Cerrahpaşa Med J 2022; 46(3): 226-229 **ORIGINAL ARTICLE**

Evaluation of Annual Occupational Doses of Technologists in Diagnostic Nuclear Medicine

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Abstract

Objective: This study aimed to determine the radiation dose contribution of radiopharmaceuticals labeled with 99mTc, 18F, and 68Ga to the technologists' annual occupational doses over 6 years.

Methods: The scintigraphic examinations were subdivided into 6 groups: (i) positron emission tomography/computed tomography (fluorine-18 fluorodeoxyglucose and Gallium-68 prostate-specific membrane antigen/Dotatate), (ii) positron emission tomography/Magnetic Resonance, (iii) single-photon emission computerized tomography/computerized tomography, (iv) single-photon emission computerized tomography, (v) thyroid scintigraphy and uptake, and (vi) dual-energy x-ray absorptiometry. A total of 19 technologists worked in the period between 2016 and 2021, and the corresponding personnel dosimeter records were evaluated retrospectively. The annual number of scintigraphic examinations and annual occupational doses to which the technologists were exposed as well as the absorbed doses per procedure were yielded in microsievert (μSv) for the working technologists.

Results: Annual occupational dose values and dose per exam were found to be 4.6 ± 2 mSv and 4.67 ± 1.75 μSv in positron emission tomography/computed tomography, 1.434 ± 0.249 mSv and 3.64 ± 0.76 μSv in positron emission tomography/Manetic Resonance MR scans, 2.008 ± 0.3 mSv and 0.98 ± 0.07 μSv in single-photon emission computerized tomography/computerized tomography scans, 1.478 ± 0.386 mSv and 0.63 ± 0.24 μSv in single-photon emission computerized tomography scans, 1.710 ± 0.154 mSv and 0.59 ± 0.06 μSv in thyroid scintigraphy and uptake measurements, and 0.334 ± 0.221 mSv and 0.052 ± 0.027 μSv in dual energy x-ray absorptiometry scans.

Conclusion: The dose contribution of positron emission tomography/computed tomography is the highest among the nuclear procedures conducted for diagnostic purposes. Our analysis highlighted that the workload of imaging technologists should be limited to 10 patients per day in positron emission tomography/computed tomography involving the routine tasks of activity preparation, injection, patient positioning, and patient discharge.

Keywords: Technologist doses, radiation doses, PET/CT staff doses

Introduction

In nuclear medicine, diagnostic and therapeutic procedures are performed with different types of radiopharmaceuticals. In common practice, radiopharmacists take the task of labeling radiopharmaceuticals and quality control tests. The imaging technologists are assigned to dispense radioactivity and inject it into the patients and then diagnostic images are acquired under the control of a specialized doctor. In addition, technologists are responsible for positioning the patients on the table and discharging them at the end of the scan. Inevitably, technologists are exposed to different radiation levels during administration and imaging with respect to the used radionuclide.[1] Single-photon emission computerized tomography (SPECT) and SPECT/computerized tomography (CT) scans are extensively performed using radiopharmaceuticals labeled with technetium 99m (99mTc) which emits monoenergy gamma rays of 140 keV. However, a significant increase in personnel radiation doses was observed with the introduction of positron emission tomography (PET)/CT in nuclear medicine.[2] Several radiopharmaceuticals are used in PET/CT scans involving fluorine-18 fluorodeoxyglucose (18F-FDG), gallium-68 prostate-specific membrane antigen (68Ga-PSMA), and 68Ga-Dotatate. The energy of the annihilation photons used in PET/CT is 511 keV, and it is about 3 times higher than the applicable energies in SPECT/CT scans that raised the radiation dose of PET/CT workers.[3]

Radiation protection officers should use a dosimeter device for ionizing radiation detection. There are 2 types of dosimeters routinely used for measuring radiation doses. Optical luminescence (OSL) and thermoluminescence (TLD) are well-known dosimeters worn on the collar of the staff for 2-month periods. At the end of each period, the used dosimeter is replaced with a new one and sent to the dose reading unit. Dose results are generally controlled by radiation safety committees to take the necessary actions and precautions in case of excessive radiation dose risks. According to the radiation safety regulation, the annual occupational dose limit was determined as 20 mSv per year for personnel working in the radiation fields.[4] The radiation dose to which technicians are exposed generally occurs during the preparation and administration of radiopharmaceuticals to the patient. However, some dose is also formed when patients are positioned for extraction. All accumulated doses formed in these applications are recorded in the technician's dosimeter.

