Technologist Radiation Exposure in Routine Clinical Practice with ^{18}F-FDG PET

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Objective: The use of ^{18}F-FDG for clinical PET studies increases technologist radiation dose exposure because of the higher γ-radiation energy of this isotope than of other conventional medical γ-radiation–emitting isotopes. Therefore, ^{18}F-FDG imaging necessitates stronger radiation protection requirements. The aims of this study were to assess technologist whole-body and extremity exposure in our PET department and to evaluate the efficiency of our radiation protection devices (homemade syringe drawing device, semiautomated injector, and video tracking of patients).

Methods: Radiation dose assessment was performed for monodose as well as for multidose ^{18}F-FDG packaging with both LiF thermoluminescence dosimeters (TLD) and electronic personal dosimeters (ED) during 5 successive ^{18}F-FDG PET steps (from syringe filling to patient departure).

Results: The mean ± SD total effective doses received by technologists ($n = 50$) during all of the working steps were 3.24 ± 2.1 and 3.01 ± 1.4 μSv, respectively, as measured with ED and TLD (345 ± 84 MBq injected). These values were confirmed by daily TLD technologist whole-body dose measurements (2.98 ± 1.8 μSv; 294 ± 78 MBq injected; $n = 48$). Finger irradiation doses during preparation of single ^{18}F-FDG syringes were 204.9 ± 24 and 198.4 ± 23 μSv with multidose vials (345 ± 93 MBq injected) and 127.3 ± 76 and 55.9 ± 47 μSv with monodose vials (302 ± 43 MBq injected) for the right hand and the left hand, respectively. The protection afforded by the semiautomated injector, estimated as the ratio of the doses received by TLD placed on the syringe shield and on the external face of the injector, was near 2,000.

Conclusion: These results showed that technologist radiation doses in our PET department were lower than those reported in the literature. This finding may be explained by the use of a homemade syringe drawing device, a semiautomated injector, and patient video tracking, allowing a shorter duration of contact between the technologist and the patient. Extrapolation of these results to an annual dose (4 patients per day per technologist) revealed that the annual extrapolated exposure values remained under the authorized limits for workers classified to work in a radioactivity-controlled area.

Key Words: radiation dose exposure; radiation protection devices; dosimetry; ^{18}F-FDG PET

The setup of a PET scanner in a nuclear medicine department (PET/CT scanner) for ^{18}F-FDG oncology imaging raised the issue of radiation dose exposure of technologists undertaking the preparation and administration of this radiopharmaceutical. Indeed, the higher γ-radiation energy of positron-emitting isotopes (511 keV) means that staff members could receive a higher whole-body dose than those working only with conventional nuclear medicine tracers. To date, however, few data have been published on technologist radiation doses received during work in dedicated PET departments (*1,2*). These studies measured whole-body doses received during 1 workday in a PET center using various positron-emitting isotopes (14.4 μSv) (*2*) or dose rates at various distances from patients injected with 370 MBq of ^{18}F-FDG (the median exposure at 2 m from the patient at 1 h after injection was 2 μSv/h) (*3*). Some other studies aimed to evaluate hand doses received during ^{18}F-FDG PET scanning and reported values of 710 μSv per technologist (*4*). All of these results are difficult to compare because radiation protection means are very dissimilar and because of differences in ^{18}F-FDG packaging among suppliers (unit-dose [monodose] or multidose vials). Moreover, the dose measurements were recorded with electronic personal dosimeters (ED) worn at waist and wrist levels and did not provide information on the doses received by the fingers or with thermoluminescence dosimeters (TLD) worn around the second finger. Ring TLD have the disadvantage of a time lag measurement of the dose once per month because they cannot be changed at every step of ^{18}F-FDG manipulation.

The aims of this study were, first, to inform technologists working with ^{18}F-FDG about their whole-body and finger radiation doses and to compare our results with the maximum admissible doses prescribed by European Directive EURATOM 96/29 05/13/1996; second, to validate our radiation protection devices (especially our homemade syringe drawing device and a commercially available semiautomated injector); and third, to measure radiation doses corresponding to different kinds of ^{18}F-FDG packaging.

MATERIALS AND METHODS

The Timone Hospital Nuclear Department PET/CT scanner is a dedicated Discovery ST scanner (GE Healthcare). Three technologists are assigned to cover a workday from 8:00 AM to 6:00 PM. On an average day, the PET/CT scanner will image 10–13 patients. The study was conducted over a period of 6 mo, and measurements were recorded from the first PET examination of the day ($n = 80$), which corresponds to the highest multidose vial activity. All of the technologists were right handed.

