Original Article

Statistical analysis of the occupational radiation doses in three different positron emission tomography–computed tomography centers in Egypt

ABSTRACT

In the present study, we investigated the radiation doses received by the positron emission tomography (PET)/computed tomography (CT) staff in three different diagnostic centers in Egypt. The whole-body effective dose measured by thermoluminescent dosimeters (TLDs) for staff working in PET and the effective dose per study received by physicist, technician, and nurse were measured by an electronic pocket dosimeter (EPD) during a period of 6 months. Statistical analysis was held between the measurements of the TLDs as well as for the EPD for the three studied PET-CT centers. After combining TLD and EPD prospective annual scores for the three studied categories in the three centers, the one-way ANOVA test results have shown that there were statistically significant differences between group means with respect to their TLD mean score ($P = 0.041$). The mean nurse group TLD score, across the three centers, appeared to be the lowest scoring 3.83 (standard deviation [SD] 0.012) compared to the physicist and technician who measured 4.62 (SD 0.231) and 6.92 (SD 0.018), respectively. Scheffe's test for complex comparisons revealed a significant difference between nurse group and technologist group ($P = 0.001$). Regarding the annual combined EPD scores, the *post hoc* test, namely Scheffe's test for complex comparisons, revealed a significant difference between nurse group and technologist group ($P = 0.001$). This was measured after the one-way ANOVA test results have shown that there were statistically significant differences between annual group EPD means ($P = 0.032$). Finally, there was no recorded significance for the studied categories across the three centers between their annual TLD and EPD dose scores ($P = 0.072$). Technicians group received the highest mean effective whole-body doses when compared with the International Commission on Radiological Protection dose limit, each individual worker can work with many more 18F-fluorodeoxyglucose (FDG) PET/CT studies for a (period time) without exceeding the occupational dose limits if the average received effective dose continues with the same rate. The study also confirmed that low levels of radiation dose are received by medical personnel involved in 18F-FDG PET/CT procedures in those centers due to implementing radiation protection measures and procedures.

Keywords: Analysis, occupational doses, positron emission tomography-computed tomography

INTRODUCTION

The radiation protection of radiation worker, general public, and environment is usually a matter of concern, especially in nuclear medicine facilities. Occupational exposure and exposure to the patient and the public cannot be avoided within nuclear medicine practice, and with respect to radiation exposures, radiation workers differ from other members in the medical field or the general public.[1] They are aware that they may receive additional doses at work.[2] Furthermore, they are trained in radiation protection,[3], and they are under stricter medical surveillance than most workers in other fields,[4] where open sources of radiation are handled and radioisotope is administered to the patients

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Access this article online	
Website: www.wjnm.org	**Quick Response Code**
DOI: 10.4103/wjnm.WJNM_42_18	

How to cite this article: Ahmed IE, Zamzam AM, Yassin HM. Statistical analysis of the occupational radiation doses in three different positron emission tomography–computed tomography centers in Egypt. World J Nucl Med 2019;18:287-92

Submission: 29-Apr-18, **Accepted:** 12-Jun-18

in the form of radiopharmaceuticals within the patient who will be a moving source of radiation.[5]

An understanding of the radiation protection and safety issues is very important to keep clinical and occupational exposure as low as reasonably achievable. The doses received by radiation workers are regulatorily measured for the purposes of controlling doses to individuals and demonstrating compliance with adopted exposure limits.[6] The radiation protection procedures and regulations in various countries may differ slightly, but in general, most countries follow internationally accepted recommendations proposed by such commissions or organizations such as International Commission on Radiological Protection (ICRP), International Atomic Energy Agency, and WHO.

Although there may be some differences in the monitoring and reporting of occupational exposures from different countries, the collected data on these exposures are a good basis for the estimation of their contribution to the total population exposures.

