Evaluation of Radiation Exposure to Staff and Environment Dose from [18F]-FDG in PET/CT and Cyclotron Center using Thermoluminescent Dosimetry

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ABSTRACT

Background: PET/CT imaging using [18F]-FDG is utilized in clinical oncology for tumor detecting, staging and responding to therapy procedures. Essential consideration must be taken for radiation staff due to high gamma radiation in PET/CT and cyclotron center. The aim of this study was to assess the staff exposure regarding whole body and organ dose and to evaluate environment dose in PET/CT and cyclotron center.

Materials and Methods: 80 patients participated in this study. Thermoluminescence, electronic personal dosimeter and Geiger–Muller dosimeter were also utilized for measurement purpose.

Results: The mean annual equivalent organ dose for scanning operator with regard to lens of eyes, thyroid, breast and finger according to mean±SD value, were 0.262±0.044, 0.256±0.046, 0.257±0.040 and 0.316±0.118, respectively. The maximum and minimum estimated annual whole body doses were observed for injector and the chemist group with values of (3.98±0.021) mSv/yr and (1.64±0.014) mSv/yr, respectively. The observed dose rates were 5.67 µSv/h in uptake room at the distance of 0.5 meter from the patient whereas the value 4.94 and 3.08 µSv/h were recorded close to patient's head in PET/CT room and 3.5 meter from the reception desk.

Conclusion: In this study, the injector staff and scanning operator received the first high level and second high level of radiation. This study confirmed that low levels of radiation dose were received by all radiation staff during PET/CT procedure using 18F-FDG due to efficient shielding and using trained radiation staff in PET/CT and cyclotron center of Masih Daneshvari hospital.

Keywords

PET/CT, Cyclotron, TLD, Radiation Dose, Environment Dose, Staff Dose, [18F]-FDG

Introduction

PET/CT with [18F]-FDG introduced as a non-invasive clinical tool for diagnosing, staging and assessing response to therapy of various malignancies. With regard to radiation hazard, [18F]-FDG PET requires special consideration due to 511 keV gamma radiations generated by positron-emitter florin 18. So it seems that radiation protection is vital in PET/CT and cyclotron centre. It is important to keep the radiation dose as low as reasonably achievable (ALARA) [1]. Various studies evaluated staff doses in different PET/CT centers. Antic et.al reported that the whole-body staff doses were 17–19 and 21–26 µSv GBq-1 in two PET/CT centers in Serbia according to 2000 PET/CT studies with [18F]-FDG radio-pharmaceutical were done per year in Serbia [2]. It should be noted that high radiation doses can receive due to both radionuclide handling and the interaction with injected patient [3-5]. S. Leide-Svegborn expressed that special care must be exercised in handling florin 18 [6]. Demir et al. showed that 18.4% of [18F]-FDG was accumulated in urine in 117 min after injection of 555 MBq [18F]-FDG [7]. It is clear that the amount of delivered radiation dose to the staff is directly related to the injection activity and the patient's procedure time in the facilities [8]. There are various ways to decrease the delivered radiation dose to staff especially using trained radiation worker related to radiation protection concepts and decreasing the operation time [9], utilizing long distance from the activity source [10] and using proper shielding material [11-13] whenever it can be practiced [5]. It is also recommended that the received staff exposure can be decreased using semi-automatic or automatic injector, video and audio monitoring systems with regard to injected patients [14]. It is interesting that using lead apron with a lead equivalent thickness of 0.5 mm was not introduced as a significant dose reduction at a distance of 0.2 meter from the cylindrical phantom of 9200 ml filled with 50 MBq [18F]-FDG (from 26 to 25 µSvh-1), whereas the same dose rate was observed at the distance of 2 meters from the activity source with and without lead apron [3].

As the first PET/CT scanner and cyclotron installed in Iran was at Masih Daneshvari Hospital in 2013, the aim of this study is the measurement of staff whole body dose and organ dose including: lens of eyes, thyroid, breast and finger using thermoluminescence dosimeter (TLD). It should be noted that the whole body dose measurements are also recorded with electronic personal dosimeters for various task groups in PET/CT producer including the dispensing, chemist, injector and scanning operator. For complete assessment, the environment dose rates and accumulative dose in our center are also evaluated by thermoluminescence dosimeter (TLD) and Geiger-Muller dosimeter with regard to various locations that injected patient attends.

