Radiation Dose to PET Technologists and Strategies to Lower Occupational Exposure

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Objective: The use of PET in Australia has grown rapidly. We conducted a prospective study of the radiation exposure of technologists working in PET and evaluated the occupational radiation dose after implementation of strategies to lower exposure.

Methods: Radiation doses measured by thermoluminescent dosimeters over a 2-y period were reviewed both for technologists working in PET and for technologists working in general nuclear medicine in a busy academic nuclear medicine department. The separate components of the procedures for dose administration and patient monitoring were assessed to identify the areas contributing the most to the dose received. The impact on dose of implementing portable 511-keV syringe shields (primary shields) and larger trolley-mounted shields (secondary shields) was also compared with initial results using no shield.

Results: We found that the radiation exposure of PET technologists was higher than that of technologists performing general nuclear medicine studies, with doses averaging 771 ± 147 and 524 ± 123 μSv per quarter, respectively ($P = 0.01$). The estimated dose per PET procedure was 4.1 μSv (11 nSv/MBq). Injection of ^{18}F-FDG contributed the most to radiation exposure. The 511-keV syringe shield reduced the average dose per injection from 2.5 to 1.4 μSv ($P < 0.001$). For the longer period of dose transportation and injection, the additional use of the secondary shield resulted in a significantly lower dose of radiation than did use of the primary shield alone or no shield (1.9 vs. 3.6 μSv [$P = 0.01$] and 3.4 μSv [$P = 0.03$], respectively).

Conclusion: The radiation doses currently received by technologists working in PET are within accepted occupational health guidelines, but improved shielding can further reduce the dose.

Key Words: PET; radiation dose; occupational exposure; thermoluminescent dosimeters

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The use of PET in Australia has grown rapidly over the last 5 y (*1–3*). An increasing demand for use of ^{18}F-FDG PET in oncology has been the main reason for its growth, in conjunction with the advent of less costly dedicated PET cameras and coincidence detection γ-cameras. At present, 8 PET centers are funded by the Commonwealth Government in Australia.

Although neurologic and cardiac studies are still performed, most clinical scans are performed for oncologic indications. At our institution, the number of clinical ^{18}F-FDG PET scans has increased almost 10-fold over the last decade to more than 2,000 studies per year. The rapid increase in demand for PET gave rise to concerns about the radiation exposure of staff members, in particular the technologists performing the scanning.

The physical characteristics of positron emissions result in a higher radiation risk for staff. The penetrating ability of the high-energy 511-keV γ-rays produced from the annihilation reaction of a positron and an electron is greater than that of the 140-keV emissions from ^{99m}Tc-based compounds (*1*). The specific γ-ray dose constant, defined as the dose rate in air for 1 MBq of an isotope at a distance of 1 m, is 6 times higher for ^{18}F (18.79E-5 [mSv/h]/MBq) than for ^{99m}Tc (3.317E-5 [mSv/h]/MBq) (*4*).

The amount of lead required to suitably shield these high-energy emissions is therefore increased. The half-value layer, which is the thickness of material that will

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decrease the amount of exposure by one half, is 0.28 mm for 140-keV photons in lead. The narrow-beam half-value layer for 511-keV photons is 4.1 mm (*5*), and the practical broad-beam half-value layer allowing for Compton scatter is >5 mm.

The aims of this study were to compare the radiation doses to PET technologists with those to general nuclear medicine technologists within our department, identify the components of the PET procedure that resulted in the greatest radiation exposure, compare different methods of shielding the dose to be administered, and implement strategies to minimize radiation dose to PET technologists.

MATERIALS AND METHODS

Initially, a thermoluminescent dosimeter study was performed on 2 experienced technologists who rotated between general nuclear medicine and PET and 4 technologists who performed only nuclear medicine studies in our department. The technologists who rotated through PET spent 2 wk in PET followed by 2 wk in general nuclear medicine, with extra time being spent in PET to relieve for annual leave and sick leave. Each technologist wore thermoluminescent dosimeter badges supplied by the Australian Radiation Protection and Nuclear Safety Agency, and readings were taken every 3 mo. Results obtained during a 2-y period were analyzed.

