Equivalent Dose Rate 1 Meter from Neuroendocrine Tumor Patients Exiting the Nuclear Medicine Department After Undergoing Imaging

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^{123}I-metaiodobenzylguanidine (MIBG) and ^{111}In-pentetrotide SPECT have been used for functional imaging of neuroendocrine tumors (NETs) for the last 2 decades. More recently, PET/CT imaging with ^{18}F-FDG, ^{18}F-fluorodihydroxyphenylalanine (FDOPA), and ^{68}Ga somatostatin-receptor ligands in NETs has been expanding. A literature search could find no direct measurements of the dose rate from NET patients exiting the nuclear medicine department after undergoing PET/CT with ^{18}F-FDOPA or ^{68}Ga-DOTATOC, a somatostatin analog. **Methods:** We measured the dose rates from 93 NET patients on leaving the department after undergoing PET/CT or SPECT/CT in our centers. In total, 103 paired measurements of equivalent dose rate at 1 m (EDR-1m) from the sternum and urinary bladder were obtained. The detector faced the sternum or bladder and was 1 m away from and directly in front of the patient. The practice for exiting the department differed according to whether the patient had been referred for PET/CT or for SPECT/CT. PET/CT patients were discharged after imaging, whereas SPECT/CT patients left the department earlier, just after radiopharmaceutical injection. **Results:** The median administered activity was 122 MBq in 53 ^{68}Ga-DOTATOC PET/CT studies, 198 MBq in 15 ^{18}F-FDOPA PET/CT studies, and 176 MBq in 13 ^{18}F-FDG PET/CT studies. The corresponding median EDR-1m was 4.8, 9.5, and 8.8 μSv/h, respectively, facing the sternum, and 5.1, 10.1, and 9.5 μSv/h, respectively, facing the bladder. The median administered activity was 170 MBq in 12 ^{111}In-pentetreotide SPECT/CT studies and 186 MBq in 10 ^{123}I-MIBG SPECT/CT studies. The corresponding median EDR-1m was 9.4, and 4.9 μSv/h, respectively, at the level of the sternum, and 9.3 and 4.7 μSv/h, respectively, at the level of the bladder. The EDR-1m was less than 20 μSv/h in all patients. Thus, when exiting the nuclear medicine department, the NET patients injected with ^{68}Ga-DOTATOC or ^{123}I MIBG emitted an average EDR-1m roughly half that of patients injected with other radiopharmaceuticals. This finding is a complementary argument for replacing SPECT by PET somatostatin-receptor imaging. **Conclusion:** Our current practice of allowing patients to exit after PET/CT imaging or just after SPECT radiopharmaceutical injection appears to be safe from a radiation protection point of view. Restrictive advice is unnecessary for NET patients being discharged from the department.

Key Words: radiation protection; dose rate; somatostatin receptor–based PET/CT; somatostatin receptor–based SPECT/CT; neuroendocrine tumors (NET)

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Among the in vivo imaging modalities, diagnostic nuclear medicine has the major advantage of providing a functional, or biologic, approach. The radiopharmaceutical is administered in minute amounts that induce no adverse effects but nevertheless expose the patient, staff, and others near the patient to radiation during the hours after imaging. When uptake of the radiopharmaceutical by the target organs or lesions is rapid enough, the patient exits the nuclear medicine department after undergoing imaging. For some other examinations, in which the radiopharmaceutical has a long uptake phase, the patient exits the department just after receiving the radiopharmaceutical and returns later for imaging.

Public concern about radiation exposure is growing. To address this concern using actual measurements, we searched the literature for the equivalent dose rate at 1 m (EDR-1m) from the sternum or bladder of a standing patient at the moment of exiting the department after receiving a radiopharmaceutical. Few data in this domain have actually been published, and data on the less frequently used and most recently introduced radiopharmaceuticals are completely lacking. We thus undertook the present study, which measured the EDR-1m of patients exiting the department after receiving a radiopharmaceutical.

