NUKLEONIKA 2010;55(1):107–112 ORIGINAL PAPER

Radiation doses to technologists working with ^{18}F-FDG in a PET center with high patient capacity

Mustafa Demir,
Bayram Demir,
Doğan Yaşar,
Haluk B. Sayman,
Metin Halac,
Asm Sabbir Ahmed,
Kazım Özcan,
Ilhami Uslu

Abstract. The increasing numbers of PET studies for routine diagnosis creates a real hazard to radiation workers. The aim of this study is to estimate the annual whole-body and finger radiation dose to technologists working with ^{18}F-FDG in a PET center with high patient potential. In our PET center, the number of PET imaging has increased almost to 5000 studies per year. Our standard dose for tumor imaging is 518 MBq of ^{18}F-FDG. Five technologists performing all steps of ^{18}F-FDG imaging (5 patients per technologist in a day) were officially involved round the week for handling and injecting ^{18}F-FDG to patients. Whole-body and finger dose measurements with TLDs were performed for two different time periods: i) before shielding precautions during the first 6 months (without a shielding for sterile syringe and without a lead container for shielded syringe) and ii) after shielding precautions during the next 6 months (with a shielding for sterile syringe and with a lead container for shielded syringe). The average annual whole-body radiation dose for one technologist before shielding precautions was 7.82 mSv and after shielding precautions was 5.76 mSv. On the other hand, while the average annual finger radiation doses for one technologist before shielding precautions were 210.36 and 293.72 mSv for the left and right hand, after shielding precautions were they 158.16 and 217.58 mSv for the left and right hand, respectively. According to our results, if one technologist performs the whole-body PET imaging of 5 patients per day, the annual radiation dose to this technologist will not exceed the recommended limits by ICRP.

Key words: whole-body dose • finger doses • personnel dosimetry • ^{18}F-FDG • PET/CT

M. Demir✉, H. B. Sayman, M. Halac,
A. Sabbir Ahmed, K. Özcan, I. Uslu
Cerrahpasa Medical Faculty,
Department of Nuclear Medicine,
Istanbul University,
34098, Cerrahpasa, Istanbul, Turkey,
Tel.: +009021 2414 3106,
Fax: +009021 2414 3000/22981,
E-mail: demirm@istanbul.edu.tr

B. Demir
Science Faculty,
Department of Physics,
Istanbul University,
Istanbul, Turkey

D. Yaşar
Secondary Standard Dosimetry Laboratory,
Cekmece Nuclear Research and Training Centre,
Turkish Atomic Energy Agency,
Istanbul, Turkey

Received: 2 June 2009
Accepted: 17 November 2009

Introduction

The PET procedure involves the administration of short-lived positron emitting radioisotopes to the body. The choice of PET as diagnostic method is increasing and the inclusion of PET systems as part of an imaging center is becoming more widespread. In our PET center, the number of clinical ^{18}F-FDG PET scans has increased almost to 5000 studies per year. The increasing demand of PET studies for routine clinical diagnosis causes an increased exposure of the staff occupied with PET examination.

The high energy tracers used for PET studies essentially require proper shielding between technologists and patients. The highly energetic gamma rays arising from ^{18}F (511 keV) yields a higher whole-body dose to the technologists than that which is received by those working only with conventional nuclear medicine tracers labeled with ^{99m}Tc or ^{123}I [7]. Apart from this, the observed radiation dose is related to the amount of activity in the source and the length of time an individual is exposed to the source [3].

The duration of each step of PET imaging varies from technologist to technologist and depends also on the condition of the patient. During PET studies, a technologist receives radiation doses in several steps: radioactivity preparation-injection (depending only on technologist's actions), transportation-positioning of the patients (depending directly on patient's actions). The body-source distance also varies for each step depending on the performance and experience of the technologist. Regardless of technologist's working conditions, achieved doses must be under control and a great effort should be given to reduce the doses further in line with the ALARA principle recommended by the International Commission on Radiological Protection (ICRP) [8]. The aim of this study is to estimate the annual whole-body and finger radiation dose to technologists working with ^{18}F-FDG in a PET center with a high patient potential.

