

# Exposure Doses to Technologists Working in 7 PET/CT Departments

Dose-Response:  
An International Journal  
July-September 2020:1-6  
© The Author(s) 2020  
Article reuse guidelines:  
sagepub.com/journals-permissions  
DOI: 10.1177/1559325820938288  
journals.sagepub.com/home/dos



Weiguo Li<sup>1</sup> , Lianying Fang<sup>1</sup> , and Jieqing Li<sup>1</sup>

## Abstract

**Objective:** The aim of this study was to measure occupational exposure doses of technologists who dispense and inject radiopharmaceuticals in 7 positron emission tomography/computed tomography (PET/CT) departments. This was done with the goal to help improving protective designs in PET departments and/or establishing national protection standards.

**Method:** Common LiF thermoluminescence dosimeters (TLDs) were placed on the chest and necklace of the technologists to monitor whole-body and thyroid doses, respectively. Ring TLDs were also worn on both index fingers to measure individual hand doses. All TLDs were assembled and measured once every 3 months for a total of 12 months. Additionally, we measured and compared the dose of TLDs attached to both the inside and the outside of the technologist's lead coat.

**Results:** Technologists received relatively high exposures, which accounted for 64% to 94% of the collective dose in their respective departments. Their thyroid doses ranged from 1.2 to 1.7 mSv/a; some technologists' hand doses exceeded 500 mSv/a. Use of a lead coat reduced the average dose by 8%.

**Conclusion:** Technologists working in PET/CT departments were the main population exposed to radiation. This work underscores the need for enhanced protective measures for these workers to better reduce their exposure, particularly for their hands.

## Keywords

PET/CT, technologists, occupational exposure dose, radiation protection, <sup>18</sup>F-FDG

## Introduction

Over the past 15 years, positron emission tomography (PET) has become a widely used diagnostic tool used in assessing vascular diseases and cancer.<sup>1,2</sup> Given this rise, PET technologists have become increasingly exposed to radiation, which increases their overall occupational radiation exposure. Some past work has explored the radiation dose received by technologists in a single PET/computed tomography (CT) department<sup>3,4</sup>; however, there has been a lack of research exploring the level received by technologists in larger regions of China. Here, our participants were all PET/CT staff across 7 departments in Shandong, China. After selecting these participants, the main goal of our study was to assess their respective radiation doses across their entire body as well as individual thyroid and hand measures.

linear range was  $10^{-7} \sim 12$  Gy, and the responsive range was 30 keV  $\sim$  3 MeV. Dispersion of the same batch was 5%.

RGD-3B thermoluminescence dose detector was manufactured by the China Liberation Army Institute of Prevention.

**Calibration.** Thermoluminescence dosimeters and thermoluminescence dose detectors were calibrated as a whole system by the Chinese Academy of Metrology Scale. Calibration occurred twice yearly. We obtained these factors to calculate subsequent dose values. Dosimeters used for measuring whole-body doses were calibrated at a depth of 10 mm under the skin. Dosimeters used for measuring thyroid and hand doses were

## Experimental Instruments and Methods

### Experimental Instruments

General thermoluminescence dosimeters (TLDs) and ring TLD were both provided by Beijing Conqueror Electronic Co. The

<sup>1</sup> Institute of Radiation Medicine, Shandong Academy of Medical Sciences, Jinan, China

Received 04 April 2020; received revised 28 May 2020; accepted 05 June 2020

### Corresponding Author:

Jieqing Li, Institute of Radiation Medicine, Shandong First Medical University (Shandong Academy of Medical Sciences), Jinan, 250062 China.  
Email: stx90@163.com



Creative Commons Non Commercial CC BY-NC: This article is distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 License (<https://creativecommons.org/licenses/by-nc/4.0/>) which permits non-commercial use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access pages (<https://us.sagepub.com/en-us/nam/open-access-at-sage>).



**Figure 1.** The wearing method of dosimeters.

calibrated at a depth of 3 mm and 0.07 mm under the skin, respectively. The 3 factors obtained by the first calibration were as follows:  $5.01 \times 10^{-4}$  mSv/Xi,  $5.13 \times 10^{-4}$  mSv/Xi, and  $6.19 \times 10^{-3}$  mSv/Xi, with Xi indicating measurement readings after deducting the background value. The factors by the second calibration were  $4.92 \times 10^{-4}$  mSv/Xi,  $5.33 \times 10^{-4}$  mSv/Xi, and  $6.33 \times 10^{-3}$  mSv/Xi.