For logistic reasons, we limited the measurements to patients who had been referred for diagnostic nuclear medicine imaging because of a neuroendocrine tumor (NET). Although this condition is infrequent, functional nuclear medicine imaging plays a major role in the management of a large proportion of NET patients (*1*). Functional imaging of NETs is currently performed using either of two main techniques of diagnostic nuclear medicine: PET or SPECT (*2*). Several radiopharmaceuticals are available for these techniques, with the selection being made on a patient basis according to the aggressiveness and primary location of the NET (*3*). For PET imaging of NETs (*4,5*), the most frequently used radiopharmaceuticals are the glucose analog ^{18}F-FDG, the amino acid analog ^{18}F-fluorodihydroxyphenylalanine (FDOPA), and a ^{68}Ga-labeled ligand of somatostatin receptors, such as ^{68}Ga-DOTATOC. For SPECT imaging of NETs,

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the catecholamine analog ^{123}I-metaiodobenzylguanidine (MIBG) and another ligand of somatostatin receptors, ^{111}In-pentetreotide, have been used for decades (*6*). Therefore, nuclear imaging of NETs has characteristics that we considered appropriate for our purpose: a reasonable sample can represent the population of NET patients, a large proportion of NET patients are referred for nuclear medicine imaging, PET or SPECT for these patients can be performed with several different radiopharmaceuticals labeled with various radionuclides, and no or few data are available on the radiation emanating from NET patients after receiving these radiopharmaceuticals.

MATERIALS AND METHODS

Patients and Radiopharmaceuticals

The EDR-1m measurements were performed on all consecutive patients referred to us for nuclear medicine imaging of a proven or suspected NET who gave written consent to the use of their anonymized data for research purposes. PET/CT with ^{68}Ga-DOTATOC, ^{18}F-FDOPA, or ^{18}F-FDG was performed at Tenon Hospital. SPECT/CT with ^{111}In-pentreotide or ^{123}I-MIBG was performed at Cochin Hospital. Before being imaged with ^{123}I-MIBG, patients underwent thyroid blockade, precluding any significant thyroid uptake that could interfere with the precocious sternal dose rate measurement.

In both centers, EDR-1m measurements were performed until the results for at least 10 patients were available for each radiopharmaceutical. All nuclear medicine examinations were performed according to the standard procedure of each department for each radiopharmaceutical (Table 1). The radiopharmaceuticals were registered and had a marketing authorization in France. The only exception was ^{68}Ga-DOTATOC, the use of which was authorized by the French Medicine Agency (Agence Nationale de Sécurité du Médicament et Des Produits de Santé) on an individual basis (Autorisation Temporaire d'Use Nominative).

Dose Rate Detectors

The measurements were performed at Tenon Hospital and Cochin Hospital using two different dose rate detectors after they had been cross-calibrated. The detector used at Tenon Hospital was an identiFINDER (FLIR Systems) γ-spectrometer. This is an NaI(Tl) scintillation detector whose equivalent dose rate range (0.01 μSv/h–1 Sv/h) includes the values expected in this study and whose energy range (15–3,000 keV) includes the values of the main photonic rays of the radionuclides administered for NET imaging (*7*): 511–1,883 keV for ^{68}Ga, 511 keV for ^{18}F, 23–245 keV for ^{111}In, and 27–529 keV for ^{123}I.

The detector used at Cochin Hospital was a PDS-100GN-ID Spectroscopic Personal Radiation Detector (Mirion Technologies) that also matches all the same criteria. The difference between dose rates measured simultaneously with the two detectors at 1 m from a ^{51}Co source corresponding to the expected dose rate range was less than 0.1 μSv/h.

Timing of EDR-1m Measurements

To maximize accuracy, a 1-m stick was used to define the distance between the patient and the detector. Two measurements were done: one with the detector facing the sternum and another facing the urinary bladder. The EDR-1m was corrected for the background of the same room in the absence of the patient; the typical background dose rate was 0.04–0.06 μSv/h.

Our aim was to determine the EDR-1m when the patient left the department: in the case of multiple imaging sessions after a single administration of the radiopharmaceutical, the measurements were taken only at the patient's first exit.

