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Assessment of external radiation dose rate after ^{18}FDG-PET/CT examination

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Abstract

Background F-18 FDG (fluorodeoxyglucose) PET/CT procedures are one of the most growing studies used for patient management in oncology, cardiology, neurology, and other indications, in which the challenges meet both patients and clinicians, especially when we are looking for the presence/absence of disease progression and cure. This study was conducted to assess the external radiation dose after 18FDG-PET/CT examination. In total, 117 patients were enrolled in the study. Radiation exposure was measured using a calibrated RadEye SPRD-ER personal radiation detector. The measurements were taken at 0, 30, 100, 150, and 200 cm distance from the patient. The time of measurement was immediately post-injection, 30 min, 60 min after injection, and at the time of releasing the patient.

Results The result showed that the mean radiation equivalent dose rate at 0 min/0 cm was 414 µSv/h, at 30 min/30 cm was 99.7 µSv/h, and 60 min/100 cm was 18.3 µSv/h. The radiation doses at different distances (0, 30, 100, 150, and 200 cm) were 160.9 µSv/h, 70.9 µSv/h, 12.4 µSv/h, 7 µSv/h, and 3.7 µSv/h, respectively.

Conclusion In conclusion, the patient can be safely released after 2 h of injection in (18F-FDG) PET/CT and the radiation dose can be limited by increasing distance from the radiation source and also instructing them to drink much more water to enhance the process of excretions. The dose rates are low in this study; if the staff interact with multiple patients, they will not approach exposure limits. Similarly, dose rates are so low at patient release that family will not receive doses above regulatory limits.

Keywords ^{18}FDG-PET/CT, Dose rate, Radiation exposure, Molecular imaging, Patient safety

Background

F-18 FDG (fluorodeoxyglucose) PET/CT procedures are one of the most growing studies used for patient management in oncology, cardiology, neurology, and other indications, in which the challenges meet both patients and clinicians, especially when we are looking for the presence/absence of disease progression and cure. PET-CT was truly one of the brilliant diagnostic imaging tools for the whole-body scan, which is used for functional and anatomical purposes, providing a significant impact on patient management, diagnosing, and staging of the malignant disease, as well as identifying and localizing the metastasis and its extensions [5]. F-18-FDG PET scan evaluates the lesions based on glucose metabolic activity within the tissue [11].

The most commonly used tracer at present is the glucose analog ([^{18}F]-fluorodeoxyglucose (FDG)) where the accumulation in tissue is proportional to the utilization of glucose by the tissue [20]. It spread to the whole body within minutes. The physical half-life is 110 min, which is excreted from the body within 3–24 h and within more than 96 h in myocardial tissue, the maximum bladder

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dose is increased as the time increases which leads to an increase in the dose to the nearby tissue also [12].

Fletcher et al. [15] stated that PET is indicated for primary presentation (diagnosis), staging on presentation, response evaluation, restaging for curable relapse, elevated serum markers, and image-guided biopsy [1, 6, 7, 14]. CT alone can provide the high-resolution anatomical information, so when it fused or performed with PET scan, it can give a powerful anatomical and functional status of tissue and cells according to its metabolic rate [28].

There is an increasing use of combined PET/CT scanner, in this case; the radiation dose is from both PET and CT. Radiation emitted from ^{18}F isotopes is originated from the annihilation process resulted in two photons of gamma rays with 511 keV for each photon in two opposite directions in which the two detectors are placed 180° apart. For this reason, barrier shielding may be required in floors and ceilings as well as adjacent walls [21]. This radiation raising occupational, as well as public safety, concerns [4]. The CT exposure factors (kVp, mA, time per rotation, and pitch) need to be optimized so that the absorbed dose from the CT component is minimized, while still obtaining the required information. Accordingly, protocols should be developed for all common procedures involving CT using automatic exposure control (AEC) wherever possible [26].