**Natural background dose.** When whole-body dosimeters were distributed to the technologists used in this study, 3 dosimeters were reserved for placement in the doctors' office of the PET/CT department. These dosimeters were then used to determine that the environmental dose rate was the same as that of the general ward of the hospital. After 3 months, the values were read, averaged, and used as the background value for that quarter. The background values across the 4 quarters of the study were nearly identical. Given this, we used an average value of 0.022 mSv as the background value for the whole-body dose in each quarter. The background values for the thyroid and hand doses were obtained in the same way and were 0.02 mSv and 0.014 mSv, respectively.

**The wearing and management of dosimeters.** Three tablets were placed in each dosimeter for the determination of a final, average value. Dosimeters were assigned to every participant. A TLD was attached to the upper pocket of each participant's overall to monitor their whole-body dose. For PET technologists, a TLD was worn at the collar located near the thyroid to monitor their thyroid dose. As shown in Figure 1, ring dosimeters were worn on both the left and the right index fingers of the technologists to measure their individual hand doses.<sup>5</sup> All dosimeters were worn by participants during their working hours. After 3 months, dosimeters were collected, and a thermoluminescence dose detector was used to read the resulting values.  $G_0$  was determined for the average value and the exposure dose was then calculated using  $G = f G_0$ , with  $f$  indicating the calibration factor. This process lasted for 12 months, with a total of 4 different collection and calculation cycles.

### Study Respondents

Staff members across the 7 PET/CT departments (termed A, B, C, D, E, F, and G) in Shandong, China, were selected as the

research participants. All participants were required to complete a questionnaire prior to the start of the study, which included questions regarding workplace, working procedures, and workload. The number of staff in each position across the 7 PET/CT departments and the required doses that would be measured during the study are shown in Table 1.

### Management of Radioactive Drug

The  $^{18}\text{F}$ -fluorodeoxyglucose ( $^{18}\text{F}$ -FDG) was used as the radionuclide tracer across the 7 PET/CT departments. The activity of  $^{18}\text{F}$  prepared for a patient was determined by his or her weight and was usually approximately 370 MBq.  $^{18}\text{F}$  has a half-life of 109 minutes and produces photons with energy of 511 keV.

**The PET/CT procedure.** First, the accelerator produces a certain activity of the  $^{18}\text{F}$ -FDG needed throughout the day, which is according to the number of patients appointed. The FDG was placed in a "hot" laboratory, which was surrounded by 55-mm-thick lead bricks. Second, a technologist drew the  $^{18}\text{F}$ -FDG (370 MBq) into a syringe that was placed inside a 5-mm-thick tungsten sleeve. Third, the syringe along with the tungsten sleeve was placed in a trolley with lead-screen and transferred to the injection room. After transferring, the  $^{18}\text{F}$ -FDG dose was injected into the patient through a catheter that had been preplaced in the patient's vein. Finally, the patient was escorted to the PET room 1 hour after the tracer infusion for image acquisition. Notably, instead of using a system with a tungsten sleeve and a trolley, technologists in the PET/CT Department A placed the syringe inside an iron box and carried it to the injection room.

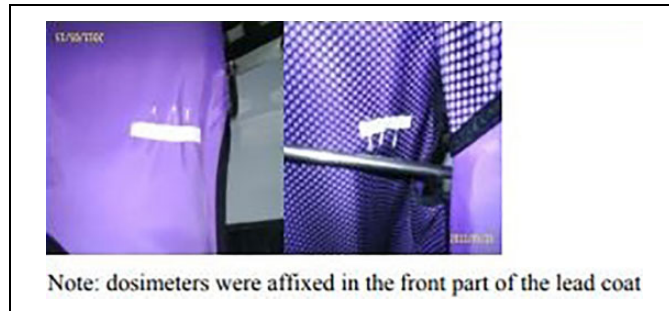
### Evaluation of Lead Coat Protection

The technologists were wearing 0.5 mm-lead-equivalent lead coats when interacting with the radioactive drug. Given this, 35 pairs of dosimeters were affixed to relatively the same position both inside and outside the new lead coat. This is shown in Figure 2 and was done to determine differences between exposure doses over 3 months.