Thus, for PET/CT examinations, the EDR-1m was measured after image acquisition, approximately 1.5–2 h after injection of the radiopharmaceutical. The patients voided before the acquisition of the PET images but only rarely voided again afterward (i.e., just before the measurements). The SPECT examinations took place several hours after injection of the radiopharmaceutical; the EDR-1m was therefore measured a few minutes after injection, just before the patient left the department.

Statistics

Comparison of EDR-1m among the 5 radiopharmaceuticals was performed by ANOVA. When the hypothesis of equality of variance was rejected by the Levene test, ANOVA was replaced by the nonparametric

TABLE 1
Radiopharmaceuticals and Practical Options at Each Center

Parameter	^{68}Ga-DOTATOC	^{18}F-FDOPA	^{18}F-FDG	^{111}In-pentetreotide	^{123}I-MIBG
Hospital	Tenon	Tenon	Tenon	Cochin	Cochin
Modality	PET/CT	PET/CT	PET/CT	SPECT/CT	SPECT/CT
Radiopharmaceutical	^{68}Ga-DOTATOC (Iason) and GalliaPharm (Eckert & Ziegler)	Iasodopa (Iason)	Metatrace (Siemens) or Gluscan (AAA)	Octreoscan (Mallinckrodt)	^{123}I-MIBG (Mallinckrodt) or Adreview (GE Healthcare)
Physical half-life (min)	68	110	110	4,032 (2.8 d)	792 (13.2 h)
Scheduled injected activity	1–2 MBq/kg BM	2.5–3.5 MBq/kg BM	2–3 MBq/kg BM	185 MBq	185 MBq
Scheduled interval between injection and imaging (min)	45–90	10 (MTC) and 60	60–120	1,440 (24 h)	240 and 1,440 (4 and 24 h)
Photonic ray for imaging (keV)	511	511	511	245 and 171	159

BM = body mass; MTC = medullary thyroid cancer.

TABLE 2
Patients, Imaging Characteristics, and EDR-1m According to Radiopharmaceutical