The PET scanner was an ECAT 951R (Siemens), which has a bismuth germanate detector with an axial field of view of 10.8 cm (*1*). An average of 6 or 7 ^{18}F-FDG examinations were performed each day, with 3 or 4 d of the week being set aside for clinical work and 1 d for research studies. The technologists were responsible for the injection and scanning of each patient. The guideline for the activity to be administered was 370 MBq ± 15%. The average number of patients injected and scanned by each rotating technologist each day was approximately 3 or 4, with the remaining examinations being performed by the full-time senior PET technologist. At the time of the study, an average of 124 PET and 80 nuclear medicine examinations were being performed per quarter by each of the 2 technologists rotating through PET, whereas technologists performing general nuclear medicine studies performed, on average, only 161 examinations per quarter.

Additional considerations for radiation safety were implemented during installation of the PET scanner. The scanner room was surrounded by high-density double-brick walls. Lead glass windows (1.5-mm lead equivalent) were installed between the scanner and console rooms. Lead containers were used for the transport of syringes from the hot lab to the injection room. Finally, patients were viewed remotely via a video monitor in the injection/uptake room and another in the scanning room.

Use of Personal Radiation Monitor

To assess which types of PET procedures contributed the most radiation exposure to the technologists, we performed a prospective study in which the technologists wore a personal monitor and doses were recorded after a task was performed. The monitor was the Bleeper Sv pocket dosimeter (Gothic Crellan Ltd.), with stated energy range of 45 KeV to 3 MeV (±25%) and a linearity of reading with dose rate (±20%).

Doses to technologists were assessed after the following tasks:

Patient Injection. Before staff dose evaluation, no syringe shields were routinely used for injecting ^{18}F-FDG. Once intravenous access was obtained, the syringe was quickly removed from the lead container and the dose was injected. The total radiation dose received by the technologist was measured from the time the syringe was taken from the container to the time the technologist left the injection room.

Patient Setup. Measurements were taken while the patient was placed on the bed and positioned for the scan.

Flushing of Urinary Catheter. Urinary catheters were used for assessment of pelvic disease only in selected oncology patients. Normal saline was used to flush the bladder via a connection in the catheter tubing. Flushing was done periodically throughout scanning to ensure the remaining urine in the bladder was diluted and drained. The dose received while the technologist handled the catheter bag was measured.

Camera Operation and Image Processing. A dosimeter was placed next to the console where the technologists operate the camera and process the images. This monitor was left to record the dose in this area over a period of 6 wk. Another dosimeter was placed in an area with only background radiation.

Evaluation of Syringe Shields

A 511-keV syringe shield (Capintec Inc.) was evaluated for reducing exposure during patient injections (the primary shield). The primary shield consisted of 12.7-mm lead-equivalent shielding made from tungsten and an 8.7-mm lead-equivalent glass window. The shield weighed approximately 1 kg and was attached to a trolley for support during injection. The dose received with use of the new syringe shield was measured by a dosimeter and compared with unshielded results. The readings for this comparison were obtained during dose administration only, not during dose transportation.

A separate dataset was acquired with the Bleeper Sv dosimeter using 2 different types of syringe shields. These measurements were obtained during transportation and administration of the dose to the patient. The dose was transported and administered in a 5- or 10-mL syringe. The first type of shielding was the primary shield already described. The second method used a custom-designed circular pot with a 20-mm-thick lead wall, with the primary shield and dose fitted inside (the secondary shield). A gap in the shielding corresponded to the lead glass window of the primary shield. Thus, a total of 32.7 mm of lead-equivalent shielding was provided by the secondary shield, with the exception of the syringe tip and plunger (which were unshielded) and the lead glass window.

Statistical Analysis

The doses received by PET technologists were compared by *t* testing. Statistical analysis was performed using Prism software (GraphPad).

RESULTS

Doses to Technologists

Technologists rotating though PET received a higher radiation dose than those performing general nuclear medicine studies only. The average quarterly thermoluminescent dosimeter reading over the 2 y investigated was 771 ± 147 μSv for technologists in both nuclear medicine and PET, compared with 524 ± 123 μSv for those in nuclear medicine only ($P = 0.01$). The estimated dose per PET procedure was 4.1 μSv (11 nSv/MBq). The average yearly dose for PET technologists, compared with technologists only in general nuclear medicine, is shown in Table 1.