**Table 1.** Number of Staff in Each Position in 7 PET/CT Departments and Required Dose.

	Number of staff in each position in 7 PET/CT departments							Required dose
	A	B	C	D	E	F	G	
Technologists	4	3	3	2	2	6	4	Whole-body dose, thyroid dose, hand dose
Doctors	5	3	3	4	2	3	3	Whole-body dose
Nurses	2	3	2	2	2	4	2	Whole-body dose
Scan workers	2	3	2	2	3	3	3	Whole-body dose
Accelerator mechanics	2	1	1	1	2	1	1	Whole-body dose

Abbreviations: PET/CT, positron emission tomography/computed tomography.



**Figure 2.** Dosimeters affixed in relatively the same position inside and outside of the lead coat.

### Statistical Processing

All values are reported as mean  $\pm$  standard deviation. The dose comparison between PET and digital radiography (DR) technologists was done using a *t* test in SPSS software version 20 (IBM). An  $\alpha$  level of .05 was the selected significance level for this study.

## Results

### Comparison of Whole-Body Doses (mSv) Received by PET/CT Technologists With Those Received by DR Technologists

A sample comparison was designed to reveal how much higher the radiation dose was in PET technologists relative to that of DR technologists. The PET/CT technologists and the DR technologists in the same hospital were divided into 2 groups according to the number of 1:2, with the same average age, length of service, and gender composition ratio of the 2 groups. Results are shown in Table 2 and Figure 3. As indicated, the average, whole-body dose for technologists in the PET/CT departments was 0.13 to 0.73 mSv per quarter. Comparatively, the dose of the DR technologists was 0.02 to 0.16 mSv per quarter. All PET/CT technologists had significantly higher radiation doses than DR technologists, except for Department B.

### Proportion of Whole-Body Dose of the Technologists to the Collective Dose in PET/CT Departments

The collective dose of all staff participants across 6 PET/CT departments over 12 months was calculated. As shown

in Figure 4, the radiation dose received by technologists in charge of dispensing and injecting radiopharmaceuticals accounted for a large proportion of the collective dose. It should be noted that some nurses and doctors in PET/CT Department A were transferred during the study period. As a result, their whole-body dose measurements were incomplete, so the proportion of the technologists' dose relative to the collective dose was not obtainable.

### Average Annual Thyroid and Hand Doses of Technologists in Charge of Dispensing and Injecting Radiopharmaceuticals

The results regarding the average annual thyroid and hand doses are shown in Table 3. There was little difference in thyroid dose across different PET/CT departments, and the value fluctuated within 1.2 and 1.7 mSv. The hand dose was notably high; moreover, the right-hand dose of technologists in Department A already exceeded the International Commission on Radiological Protection (ICRP) dose limit of 500 mSv.

### Lead Coat Protective Results

The average exposure dose received outside and inside of lead coat was 0.186 mSv and 0.171 mSv in 3 months, and the lead coat could reduce the radiation dose by 8%.

## Discussion

There are a number of radioactive sources in PET/CT departments, including unshielded radioactive drugs, patients who have been injected with drugs, patients' toilets, radioactive waste, and the CT scanners themselves. Positron emission tomography technologists are in an environment with multiple radioactive sources for a long time. Given this, they have a higher chance of receiving occupational exposure. Moreover, the doses they receive may easily exceed those of either DR or Gamma Camera technologists.<sup>6,7</sup> When dispensing or injecting radiopharmaceuticals, the technologists are close to the radionuclides themselves. As a result, they are exposed to higher levels of radiation, with past International Atomic Energy Agency reports indicating a high, whole-body dose of 8 mSv/year.<sup>8</sup>