^{18}F-FDG Packaging

^{18}F-FDG is supplied either in monodose vials (Cis-Bio Schering) or in multidose vials (4 doses; IBA) in lead containers with radioactivity per vial ranging from 450 MBq to 4 GBq.

^{18}F-FDG Manipulation and Protection Devices

The ^{18}F-FDG PET procedure was divided into 5 working steps. The first step is receipt of the ^{18}F-FDG containers. The radiotracer is handled within a dedicated "hot" laboratory, being drawn up behind a large bench-mounted 60-mm-thick lead shield that has a 55-mm lead-equivalent glass insert (Lemer Pax). The dramatic high activity of ^{18}F-FDG multidose vials led us to develop a homemade drawing device to allow syringe filling without direct contact with the vial, which remains in the hole of the dosimeter (Figs. 1A–1C). The second step is measurement of the total activity of the vial and the drawing up of the ^{18}F-FDG dose (5 MBq/kg) in a syringe placed inside a 10-mm tungsten syringe shield (Lemer Pax). The third step is placement of the syringe in its shield into a semiautomated injector surrounded by a 30-mm-thick lead shield to avoid manual handling of the syringe. The fourth step is infusion of the ^{18}F-FDG dose into the patient through a catheter that is withdrawn 40 min later. The last step includes the time spent in collecting the patient 1 h after the tracer infusion, escorting the patient to the PET room, positioning within the camera and, finally, after image acquisition, escorting the patient out of the department.

The technologists spend most of the scanning time in the control room, with a direct view of the patient through lead glass and a video link. The time spent in each step, the ^{18}F-FDG activity injected, and the identified technical incidents are systematically monitored.
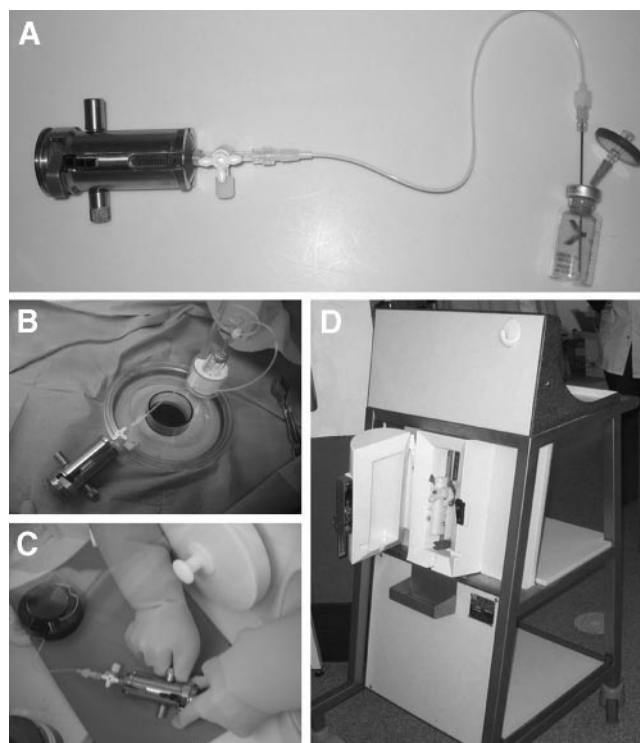

FIGURE 1. Schematic representation of our homemade drawing device. (A) Global view of device. (B) Positioning of ^{18}F-FDG vial in hole of dosimeter. (C) Syringe filling. (D) Shielded semiautomated injector.

Dosimetry

^{18}F-FDG Multidose Vials. ED (Siemens EPD mk2.3) placed in the upper left pocket of technologist overalls allowed measurement of the whole-body individual dose at the end of each step of the ^{18}F-FDG and patient manipulations. These dosimeters were calibrated twice each year by the Commissariat à l'Energie Atomique. The whole-body dose also was determined with 3 cylindric LiF TLD (diameter, 4.5 mm; thickness, 0.8 mm; GR200A; Société Fimel) placed in the upper left pocket of overalls worn by 3 agents during an entire PET center workday. The dose received by the irradiated TLD was determined with a PCL3 thermoluminescence reader (Société Fimel) according to manufacturer instructions. Measurements were recorded from 50 preparations. The values obtained were divided by the number of patients undergoing PET scans (mean of 12 patients per day) to confirm more accurately the whole-body dose received per patient. The dose reported for each pack of 3 TLD was the mean of the 3 measurements.

