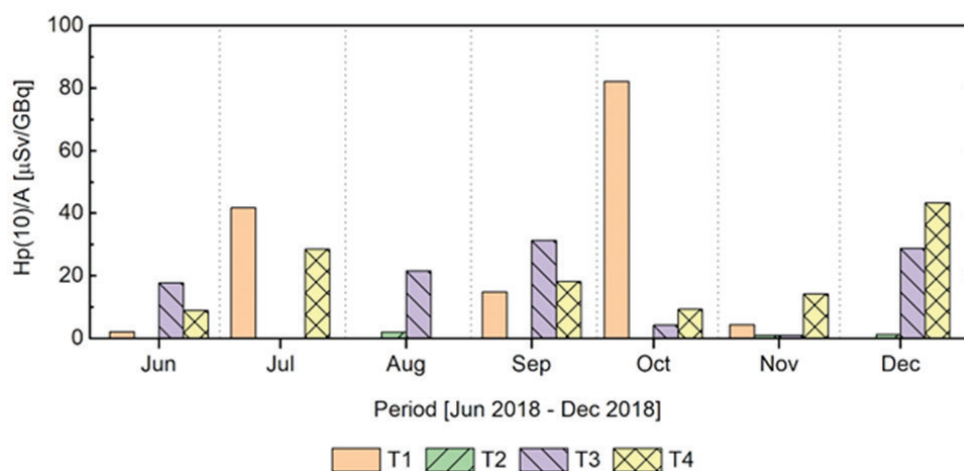


Figure 3 Normalised whole-body exposure dose per GBq of injected ¹⁸F-FDG activity per month for technologists

876, which clearly confirms an increasing trend in PET/CT scans observed worldwide (5).

From the total number of procedures and injected activities over the seven months of our study (Table 1) we calculated the average activity of 258 MBq per procedure, which is slightly lower than activities per procedure reported in Lithuania (283 MBq) (7), Oman (298 MBq) (8), or India (308 MBq) (15) and mainly reflects differences in parameters between patients (15), use of different guidelines for radiopharmaceutical injection in terms of patient age and weight, and the uncertainties in injection dose measurements.

Figures 3 and 4 show normalised monthly whole-body and dominant-hand exposure doses for technologists. We can see that normalised doses are not uniformly distributed across the months and individual technologists, as they depended on the distribution of working days and workload of each technologist. Normalised monthly whole-body and dominant-hand exposure doses for nurses are shown in Figures 5 and 6.

Cumulative normalised doses for whole-body and dominant-hand exposure for the same period are shown in Figures 7a and b for the technologists and 8a and 8b for the nurses. These figures show that the nurses' hands were more exposed to radiation than those of the technologists.

Table 2 compares the monthly normalised exposure doses for technologists and nurses. We found a strong correlation between normalised exposure doses Hp(10)/A and Hp(0.07)/A for technologists ($r=0.61$), Hp(10)/A and Hp(0.07)/A for nurses ($r=0.85$), and between Hp(10)/A for technologists and nurses ($r=0.65$). These results reveal that the compared pairs of normalised doses changed similarly over time. In contrast, the correlation between Hp(0.07)/A for technologists and nurses was weak ($r=0.25$). No significant differences between mean normalised doses were found.

Table 3 presents the Hp(10) and Hp(0.07) cumulative doses and activities per staff member for the observed seven months. Average cumulative Hp(10) and Hp(0.07) doses (with standard error of the mean, SEM) were (505 ± 171) μSv and (462 ± 91) μSv for the technologists and (850 ± 258) μSv and (1385 ± 353) μSv for the nurses, respectively. The average cumulative Hp(10) and Hp(0.07) doses for all staff members were (0.62 ± 0.17) mSv and (0.76 ± 0.21) mSv, respectively. As the cumulative dose is a linear function of time (5, 16), we extrapolated the average annual cumulative dose for the PET/CT staff to be (1.06 ± 0.29) mSv for Hp(10) and (1.15 ± 0.32) mSv for Hp(0.07), which is significantly lower than the respective limits of 20 mSv (or the dose constraint of 2 mSv) and 500 mSv (11).