**Table 2.** Comparison of the Whole-Body Doses (mSv) of PET/CT Technologists With Those of DR Technologists.

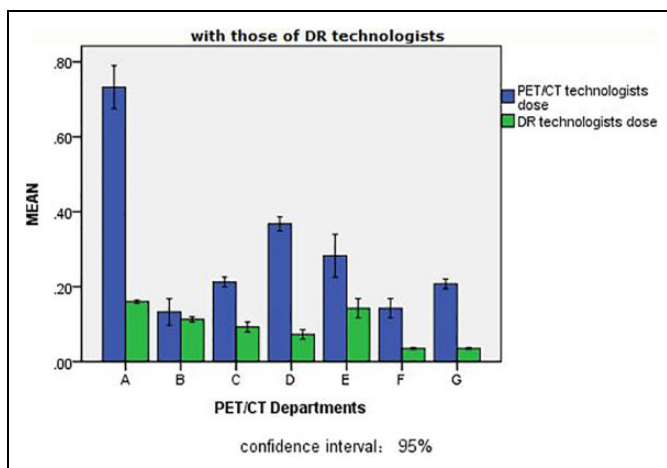
Hospital	Quarter 1st	Quarter 2nd	Quarter 3rd	Quarter 4th	Quarterly average	Number of patients <sup>a</sup>	t value	P ( $\alpha = .05$ )
<b>A</b>								
PET <sup>b</sup>	0.79 ± 0.16	0.80 ± 0.09	0.65 ± 0.11	0.69 ± 0.12	0.73 ± 0.13	165	33.76	.001
DR <sup>c</sup>	0.17 ± 0.22	0.16 ± 0.14	0.15 ± 0.12	0.16 ± 0.13	0.16 ± 0.14	850		
<b>B</b>								
PET <sup>b</sup>	0.10 ± 0.14	0.20 ± 0.16	0.12 ± 0.14	0.11 ± 0.23	0.13 ± 0.15	95	1.75	.093
DR <sup>c</sup>	0.10 ± 0.11	0.12 ± 0.12	0.13 ± 0.14	0.10 ± 0.12	0.11 ± 0.13	1100		
<b>C</b>								
PET <sup>b</sup>	0.22 ± 0.11	0.19 ± 0.19	0.23 ± 0.15	0.21 ± 0.17	0.21 ± 0.15	110	12.48	.001
DR <sup>c</sup>	0.12 ± 0.11	0.06 ± 0.13	0.11 ± 0.12	0.08 ± 0.13	0.09 ± 0.12	1050		
<b>D</b>								
PET <sup>b</sup>	0.37 ± 0.11	0.36 ± 0.12	0.34 ± 0.14	0.40 ± 0.13	0.37 ± 0.12	95	29.11	.001
DR <sup>c</sup>	0.05 ± 0.04	0.07 ± 0.05	0.06 ± 0.05	0.11 ± 0.12	0.07 ± 0.12	800		
<b>E</b>								
PET <sup>b</sup>	0.36 ± 0.10	0.33 ± 0.11	0.23 ± 0.18	0.21 ± 0.26	0.28 ± 0.17	60	5.85	.001
DR <sup>c</sup>	0.16 ± 0.14	0.21 ± 0.15	0.09 ± 0.12	0.11 ± 0.13	0.14 ± 0.14	1200		
<b>F</b>								
PET <sup>b</sup>	0.18 ± 0.17	0.11 ± 0.13	0.16 ± 0.13	0.12 ± 0.10	0.14 ± 0.13	30	13.97	.001
DR <sup>c</sup>	0.03 ± 0.05	0.04 ± 0.05	0.04 ± 0.08	0.03 ± 0.03	0.05 ± 0.05	170		
<b>G</b>								
PET <sup>b</sup>	0.21 ± 0.15	0.23 ± 0.13	0.19 ± 0.15	0.20 ± 0.19	0.21 ± 0.14	50	40.29	.001
DR <sup>c</sup>	0.04 ± 0.06	0.04 ± 0.04	0.03 ± 0.04	0.03 ± 0.03	0.04 ± 0.03	990		

Abbreviations: DR, digital radiography; PET/CT, positron emission tomography/computed tomography.

<sup>a</sup>Average number of patients checked by each technologist per quarter.

<sup>b</sup>Dose of technologists in charge of dispensing and injecting radiopharmaceuticals.

<sup>c</sup>Dose of DR technologists.



**Figure 3.** Comparison of the whole-body doses (mSv) of PET/CT technologists with those of DR technologists. DR indicates digital radiography; PET/CT, positron emission tomography/computed tomography.