Assessment of Personal Monitor

A large proportion of the dose was received during patient injection, with a smaller amount contributing during patient positioning and urinary catheter flushing (Table 2).

Evaluation of Console Area

The average daily reading in the console area was 3.0 μSv, as measured over a working day of 8 h, 6 h of which were spent by the technologist in sitting at the console. A monitor that had been placed in an office at least 10 m from any radiation source received an average dose of 2.1 μSv per 8-h working day. Thus, the dose technologists received while sitting in the console area was 1.4 times the background level in the department as detected by the personal monitor.

Evaluation of Syringe Shield

A comparison of the doses received with the primary shield and no shield is shown in Table 2. The primary shield reduced the average dose by 44% ($P < 0.001$).

TABLE 1
Dose Received by Technologists Rotating Through PET and Nuclear Medicine, Compared with Technologists in Nuclear Medicine Only

Mean dose ± SD, per year (mSv)	
PET/nuclear medicine	Nuclear medicine
3.05 ± 0.37	1.97 ± 0.40
3.12 ± 0.29	2.22 ± 0.66

Readings for 2 consecutive years are shown.

TABLE 2
Dose Received by Technologists for PET Procedures Before Implementing Shielding Procedures

		Mean dose ± SD	
Procedure	*n*	μSv/procedure	nSv/MBq
Injection, no shield	26	2.5 ± 1.0	6.8 ± 2.7
Injection, primary shield	50	1.4 ± 0.7	3.8 ± 1.9
Patient setup	20	1.3 ± 0.7	3.5 ± 1.9
Catheter flush	5	0.8 ± 0.5	2.2 ± 1.4

Dose per megabecquerel is calculated for an assumed activity of 370 MBq.

The results for the primary and secondary shields are shown in Table 3. Sixty-nine patients were injected using the combination of the primary and secondary shields. Fewer patients (9 each) were injected using the primary shield (9 patients) or using no shield (9 patients). The activity administered was also measured and used to calculate the dose per megabecquerel. The readings in Table 3 were taken during dose transportation and injection, whereas those in Table 2 were taken during injection only. For the data in Table 3, no significant difference in the dose received was found when the primary shield was compared with no shield, although the numbers were small. The dose received was significantly less when the primary and secondary shields were combined than when the primary shield was used alone ($P < 0.001$) or when no shield was used ($P < 0.001$).

DISCUSSION

Australian nuclear medicine practices follow the guidelines set by the International Commission on Radiologic Protection and the Australian National Health and Medical Research Council. The recommended limit for radiation exposure to a radiation worker is 20 mSv per year averaged over 5 y or a maximum of 50 mSv in any single year (*6*). In our study, the average yearly doses to PET technologists (approximately 3 mSv) and nuclear medicine technologists (approximately 2 mSv) were well within these limits.

Although the principles of time, distance, and shielding are always practiced for any procedure involving radioactive administration, particular care needs to be taken to enforce these when working in PET. We found that dose injection contributed more to total radiation exposure than

TABLE 3
Dose Received by Technologists Using Different Methods to Shield Injection Dose

		Mean dose ± SD	
Shielding type	*n*	μSv/procedure	nSv/MBq
None	9	3.4 ± 1.7	9.7 ± 2.3
Primary	9	3.6 ± 1.5	8.6 ± 2.9
Primary and secondary	69	1.9 ± 0.9	4.5 ± 2.2

Dose includes period of dose transport and injection. Primary and secondary shielding refers to total of 32.7 mm of lead-equivalent shielding.

did catheter flushing or patient setup. To minimize this exposure, we implemented 511-keV syringe shields. Combination of the primary and secondary shields was superior to no shield or the primary shield alone. The primary shield was superior to no shield (Table 2), although this result was not confirmed in our second dataset collected from a separate group of patients (Table 3), most likely because few patients were assessed in each group. The doses recorded with use of either no shield or the primary shield were larger in Table 3 than in Table 2, most likely because the data in Table 3 were collected during both dose transportation and dose injection whereas the data in Table 2 were collected only during dose injection.