Table 2 Normalised monthly doses per unit of injected activity

	Hp(10)/A ($\mu\text{Sv}/\text{GBq}$)		Hp(0.07)/A ($\mu\text{Sv}/\text{GBq}$)	
	Technologists	Nurses	Technologists	Nurses
June	9.2 \pm 2.7	18 \pm 6	9 \pm 3	40 \pm 14
July	42 \pm 13	23 \pm 8	40 \pm 12	30 \pm 10
August	19 \pm 6	9 \pm 3	3.2 \pm 1.0	13 \pm 4
September	20 \pm 6	18 \pm 6	35 \pm 10	31 \pm 10
October	24 \pm 7.1	20 \pm 7	10 \pm 3	30 \pm 10
November	5.3 \pm 1.6	9 \pm 3	16 \pm 5	12 \pm 4
December	19 \pm 6	20 \pm 7	16 \pm 5	36 \pm 13

Hp(10)/A – normalised whole-body dose per GBq of injected ^{18}F -FDG activity. Hp(0.07)/A – normalised dominant-hand dose per GBq of injected ^{18}F -FDG activity

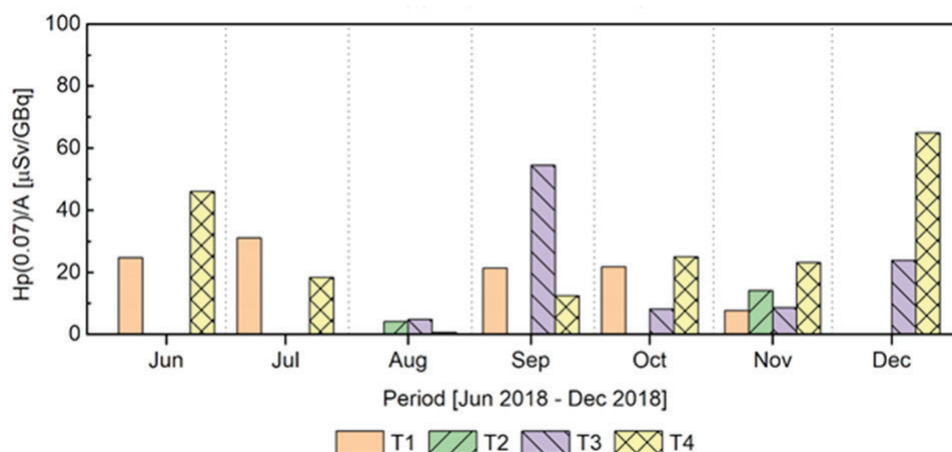


Figure 4 Normalised dominant-hand exposure dose per GBq of injected ^{18}F -FDG activity per month for technologists

Table 3 Staff cumulative doses and total administered activities for the seven-month period

Staff	Hp(10) (mSv)	Hp(0.07) (mSv)	Injected ¹⁸ F-FDG activity (GBq)
Technologist 1	0.76±0.21	0.50±0.14	31±3
Technologist 2	0.08±0.02	0.27±0.08	14.2±1.4
Technologist 3	0.37±0.10	0.38±0.11	25.9±2.6
Technologist 4	0.81±0.23	0.70±0.20	38±4
Nurse 1	0.59±0.19	1.0±0.3	51±5
Nurse 2	1.1±0.4	1.7±0.6	58±6