Material and Methods

Patient Study

In this study, 78 adult patients including 49 men and 29 women, aged (mean±SD, 47/13±12/85yrs), weighed (mean±SD, 84/59±16/73kg) and height (mean±SD, 182/28±6/11cm) were evaluated. As well as 2 children (2 males), aged (mean±SD, 6/5±2/12yrs), weighed (mean±SD, 19±5/65 kg) and height 100 cm were also chosen randomly from the total patients who were candidates to PET/CT imaging. The amount of (mean±SD, 374.28±100.30 MBq) [18F]-FDG was injected via venous cannula to patients intravenously. All studies were performed using a Discovery 690 GE PET/CT scanner (GE Healthcare, Milwaukie, USA) equipped with 64-slice CT scanner.

PET/CT Work Flow

Our PET/CT protocol consisted of various steps. If the glucose level of patient was in the convenient range, the radiotracer was dispensed in the tungsten shielded syringe by the dispenser staff using automatic dispenser (THEODORICO, COMECER S.p.A., Castel Bolognese (RA), Italy) and calibrated properly. Then, after checking the patient's name and the amount of dispensed radiopharmaceutical by injection staff, the [18F]-FDG transport was performed to the uptake room according to IAEA radiation protection law. On the next step, the injection of radiotracer was done by automatic injector in the private uptake room and then the residual activity was measured. After one- hour uptake time, the injector staff asked patient to void the bladder before PET/

CT imaging and then escorted the patient to the PET/CT room. On the next step, the scanning operator positioned the patient. The imaging duration took around 20-35 minutes according to determined imaging protocol for each patient. At last, the injector staff followed the patient to the waiting room for the evaluation of the reconstructed images by the physician and then escorted the patient to changing room. It should be noted that for one work day (7 patients) the radiation team consisted of two physicians, one medical physicist, one dispenser staff, one chemist, two injector staff and two scanning operators while the total staff for one week including four physicians, one medical physicist, three dispenser staff, three chemists, two injector staffs and five scanning operators. It should be noted that the spending time with the radioactive materials and injected patient was nearly 20 seconds for dispenser staff and chemist, 50 seconds for injector staff and 30 seconds for scanning operator.

Environment Dose Measurement

In this study, 21 locations as illustrated in Figure 1 were considered for evaluation of accumulative dose and dose rate in order to assess the amount of radiation received by radiation staff and public by thermoluminescent dosimeter (TLD) and Geiger-Muller dosimeter (BNS-92, Gamma Technical Corporation, Budapest, Hungary) routinely used in our center.

It should be noted that, the background measurement was considered in the physicist's room. It must be clarified that both dosimeters were placed together in each location and the results of both dosimeters were compared. For accurate analysis, we used three chips of TLD-100(LiF:Mg ,Ti), sized 3*3*0.9 mm3 (Thermo Electron Corporation, Oakwood Village, OH, USA), in one plastic pocket called TLD badge and the estimation of absorbed dose was considered according to average value. For environment dose measurement, our strategy for accurate measurement consisted of 6 groups including A to F corresponding to uptake facility (two uptake rooms, one washing room and one corridor), PET/CT facility (PET/CT room and control room) corridor, two changing rooms, public and background, respectively. It should be noted that, all measurements were performed in 100 cm height except the location of gantry control panel in PET/CT room.

We utilized a CCTV (closed circuit TV) system in our center to control the injected patient by injector staff in order to decrease the spending time for the injected patient. But in some situations, it was necessary for injection staff to go to the uptake room to take care of patients, so with regard to our work flow, various practical locations in uptake facility were eval-