Parameter	^{68}Ga-DOTATOC	^{18}F-FDOPA	^{18}F-FDG	^{111}In-pentetreotide	^{123}I-MIBG	Comparison
Patients (*n*)	53	15	13	12	10	χ^2: NSD in sex repartition
Male	29	6	8	6	3	
Female	24	9	5	6	7	
Age (y)	56.7 ± 12.3; 58 (30–76)	60.9 ± 12.1; 61 (29–78)	64.5 ± 17.0; 66 (37–89)	62.1 ± 12.6; 63 (38–81)	51.0 ± 10.2; 53 (30–65)	ANOVA: NSD
Body height (m)	1.70 ± 0.09; 1.71 (1.53–1.96)	1.70 ± 0.09; 1.67 (1.57–1.83)	1.66 ± 0.08; 1.69 (1.51–1.77)	1.70 ± 0.12; 1.72 (1.45–1.86)	1.68 ± 0.10; 1.69 (1.56–1.83)	ANOVA: NSD
Body mass (kg)	72.4 ± 13.8; 71 (49–105)	72.3 ± 13.5; 75 (50–91)	68.4 ± 20.6; 60 (39–120)	72.7 ± 13.7; 73.5 (54–95)	73.3 ± 11.0; 76.5 (58–88)	ANOVA: NSD
Body mass index ($kg \cdot m^{-2}$)	24.9 ± 4.27; 24.5 (17.3–37.1)	24.6 ± 4.27; 24.4 (17.2–34.5)	24.6 ± 6.01; 23.9 (15.2–38.7)	25.1 ± 3.79; 24.4 (18.7–30.7)	26.3 ± 4.03; 25.3 (21.3–33.6)	ANOVA: NSD
Injected activity (MBq)	121 ± 23; 122 (80–170)	199 ± 48; 198 (97–262)	176 ± 56; 167 (98–321)	170 ± 7; 170 (158–179)	186 ± 5; 184 (176–194)	^{68}Ga-DOTATOC < all others; KW: $P << 0.001$
Injected activity per kg body mass (MBq/kg)	1.72 ± 0.42; 1.77 (0.89–2.80)	2.74 ± 0.42; 2.83 (1.87–3.27)	2.59 ± 0.38; 2.51 (2.23–3.81)	2.41 ± 0.48; 2.30 (1.77–3.29)	2.58 ± 0.45; 2.43 (2.00–3.27)	^{68}Ga-DOTATOC < all others; ANOVA: $P < 0.001$
Interval between injection and EDR-1m measurement (min)	90 ± 16; 87 (66–126)	114 ± 14; 117 (86–130)	112 ± 39; 95 (82–220)	6.2 ± 3.5; 5 (2–15)	5.7 ± 2.6; 5 (3–10)	PENT & ^{123}I-MIBG < ^{68}Ga-DOTATOC < ^{18}F-FDOPA & ^{18}F-FDG; KW: $P << 0.001$
EDR-1m from sternum (μSv/h)	4.73 ± 1.41; 4.75 (2.10–9.10)	9.76 ± 3.61; 9.50 (3.92–17.7)	9.34 ± 3.51; 8.80 (3.50–18.8)	9.56 ± 0.93; 9.43 (8.50–11.0)	4.94 ± 0.31; 4.89 (4.45–5.49)	^{68}Ga-DOTATOC & ^{123}I-MIBG < all others; KW: $P << 0.001$
EDR-1m from bladder (μSv/h)	5.04 ± 1.37; 5.10 (2.13–8.20)	10.2 ± 3.20; 10.1 (4.57–15.8)	10.5 ± 4.28; 9.50 (3.80–21.2)	9.21 ± 1.31; 9.30 (5.81–11.2)	4.41 ± 0.93; 4.68 (2.80–5.65)	^{68}Ga-DOTATOC & ^{123}I-MIBG < all others; KW: $P << 0.001$
EDR-1m from sternum per injected MBq (nSv/h/MBq)	39.4 ± 10.7; 37.7 (21.9–89.7)	51.7 ± 25.1; 45.5 (25.0–116)	54.4 ± 13.8; 57.1 (16.5–71.5)	56.3 ± 4.6; 55.5 (50–64)	26.6 ± 1.5; 26.5 (23.6–29.5)	^{123}I-MIBG < ^{68}Ga-DOTATOC & ^{18}F-FDOPA < ^{18}F-FDG & PENT; KW: $P << 0.001$
EDR-1m from bladder per injected MBq (nSv/h/MBq)	41.9 ± 10.0; 41.0 (25.4–88.5)	54.0 ± 23.0; 44.8 (26.1–104)	60.4 ± 15.5; 62.1 (17.9–82.9)	54.3 ± 7.3; 56.0 (34.1–62.5)	23.7 ± 4.9; 25.0 (15.3–29.1)	^{123}I-MIBG < ^{68}Ga-DOTATOC < ^{18}F-FDOPA & PENT < ^{18}F-FDG; KW: $P << 0.001$

NSD = no significant difference; KW = Kruskal–Wallis test; PENT = ^{111}In-pentetreotide.
Data are mean ± SD, or median followed by range in parentheses.

Kruskal–Wallis test. The sternal EDR-1m measurements were compared with the bladder EDR-1m measurements using the *t* test for paired values.

RESULTS

The EDR-1m measurements were performed from April to October 2016, ending when data were available for at least 10 patients for each radiopharmaceutical. In total, 103 paired measurements facing the sternum and the bladder were performed for 98 patients, since 4 patients underwent more than one examination: ^{68}Ga-DOTATOC, ^{18}F-FDG, and ^{111}In-pentetreotide in 1 patient, ^{68}Ga-DOTATOC and ^{18}F-FDOPA in 2 patients, and ^{111}In-pentetreotide twice in 1 patient.