Hp(10) – whole-body received dose. Hp(0.07) – dominant-hand received dose

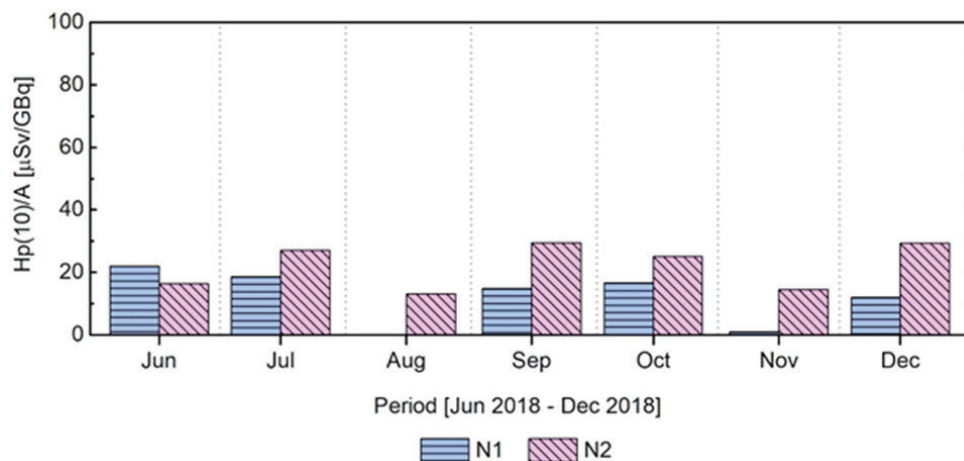


Figure 5 Normalised whole-body exposure dose per GBq of injected ¹⁸F-FDG activity per month for nurses

Table 4 Comparison between ours and other studies available in the literature (maximum values shown in parentheses)

Study	Staff by profession	Hp(10)/ procedure (µSv)	Hp(10)/A (µSv/GBq)	Hp(0.07)/ procedure (µSv)	Hp(0.07)/A (µSv/GBq)	Automatic injector & dispenser
Our study	Technologist	4.78 (15.64)	18.55	4.37 (15.38)	16.99	Yes
	Nurse	4.02 (8.83)	15.61	6.55 (28.17)	25.44	
Study 1 (ref. 5)	Technologist	4.2–7.0	17–19	-	-	Yes
Study 2 (ref. 6)	Technologist	2.5±2.1	-	-	-	Yes
Study 3 (ref. 7)	Technologist	1.72±0.33/	-	-	-	Yes
		1.16±0.11				
Study 4 (ref. 8)	Technologist	4.17	-	-	-	Yes
Study 5 (ref. 15)	Physicians	2.1	6.8	-	-	No
	Technologist	0.6	1.9	-	-	
	Technologist	4.77±0.52	10.3±1.1	-	-	
Study 6 (ref. 17)	Nurse	5.79±0.59	12.5±1.2	-	-	No
	Med. physicist	5.07±0.51	10.9±1.1	-	-	
Study 7 (Ref. 18)	Technologist	-	-	38.77±7.33	-	No
	Nurse	-	-	59.6±6.33	-	
	Med. physicist	-	-	203.5±17.74	-	

Hp(10)/A – normalised whole-body dose per GBq of injected ¹⁸F-FDG activity; Hp(0.07)/A – normalised dominant-hand dose per GBq of injected ¹⁸F-FDG activity. Hp(10) – whole-body dose; Hp(0.07) – dominant-hand dose

Table 4 provides a comparative analysis of our data to those published in the literature. Hp(10)/procedure and Hp(10)/A of injected ¹⁸F-FDG established in our study are in good agreement with several other reports (5, 6, 8, 17) but not with some other studies (7, 15), probably due to different workflow between the compared centres. Hp(0.07)/procedure in our study was compared with only one study (18), and a weak agreement was found. In our opinion, this is mainly due to the different processes of dispersion and injection of the radiopharmaceutical. To our knowledge, there are no other data for Hp(0.07)/A of injected ¹⁸F-FDG in the literature that could be compared to our values.

CONCLUSION

Our study has several limitations. First, the dosimeters are supposed to be read in regular intervals (once a month),

but retrospectively we found that readout times sometimes were longer than a month. Another issue with retrospective studies of this kind is that one cannot check whether dosimeters were worn correctly or whether additional exposure occurred from accidental ¹⁸F-FDG extravasation in patients with obstructed veins.

The doses received by our staff were well below the legal limits and are in good agreement with the doses reported in other available studies. Regardless of this, it is necessary to further optimise the procedure following the ALARA principle and to investigate in more detail the ergonomics and exposure potential of each step.

Future studies in this field should address staff eye doses for PET/CT procedures, as almost all studies made so far lack these data.