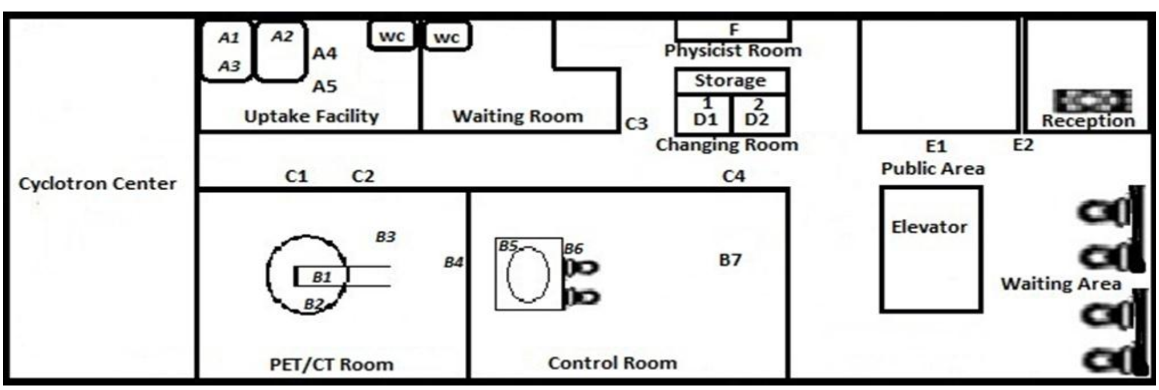

Figure 1: Locations of the TLD and GM dosimeters for recorded dose in our PET/CT center.

uated. These locations consist of A1 to A5 corresponding to A1 and A2 were in uptake room 1 and 2 respectively in 50 cm distance to the patient and A3 is the location in uptake room 1, 1meter distance of patient behind the portable shield (1 cm lead) side of injector staff. A4 and A5 were in 1.5 and 2.5-meter distance of washing room. For estimation of absorbed dose by scanning operator, the different locations in PET/CT facility were considered (7 points). These locations were the closest distance to the patient head in the table of PET/CT scanner (B1), gantry control panel (B2), in 150 cm distance to the patient in the room (B3), lead glass in the PET/CT room (B4) and the work station in the control room (B5), in the 150 cm distance of lead glass (B6) and in the floor of control room in 4 meter distance of lead glass (B7).

For comprehensive dose measurement for injection staff, the corridor consists of 4 points in 1.8 and 2.5 meter distance of uptake facility (C1, C2) and 1.5 and 1.8 meter distance of two changing rooms C3, C4, also D1 and D2 considered to changing rooms 1 and 2 to evaluate the dose of patient at the end of procedure. For evaluation of public dose, we put the dosimeters in the corridor adjacent to private elevator at the distance of 350cm (E1) and at the distance of 250 from the reception area (E2); the background radiation is measured in the physicist's room (F).

Personal Dose Measurement

The measurement of absorbed dose was executed on 14 staff radiation workers in PET/CT and cyclotron center of Masih Daneshvari hospital. For accurate evaluation, two injector staff and one scanning operator were repeated in our study. Staff absorbed dose of thyroid, lens of eyes, breast, finger and whole body of the personnel were measured using TLD badge consisting of three TLD chips (the estimation of absorbed dose was considered by average value in each badge). In order to have an accurate analysis, the results of electronic personal whole-body dosimetry (RAD-60 Dosimeter, RADOS Technology Oy, Turku, Finland) and the film badge which were positioned on the pocket of each individual radiation staff were also assessed. For evaluation of finger dose, the TLD badge was placed on the first phalanx of the right index finger. It should be noted that, the dose measurements of the lens of the eyes, the thyroid, the breast and the whole body were performed using the TLD badge on the forehead between the eyes, on the skin of the throat, on the chest between the two breasts and on the pocket, respectively. After each work day, the TLD badge were removed from the radiation staff and read-out using TLD reader (Harshaw com, usa-3500 Charge coupled device (CCD)). The whole body dose measurement obtained of TLD and electronic personal dosimeter were compared to each other.

Statistical Analysis

The dose rate and accumulative dose values with regard to staff and environment dose evaluation were compared using Tukey test and Kruskal-Wallis test, respectively. P values less than 0.05 were considered statistically significant. Statistical analysis was performed using SPSS software (SPSS Inc., Chicago, Illinois, USA, version 18).

Results

The mean effective whole body doses expressed per MBq of radiotracer injected using TLD, for all radiation staff involved in this study are presented in Table 1. It seems that the injector staff received the highest dose while the dispenser and chemist groups received the lowest dose level among all radiation worker groups.

The dose rates recorded by two types of dosimeters consisting of TLD and electronic personal dosimeter related to all radiation staff are illustrated in Figure 2. It is obvious that the electronic personal dosimeter shows a higher dose rate in comparison with TLD.

Table 1: Mean effective whole body dose using TLD for all radiation staffs in this study.