Materials and methods

Equipments

Our PET center has one PET camera; an integrated PET/CT scanner which consists of a full-ring HI-REZ LSO PET and a 6-slice CT (Siemens Biograph 6, Knoxville, Tennessee, USA). Average of 25 (means 25±1.1) ^{18}F-FDG studies were performed in each working day. Every technologist involved in this study was responsible for dose preparation (drawing up the tracer, measuring the activity, transporting it to the patient's preparation room), injection, escorting the patients to the PET suite, positioning under the camera and escorting the patient out of the department after examination. Five technologists were occupied only on PET imaging during this study, and thus, radiation doses reported resulted from only ^{18}F. During 6 months, every technologist was responsible throughout all steps of the PET imaging for his/her own patients (Table 1). An amount of 518 MBq (14 μCi) ^{18}F-FDG (range, 463 MBq to 566 MBq) was injected to patients intravenously. The five technologists worked either from 7.30 to 15.00 or from 15.00 to 22.00 h with in five days a week.

^{18}F-FDG preparations were performed in a dedicated hot laboratory, where the technologist stands behind a large bench-mounted with a 80 mm thick lead shield, which has a 12 × 12 cm^2 lead glass of 10 cm thickness. Apart from this shielding precaution in the hot laboratory, two important shielding precautions were also put into practice in the course of time: i) shielding for a sterile syringe and ii) a lead container for the shielded syringe. The shielded syringe which has a 12.7 mm lead-equivalent shielding made from tungsten and a 8.7 mm lead-equivalent glass window was used in the study. The half-value layer (HVL) of tungsten is 4.1 mm for 511 keV gamma energy. The viewing window of the tungsten syringe contains only 1.2–1.6 mm lead equivalent; therefore, the overall reduction is about 25%. So, after drawing up the ^{18}F-FDG, the shielded syringe was placed into another lead container with a dimension of 10 × 10 × 20 cm^3 and 1.8 cm wall thickness and was carried to the patient preparation room where the tracer was injected to the patient. The patient received ^{18}F-FDG intravenously by means of a sterile cannula placed to the patient's arm before the injection. There were 3 patient preparation rooms attached to the PET suite. The walls of the PET suite, patient-rooms and hot laboratory were shielded by 1.8 cm thick lead. The distances between the patient preparation rooms and the PET suite were 3.2, 4.5 and 5.2 m, respectively. Technologists stood in the PET control room protected by a lead glass during the scanning.

EPD measurements

The whole-body measurements with EPD (electronic personal dosimeter) were performed for two different time periods: i) before shielding precautions during 5 days (without shielding for the sterile syringe and without a lead container for the shielded syringe) and ii) after shielding precautions during 5 days (with shielding for the sterile syringe and with a lead container for the shielded syringe). The EPD measurements before and after shielding precautions were performed on the population of 125 patients (25 patients per technologists) per time periods.

EPD is a suitable involment for determining the doses during short procedures, and a minimum measurable dose with EPD is 1 microsievert (μSv) [9]. Accuracy of EPD stated by the manufactured is 15%. In the present study, EPDs (Polimaster, PM1621, POLIMASTER Inc. 2300 Clarendon Blvd., Suite 708 Arlington, VA, 22201 USA) were used to determine the radiation doses per PET imaging including the steps of dose preparation, dose administration, escorting the patients to the PET room, patients' positioning and escorting the patient off the department. A calibrated EPD was fastened to each technologist's belt under the apron during 5 days.