^{18}F-FDG can cause radiation harm to both work in the radiation field and attendants; for the public, an individual is exposed just one time unlikely to be exposed more than once; in fact, the overall dose received by others is mostly affected by the effective half-life of radionuclide, length of contact time with the patient, and distance from the patient, for longer-lived radionuclide such ^{18}F half-life should be taken into account [12].

The radiation protection goals for the public are to limit the exposure so that no individual can receive more than 100 mrem/year which is equivalent to 1 mSv/year [17]. These guidelines mirrored by state regulations in agreement states; means weekly controlling the dose to 2mrem level which represents 30% of the mean effective dose rate from natural background radiation in the USA. Also in the accessible areas to the public, the dose should not exceed 2mrem/hour (0.02 mSv/h) [13].

Safe patient discharge is most important because patients undergoing nuclear medicine scan can be a source of radiation exposure for staff, family, and the public. This factor depends on the amount of activity injected into the patient (dose administered), the time that he spends in the department before completing the study, and the amount of radioactivity being excreted naturally as an excretory route (urinary excretion). Studies have been conducted to measure the doses for a range of scenarios, to hospital staff, to the public, and to the patients' co-workers and family. The estimated dose for all scan types, and all scenarios, doses are estimated to be substantially less than the trigger level of 300 μSv [2]. Furthermore, during the radiopharmaceutical incorporation, a person who stays with another injected patient in the same waiting room may receive up to 0.59 mSv [24].

National practical guidelines have been established with the aim of unifying the application of basic international recommendations for radiological discharge of patients treated with radiopharmaceuticals (Protection [25]). On the other hand, some studies have assessed the dose received by technical personnel during diagnostic procedures including PET [3, 8]. This study focused on the measurement of external radiation dose from the time of injection till the time patient leaves the department (after completing the study).

Methods

A total of 117 patients with age ranged from 10 to 86 years and mean weight of 75.4 kg (range 42–135) included in this study. The study was done at (Jaber Al Ahmed Center for Molecular Imaging) institute in the period from June to August 2020; patients with known diagnostic and pathological information where the FDG scan was indicated were referred for ^{18}F-FDG-PET/CT using Discovery MI PET/CT (GE Health care—USA) according to the Departmental Center. The mean dose level (IV) injected to the patient was 4.5 ± 1.032 mCi, a range of 2 mCi to 8 mCi (as the injected dose based on patient weight formula).

Measurement was taken using a calibrated survey meter (Thermo Scientific™ Rad-Eye PRD Personal Radiation Detector, Detectors NaI (Tl) detector with high-quality micro-photomultiplier; energy range 60 keV to 1.3 MeV) immediately after the injection, 30 min, 60 min, and at time of patient release; each measurement was repeated at 0 cm, 30 cm, 100 cm, 150 cm, and 200 cm distances for each time to assess the differences in time and distance to identify their effect on radiation exposure reduction; all measurements were taken at the front chest.

Data were analyzed using SPSS (Statistical Package for Social Sciences) version 21, mean and STD for each measurement in μSv/h were calculated, and paired sample t test was performed to show the difference in dose reduction level at different distances, and p-value of < 0.05 was considered as statistically significant.

Results

See Figs. 1 and 2, Tables 1, 2, 3, and 4.

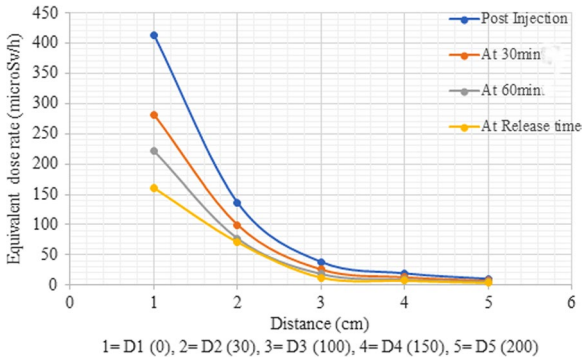

Fig. 1 A line graph demonstrates the external dose reduction rate (μSv/h) status for different time (T) and distance (cm)