Radiation Worker	Effective Whole Body Dose (mean±SD, (μSv/MBq.s)× 10^{-4})
Dispenser Staff 1	0.48± 0.02
Dispenser Staff 2	0.58 ± 0.03
Chemist Staff 1	0.46± 0.06
Chemist Staff 2	0.57± 0.06
Injector Staff 1	1.12 ± 0.5
Injector Staff 2	1.32± 0.1
Injector Staff 3	1.28± 0.14
Injector Staff 4	1.34± 0.15
Scanning Operator 1	0.80 ±0.002
Scanning Operator 2	0.63± 0.009
Scanning Operator 3	0.75 ± 0.011
Scanning Operator 4	1.01 ± 0.03
Scanning Operator 5	0.39 ± 0.03
Scanning Operator 6	1.12 ± 0.05

More relative difference with regard to accumulative dose between electronic dosimeter and TLD (Table 2) is observed in two injector staff (28.2%, 24.4%) and one scanning operator (32.6%).

The mean equivalent dose received by lens of eyes, thyroid, breast and finger for all radiation worker groups according to TLD are illustrated in Figure 3. The organ dose per MBq of radiotracer injected were maximum for injector group so that the finger dose was 15.0±2.58 (μSv/MBq.s) ×10^{-5} (maximum value) and the lens of eyes dose were 12.8±0.98 μSv/MBq.s) × 10^{-5}(minimum value). The scanning operator received the second level maximum radiation dose. The finger dose and breast showed the highest and the lowest value in this group 10±3.76 and 8.14±1.48 (μSv/MBq.s) × 10^{-5}, respectively. It should be noted that the chemist and dispenser staff received the lowest radiation levels in this study.

The comparison between recorded radiation in 20 locations in our PET/CT center using TLD and GM dosimeter in terms of μSv/h are shown in Figure 4. It is clear that the values received by two kinds of dosimeters are close to each other.

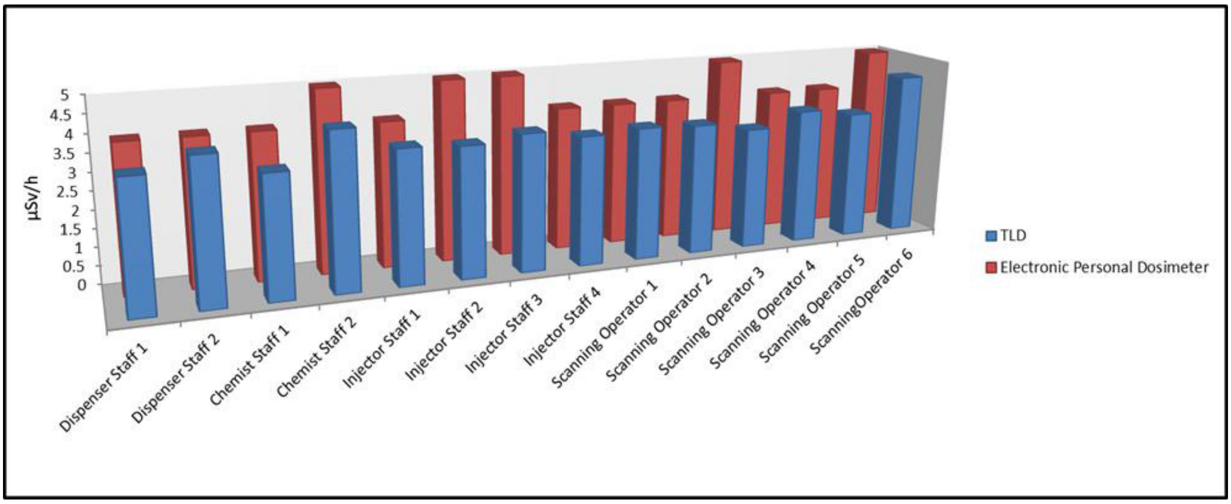

Figure 2: Comparison of recorded dose rate with regard to TLD and digital personal dosimeter for all radiation workers in this study.