There are many professions where workers use radiation sources or come into contact with radiation while performing their normal daily duties. In most cases, the doses received are very low or they are received only occasionally, but there are also occupations where workers acquire small doses during their routine jobs (e.g., physicists, radiographers, and nurses).[7]

In all these occupations, every effort is made to reduce the radiation levels; nevertheless, there are always some radiation remaining which exceeds the level of the natural background. Worker staff can be exposed to high dose levels due to the long scan procedures performed. Staff dosimetry can produce information about the optimization level of radiation protection, which is influenced by the equipment performance, auxiliary protection devices, training in radiation protection, and procedure complexity.[8] Increasingly, hospitals are showing an interest in developing their imaging services to include positron emission tomography (PET). Therefore, there is a need to have a good knowledge of the radiation doses for crucial working groups. To investigate the effective whole-body dose received by technologists within PET centers, each staff member should wear a dose rate meter and instructed to record the time spent in contact with any radioactive source, the dose received per working day, and the daily injected activity by him.[9]

The inclusion of diagnostic modality like computed tomography (CT) along with the PET scanners allows the involvement of anatomic information to the functional metabolic clinical findings from PET, but from the radiation protection point of view, it may involve more exposure to the staff in case of not following the guidelines for the protection.

The radiation exposure surveillance for the staff of PET-CT centers depends on different factors such as their professional behavior during their work, the working duration, the radiation doses recommended for each patient, the number of patients scanned during the work duration, as well as the protection measures in their work environment. This may vary from center to center and also from country to country measurement.[10]

The aim of the study

The study aims to investigate and analyze the radiation doses received by the PET/CT staff in three different diagnostic centers in Egypt.

MATERIALS AND METHODS

In the three centers under our investigation, the occupational exposure for each group of workers (physicists, technicians, and nurses) was collected and recorded during all 18F-fluorodeoxyglucose (FDG) PET/CT procedure (preparation tracer, transportation, and injection radiopharmaceutical, escorting and positioning injected patient) for 6-month duration.

The occupational exposure was evaluated by two different methods during 6 months' period of the study such as:

1. Thermoluminescent dosimeter (TLD) measurements periodically every 3 months
2. Pocket dosimeter measurements periodically every month.

The three centers differ from each other in several issues, such as the basic design, the radiation protection measures used, the skill of the workers, and their professional behavior with radiopharmaceuticals during their work period.

Center (A)

This center at all-time administered by one nurse, one medical physicist, one technician is operating in the 18F-FDG PET/CT. Nuclear Medicine procedures require patient interaction relating to patient's preparation administration of radioactive medication or parental route, explaining the procedure comforting and reassuring the patients. The workers were assigned to cover a workday from 8:00 AM to 4:00 PM for 6 days/week, and on an average day, the PET/CT scanner will image 4–6 patients who received 300–350 MBq with average activity (~325 MBq) of 18F-FDG each. The center consists of a hot laboratory, injection room, scanner room, control room, two hot toilets and dressing rooms, and some other facilities

Center (B)

This center was administered by three workers (physicists, technician, and nurse) who perform all 18F-FDG PET/CT scans. They are assigned to cover a workday from 8:00 AM to 5:00 PM for 6 days/week, and on an average day, the PET/CT scanner will image 8–12 patients who received 275–315 MBq with average activity (~298 MBq) of 18F-FDG each. The center consists of a hot laboratory, injection room, uptake room, scanner room, control room, two hot toilets and dressing rooms, and some other facilities attached to the center

Center (C)

This center administered by two groups, each group consisting of one nurse, one medical physicist, one technician was operating in the 18F-FDG PET/CT. They are assigned to cover a workday from 8:00 AM to 5:00 PM for 3 days/week, and on an average day, the PET/CT scanner will image 13–15 patients who received 333–355 MBq with average activity (~345 MBq) of 18F-FDG each. The center consists of a hot laboratory, two injection room, scanner room, control room, two hot toilets and two dressing rooms, and some other facilities attached to the center.