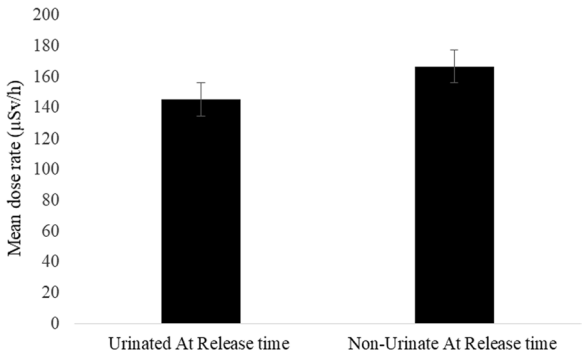

Fig. 2 Bar chart demonstrates the difference in dose reduction for urinated and not urinated patients at release time

Table 1 The mean difference in equivalent dose rate (μSv/h) measured at a different time (minute) and distance D (cm) for FDG/PET-CT radiopharmaceuticals

Time	*D* = 0	*D* = 30 cm	*D* = 100 cm	*D* = 150 cm	*D* = 200 cm
Post-injection	414	136.5	38.4	19.3	10.3
At 30 min	282	99.7	25.8	12.8	6.9
At 60 min	222	77.1	18.3	8.8	5.1
At release time	161	70.9	12.4	7.00	3.7

Discussion

This study was conducted to assess the external radiation exposure rate (converted to equivalent radiation dose per hour- μSv/h) to the external populations that originated from the intravenous injection of FDG-PET/CT dose.

Occupational exposure was the main focus; an earlier study identified higher radiation exposure to a nuclear medicine technician or the person who interacts with the patient (including all medical staff and general populations) during PET scanning. Radiation exposure at any area of radiation according to the ICRP classification [9, 10] should be monitored and measured to protect the patient and the others, especially in the NM department as well as any area of radiation exposure.

The patient in PET scan as we know becomes a source of exposure when is injected with radiopharmaceuticals (^{18}F), and the measurement was taken for every patient to ensure safe patient discharge which is depending on time and distance as shown in Table 1; the highest radiation dose measured at this study at time zero (immediately post-injection of FDG) was 414 μSv/h which is lower than the previous studies [19, 27], and this could be due to lower fixed standard injection activity and body mass adjusted injection activity. Also at 30 min time-D0 was 282 μSv/h, and at 60 min D0 was 221.8 μSv/h, and at releasing time distance (0) was 160.9 μSv/h. These results indicate that safe and optimum radiation protection to the staff and patient relatives when releasing or interacting with the patient taking into account the rules of radiation protection according to ICRP reports [18]. See Table 1 for the rest of the findings according to the time and distance factor.

When discussing the reduction of dose at different distance and time intervals, the gradient of the dose reduction was significant, the reduction is higher in the first time interval between 0 and 30 min, but the minimum difference is noted between 60 min and release time which indicates that the amplitude of dose reduction according to the time is happened between 0 and 30 min from 414 to 282 μSv/h (see Table 1) Fig. 1 as an example of reduction phenomena. The reduction of radiation dose from the patient is reduced to the minimum after 30 min

Table 2 The mean dose rate (μSv/h) for patient urinated and not urinated post-injection and at the time of patient release

Time	*D* = 0	*D* = 30 cm	*D* = 100 cm	*D* = 150 cm	*D* = 200 cm
Urinated post-injection	389	132.3	37.7	19.0	9.2
Non-urinate post-injection	423	138.0	40.1	19.8	10.7
Urinated at release time	145.4	53.9	12.2	5.9	3.2
Non-urinate at release time	166.7	115.4	13.0	7.4	3.9

Table 3 Paired samples statistics for the difference in dose (μSv/h) measurement at patient release time at different distances compared to the distance (0)

Paired samples statistics	Mean	SD
Pair 1		
Immediately post-injection at distance = 0	414.0	131.5
Immediately post-injection at distance = 200 cm	10.3	6.5
Pair 2		
Immediately post-injection at distance = 0	414.0	131.5
30 min after injection at distance 0	282.8	78.5
Pair 3		
Immediately post-injection at distance = 0	414.0	131.5
60 min after injection at distance = 0	211.8	63.5
Pair 4		
Immediately post-injection at distance = 0	414.0	131.5
Post-acquisition at distance equal 0	160.9	53.9

of dose injection at 150 cm distance and 200 cm. This reduction phenomenon is noted in the exponential low of decay graphs [22] where the dose decreases as time and distance increased. Both factors are very important in terms of patient discharge.