Table 1. Mean study-time and whole-body doses per study recorded by EPD. (The step of radioactivity preparation includes i) drawing up of ^{18}F-FDG, ii) measurement of syringe in dose calibrator, iii) transporting activity to injection room)

Steps of PET Imaging procedure	Before shielding precautions (from 125 patients)		After shielding precautions (from 125 patients)	
	Minutes per study (mean ± SD)	μSv per study (mean ± SD)	Minutes per study (mean ± SD)	μSv per study (mean ± SD)
Radioactivity preparation	1.7 ± 0.4	2.3 ± 0.4	1.8 ± 0.4	1.2 ± 0.6
Radioactivity administration	0.7 ± 0.3	1.6 ± 0.3	0.8 ± 0.5	0.9 ± 0.6
Escorting the patients to the PET room	1.4 ± 0.6	2.2 ± 0.6	1.3 ± 0.2	2.3 ± 0.6
Positioning within the camera	1.7 ± 0.5	1.6 ± 0.4	1.6 ± 0.8	1.7 ± 1.2
After imaging, escorting the patient off the department	1.9 ± 0.6	1.6 ± 0.6	2.0 ± 0.3	1.5 ± 0.4
Sum	**7.4 ± 0.5**	**9.3 ± 0.5**	**7.5 ± 0.4**	**7.6 ± 0.7**

EPD doses were recorded just prior and after each task--defined above, as well as at the beginning and the end of every workday. EPDs were calibrated at the Turkish Atomic Energy Secondary Standard Laboratory with a reference ^{137}Cs source (energy 662 keV). Apart from the radiation doses per PET imaging, we also determined separately the study-time (net exposure time for each technologist during the imaging in the PET center) of each step with a chronometer.

TLD measurements

Whole-body and finger dose measurements with TLDs (thermoluminescent dosimetry) were also performed for two different time periods: i) before shielding precautions during 6 months (without shielding for the sterile syringe and without a lead container for the shielded syringe) and ii) after shielding precautions during 6 months (with shielding for the sterile syringe and with a lead container for the shielded syringe). The measurements before shielding precautions were performed on the average population of 620 patients per technologist and the measurements after shielding precautions were performed on the average populations of 624 patients for each technologist.

The TLDs (diameter 4.8 mm, 0.9 mm thick) (Harshaw LiF TLD-100; Saint-Gobain Industrial Ceramics, Solon, OH, USA) used in this study were mounted on finger-rings. These detectors were sensitive for the doses ranging from 100 μGy to 1 Gy. Every technologist wore one ring on the second finger of each hand. Thus, a total of 10 TLDs were used for finger dose measurements. Whole-body doses received by the technologists were determined with 3 cylindrical TLDs placed in the same plastic box (size of $5 \times 5 \times 2$ cm^3), 2 cm apart from each other. Thus, total TLD numbers used for the whole-body measurements on five technologists were 15. The box of TLDs under the apron was fixed on the upper left side of the technologist. The aprons used in our clinic have a 0.5 mm lead equivalent shielding material. The tenth--value layer (TVL) of 511 keV for lead is 13.2 mm and the interposition of a 0.5 mm thickness of lead decreases the external radiation by 7%. The doses received by the irradiated TLDs were read using a thermoluminescence reader (Harshow 4500). TLDs of finger and whole body were evaluated monthly and a total of 6 readings for each time period was recorded.

Results

Whole-body radiation doses

EPD results

The EPD measurements before and after shielding precautions were done for a shorter period and for a smaller patient group than TLD's. During these periods, every technologist injected an average of 2590 MBq activity in every working day and up to 13,000 MBq of total activities for 5 days. The study-time of PET imaging steps shown in Table 1 were separately recorded using a chronometer. It was determined that there was not any important difference between the study-time before and after shielding precautions. For example, the average study-time of the longest task (escorting the patient off the department, after imaging) before shielding precautions was 1.9 min and after shielding precautions was 2.0 min. The mean study-time per PET imaging for a technologist before shielding precautions was 7.4 min and after shielding precautions was 7.5 min.

On the other hand, it was determined that there were very important effects of shielding on the technologist radiation doses in the step of radioactivity preparation and administration. While the maximum dose before shielding precautions were recorded as 2.3 μSv/study during the step of radioactivity preparation, the maximum radiation doses after shielding precautions were recorded as 2.3 μSv/study during the step of escorting the patients to the PET room. When all steps of PET imaging in Table 1 were taken into account, the mean whole-body dose per study before and after shielding precautions was 9.3 μSv and was 7.6 μSv, respectively.