Statistical methods

As previous statistical studies have presented, ANOVA *F*-test is considered the most popular data analytic technique among educational researchers and that it is used most frequently within the context of one-way and factorial between-subjects' univariate designs. As anticipated, the ANOVA *F*-test was the method of choice for examining the study groups mean differences, despite its reliance on the stringent assumptions of normality and variance homogeneity. Although ANOVA *F*-test may be relatively insensitive to violations of the normality assumption in terms of Type I error control, it is considered a highly sensitive test for differences in population variances. This sensitivity is accentuated when group sizes are unequal, which was not the case in our study. As a result, one-way ANOVA was used to compare means from the independent groups using the *F*-distribution. The null hypothesis for the test was that the group means were equal. Tukey's honest significant difference (HSD) *post hoc* test will be used to confirm where the differences occurred between groups and will only be utilized when an overall statistically significant difference in group means is calculated (i.e., a statistically significant one-way ANOVA result). Tukey's HSD and Games–Howell *post hoc* tests, which are single-step multiple comparison procedures, were the *post hoc* tests of choice. Whenever the data met the homogeneity of variances assumption and to prevent Type I error, Tukey's HSD test will be chosen; otherwise, if the data did not show homogeneity, Games–Howell *post hoc* test will be considered. Moreover, Scheffe's procedure, as the most flexible and most conservative *post hoc* test, may be used to correct alpha for all complex comparisons of means. It is important to note that Scheffe's test complex comparisons involve contrasts of more than two means at a time. Finally, SPSS software version 23 (SPSS Inc., Chicago, IL, USA) was used for data entry and analysis. All analyses were carried out at a significance level of 0.05.

RESULTS

In the three centers under investigation (A, B, and C), the occupational exposure was evaluated by two different methods during 6 months' period of the study:

1. TLDs measurements periodically every 3 months
2. Pocket dosimeter measurements periodically every month.

The following results are illustrated for each center for the two used methods as follows:

Measurements for center (A)

The dose measurements and the prospective annual dose for center (A) are illustrated in Table 1, while the dosimetric measurements for center (A) during 6 months' period measured by electronic pocket dosimeter (EPD) and the estimated prospective annual dose are illustrated in Table 2.

Measurements for center (B)

The dose measurements and the prospective annual dose for center (B) are illustrated in Table 3, while the dosimetric measurements for center (B) during 6 months' period measured by EPD and the estimated prospective annual dose are illustrated in Table 4.

Measurements for center (C)

The dose measurements and the prospective annual dose for center (C) are illustrated in Table 5, while the dosimetric measurements for center (C) during 6 months' period measured by EPD and the estimated prospective annual dose are illustrated in Table 6.

Regarding the TLD measurements done in center (A) on the study's three different groups, one-way ANOVA test results have shown that there were statistically significant differences between group means ($P = 0.015$). Tukey's HSD test revealed a significant difference between nurse group and technologist group on one side ($P = 0.001$) and between physicist group and technologist group on the other ($P = 0.001$). Furthermore, after testing the EPD measurements done in

Table 1: Thermoluminescent dosimeters dose measurements and the prospective annual dose of the center (A)

Work group	Mean±SD			Prospective annual dose (mSv)
	Number of patients/3 months	Activities/3 months (GBq)	TLDs (μSv)/3 months	
Physicist	390±14.14	126.6±6.25	955±7.07	3.82±0.028
Technician	390±14.14	126.6±6.25	1320±84.85	5.28±0.34
Nurse	390±14.14	126.6±6.25	600±56.57	2.4±0.226

SD: Standard deviation; TLDs: Thermoluminescent dosimeters

Table 2: Dosimetric evaluation of the center (A) during 6 months' period measured by electronic pocket dosimeter and estimated prospective annual dose

Work group	Mean±SD			
	Number of patients/month	Activities/month (MBq)	EPD (μSv)/month	Prospective annual dose (mSv)
Physicist	130±11.52	42,199±4656	327.83±34.84	3.93±0.42
Technician	130±11.52	42,199±4656	449.33±60.59	5.39±0.724
Nurse	130±11.52	42,199±4656	207.5±24.24	2.49±0.29

SD: Standard deviation; EPD: Electronic pocket dosimeter

Table 3: Thermoluminescent dosimeters dose measurements and estimated prospective annual dose of the center (B)

Work group	Mean±SD			Prospective annual dose (mSv)
	Number of patients/3 months	Activities/3 months (MBq)	TLDs (μSv)/3 months	
Physicist	691.5±31.82	205,998±13,350	1200±70.71	4.8±0.282
Technician	691.5±31.82	205,998±13,350	1578±82.02	6.31±0.328
Nurse	691.5±31.82	205,998±13,350	867.5±41.72	3.47±0.167