Another factor that plays an important role in reducing the radiation dose to the public or the radiation worker in the medical field is the amount of radiation dose injected. The departments should consider the reduction of radiation dose and the image quality and diagnostic information; in our center, the dose injected was 0.06 mCi/kg, and this technique of reducing the injected dose is adopted by Marafi et al. [23].

Also, this study tested the difference of the patient who empties the bladder or not where the mean difference reveals that there is no significant difference, but the dose for those who empty the bladder at a mean time of 53 min was 145.4 μSv/h compared to 166.7 μSv/h for not urinated patient at time of releasing patient (Table 2, Fig. 2). This result was in line with the previous study which stated that an active emptying of bladder in patients having PET/CT scans where ^{18}F-FDG radiopharmaceutical is involved is an effective method for the radiation safety of both health workers and patients [16].

A significant difference was noted in the measured radiation dose rate (mSv/h) at the release time of the patient at a different distance. This difference noted for all release time external dose rate (p-value was 0.000) mean values of radiation dose at releasing time is significantly reduced from 160.9 μSv/h at 0 distance to 3.7 μSv/h at 200 cm distance, and this indicates the effect of distance in the reduction of exposure rate (dose rate) as shown in (Tables 3, 4).

Conclusions

The study concluded that the patient can be safely released after 2 h of injection in (^{18}F-FDG) PET/CT and the radiation dose can be limited by increasing distance from the radiation source and also instructing them to drink much more water to enhance the process of excretions. The short half-life of ^{18}F limits the dose that members of the public are likely to receive. The dose rates are low in this study; if the staff interact with multiple patients, they will not approach exposure limits. Similarly, dose rates are so low at patient release that family will not receive doses above regulatory limits.

Abbreviations

CT	Computed tomography
FDG	Fluorodeoxyglucose
PET	Positron emission tomography

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Author contributions

All authors contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript.

Table 4 The paired samples t test (at p-value is significant below 0.05, and confidence level equal to 95%) which demonstrates the significant difference in measured external radiation dose at the release time (T) of the patient at a different distance (D)

		Paired differences				t	Sig. (2-tailed)
		Mean	SD	95% confidence interval of the difference			
				Lower	Upper		
Pair 1	T0D0–T0D2m	403.7	129.6	379.9	427.5	33.7	0.000
Pair 2	T0D0–T30D0	131.2	86.8	115.3	147.1	16.4	0.000
Pair 3	T0D0–T60D0	202.3	105.7	182.9	221.6	20.7	0.000
Pair 4	T0D0–PAD0	253.1	122.5	230.7	275.6	22.4	0.000

PA Post-acquisition

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Not applicable.

Availability of data and materials
Derived data supporting the findings of this study are available from the corresponding author Ahmed Abukonna on request.

Declarations

Ethics approval and consent to participate
This study was approved by the Institutional Ethics Committee. Informed consent was obtained from patients after being informed by the procedure and their refusal will not affect the quality of management they were going to have.

Consent for publication
The Authors consent to publication of the Work in the Egyptian Journal of Radiology and Nuclear Medicine. The Authors warrant that the Work has not been published before in any form except as a preprint, the Work is not being concurrently submitted to and is not under consideration by another publisher, the persons listed above are listed in the proper order and that no author entitled to credit has been omitted, and the Author has the right to make the grants made to the Publisher complete and unencumbered. The Author also warrants that the Work does not libel anyone, infringe anyone's copyright, or otherwise violate anyone's statutory or common law rights.

Competing interests
The authors declare that they have no competing interests.

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