The dose received by the fingers during the first 3 steps of ^{18}F-FDG manipulation was assessed with 2 of the TLD placed on the inside of the second finger of each hand. The TLD were selected and calibrated after exposure to 160 mGy of ^{60}Co irradiation (1000 IEC ^{60}Co generator; Theratron). Measurements were recorded from 50 preparations. The dose reported for each pair of TLD was the mean of the 2 measurements.

^{18}F-FDG Monodose Vials. Because the difference in exposure related to the manipulation of monodose or multidose vials of ^{18}F-FDG is related only to steps 1 and 2, we compared the values obtained for whole-body irradiation and finger irra-

TABLE 1
Mean ± SD ($n = 50$) Whole-Body Doses During Steps 3, 4, and 5, as Estimated by ED and TLD
Worn in Upper Left Pocket of Overalls

Step	Step duration (s)	Activity (MBq)	Effective dose (μSv) measured with:		Effective dose per MBq injected (nSv) measured with:	
			TLD	ED	TLD	ED
3	19.1 ± 7.3	345 ± 71	0.76 ± 0.87	0.88 ± 0.68	2.03 ± 1.63	3.39 ± 2.5
4	108.9 ± 47	345 ± 71	1.08 ± 1.6	0.81 ± 1	4.53 ± 6.9	3.26 ± 4.1
5	157.4 ± 65	345 ± 71	0.72 ± 1.1	0.76 ± 1.1	3.01 ± 5.1	2.99 ± 4.2

diation during these first 2 steps with monodose or multidose vials of ^{18}F-FDG. Measurements were recorded from 30 preparations.

To estimate the protection afforded by the semiautomated injector, 3 TLD were placed directly on the syringe shield, and 3 other TLD were placed on the external face of the injector. Ten pairs of TLD were used for this determination.

Statistical Analysis

All values are reported as mean ± SD. The Mann–Whitney test was performed to statistically compare values obtained with TLD for whole-body and finger exposures during the first 2 steps with each ^{18}F-FDG package and whole-body doses obtained with TLD and ED. A P value of <0.05 was considered significant.

RESULTS

The effective doses measured during steps 1 and 2 with TLD and ED were negligible (step 1, ED: 0.29 ± 0.4 μSv; step 2, ED: 0.10 ± 0.1 μSv); therefore, Table 1 shows only the mean ± SD for whole-body doses during steps 3, 4, and 5 of manipulation of multidose vials of ^{18}F-FDG, as recorded by ED and TLD worn in the upper left pocket of the overalls ($n = 50$). The mean ± SD total effective doses received by technologists during all of the steps of 1 ^{18}F-FDG dose preparation were 3.24 ± 2.1 and 3.01 ± 1.4 μSv for ED and TLD, respectively (345 ± 84 MBq injected). These 2 groups of values (ED and TLD) did not differ significantly.

Table 2 shows the mean ± SD for finger irradiation during the first 3 steps of manipulation of ^{18}F-FDG multidose vials

($n = 50$). The mean ± SD total doses received at the finger level were 231.9 ± 36 and 206.3 ± 32 μSv for the right hand and the left hand, respectively. The mean ± SD total doses received at the finger level during the first 2 steps of 1 ^{18}F-FDG dose preparation were 204.9 ± 24 and 198.4 ± 23 μSv, respectively, for the right hand and the left hand, respectively (mean ± SD vial activity: 3,240 ± 1,102 MBq; mean ± SD syringe activity: 345 ± 93 MBq).

Table 3 shows the mean ± SD finger doses during the first 2 steps of manipulation of monodose vials of ^{18}F-FDG ($n = 30$). The mean ± SD total doses received at the finger level for 1 ^{18}F-FDG dose preparation were 127.3 ± 76 and 55.9 ± 47 μSv for the right hand and the left hand, respectively (mean ± SD vial activity: 405 ± 22 MBq; mean ± SD syringe activity: 302 ± 43 MBq).

The mean ± SD irradiation rates for TLD positioned either directly on the syringe shield or on the external face of the injector are shown in Table 4 ($n = 10$). The mean ± SD ratio of the dose received by the syringe TLD and the dose received by the injector TLD was 1,852 ± 860, a value that corresponds to nearly complete protection.

The mean ± SD dose received by TLD worn in the upper left pocket of the overalls by 3 agents during an entire PET center workday, determined in relation to the number of patients undergoing PET scans ($n = 48$), was 2.98 ± 1.8 μSv. The mean ± SD activity injected into the patients was 294 ± 78 MBq.

Technical problems occurring throughout the ^{18}F-FDG manipulations dramatically increased the doses received by the technologists and are shown in Table 5.