The limitations of this retrospective study also provide a helpful indication how to improve further research by

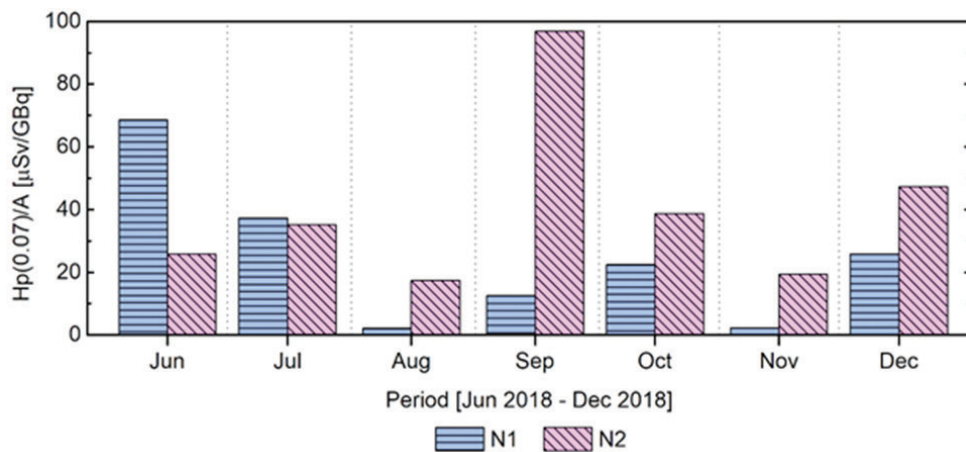


Figure 6 Normalised dominant-hand exposure dose per GBq of injected ¹⁸F-FDG activity per month for nurses

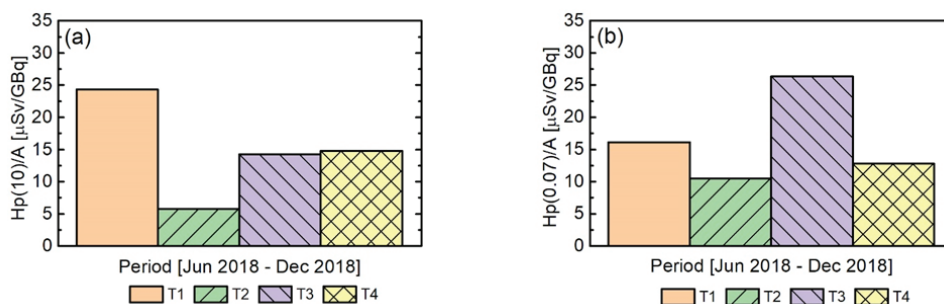


Figure 7 Normalised cumulative a) whole-body and b) dominant-hand dose over the seven months of the study for technologists

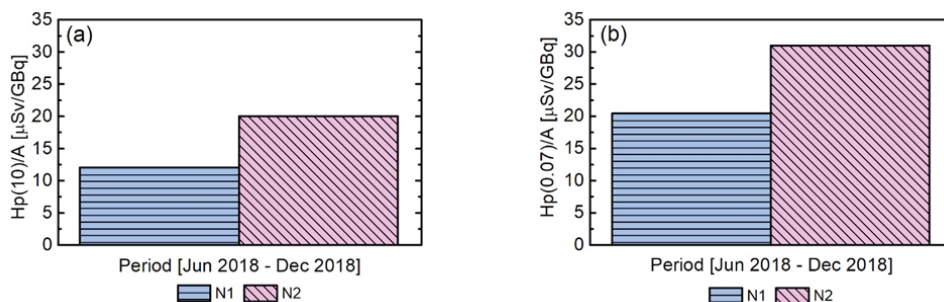


Figure 8 Normalised cumulative a) whole-body and b) dominant-hand dose over the seven months of the study for nurses

prospectively monitoring staff at risk of exposure with real-time dosimeters in combination with TLDs and by tracking exposure from various radiopharmaceuticals.