Other techniques were attempted to minimize the radiation exposure of the technologists. Before giving the injection, the technologist thoroughly explained the procedure to the patient, allowing time for questions and ensuring patient comfort in the supine position. After giving the injection, the technologist left the room as promptly as possible. Time spent with the patient on completion of the scan was also minimized.

Another possible method of minimizing the radiation exposure of technologists is the use of mobile radiation shields. These were not used in our study but consist of 2.5- to 5.0-cm-thick lead plates mounted on wheels. Some mobile shields are height adjustable.

The study showed that flushing the catheter bag resulted in a dose to the technologist of 0.8 μSv per procedure. We considered placing shielding around the catheter bag but concluded that the effect on overall exposure would be minor because urinary catheterization is seldom performed.

The personal monitor beside the console revealed that the dose behind the lead shielding and lead glass from the scanner room was not significantly higher than background levels, suggesting that technologists were not significantly exposed to radiation during scanning and patient monitoring after dose administration.

Chiesa et al. (*7*) demonstrated that radiation doses received by PET technologists were higher than those received by technologists working only in general nuclear medicine, although some more recent studies found an insignificant increase in exposure (*8,9*). Comparison of studies performed in different departments is made difficult by varying work practices. Factors that would result in a larger total dose to our PET technologists are the average amount of activity administered (370 MBq) and their being responsible for most patient injections. Work practices in which other staff members, such nurses or doctors, perform patient injections would reduce the dose to technologists, at the cost of increased radiation exposure to those other members of the staff. In addition, recent improvements in PET technology have led to the development of new-generation PET cameras that have an increased throughput and thus potentially increase technologist doses because of a higher workload (*10,11*).

CONCLUSION

We found that technologists working in PET received slightly higher doses of radiation than did those working only in general nuclear medicine, but the doses were within the accepted guidelines for occupational exposure. These doses could be reduced by using a 511-keV syringe shield and even further by shielding the radiation source more extensively. Monitoring exposure is an ongoing process, especially as the demand for PET rises and improvements in PET technology increase throughput and shorten scanning times.

REFERENCES

1. Tochon-Danguy HJ, Sachinidis JI, Egan GF, et al. Positron emission tomography: radioisotopes and radiopharmaceutical production. *Australas Phys Eng Sci Med.* 1999;22:136–144.
2. Hicks RJ, Binns DS, Fawcett ME, et al. Positron emission tomography (PET): experience with a large-field-of-view three-dimensional PET scanner. *Med J Aust.* 1999;171:529–532.
3. Scott AM. Current status of positron emission tomography in oncology. *Int Med J.* 2001;31:27–36.
4. Shleien B. Exposure and shielding from external radiation. In: Shleien B, ed. *The Health Physics and Radiological Health Handbook.* Silver Spring, MD: Scinta; 1992:163–218.
5. Bixler A, Springer G, Lovas R. Practical aspects of radiation safety for using fluorine-18. *J Nucl Med Technol.* 1999;27:14–17.
6. International Commission on Radiological Protection. *ICRP Publication 60: 1990 Recommendations of the IRCP.* New York, NY: Pergammon; 1991.
7. Chiesa C, De Sanctis V, Crippa F, et al. Radiation dose to technicians per nuclear medicine procedure: comparison between technetium-99m, gallium-67, and iodine-131 radiotracers and fluorine-18 fluorodeoxyglucose. *Eur J Nucl Med.* 1997;24:1380–1389.
8. Benatar NA, Cronin BF, O'Doherty MJ. Radiation dose rates from patients undergoing PET: implications for technologists and waiting areas. *Eur J Nucl Med.* 2000;27:583–589.
9. White S, Binns D, Johnston V, et al. Occupational exposure in nuclear medicine and PET. *Clin Positron Imaging.* 2000;3:127–129.
10. Humm JL, Rosenfeld A, Del Guerra A. From PET detectors to PET scanners. *Eur J Nucl Med.* 2003;30:1574–1597.
11. Townsend DW, Beyer T, Blodgett TM. PET/CT scanners: a hardware approach to image fusion. *Semin Nucl Med.* 2003;33:193–204.