TLD results

During each of 6 months measurement, each technologist injected an average of 2590 MBq activity per workday which ended up a total activity of 321 GBq for the 620 patients before shielding precautions and a total activity of 323 GBq for the 624 patients after shielding precautions. The total whole-body radiation doses received by technologists during each period are shown in Table 2. By using an average study-time (7.45 min) per examination obtained from 250 patients included

Table 2. Total whole-body doses by TLD and total net study-time of technologists during 6 months (before precautions and after precautions)

Technique no.	Before shielding precautions			After shielding precautions		
	Net total study-time (h)	Number of patients in 6 months	Whole-body radiations dose (mSv) (mean)	Net total study-time (h)	Number of patients in 6 months	Whole-body radiations dose (mSv) (mean)
1	77	630	4.10	78	625	3.32
2	76	615	3.80	75	597	2.33
3	79	632	4.20	81	651	3.69
4	76	598	3.60	76	611	2.69
5	78	627	3.85	79	637	2.36
Mean	77	620	3.91	78	624	2.88
Annual	154	1240	7.82	156	1248	5.76

in the EPD measurements, the total study-time for each technologist during each of 6 months was annually calculated by adding up the study-time of each study. The difference between the study-time of each period is negligible. The average study-time before shielding precautions was determined as 154 h/year and after shielding precautions was determined as 156 h/year. But, when it comes to the whole-body radiation doses, there were very important alterations. While the annual whole-body radiation dose, measured with TLD, before shielding precautions was 7.82 mSv, it was 5.76 mSv after shielding precautions.

Finger radiation doses

Finger radiation dose measurements were done with the same patient populations included in the whole-body dose measurements. Thus, the study conditions of finger radiation dose measurements such as injected activity, patient populations, and study-time were the same with the whole-body measurements. Table 3 shows the mean of finger radiation doses of technologists for measurements before shielding precautions and after shielding precautions. As mentioned above, the study-time of each period is almost equal. But, very important reductions in the finger radiation doses were observed after shielding precautions compared to those before shielding precautions. While the annual finger radiation doses of five technologists before shielding precautions were 210.36 and 293.72 mSv for the left and right hand, respectively, after shielding precautions were 158.16 and 217.58 mSv for the left and right hand, respectively. As it was expected, the radiation doses received by the right hand were obviously significantly higher than for the left hand, because the right hand was in closer contact with the ^{18}F-FDG vial and syringe.

Discussion

The recommended limit for radiation exposure to a radiation worker is 20 mSv per year (500 mSv per year for fingers) by ICRP [8] and EURATOM [5]. But, the dose limits for radiation workers under 18 years were lowered to 6 mSv for radiation works as annual limit by EURATOM [5]. These lowered radiation doses recommended by authorities are not to reach. Therefore, a great effort should be given to reduce the radiation doses further in line with the ALARA principle recommended by the ICRP [8]. Although the principle of time, distance, and shielding are always practiced for any procedure involving radioactivity for radiation protection, these precautions tightly depend on technologist efforts. Thus, technologists obeying these rules should be controlled during routine work in the area involving radiation and sometimes extra protection precautions should be taken, if necessary.

Due to the large number of PET imaging per day, it is important to estimate the technologist doses received for each step of PET imaging. If the doses received by technologist are high, the study-time of the PET imaging steps should be reduced or some extra shielding precautions should be taken. In this study, after the EPD measurements shown in Table 1, we realized that the radiation doses of radioactivity preparation and administration steps were high and we put into practice some extra shielding precautions for the syringe to reduce the radiation doses of these steps. While the effect of shielding on the study-time of steps was not so important, radiation dose in the radioactivity preparation and administration steps were significantly decreased. According to the EPD results, a reduction of 22.4% in technologist radiation doses was obtained by means of shielding precautions taken for the syringe.