SD: Standard deviation, TLDs: Thermoluminescent dosimeters

Table 4: Dosimetric evaluation of the center (B) during 6 months' period measured by electronic pocket dosimeter and estimated prospective annual dose

Work group	Mean±SD			
	Number of patients/month	Activities/month (MBq)	EPD (μSv)/month	Prospective annual dose (mSv)
Physicist	230.5±15.78	68,666±6154	402.16±26.74	4.82±0.32
Technician	230.5±15.78	68,666±6154	527.12±36.07	6.32±0.43
Nurse	230.5±15.78	68,666±6154	289.8±19.84	3.47±0.23

SD: Standard deviation; EPD: Electronic pocket dosimeter

Table 5: Thermoluminescent dosimeters dose measurements and estimated prospective annual dose of the center (C)

Work Group	Mean±SD			
	Number of patients/3 months	Activities/3 months (MBq)	TLDs (μSv)/3 months	Prospective annual dose (mSv)
Physicist3	504±8.485	174,733±4157	1405±35.36	5.62±0.141
Physicist4	508.5±6.364	175,567±3574	1385±21.21	5.54±0.084
Technician3	504±8.485	174,733±4157	1805±49.5	7.22±0.198
Technician4	508.5±6.364	175,567±3574	1790±42.43	7.16±0.169
Nurse3	504±8.485	174,733±4157	995±21.21	3.98±0.084
Nurse4	508.5±6.364	175,567±3574	1000±42.43	4±0.169

SD: Standard deviation; TLDs: Thermoluminescent dosimeters

center (A) on the study's three different groups, the one-way ANOVA test results have shown that there were statistically significant differences between group means ($P = 0.032$). Tukey's HSD test revealed a significant difference between nurse group and technologist group on one side ($P = 0.003$). After comparing each profession's TLD and EPD annual dose mean using the *t*-test, there was no significant difference recorded for the physicist, technician, and nurse category with $P = 0.421$, 0.074, and 0.102, respectively.

For center (B), one-way ANOVA test results have shown that there were statistically significant differences between group means ($P = 0.005$). After the proposed *post hoc* test, Tukey's HSD, a significant difference between nurse group and technician group on one side ($P = 0.001$), as the nurse group TLD mean score was considerably lower than that of the technician mean score. These findings were repeated when considering the mean differences in EPD scores, the one-way ANOVA test results have shown that there were

Table 6: Dosimetric evaluation of the center (C) during 6 months' period measured by electronic pocket dosimeter and estimated prospective annual dose

Work group	Mean±SD			Prospective annual dose (mSv)
	Number of patients/month	Activities/month (MBq)	EPD (μSv)/month	
Physicist3	168±4.243	58,244±2187	470.3±14.51	5.64±0.17
Physicist4	169.5±5.612	58,522±2575	466.7±15.58	5.6±0.18
Technician3	168±4.243	58,244±2187	607.2±18.14	7.28±0.22
Technician4	169.5±5.612	58,522±2575	603.2±26.76	7.23±0.32
Nurse3	168±4.243	58,244±2187	333.2±13.57	3.99±0.16
Nurse4	169.5±5.612	58,522±2575	333.8±17.08	4±0.2

SD: Standard deviation; EPD: Electronic pocket dosimeter

statistically significant differences between group EPD score means ($P = 0.002$). Tukey's HSD test revealed a significant difference between nurse group and technologist group on one side ($P = 0.015$). The *t*-test comparing annual TLD and EPD mean scores in center (B) showed no significant difference across the three studied categories, with *P* values for the physicist, technician, and nurse being 0.129, 0.154, and 0.912, respectively.

Finally, regarding center (C), the one-way ANOVA test results have shown that there were statistically significant differences between group means with respect to their TLD mean score ($P = 0.021$). This result was anticipated as mean nurse TLD score appeared to be lowest scoring of 3.9 (SD, 0.084) mSv compared to the physicist and technician who measured 5.62 (SD 0.141) mSv and 7.22 (SD 0.198) mSv, respectively. Tukey's HSD test revealed a significant difference between nurse group and technologist group on one side ($P = 0.001$) and between nurse group and physicist group on the other ($P = 0.021$). After a significant difference regarding the annual EPD dose between the three groups ($P = 0.021$), the *post hoc* test revealed the same significant differences as TLD scores, were a significant difference between nurse group and technologist group was measured on one side ($P = 0.001$) and between nurse group and physicist group on the other ($P = 0.021$). The *t*-test comparing annual TLD and EPD mean scores for center (C) showed no significant difference across the three studied categories, with *P* values for the physicist, technician, and nurse being 0.723, 0.934, and 0.832, respectively.