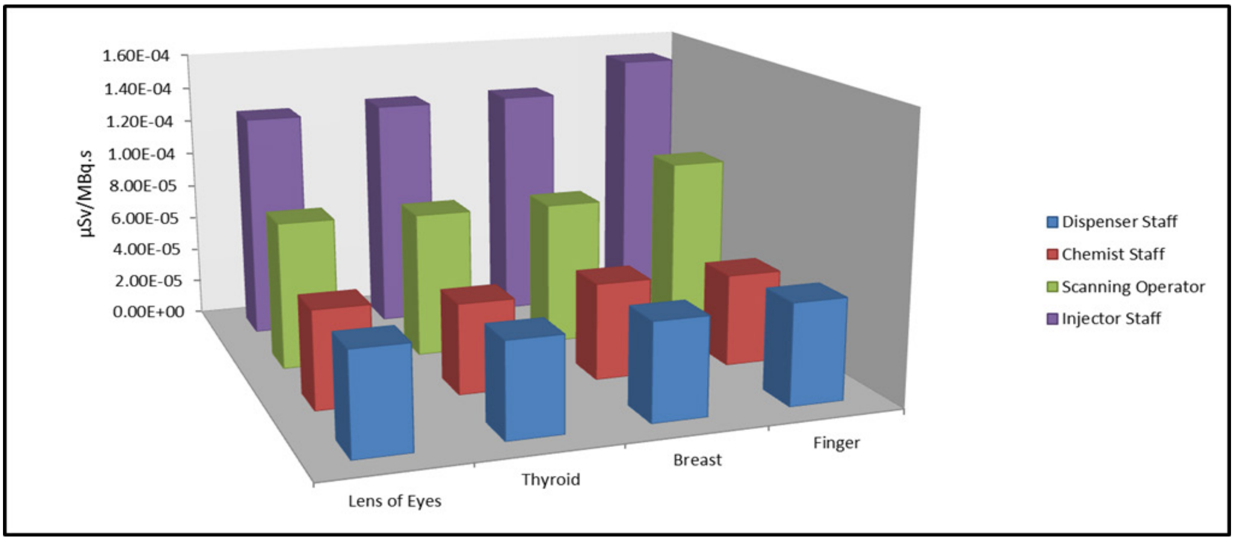

Figure 3: Illustration of mean equivalent organ dose using TLD for all radiation workers in our PET/CT center.

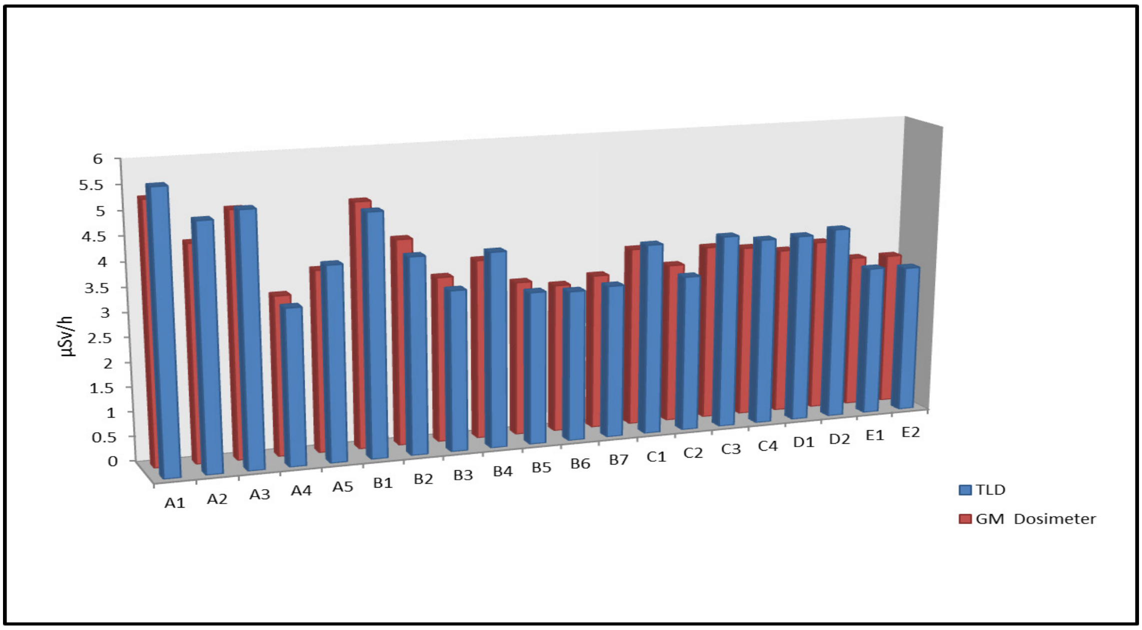

Figure 4: Comparison of recorded dose rate with regard to TLD and GM dosimeter for all 20 locations in our PET/CT center.