The radiation doses for short procedures, such as radioactivity preparation, radioactivity injection, patient's transportation and patient's positioning can be recorded

Table 3. Finger doses of five technologists before shielding precautions and after shielding precautions

Technique no.	Total injected activity (GBq)	Total finger doses (mSv) (mean)		Finger dose per MBq (μSv/MBq) (mean)	
		Left hand	Right hand	Left hand	Right hand
Before shielding precautions (average 620 patients for a technologist in 6 months)					
1	330	100.72	145.05	0.31	0.44
2	324	108.62	144.71	0.34	0.45
3	318	117.26	158.26	0.37	0.50
4	323	104.52	131.73	0.32	0.41
5	330	102.70	143.68	0.31	0.44
Mean	325	106.76	144.69	0.34	0.45
Annual	650	210.36	293.72	0.34	0.45
After shielding precautions (average 624 patients for a technologist in 6 months)					
1	325	76.83	107.56	0.24	0.33
2	319	78.24	110.31	0.25	0.35
3	322	89.82	121.25	0.28	0.38
4	328	74.46	96.79	0.23	0.30
5	322	76.08	108.03	0.24	0.34
Mean	323	79.08	108.79	0.25	0.34
Annual	646	158.16	217.58	0.25	0.34

by electronic personnel dosimeters (EPD). On the other hand, thermoluminescence dosimeters (TLDs) for routine dose estimation in long terms can be used by the technologists to measure the whole-body and hand radiation doses. Apart from EPD measurements made for a short period of 5 days, the whole-body radiation doses and finger radiation doses of technologists were also determined by TLD for 6 month periods. Annually, a reduction of 26.5% in the whole-body irradiation of technologists was obtained by means of shielding precautions applied for a sterile syringe.

The annual whole-body radiation doses for PET technologists were also reported by different investigators in the literature; for example as 3 mSv by Robert *et al*. [13], as 3.5 mSv by Benatar *et al*. [1], as 2–3 mSv by Seierstad *et al*. [15], as 6 mSv by Cronin *et al*. [6], as 7.5 mSv by Biran *et al*. [2], as 6.6 mSv by Robinson *et al*. [14] and as 12 mSv by Zeff *et al*. [17]. Our study reports a whole-body radiation dose of 5.76 mSv per year. It is difficult to make a direct comparison among these radiation doses because the study conditions of PET centers (i.e. patient doses, technologist performances and patient numbers) vary from center to center. But, the received dose is closely related with the administered activity and it is almost linear with the amount of activity. Thus, we can compare between our study and the others by using the radiation dose per MBq in Table 4. Reported values using EPD were 17 nSv/MBq by Zeff *et al*. [17], 23 nSv/MBq by Chiesa *et al*. [4], 18 nSv/MBq by Benatar *et al*. [1], 19 nSv/MBq by Biran *et al*. [2], 19 nSv/MBq by McElroy [11], 9 nSv/MBq by Gulliet *et al*. [7]. The reported radiation doses using TLD were 11 nSv/MBq by Robinson *et al*. [14], 24 nSv/MBq by Seiersted *et al*. [15], 46 nSv/MBq by McCormic and Miklos [10]. When our long term results obtained by TLD were taken into consideration, we reported an average of 8.92 nSv/MBq in this study which is very concordant with other investigators. In comparison to other studies, it is found that, although the technologists participated in this study handled a higher amount of activity and a higher number of patients than those reported in other studies, the radiation doses received by technologists were not higher than in other studies. In our opinion, the quick handling of radioisotope is the main source of this low radiation exposure. To the best of our knowledge, our study-time for a PET imaging procedure is the one of the shortest study-times reported in the literature as shown in Table 4. Because of high energetic gamma radiation of ^{18}F and increasing patient numbers, PET imaging can cause high radiation doses to the technologists. Therefore, the short study-time becomes more important in terms of radiation protection. Despite of the high PET patient numbers, we managed the lower radiation doses than the limits given by EURATOM [5] and ICRP [8].