TABLE 2
Mean ± SD ($n = 50$) Finger Irradiation During First 3 Steps of Manipulation of ^{18}F-FDG Multidose Vials

Step	Step duration (s)	Activity (MBq)	Finger dose (μSv)		Finger dose (μSv) per MBq injected	
			Left hand	Right hand	Left hand	Right hand
1	177 ± 111	3,240 ± 876	135.2 ± 19.2*	59.2 ± 53	0.041 ± 0.045	0.019 ± 0.015*
2	128.1 ± 98.7	345 ± 71	43.4 ± 70.8	211.3 ± 180[†]	0.15 ± 0.22	0.76 ± 0.52
3	19.1 ± 13	345 ± 71	21.0 ± 19.1	25.7 ± 70	0.086 ± 0.048	0.10 ± 0.17

*P < 0.05 in comparison with values for monodose vials.

[†]P < 0.05 in comparison with value for left hand.

TABLE 3

TABLE 3
Mean ± SD (n = 30) Finger Doses During First 2 Steps of Manipulation of ^{18}F-FDG Monodose Vials

Step	Step duration (s)	Activity (MBq)	Finger dose (μSv)		Finger dose (μSv/h) per MBq injected	
			Left hand	Right hand	Left hand	Right hand
1	112.7 ± 41	405 ± 235	14.9 ± 20*	22.2 ± 45	0.039 ± 0.05	0.068 ± 0.17*
2	138.4 ± 40	302 ± 57	44.9 ± 39	110.2 ± 63†	0.14 ± 0.11	0.37 ± 0.20

*$P < 0.05$ in comparison with values for multidose vials.

†$P < 0.05$ in comparison with value for left hand.

DISCUSSION

Numerous studies (5–11) have reported the effective doses received by nuclear medicine technologists, but few have considered specifically positron-emitting tracers. The results presented in our study show that, for 12 mo in succession, the radiation exposure at the whole-body and finger levels of technologists during ^{18}F-FDG manipulation in our PET center is dramatically lower than the maximum values allowed in European Directive EURATOM 96/29 05/13/1996 (whole-body effective dose: <20 mSv/y; equivalent finger dose: 500 mSv/y).

During step 1, the doses received by the left hand were obviously significantly higher when multidose vials were used than when monodose vials were used (135.2 ± 192 μSv vs. 14.9 ± 20 μSv) because of close contact with the ^{18}F-FDG vial, whose activity is near 3.5 GBq at the time of supplying.

During step 2, right-hand exposure was significantly higher than left-hand exposure, as the right hand was close to the tubing of the drawing device filled with ^{18}F-FDG (Fig. 1C). This discrepancy was more evident when multidose vials were used than when monodose vials were used (211.3 ± 180 μSv vs. 43.4 ± 39 μSv) because of the higher volumic activity (multidose: 555 MBq/mL; monodose: 250 MBq/mL). Shielding of the tubing has been considered, but it would impede visual control of syringe filling.

However, the higher doses received with multidose vials than with monodose vials must be balanced for 2 reasons: first, the mean time spent during step 1 (177 ± 111 and 112.7 ± 41 s for multidose and monodose vials, respectively) must be repeated for each patient with monodose vials, whereas with multidose vials, the procedures are performed every 4 patients; second, the total activity of the multidose vials decreases according to the ^{18}F-FDG half-life.

TABLE 4
Mean ± SD (n = 10) Dose Rates Measured by TLD Positioned Either on Syringe Shield Inside Injector or on External Face of Injector

TLD location	Dose rate (mSv/h)	Dose rate (mSv/h) per MBq
Syringe	58.7 ± 13	0.19 ± 0.02
Injector	0.047 ± 0.062	0.00017 ± 0.000014

It is difficult to strictly compare PET centers because of variability in protocols, acquisition times, injected activity, and radiation protection devices used, but we can nevertheless compare the effective dose measured during the entire PET procedure in our study with those reported in the literature. Published data on the radiation exposure of technologists during ^{18}F-FDG PET scanning are very sparse. Chiesa et al. (1) and Benatar et al. (2) reported similar technologist effective doses per whole-body ^{18}F-FDG PET scanning of 5.9 μSv (500 MBq per patient) and 5.5 μSv (14.4 μSv/d; 320 MBq per patient; 2–3 patients per day), respectively. However, Linemann et al. (4) in Germany reported a mean total personal dose of at least 10 μSv per technologist.

The technologist exposure doses reported above are higher than our ED or TLD measured doses. In the study of Chiesa et al. (1), the higher injected activity could partly explain this difference (500 MBq vs. 345 MBq). Moreover, less close contact with the radioactive source in the present study than in the study of Benatar et al. (2) (9.2 min per technologist per patient vs. 13.9 min per technologist per patient), the use of a semiautomated injector, and the video and audio tracking of the injected patients could be involved in the lower radiation exposure in the present study.