Table 2: Relative differences between two types of dosimeters (electronic personal dosimeter and TLD) according to accumulative dose for all radiation staff.

Radiation Worker	Relative Differences
Dispenser Staff 1	11.5 %
Dispenser Staff 2	2 %
Chemist Staff 1	16.75 %
Chemist Staff 2	14.4 %
Injector Staff 1	8.5 %
Injector Staff 2	28.2 %
Injector Staff 3	24.4 %
Injector Staff 4	10.75 %
Scanning Operator 1	8.5 %
Scanning Operator 2	9.75 %
Scanning Operator 3	32.6 %
Scanning Operator 4	6 %
Scanning Operator 5	11 %
Scanning Operator 6	9.6 %

The doses recorded per MBq of radiotracer injected in various locations using TLD are illustrated in Figure 5. The largest recorded dose is observed in uptake room 1 (0.0133µSv/MBq). The amount of radiation exposure was more in uptake room 1 in comparison with uptake room 2 due to more patients included in this room. It is obvious that the PET/CT room showed the second-high level of radiation. The closest location to the head of patient and gantry control panel recorded the 0.0063 µSv/MBq and 0.0057µSv/MBq radiation dose, respectively.

The measured doses in terms of (µSv/MBq) using TLD in different locations in our center are presented in Table 3. With regard to P-value, the uptake room 1, uptake room 2 and PET/CT room including the closest location to patient head and gantry control panel showed significant variation in comparison with other locations (p value = 0.583). It should be noted that for the other 16 locations there were no significant variation in received radiation dose (p-value=0.728).

The estimation of annual measured dose for all radiation workers in our center are demon-

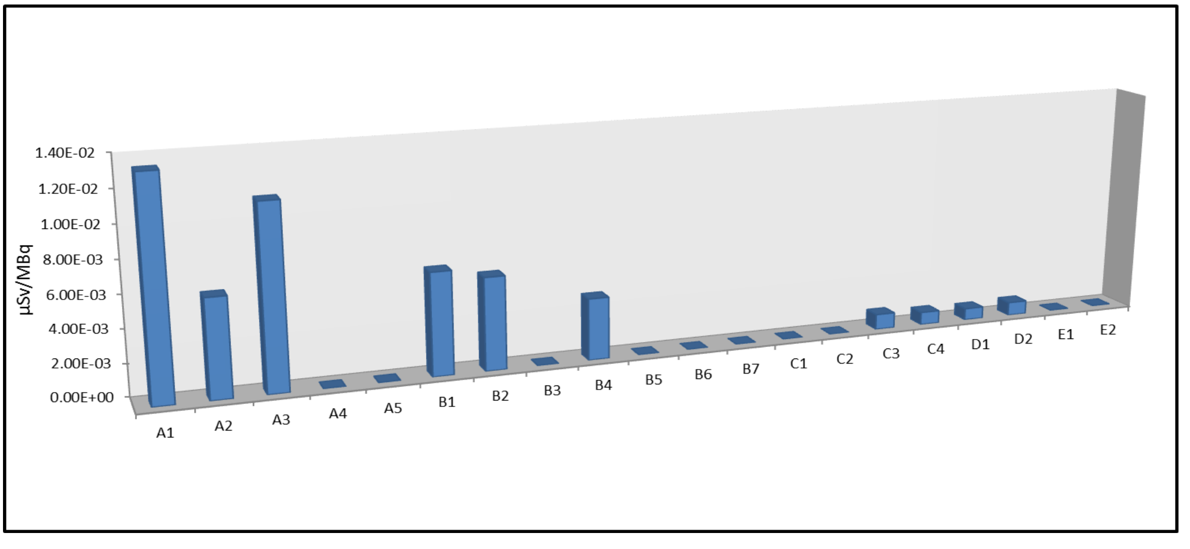

Figure 5: Comparison among 20 locations with regard to recorded dose per MBq of radiotracer injected using TLD in our PET/CT center.