We also studied the finger radiation doses. Lineman *et al*. [9] reported a mean finger exposure of 710 μSv for each hand with 260–370 MBq ^{18}F-FDG. The dose of left and right hands were reported as 0.75 μSv/MBq and 1.2 μSv/MBq by Guillet *et al*. [7] and Tandon *et al*. [16] reported the finger doses as 0.48 μSv/MBq. Biran *et al*. [2] reported the dose delivered to the right hand when using shielded syringes as 0.19 μSv/MBq. In our study, all technologists were right-handed. The finger radiation doses before shielding precautions for syringe were 0.34 μSv/MBq and 0.45 μSv/MBq, and after shielding precautions for syringe were 0.25 μSv/MBq and 0.34 μSv/MBq for the left and right hands, respectively. These differences among the studies can probably be explained by using a different thickness of shielding, study-time of the radioactivity preparation-injection steps and a different amount of injected radioactivity. In our clinic setting, a reduction of 35% in the left hand and of 33% in the right hand was obtained by means of shielding precautions. The results presented in our study showed that, for 12 months in succession, the radiation exposure of the finger levels of the technologists during ^{18}F-FDG manipulation in our PET center is lower than the limits by ICRP (500 mSv/year) [8]. Guillet *et al*. [7] reported that radiation doses were always lower than the limits reported for 12 months in succession for a technologist scanning 4 patients per day in Council Directive of EURATOM [5]. Our results obtained for 5 patients per day were in accordance with the opinion of Guillet *et al*. [7].

A radiation dose of 24 nSv/MBq was reported by Seierstad *et al*. [15]. According to their suggestions, the dose limit is reached after handling almost 3000 patients per year. In our study, we determined the whole-body radiations as 8.92 nSv/MBq. Considering a total of 1250 patients performed by one technologist per year (if one technologist performs all steps of ^{18}F-FDG study for 5 patients in a day), the annual whole-body radiation dose was found as 5.76 mSv and the annual finger radiation dose for the right hand was found as 217.5 mSv. According to our whole-body dose results, the dose

Table 4. The whole-body radiation dose per study and study-time from ^{18}F-FDG in the literature

Study	Radiation doses per study (μSv/study)	Injected activity per patient (MBq)	Dose/MBq (nSv/MBq)	Minutes per study
Zeff *et al*. [17]	8.9	518	17.18	13
Chiesa *et al*. [4]	8.5	370	22.97	9.2
Benatar *et al*. [1]	6.5	352	18.46	13.9
Biran *et al*. [2]	7.2	370	19.45	–
McElroy [11]	6.9	370	18.64	–
Gulliet *et al*. [7]	3.1	345	8.99	10.6
Seierstad *et al*. [15]	9	370	24.32	6–12
McCormic [10]	17	370	45.95	–
Robinson *et al*. [14]	7.75	370	11.08	8
Our study	4.62	518	8.92	7.45

limits recommended by ICRP [8] will exceed after 4300 patients. But, when our right hand dose result is taken into account, the maximum dose limits recommended by ICRP [8] will exceed after almost 3000 patients.

When EPD results after shielding precautions (for example, 7.6 μSv per study from Table 1) and TLD results after shielding precautions (for example, 4.62 μSv per study from Table 4) are compared with each other, it is immediately seen that EPD results are higher than the TLD results. In our opinion, the main source of these discrepancies between TLD and EPD results is the position difference of the dosimeters on the technologist body. While EPDs are fastened on a technologist belt over the apron, TLDs are fixed over the apron at the level of chest. The half-life of ^{18}F is 110 min and 20% of it is collected in the bladder in 2 h after injection [12]. Because EPD is more closed to the patient's bladder than TLD, the dose recorded by EPD might be higher than the TLD.