REFERENCES

1. Wernick MN, Aarsvold JN. Emission Tomography: The Fundamentals of PET and SPECT. Cambridge (MA): Elsevier Academic Press; 2004.
2. Alenezi A, Soliman K. Trends in radiation protection of positron emission tomography/computed tomography imaging. *Annals of the ICRP* 2015;44(Suppl 1):259–75. doi: 10.1177/0146645314551671
3. IAEA Safety Standards. Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards. IAEA Safety Standards Series No. GSR Part 3, 2014 [displayed 25 August 2021]. Available at https://www-pub.iaea.org/MTCD/publications/PDF/Pub1578_web-57265295.pdf
4. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP publication 103. *Ann ICRP* 2007;37(2–4):1–332. doi: 10.1016/j.icrp.2007.10.003
5. Antic V, Ciraj-Bjelac O, Stankovic J, Arandjic D, Todorovic N, Lucic S. Radiation exposure to nuclear medicine staff involved in PET/CT practice in Serbia. *Radiat Prot Dosimetry* 2014;162:577–85. doi: 10.1093/rpd/ncu001
6. Tomše P, Biček A. Radiation exposure in routine practice with PET/CT and automatic infusion system - Practical experience report. In: Bamidis PD, Pallikarakis N, editors. IFMBE Proceedings of XII Mediterranean Conference on Medical and Biological Engineering and Computing 2010; Vol 29. 27–30 May 2010. Chalkidiki, Greece 2010. p. 719–21.
7. Skovorodko K, Bareikė M, Gudelis A, Gričienė B. Occupational exposure in a PET/CT facility using two different automatic infusion systems. *Phys Med* 2020;7:169–75. doi: 10.1016/j.ejmp.2020.08.014
8. Al-Aamria M, Al-Balushia N, Bailey D. Estimation of radiation exposure to workers during [¹⁸F] FDG PET/CT procedures at Molecular Imaging Center, Oman. *J Med Imaging Radiat Sci* 2019;50:565–70. doi: 10.1016/j.jmir.2019.05.009
9. Li W, Fang L, Li J. Exposure doses to technologists working in 7 PET/CT departments. *Dose Response* 2020;18(3):1559325820938288. doi: 10.1177/1559325820938288
10. Boellaard R, Delgado-Bolton R, Oyen WJ, Giammarile F, Tatsch K, Eschner W, Verzijlbergen FJ, Barrington SF, Pike LC, Weber WA, Stroobants S, Delbeke D, Donohoe KJ, Holbrook S, Graham MM, Testanera G, Hoekstra OS, Zijlstra J, Visser E, Hoekstra CJ, Pruim J, Willemsen A, Arends B, Kotzerke J, Bockisch A, Beyer T, Chiti A, Krause BJ, European Association of Nuclear Medicine (EANM). FDG PET/CT: EANM procedure guidelines for tumour imaging: version 2.0. *Eur J Nucl Med Mol Imaging* 2015;42:328–54. doi: 10.1007/s00259-014-2961-x
11. Regulation on Radiation Protection for Occupational and Public Exposure. Official Gazette B&H No 102/11 [displayed 25 August 2021]. Available at <http://www.darns.gov.ba/en/EnglishDARNS/RegulationsDescription>
12. MEDRAD, INC. MEDRAD™ Intego™ Infusion System. Operation Manual, 2008–2013 [displayed 25 August 2021]. Available at http://omr.imaxeon.com.au/omr/online/Download/OM_INTEGO_2_3031103.pdf
13. Cohen JW. *Statistical Power Analysis for the Behavioral Sciences*. 2nd ed. Hillsdale (NJ): Lawrence Erlbaum Associates; 1988.
14. Fonseca RB, Amaral A. Effectiveness of lead aprons in positron emission tomography. In: IRPA 12: 12th International congress of the International Radiation Protection Association (IRPA): Strengthening radiation protection worldwide; Buenos Aires, Argentina, 2008 [displayed 25 August 2021]. Available at https://inis.iaea.org/collection/NCLCollectionStore/_Public/41/003/41003294.pdf?r=1&r=1
15. Kumar S, Pandey AK, Sharma P, Shamim SA, Malhotra A, Kumar R. Instantaneous exposure to nuclear medicine staff involved in PET-CT imaging in developing countries: experience from a tertiary care centre in India. *Jpn J Radiol* 2012;30:291–5. doi: 10.1007/s11604-011-0045-4
16. Costa PF, Reinhardt M, Poppe B. Occupational exposure from F-18-FDG PET/CT: implementation to routine clinical practice. *Radiat Prot Dosim* 2018;179:291–8. doi: 10.1093/rpd/ncx276
17. Emad El-din MM, Mahmoud RMM, Abaza A, Ez El-din MR, Eid I, Rizk RA. Occupational radiation exposure in PET/CT units. *Arab J Nucl Sci Appl* 2017;50:58–65.
18. Saad I, Yassin H. Finger radiation doses received by different nuclear medicine working professions in three PET/CT centers. *Egyptian J Nucl Med* 2018;17:63–77. doi: 10.21608/egyjn.2018.46235