Table 3: Comparison of recorded radiation dose in different locations using TLD.

Location	Recorded Dose (µSv/MBq)				
	Column 1	Column 2	Column 3	Column 4	Column 5
B6	4.95×10^{-6}				
B7	5.21×10^{-6}				
B5	5.24×10^{-6}				
A4	5.42×10^{-6}				
C2	5.45×10^{-6}				
B3	5.56×10^{-6}				
C1	5.78×10^{-6}				
A5	1.09×10^{-5}				
E2	2.45×10^{-5}				
E1	2.52×10^{-5}				
D1	7.34×10^{-4}				
D2	8.31×10^{-4}				
C4	8.32×10^{-4}				
C3	9.67×10^{-4}				
B4		3.86×10^{-3}			
B2			5.70×10^{-3}*		
B1			6.30×10^{-3}*		
A2			6.75×10^{-3}*		
A3				1.12×10^{-2}*	
A1					1.33×10^{-2}*

*The significant variation was observed in column 5 versus to column 4 and column 4 versus column 3.

strated in Table 4. The injector staff received 3.98±0.021/4.90±0.038 mSv/year (mean±SD) radiation dose using TLD/electronic personal dosimeter respectively obtaining the largest radiation exposure in our center.

Discussion

PET/CT imaging has progressed during the last decade in both clinical and research application. As the radiation of annihilation photons is high, radiation protection in PET/CT facility is essential. It should be noted that, various steps from dispensing of radiotracer to patient escorting are observed in routine PET/CT imaging and taking care of handling of radiotracer and administration can introduce important issues. So, the knowledge of received radiation dose to the radiation staff during PET/CT imaging is vital. Moreover, the radiation dose to the staff worker can decrease by using proper education related to handling of radiopharmaceutical, decreasing time, increasing distance and using convenient shielding tools. In addition, the shielding designs of PET/CT facility presents special concept because the patient becomes the radioactive source after administration of radiopharmaceutical. There were some investigations related to received dose to staff worker in PET/CT procedures in various centers [7, 15-21]. The radiation received by the radiation staff can depend on several parameters consisting of the shielding design, the amount of injection activity, the number of patients referred to the center, the routine use of PET/CT protocol, the number of staff workers and proper implementation radiation

Table 4: Estimation of annual received dose for all radiation staffs in this study.

Organ/Whole Body	Estimation of annual received dose (Mean±SD, (mSv per year))			
	Dispenser Staff	Chemist Staff	Injector Staff	Scanning Operator
Lens of Eyes	0.178 ±0.011	0.173 ±0.069	0.416±0.012	0.262±0.044
Thyroid	0.166 ±0.012	0.159±0.0045	0.405±0.031	0.256±0.046
Breast	0.172± 0.008	0.171± 0.0098	0.413±0.029	0.257±0.040
Finger	0.179±0.024	0.163±0.0018	0.475±0.081	0.316±0.118
Whole Body (TLD/ Electronic Personal Dosimeter)	1.67±0.012/1.79±0.023	1.64±0.014/1.94±0.028	3.98±0.021/4.90±0.038	2.56±0.058/3.71±0.081

protection laws by trained staff [5,12], so this study is performed for the determination of accumulative dose and dose rate dedicated to our PET/CT center.

With regard to seven patients per day and 5 work days in a week (activity administered per patient, (mean±SD,374.28±100.30 MBq), the estimation of annual effective whole body doses for injector staff in terms of Hp (10) in our center using TLD and electronic personal dosimeters were the highest. According to Table 4, the chemist and dispenser staff received the least annual radiation dose in our study (1.64±0.014 (mSv/yr) and 1.67±0.012(mSv/yr), respectively). As the major part of radiation dose is due to injection activity and escorting the patient from the washing room to the scanning room, injection staff received more radiation against other groups in this study.

In our investigation as the background measurement can also be detected by personal dosimeter and due to the fact that we subtracted the background radiation for the measurement of TLD results, the observed difference between the accumulative doses between two types of dosimeters can be obvious in our results.