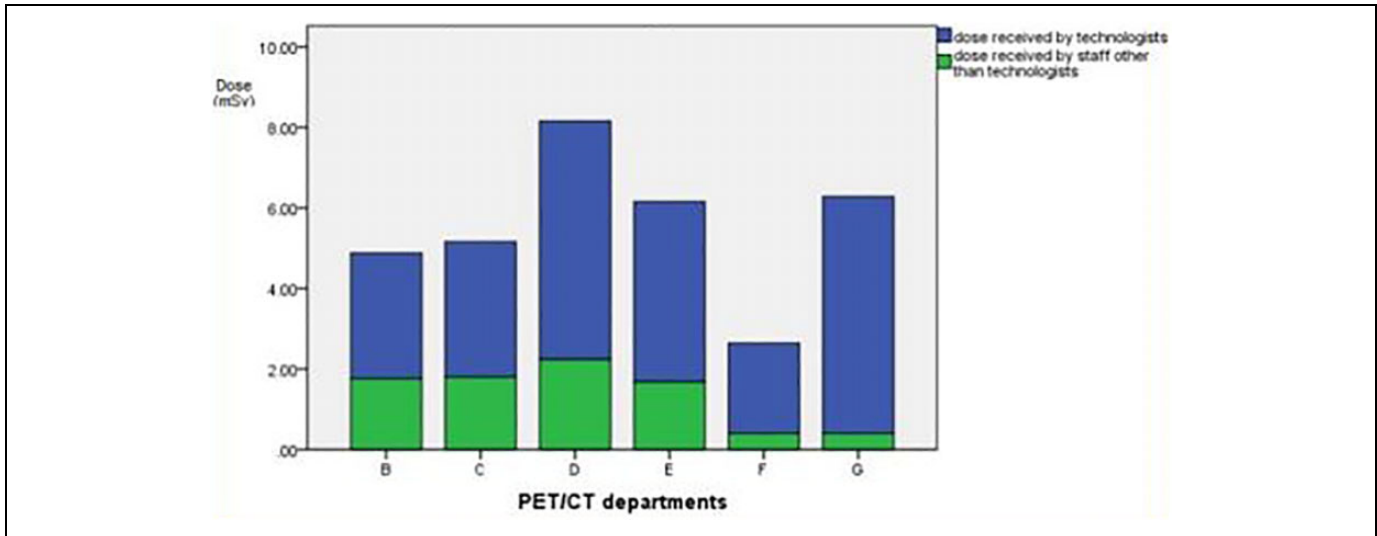
It is difficult to accurately compare PET departments across different medical institutions, since there are variations in procedures, technologists' proficiencies, injection activity, and/or radiation protection devices. However, the DR technologists' dose is useful as a reference to better understand the dose level of PET technologists. From the results presented in section "Comparison of Whole-Body Doses (mSv) Received by PET/CT Technologists With Those Received by DR Technologists" and in addition to the technologists in PET/CT Department B,

technologists across the other 6 PET/CT departments received higher doses than those of the DR technologists in their respective hospitals.

From the abovementioned analysis, the technologists in charge of dispensing and injecting <sup>18</sup>F-FDG were the most exposed to radiation,<sup>9</sup> with the rest of the staff receiving less exposure. From the results presented in section "Proportion of Whole-Body Dose of the Technologists to the Collective Dose in PET/CT Departments", the PET/CT technologists contributed the majority of the collective dose. Notably, this reached 94% of the collective dose in Department G. According to the calculations provided by the National Academies' Biological Effects of Ionizing Radiation VII Report, an adult worker has a 1/136 chance of developing cancer if they receive 2 mSv of a whole-body dose every year.<sup>10</sup> Given this recommendation, it is clear that some PET/CT technologists may be at risk of carcinogenic effects from their exposure levels.

The thyroid gland is a radiation-sensitive organ. However, the chance of developing a lethal cancer is small, so the tissue weight factor is only 0.05. The ICRP did not raise the annual dose limit for the thyroid gland, and the relationship between low-dose radiation and thyroid lesions has not been clearly described. As shown in Table 2, the thyroid dose in this study was not high. However, if the thyroid was exposed to a certain level of radiation for a long period, it may increase the likelihood of changes to thyroid functioning.<sup>11</sup>

During drug dispensation and injection, there is a 1-mm-thick syringe plastic wall between the skin of the fingers and the radioactive drug itself. Despite this, the plastic wall affords