Because the measured values were subdivided into separate contributions from each phase of the manipulation of ^{18}F-FDG, it is possible to compare step by step the whole-body and finger doses measured with the very sparse published data.

Concerning the effective dose, as a consequence of the maximum shielding of the hot cell, the first 2 steps of ^{18}F-FDG manipulation led to negligible values comparable to ours (<1 μSv) (4). In contrast, steps 3, 4, and 5 induced greater radiation exposure, which is highly dependent on the radiation protection means used, especially a shielded automated injector or a lead screen for injection and a video link to avoid close contact with the injected patients. None of the published data evaluated radiation exposure during the transfer of the syringe from the hot cell to the patient. According to the work of Linemann et al. (4), the effective dose measured during the injection step led to about 3 μSv per injection, a value that is higher than the values measured by our ED (1.08 ± 1.6 μSv) or TLD (0.81 ± 1.0 μSv) during this step. It is worth noting that these authors did not describe the protection devices used for injection; the discrepancies in effective doses measured are probably attributable to the use in our study of the shielded semiautomated

TABLE 5
Whole-Body and Finger Doses Related to Technical Problems Occurring Throughout ^{18}F-FDG Manipulation

Incident	Increased duration (s)	ED whole body (μSv)	TLD whole body (μSv)	TLD right hand (μSv)	TLD left hand (μSv)	Activity (MBq)	n
Long transfer duration	63.6 ± 55*	2.50 ± 0.84*	3.51 ± 2.5*			318 ± 37*	8
Long syringe filling	660			1,183	424	222	1
Long injection duration	294	4	4			259	1
Long patient positioning duration	275	2.8	2.8			259	1

*Mean ± SD.

injector, which afforded nearly complete protection. In our PET center, where patients are located in rooms without direct communication with the hot laboratory, this automated injector is very useful for transferring the dose from the hot laboratory to the injection rooms.

The only published study focusing on the dose received by the hands, estimated by TLD, was that of Linemann et al. (*4*), who reported a mean finger exposure of 710 μSv during syringe preparation from ^{18}F-FDG multidose vials. Under these conditions, if we sum the right and left hand doses from our first 3 steps, whatever the ^{18}F-FDG packaging used, the mean values obtained are at least 3 times lower (mean ± SD finger dose from steps 1, 2, and 3 for multidose vials: right hand = 231.9 ± 36 μSv and left hand = 206.3 ± 32 μSv; mean ± SD finger dose from steps 1, 2, and 3 for monodose vials: right hand = 157.3 ± 67 μSv and left hand = 78.2 ± 43 μSv). These differences probably can be explained by the use of our homemade drawing device, which avoids close contact between the technologist's hands and the ^{18}F-FDG vial and which appears to be more effective than the grip used by Linemann et al. (*4*). Moreover, the use of the shielded semi-automated injector, which avoids syringe handling during the injection, also may contribute to the reduction in hand exposure.

In parallel, we identified some technical problems (Table 5). The first problem occurred during syringe filling (step 2) and was attributable to syringe disconnection from its shield protection, which led to a longer dose preparation time and to higher finger doses. Several other problems led to an increase in the duration of the dose transfer from the hot cell to the semiautomated injector. These problems included expelling air from the syringe, handling the syringe near the technologist's chest, or difficulties with the syringe interlocking with the semiautomated injector. Moreover, the semiautomated injector got jammed once and therefore caused a longer duration of the injection and an increase in the TLD whole-body dose. One case of a noncompliant patient also occurred, making it necessary to spend more time on positioning and therefore causing an increase in the TLD whole-body dose.

CONCLUSION

It can be concluded from this study that, in our PET center, whatever the ^{18}F-FDG packaging supplied, the use

of our homemade drawing device in association with a shielded semiautomated injector and video tracking of patients led to lower technologist radiation exposure at the whole-body and finger levels than the published values. The use of ^{18}F-FDG multidose vials obviously led to higher finger exposure during receipt of the ^{18}F-FDG containers and syringe filling, but this exposure was associated with packaging containing 4 ^{18}F-FDG doses and so required only 1 receipt step and drawing device installation every 4 patients. Moreover, for 12 mo in succession and for technologists scanning 4 patients per day, the doses measured with either monodose or multidose vials were always lower than the maximum acceptable values reported in European Directive EURATOM 96/29 05/13/1996, even with the technical problems encountered during ^{18}F-FDG manipulation.

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