Izloženost osoblja nuklearne medicine ionizirajućem zračenju u ^{18}F -FDG PET/CT dijagnostici – preliminarna retrospektivna studija

Ova retrospektivna studija pruža uvid u razinu izloženosti ionizirajućem zračenju za šestoro zaposlenih (četiri radiološka tehničara i dvije medicinske sestre) koji izvode rutinska dijagnostička ispitivanja primjenom ^{18}F -FDG na PET/CT-u u Kliničkom zavodu za nuklearnu medicinu i bolesti štitne žlijezde Univerzitetskoga kliničkog centra Republike Srpske (Banja Luka, Bosna i Hercegovina). Analiza podataka obuhvatila je mjesečnu izloženost osoblja, koja je od lipnja do prosinca 2018. mjerena osobnim termoluminiscentnim dozimetrima (TLD-ima), a izražena je normaliziranom dozom za cijelo tijelo [$\text{Hp}(10)$] te dozom za dominantnu ruku [$\text{Hp}(0,07)$]. Također, u obzir je uzeta i usporedba tih veličina između svakoga člana osoblja te između dviju skupina (radiološki tehničari i medicinske sestre). Cilj studije bio je usporediti izvješća našega Zavoda i drugih PET/CT centara u svijetu u pogledu godišnjega broja postupaka, granica izloženosti osoblja te mogućnosti uvođenja dodatnih poboljšanja mjera zaštite od zračenja. Ustanovljeno je da se broj postupaka znatno povećao (s 208 u 2016. na 876 u 2019. godini), a tijekom praćenoga sedmomjesečnog razdoblja iznosio je 423. Srednja vrijednost pojedinačne doze za cijelo tijelo po jedinici aplicirane aktivnosti ^{18}F -FDG [$\text{Hp}(10)/\text{A}$] iznosila je $18,55 \mu\text{Sv}/\text{GBq}$ za četvero radioloških tehničara i $15,61 \mu\text{Sv}/\text{GBq}$ za dvije medicinske sestre. Srednja vrijednost doze za dominantnu ruku po jedinici aplicirane aktivnosti ^{18}F -FDG [$\text{Hp}(0,07)/\text{A}$] iznosila je $16,99 \mu\text{Sv}/\text{GBq}$ i $25,44 \mu\text{Sv}/\text{GBq}$ za te dvije skupine. Srednja vrijednost godišnje kumulativne doze za svih šestoro zaposlenih iznosila je $(1,06 \pm 0,29) \text{mSv}$ za $\text{Hp}(10)$ i $(1,15 \pm 0,32) \text{mSv}$ za $\text{Hp}(0,07)$. Ovi su rezultati usporedivi s rezultatima sličnih studija. Doze za osoblje bile su znatno ispod propisanih godišnjih limita. Medicinske sestre imale su nešto više vrijednosti doza za ekstremitete (ruke) nego radiološki tehničari. Imajući u vidu tendenciju povećanja broja PET/CT postupaka, potrebno je nastaviti monitoring doza za osoblje kako bi se identificirale faze radnoga procesa koje dovode do najveće izloženosti osoblja, a zatim smanjile doze za osoblje.

KLJUČNE RIJEČI: ^{18}F -fluorodeoksiglukoza; ALARA; sustav za automatsko ubrizgavanje radiofarmaka; pozitronska emisijska tomografija s kompjutoriziranom tomografijom; profesionalna doza; termoluminiscentni dozimetri; TLD