**Figure 4.** Proportion of technologists' dose to collective dose.

**Table 3.** Annual Dose (mSv) of Thyroid and Hand of PET/CT Technologists.

Hospital	Dose of thyroid	Dose of hand	
		Left	Right
A	1.70 ± 0.05	424 ± 150	676 ± 194
B	1.22 ± 0.06	374 ± 99	344 ± 76
C	1.22 ± 0.17	50 ± 22	42 ± 15
D	1.33 ± 0.66	52 ± 12	70 ± 21
E	1.46 ± 0.05	46 ± 16	54 ± 18
F	1.20 ± 0.09	64 ± 19	72 ± 23
G	1.62 ± 0.10	46 ± 19	62 ± 22

Abbreviations: PET/CT, positron emission tomography/computed tomography.

little protection against 511 keV of photons, so the hand is exposed to higher doses radiation overall.<sup>12</sup> Previous work by Leide-Svegborn found that the hand dose of staff who used <sup>18</sup>F was up to 3.0 μGy/MBq, with an annual doses that could easily exceed 500 mSv/a.<sup>5</sup> Here, the dose obtained by the ring dosimeters worn on the technologists' finger bases were not good representations of the dose received by fingertips exposed to radioactive drugs. It is well-known that the dose received by an organ is inversely proportional to the square of the distance from the radiation source. Given this, the dose of the finger bases and fingertips should be very different. To this end, Janowski and colleagues measured the hand dose distribution of the technologists using radioactive drugs. Their results confirmed that the nail doses of the thumb and index fingers were approximately 5 times that of the finger bases themselves. Additional measurement of the dose rate indicated that the dose at the finger tips was 8.7 times that of the fingernails.<sup>13</sup> It has been speculated that the dose of the thumb and index finger tips may be 40 times that of the finger bases. As presented here (Table 2), the finger base dose for all technologists across the

7 PET/CT departments exceeded 40 mSv. Given this, we estimated that the fingertip dose might be dozens of times larger, especially the fingertip doses of PET/CT technologists in Departments A and B. The abovementioned analysis may explain why radiation injuries suffered by nuclear medical technologists are usually skin burns.

As the number of patients increases, technologists working closely with radiopharmaceuticals will inevitably experience increasing radiation exposure. In most PET/CT departments across China, syringes with tungsten sleeves and injection trolleys with lead screens have been used to reduce hand exposure to radiation. To this end, Erdman and colleagues reported that tungsten sleeve and lead-screen injection trolley use could reduce hand radiation doses by up to 65%.<sup>14</sup> Notably, these 2 protection measures were not provided in the PET/CT Department A. In addition, Department A saw more than 200 patients a month, which was far more than any other of the PET/CT departments included here. Finally, technologists in Department A were also slow to operate, which may have further resulted in the dramatically higher hand doses.<sup>15</sup>

Here, we found that some technologists in some of the PET/CT departments did not wear lead coats, caps, scarves, other lead-mediated protective supplies. This may have been because they thought a 0.5-mm lead-equivalent protective material has very limited effect against γ photons. Nevertheless, the results presented here in section "Lead Coat Protective Results" affirmed the protective effects of a lead coat.

Work by Leide-Svegborn showed that although whole-body and thyroid doses for the technologists were significantly lower than the dose limit, the dose values were increasing yearly.<sup>5</sup> Some experts have expressed doubt that increases in radiation exposure increase the occupational risk of cancer.<sup>10,16,17</sup> Fortunately, some measures are useful at dramatically reducing radiation exposure. For instance, increasing the number of technologists who share the dose is a simple way to reduce the average dose exposure.<sup>18</sup> Moreover, skilled operation may

shorten the operating time and reduce exposure,<sup>19</sup> as might the use of personal protective equipment.<sup>20</sup> Finally, automatic dispensing and injecting systems reduce both whole-body and hand doses by 50% and 95%, respectively.<sup>6</sup> In future, it may be possible to also effectively reduce radiation exposure by reducing radionuclide activity and upgrading imaging software.

## Conclusion

Technologists in PET/CT departments took the bulk of the collective radiation dose and received significantly higher doses than the other staff. Critically, the hand doses of these technologists sometimes exceeded the dose limit of 500 mSv/year. In addition to syringes with lead sleeves, injection trolleys with lead screens, and lead coats, more effective measures will need to be implemented to protect these workers from increasing radiation exposure.