As expected, the choice of radiopharmaceutical differed according to the reason the patient had been referred for nuclear imaging. Of the 53 ^{68}Ga-DOTATOC PET/CT studies, 19 were performed for staging or restaging of a pancreatic NET, 10 for staging or restaging of an intestinal or rectal NET, 6 for staging or restaging of a bronchial or thymic NET, 11 for characterization of a tumor suspected to be NET, and 7 for a NET of unknown primary. Of the 15 ^{18}F-FDOPA PET/CT studies, 12 were performed for staging or restaging of a NET of the ileum, 2 for a NET of unknown primary, and 1 for surveillance of medullary thyroid cancer. Of the 13 ^{18}F-FDG PET/CT studies, 12 were performed for characterization of tumors, mainly lung nodules, suggestive of a NET and 1 for surveillance of an atypical NET of the thymus. Of the 12 ^{111}In-pentetreotide SPECT/CT studies, 4 were performed for staging or restaging of an intestinal NET, 2 for staging or restaging of a pancreatic NET, 3 for characterization of tumors suggestive of a NET, 2 for paraneoplastic Cushing syndrome, and 1 for surveillance of an atypical NET of the thymus. Of the 10 ^{123}I-MIBG SPECT/CT studies, 5 were performed for staging or restaging of a pheochromocytoma, 4 for characterization of lesions suspected of being pheochromocytoma, and 1 for paraneoplastic Cushing syndrome.

The main results of the study are reported in Table 2. There was no significant difference in patient characteristics (sex, age, body height, body weight, and body mass index) among examination types. The injected activity was significantly lower for ^{68}Ga-DOTATOC than for any other radiopharmaceutical. The SD was smaller for SPECT tracers (^{111}In-pentetreotide and ^{123}I-MIBG), since the team at Cochin Hospital uses a fixed-activity approach for those radiopharmaceuticals.

As expected, the interval between injection and measurement was far shorter when the patient had been referred for SPECT/CT than when the patient had been referred for PET/CT. For PET/CT, the patient stayed in the department until the nuclear medicine specialist had reviewed the PET/CT images and allowed the patient to leave. The total stay in the department after injection was significantly shorter when ^{68}Ga-DOTATOC was used than when either of the 2 fluorinated radiopharmaceuticals was used, although the image acquisition could begin at 60 min after injection for all three. The shorter stay for ^{68}Ga-DOTATOC was probably due to the technical constraint related to the shorter physical half-life of ^{68}Ga.

One main result is that the EDR-1m of patients injected with ^{68}Ga-DOTATOC or ^{123}I-MIBG was significantly lower than that with any of the other 3 radiopharmaceuticals.

Comparing the EDR-1m measurements for sternum and bladder in the same patient, we found that the latter was greater overall (paired *t* test, $P < 0.01$). There was a clear difference in bladder EDR-1m between the PET and SPECT tracers, with the measured value being higher for the PET tracers ($n = 81$, $P < 0.001$) and lower, although not significantly so, for the SPECT tracers ($n = 22$, $P = 0.07$).

As expected, there was a strong correlation between EDR-1m and injected activity (MBq or MBq/kg) (all $r > 0.5$, $P < 0.001$).

TABLE 3
Studies Reporting Measurement of EDR-1m After Injection of ^{18}F-FDG

^{18}F-FDG	Present study	Fayad et al. (*11*)	Demir et al. (*12*)	Cronin et al. (*13*)
Patients (*n*)	13	6	30	75
Injected activity (MBq)			550	323; 297
Mean ± SD	176 ± 56	241 ± 33		
Range	98–321	130–311		
Median	167			
Time between injection and EDR-1m measurement (min)	95	90		113; 116
Mean ± SD	112 ± 39		117 ± 11	
Dose rate detector	identiFINDER	AT1123 (APVL Ingénierie)	ESP-2 (Eberline)	Series 1000 (Mini-Instruments)
EDR-1m from sternum (μSv/h)			50	14.7
Mean ± SD	9.34 ± 3.51	6.83 ± 1.58		
Range	3.50–18.8			3.5–32
Median	8.80			14
EDR-1m from sternum per injected MBq (μSv/h/MBq)		NA	90	47
Mean ± SD	54.4 ± 13.8			
Range	16.5–71.5			13–120
Median	57.1			43

NA = not available.