After combining TLD and EPD annual scores for the three studied categories in the three centers, the one-way ANOVA test results have shown that there were statistically significant differences between group means with respect to their TLD mean score ($P = 0.041$). As mean nurse TLD score, across the three centers, appeared to be the lowest scoring 3.83 (SD 0.012) mSv compared to the physicist and technician who measured 4.62 (SD 0.231) mSv and 6.92 (SD 0.018) mSv respectively. Scheffe's test for complex comparisons revealed a significant difference between nurse group and technologist group ($P = 0.001$). Regarding the annual combined EPD scores, the *post hoc* test, namely Scheffe's test, for complex comparisons, revealed a significant difference between nurse group and technologist group ($P = 0.001$). This was measured after the one-way ANOVA test results have shown that there were statistically significant differences between annual group EPD means ($P = 0.032$). Finally, there was no recorded significance for the studied categories across the three centers between their annual TLD and EPD dose scores ($P = 0.072$).

DISCUSSIONS

There were several reports on whole-body dose per study in the literature; Chiesa *et al*. have determined the nonextremity gamma dose received by a technician while performing an ordinary nuclear medicine procedure or a static (i.e., without blood sampling) fluorine-18 (FDG) PET study. The dose was measured by two technicians for a total of 314 clinical cases, covering the most common nuclear medicine procedures, including 44 static, two-level FDG PET studies with repositioning of the patient on the couch between the transmission and the emission scan and seven whole-body PET studies. The technician doses for the whole-body PET was 5.9 ± 1.2 mSv/scan.[11] Another study by Benatar *et al.* investigated the doses received for technicians during their daily working hours and found that the estimated average yearly exposure is 6.0 mSv/annum. They performed modeling for the number of situations, showing that, with correct planning, FDG studies should not significantly increase the effective doses to technologists.[9] Zeff and Yester studied the annual exposure for technologists and founded that at the time of this study, approximately 1000 studies/year were performed in their PET center, and the technologists received approximately 10 mSv/year.[12] With regard to the shielding materials' usage effect, a study by Biran *et al.* revealed the occupational exposure for a technologist performing 18F FDG PET scans with and without syringe shields. The resulting effective dose measured with TLD was 10 mSv with unshielded and 7.5 mSv with shielded syringes (25% dose reduction). The measured doses of TLD were higher than those measured by EPD, suggesting that EPD measurements might underestimate occupational doses.[8] The present study covered the occupational dose for the different working categories such as physicists, technologists, and nurses. Furthermore, the study was performed on PET-CT facility not only PET which may influence the measured exposure to the workers. Hence, it is difficult to compare these doses with the present exposers in our study because of the variability in the condition factors in each individual facility, such as the patient doses, the procedure, the number of patients per year, the staff performance, the job description of each category of worker, the facility design, and the use of shielding devices.

On the other hand, our results match the previous results when compared to the ICRP occupational dose limits,[13] because all the estimated annual exposure does not exceed the recommended limits for ICRP of 20 mSv/year. If each of our staffs continues to work with their maximum capacity, e.g., 1200 PET/CT studies during a whole year. For the physicist, nurses, and technician, all would be very minimal and far below the limit.

CONCLUSION

Technicians received highest mean effective whole-body doses per study. If compared with the ICRP dose limit. Each individual worker can work with many more 18F-FDG PET/CT studies for a (period) without exceeding the occupational dose limits if the average received effective dose continues with the same rate. The study also confirmed that low levels of radiation doses are received by medical personnel involved in 18F-FDG PET/CT procedures in those centers due to implementing radiation protection measures and procedures.

Financial support and sponsorship
Nil.

Conflicts of interest
There are no conflicts of interest.

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