## Declaration of Conflicting Interests


The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

## Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study was supported by the Natural Science Foundation of Shandong [ZR2017YL007] and the Subsidy Fund for Medical Science and Technology Innovation Project of Shandong Academy of Medical Sciences.

## ORCID iD

Weiguo Li  <https://orcid.org/0000-0003-0026-0219>

Lianying Fang  <https://orcid.org/0000-0002-9423-1621>

## References

- Juweid ME, Cheson BD. Positron emission tomography and assessment of cancer therapy. *New Engl J Med*. 2006;354(2):496-507.
- Al-Aamria M, Al-Balushia N, Dale B. Estimation of radiation exposure to workers during [18F] FDG PET/CT procedures at molecular imaging center, Oman. *J Med Imaging Radiat Sci*. 2019;50(4):565-570.
- Martinez NE, Kraft SL, Johnson TE. A proposed simple model for estimating occupational radiation dose to staff from veterinary F-18-FDG pet procedures. *Health Phys*. 2014;106(5):583-591.
- Younas S, Yar A, Qadir E. Radiation dose management of 18FDG for occupational workers and comforters. *Pakistan J Nuclear Med*. 2015;5(2):58-66.
- Leide-Svegborn S. External radiation exposure of personnel in nuclear medicine from 18F, 99mTc and 131 I with special reference to fingers, eyes and throid. *Radiat Prot Dosimetry*. 2012;149(2):196-206.
- Covens P, Berus D, Vanhavere F, et al. The introduction of automated preparing and injection during PET procedures: a step in the optimisation of extremity doses and whole body doses of nuclear medicine staff. *Radiat Prot Dosimetry*. 2010;140(6):250-258.
- Chung WK, Yang NH, Dong KR, et al. Duties of radiation workers at the department of nuclear medicine. *Radiat Prot Dosimetry*. 2019;20. doi:10.1093/rpd/ncz249
- International Atomic Energy Agency. *Radiation Protection in Newer Medical Imaging Techniques: PET /CT*. Safety Reports Series; (58)2008.
- Ahmed IES, Zamzam AMM, 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(1):287-292.
- Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation. *Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2*. The National Academies Press; 2006. Accessed October 10, 2008. <http://www.nap.edu/reportbrief/11340rb.pdf>
- Golán T, Dienstbier Z, Hermanská Z. The effect of radiation on thyroid gland function. *Cas Lek Cesk*. 1989;128(3):65-67.
- Carmody M. Finger doses for nuclear medicine technologists in the era of increasing PET-CTs. *Int Med J*. 2016;46(1):39-40.
- Jankowski J, Olszewski J, Kluska K. Distribution of equivalent doses to skin of the hands of nuclear medicine personnel. *Radiat Prot Dosimetry*. 2003;106(2):177-180.
- Erdman M, King S, Mille K. Recent experiences with shielding a PET/CT department. *Health Phys*. 2004;87(2 suppl):S37-S39.
- Rao VV, Manthri R, Hemalatha P, Vuyyuru NK, Mohammad A. Time reducing exposure containing <sup>18</sup>flurine flouredeoxyglucose master vial dispensing in hot lab: Omega technique. *Indian J Nucl Med*. 2016;31(2):158-160.
- Mattsson S, Sderberg M. Radiation dose of management in CT, SPECT/CT and PET/CT techniques. *Radiat Prot Dosimetry*. 2011;147(1-2):13-21.
- Al-Haj AN, Lobriguito AM, Arafah A, Ruchana P. Deriving staff and public doses in a PET/CT department from measured radiation levels using thermoluminescent dosimetry. *Radiat Prot Dosimetry*. 2011;144(1-4):487-491.
- Australian Radiation Protection and Nuclear Safety Agency. Radiation protection in nuclear medicine. Radiation protection series. No.14.2; 2013.
- Yasuyuki T, Shota H, Takakiyo T, et al. Time-related study on external exposure dose of 2-deoxy-2[F-18]fluoro-D-glucose PET for workers' safety. *Radiol Phys Technol*. 2020;13(1):98-103.
- Guillet B, Quentin P, Waultier S, et al. Technologist radiation exposure in routine clinical practice with <sup>18</sup>F-FDG PET. *J Nucl Med Technol*. 2005;33(2):175-179.