TABLE 4
Studies Reporting Measurement of EDR-1m After Injection of ^{111}In-Pentetreotide

^{111}In-pentetreotide	Present study	Fayad et al. (*11*)	Morán et al. (*14*)	Kurtaran et al. (*15*)
Patients (*n*)	12	6	2	16
Injected activity (MBq)				
Mean ± SD	170 ± 7	119 ± 67		140 ± 40
Range	158–179	105–128	200–220	
Time between injection and EDR-1m measurement (min)		15		
Mean ± SD	6.2 ± 5			
Range			230–240	10–20
Dose rate detector	PDS-100GN-ID	AT1123 (APVL Ingénierie)	MiniTRACE γ (Genitron)	LB 133 (Berthold Technologies)
EDR-1m from sternum (μSv/h)			9.5	
Mean ± SD	9.56 ± 0.93	5.5 ± 0.51		2.86 ± 1.22
Range	8.50–11.0			
Median	9.43			
EDR-1m from sternum per injected MBq (μSv/h/MBq)		NA	43	NA
Mean ± SD	54.3 ± 7.3			

NA = not available.

To test whether the lower EDR-1m with ^{68}Ga-DOTATOC was a consequence simply of its having a lower injected activity than the other radiopharmaceuticals, we compared EDR-1m divided by injected activity (last 2 rows of Table 2). Per unit of injected activity, EDR-1m values were the lowest for ^{123}I-MIBG and the next lowest for ^{68}Ga-DOTATOC, with significantly lower EDR-1m values than those for ^{111}In-pentetreotide, its SPECT alternative. In contrast, we observed no significant correlation between EDR-1m and body mass index ($r = 0.1$).

DISCUSSION

The present study found that EDR-1m was less than 20 μSv/h in all patients, even though the highest values with ^{18}F-FDOPA or ^{18}F-FDG were close to that limit (Table 2). Actually, there is no constraint threshold for this dose rate in the European Union or anywhere else in the world. Furthermore, the few thresholds that have been proposed concerned patients leaving the nuclear medicine department after a therapeutic procedure, not after a diagnostic procedure. The lowest and most recently proposed limit was 20 μSv/h (*8*). In 2010, the practical rules of the Heads of the European Radiological Protection Competent Authorities recommended a limit of 40 μSv/h (*9*).

When exiting the department, patients injected with ^{68}Ga-DOTATOC or ^{123}I-MIBG delivered an average EDR-1m roughly half that delivered by patients injected with other radiopharmaceuticals. For an injected activity of the same order of magnitude, the shorter physical half-life of photons emitted by PET radiopharmaceuticals compensated for their higher energy because the patient had to remain longer before exiting. This finding is a complementary argument for replacing SPECT by PET for imaging of somatostatin receptors.

There were two major differences between PET and SPECT in routine practice. First, a fixed activity was used for patients referred for SPECT, in accord with the scheduled injected activities of the 2 SPECT radiopharmaceuticals in Table 1 and as revealed by the SDs

TABLE 5
Studies Reporting Measurement of EDR-1m After Injection of ^{123}I-MIBG

^{123}I-MIBG	Present study	Ofluoglu et al. (*10*)
Patients (*n*)	10	16
Injected activity* (MBq)	186 ± 5	340 ± 30
Time between injection and EDR-1m measurement (min)	5.7 ± 2.6*	10
Dose rate detector	PDS-100GN-ID	LB 133 (Berthold Technologies)
EDR-1m* (μSv/h)	Sternum: 4.94 ± 0.31; bladder: 4.41 ± 0.93	3.7 ± 0.7

*Data are mean ± SD.

in Table 2. In contrast, the injected activity for PET radiopharmaceuticals was more variable, depending not only on patient body mass (in accord with the scheduled injected activities of the 3 PET radiopharmaceuticals in Table 1) but also on logistic constraints (the delivered activity in the multidose vial for fluorinated radiopharmaceuticals; the eluted activity from the ^{68}Ge/^{68}Ga generator and the labeling yield for ^{68}Ga-DOTATOC).