The estimation of equivalent dose per year according to TLD measurement for the lens of eye, thyroid, breast and finger are evaluated in this investigation. The dispenser and chemist groups were illustrated the least radiation dose. The thyroid doses also received the least radiation exposure in these two groups (0.166 ±0.012 (mSv/yr) and 0.159±0.0045 (mSv/yr), respectively). It should be noted that, for the dispenser staff the finger dose illustrated the highest radiation organ dose 0.179±0.024 (mSv/yr) but in the chemist group, the lens of eyes was at level 0.173 ±0.069 (mSv/yr).

As the distribution of radiation received will be different in various locations of hand and also for different persons done by the same procedure [22], Carnicer et al. [23] recommended that the convenient position for TLD is the base of the index finger of the non-dominant hand in which the sensitive part of dosimeter is directed to the palm side, but this location dose not receive maximum radiation and required some correction factors [23, 24]. In our study, the finger dose (TLD placed on the first phalanx of the right index finger) in the injector group were the highest value and the chemist staff were the least value, while in the scanning operator group, the highest and the lowest levels of received radiation were for finger and breast organ doses, respectively. In our PET/CT and cyclotron center, we used either automatic dispenser or automatic injector as well as the handling of radiopharmaceutical is performed by proper tungsten shield and trolley, so the accumulative equivalent finger dose for both dispenser and injector staff were very low related to ICRP recommendation (hands equivalent dose is 500 mSv in a year) [13, 25].

In our center, the injector group received the high level of radiation dose, the scanning operator were the second level and the dispenser and chemist group obtained the third and fourth levels of received radiation organ doses. In our study, injector staff showed significant difference in all organs and whole body dose with other staff (P-value <0.05).

Measurement of dose rate in various locations in our center is vital for the evaluation of staff dose due to the fact that the injected patient can be considered as an open source. So, special concern was taken for escorting the patient from uptake room to scanning room as well as the positioning of patient, and escorting patient to changing room. Additionally, the amount of determined radiation was prominent in 6 locations versus other places including: the distance 50 cm and 100 cm near the patient in the uptake rooms, side of patient head, location of gantry control panel and lead glass window (3m far from patient in PET/CT room). It is interesting that the values related to the uptake rooms were higher related to the scanning room due to uptake time which was nearly 60 minutes and severity radiation is high in this location. The radiation in other parts of PET/CT center was not significant even near the washing room corridor due to spending a little time in this location. It should be noted that at the end of PET/CT procedure in our center, the patient went to changing room area. In this location, the severity of radiation is lower than the hot area but as the patient must spend lots of time there, we saw the value of µSv/h 3.87 and 3.96 µSv/h radiation in the changing rooms. As the patient spent a lot of time changing his/her clothes, the corridors near them (dose rate: 3.97, 3.85 µSv/h) were shown more dose rate versus the corridors between uptake facility and PET/CT facility (dose rate 3.91, 3.20 µSv/h).

The dose rate in uptake room 1, the distance of 50 cm of patient was 5.67(µSv/h), behind the portable shield (1 cm lead) was 5.14(µSv/h). After spending uptake time, the dose rate decreases to value 4.94 (µSv/h) close to the patient's head and gantry control panel 4.01(µSv/h), but as the scanner can shield some gamma radiation and due to large distance (150 cm) of patient in PET/CT room the dose rate was 3.28 (µSv/h) in this location. In our center, the public areas were also evaluated. We showed the dose rate were E1=3.08 µSv/h and E2=3.04 µSv/h in these locations.

In our study, some discrepancies of received radiation dose were observed among radiation staff in our PET/CT center. These differences can be explained by several important parameters such as various spending time, distance with regard to taking care of patients as well as, the amount of injected activity, the patient's characteristics (old patient, children and patient with a lot of pain) along with some emergency situations which must be considered.

The results from the present study with regard to the whole body annual dose and equivalent organ dose demonstrated that the radiation exposure related to all staff in PET/CT and cyclotron center of Masih Daneshvari hospital are within limits prescribed by ICRP recommendations [25].

Conclusion

We observed the received dose in sensitive organs such as lens of eyes, thyroid and breast were dramatically low in our PET/CT and cyclotron center of Masih Daneshvari Hospital. The staff whole body radiations were also below the dose limits recommended by ICRP. These dose reductions in our center can be explained by the use of appropriate shielding design, proper education to the radiation worker, using ICRP guidelines related to decreasing time, increasing distance and using appropriate shielding tool such as automatic dispenser, injector system and utilizing patient video monitoring system in our center.

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Conflict of Interest

None

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