Conclusion

Although the personal dose results are significantly lower than the recommended annual dose limit, it must be considered that a greater effort should be made to reduce the radiation doses further with the ALARA principles. Protection of PET personnel is more complicated, as most of the technologist occupational irradiations are from close interaction with the patient. Certainly, appropriate shielding is necessary to reduce technologist dose. Although our technologist doses are not as high as many maximum permitted doses by ICRP [8], we have planned some extra shielding precaution after this study to decrease the radiation doses further with the ALARA principles. A semi-automatic dose dispenser is incorporated in the hot laboratory to draw ^{18}F-FDG from vial to syringe that significantly reduces the dose preparation time. A trolley is now used to transport the shielded syringe from the hot laboratory to the patient room.

Acknowledgment. This work was supported by the Research Fund of the University of Istanbul, Project no. UDP-4064/16072009.

References

1. Benatar NA, Cronin BF, O'Doherty MJ (2000) Radiation dose rates from patients undergoing PET: implications for technologists and waiting areas. Eur J Nucl Med 27:583–589
2. Biran T, Weininger J, Malchi S, Marciano R, Chisin R (2004) Measurements of occupational exposure for a technologist performing ^{18}F-FDG scans. Health Phys 87;5:539–544
3. Bixler A, Springer G, Lovas R (1999) Practical aspects of radiation safety for using fluorine-18. J Nucl Med Technol 27:14–16
4. Chiesa C, De Sanctis V, Crippa F *et al.* (1997) Radiation dose to technicians per nuclear medicine procedure: comparison between technetium-99m, gallium-67 and iodine-131. Eur J Nucl Med 24;11:1380–1389
5. Council of the European Union (1996) Council Directive 96/29/ EURATOM of 13 May 1966 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation. Official J Eur Common L159:1–14
6. Cronin B, Marsden PK, Q'Doherty MJ (1999) Are restrictions to behavior of patients required following fluorine-18 fluorodeoxiglucose positron emission tomographic studies? Eur J Nucl Med 26:121–128
7. Guillet B, Qentin P, Waultier S, Bourrrell M, Pisano P, Mundler O (2005) Technologist radiation exposure in routine clinical practice with ^{18}FDG PET. J Nucl Med Technol 33:175–179
8. International Commission on Radiological Protection (1991) ICRP Publication 60: 1990 Recommendation of the ICRP. Pergamon Press, New York
9. Lineman H, Will E, Beuthien-Baumann B (2000) Investigations of radiation exposure of the medical personnel during F-18-FDG PET studies. Nuklearmedizin 39:77–81
10. McCormic VA, Miklos JA (1993) Radiation dose to positron emission tomography technologists during quantitative vs. qualitative studies. J Nucl Med 34:769–772
11. McElroy NL (1998) Worker dose analysis based on real time dosimetry. Health Phys 74:608–609
12. Mejia AA, Nakamura T, Masatoshi I, Hatazawa J, Masaki M, Watanuki S (1991) Estimation of absorbed doses in humans due to intravenous administration of fluorine-18-fluorodeoxyglucose in PET studies. J Nucl Med 32;4:699–706
13. Robert FO, Gunawardana DH, Pathmaraj K *et al.* (2005) Radiation dose to PET technologists and strategies to lower occupational exposure. J Nucl Med Technol 33:44–47
14. Robinson CN, Young JG, Wallace AB, Ibbetson VJ (2005) A study of the personal radiation dose received by nuclear medicine technologists working in a dedicated PET scanner. Radiat Safety J 88;1:17–21
15. Seierstad T, Stranded E, Bjering K *et al.* (2007) Doses to nuclear technicians in a dedicated PET/CT centre utilising ^{18}F fluorodeoxyglucose (FDG). Radiat Prot Dosim 123;2:246–249
16. Tandon P, Venkatesh M, Bhatt BC (2007) Extremity dosimetry for radiation workers handling unsealed radionuclides in nuclear medicine departments in India. Health Phys 92;2:112–118
17. Zeff BW, Yester MV (2005) Patient self-attenuation and technologist dose in positron emission tomography. Med Phys 32;4:861–865