The second major difference between PET and SPECT in routine practice is that patients who were referred for SPECT left the department a few minutes after injection and came back later for imaging, whereas patients referred for PET did not leave the department until after imaging, at least 1 h after injection (Table 2). This difference in the delay between injection and measurement explains why bladder EDR-1m was significantly greater than sternal EDR-1m for PET radiopharmaceuticals but not for SPECT radiopharmaceuticals. Because all 5 radiopharmaceuticals are excreted through the kidneys, urinary excretion and bladder accumulation of SPECT radiopharmaceuticals are just beginning when the patient exits the department, whereas for the PET radiopharmaceuticals, measured more than 1 h after injection, the bladder has become a radiation source. In this context, the variability of individual biologic half-lives between patients and the frequency of voiding enhance differences in individual equivalent dose rates.

Both factors (more homogeneous injected activity and shorter delay after injection) explain why the EDR-1m values had a much narrower range for SPECT radiopharmaceuticals than for PET radiopharmaceuticals (Table 2).

To the best of our knowledge as derived from an extensive bibliographical survey, no data have yet been published concerning EDR-1m at the time patients leave the nuclear medicine department after undergoing ^{68}Ga-DOTATOC or ^{18}F-FDOPA PET/CT. This lack enhances the interest of the present ^{68}Ga-DOTATOC data derived from a rather large sample ($n = 53$) representative of all NET indications, with a growing demand. The sample size was more limited for ^{18}F-FDOPA, but those data are probably the first of their kind. Very few data have been published concerning ^{18}F-FDG (Table 3), ^{111}In-pentetreotide (Table 4), or ^{123}I-MIBG (Table 5). Overall, all series are in accordance with the fact that the patient may leave the nuclear medicine department according to the current practice, that is, just after injection for ^{111}In-pentetreotide or ^{123}I-MIBG, without risk of exposing the public to excessive radiation. It is also clear that new developments in PET/CT scanners, particularly time-of-flight technology, have allowed a reduction in ^{18}F-FDG injected activity and consequently a reduced EDR-1m (Table 3). In contrast, Demir et al. (*12*), who injected on average 3 times more ^{18}F-FDG than we did, reported EDR-1m measurements of well above 20 μSv/h. Even when it was possible to normalize EDR-1m per megabecquerel of injected activity, a rather large variation in results between studies of similar design could be observed. One possible explanation is the small number of patients in most studies, including ours (apart from ^{68}Ga-DOTATOC). Differences in individual functional processes lead to variability in EDR-1m enhanced by PET patients' lengthened stay in the department compared with SPECT patients. Nevertheless, this factor seems insufficient to explain a ratio of 3 in EDR-1m for ^{111}In-pentetreotide between the series of Kurtaran et al. (*15*) and ours: the waiting time is short and the injected activities are not in the same proportion. A similar question can be raised when comparing EDR-1m values after administration of ^{123}I-MIBG; these values were significantly lower in the series of Ofluoglu et al. (*10*) than in ours, although the injected activity was almost twice greater. An alternative hypothesis involves the detectors themselves. Although our two detectors, produced by two different manufacturers, gave similar EDR-1m values, one cannot exclude the possibility that different dose rate detectors give discrepant results for the same measurements, particularly when the measurements have been performed over 14 y or more.

CONCLUSION

When patients left the nuclear medicine department after undergoing ^{68}Ga-DOTATOC PET/CT, their EDR-1m was lower than that after ^{111}In-pentreotide injection, but the EDR-1m of patients who left after undergoing ^{18}F-FDOPA PET/CT was higher than that after ^{123}I-MIBG injection. Nevertheless, EDR-1m was less than 20 μSv/h in all patients for all 5 radiopharmaceuticals. Our nuclear medicine departments' current practice regarding exiting of NET patients after receipt of radiopharmaceuticals appears to be safe from a radiation protection viewpoint. There is no need to restrict patients from traveling by public or private transportation when authorizing them to leave the department after receiving nuclear medicine radiopharmaceuticals.

DISCLOSURE

No potential conflict of interest relevant to this article was reported.

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