According to information obtained from previous studies, the radiation exposure of personnel working in nuclear medicine is usually due to patients who have been administered radiopharm

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aceuticals.[5] In addition, radiation is also exposed in routine procedures such as the preparation of radiopharmaceuticals and injections of patients. Technologists are closest to patients in diagnostic nuclear medicine applications. The nuclear medicine center where this study was conducted is one of the leading centers in our country, both in terms of equipment and the number of scintigraphic examinations performed.

In this study, the annual radiation doses were retrospectively analyzed by the imaging technologists who worked with 99mTc, 18F, and 68Ga over a period of 6 years. The dose contribution as well as the dose per procedure for each agent was derived.

Methods

This study was approved by the Istanbul Univfersity-Cerrahpa sa, Cerrahpaşa Medical Faculty Ethics Committee (Date: February 22, 2022- Decision No:32). This study was conducted in one of the leading centers in Turkey in terms of instrumentation and the number of scintigraphic examinations. The scintigraphic examinations performed in Cerrahpaşa Medical Faculty/Nuclear Medicine were classified into 6 units: (i) PET/CT (18F FDG and 68Ga PSMA/Dotatate), (ii) PET/MR, (iii) SPECT/CT, (iv) SPECT, (v) thyroid scintigraphy and uptake, and (vi) dual-energy x-ray absorptiometry (DEXA). A total of 19 technologists worked in the department where this study was conducted. Among them, 6 technologists worked in PET/CT (18F) scans, 3 technologists in PET/MR scans, 3 technologists in SPECT/CT scans, 2 technologists in SPECT scans, 2 technologists in thyroid scintigraphy and thyroid uptake measurements, and 2 technologists in DEXA measurements.

Statistical Analysis

A total of 216 dosimeter readings were made in 2-month periods over 6 years by 6 technologists who were in charge of PET/CT scans, one of the diagnostic procedures. Three technologists were working in PET/MR 108 times, 4 technologists were working in SPECT/CT 144 times, 2 technologists were working in SPECT 72 times, 2 technologists were working in thyroid uptake test 72 times, and 2 technologists were working in bone mineral density measurement 72 times. Reading has been taken. Statistical significance between dosimeter readings was evaluated with the Mann–Whitney *U* test.

Results

The dose records were retrospectively analyzed showing the following results. In group I, a total of 6 technologists were involved in PET/CT scans (18F FDG and 68Ga PSMA and DOTATATE) over 6 years. The average AOD value of the technologists was calculated as 4592 ± 200 μSv (4.6 ± 2 mSv) over 6 years (Table 1). In group II, 3 technologists in PET/MR showed AOD value of 1431 ± 243 μSv (Table 2). In group III, SPECT/CT scans included whole-body bone scintigraphy, 3-phase bone scintigraphy, bone SPECT scans, myocardial perfusion scintigraphy, A multigated acquisition (MUGA) scan, parathyroid scintigraphy, 177Lu PSMA whole-body scintigraphy, 177Lu Dotatate whole-body scintigraphy, and 131I whole-body scintigraphy. Two technologists who actively worked in SPECT/CT for 5 years showed mean AOD of 2008 ± 324 μSv (Table 3). In group IV, SPECT scans included lung perfusion/venti lation scintigraphy, conventional brain scintigraphy and brain perfusion scintigraphy, cisternography, 3-phase whole-body bone scintigraphy, hepatobiliary scintigraphy, liver spleen scintigraphy, marked leukocyte scintigraphy, hemangioma scintigraphy, all scintigraphy body tumor imaging, and sentinel lymph node scintigraphy. The 6-year average absorbed doses of 2 technologists working as attendants in SPECT units were found to be 1478 ± 386 μSv.

In group IV, SPECT scans included lung perfusion/ventilation scintigraphy, conventional brain scintigraphy and brain perfusion scintigraphy, cisternography, 3-phase whole-body bone scintigraphy, hepatobiliary scintigraphy, liver spleen scintigraphy, marked leukocyte scintigraphy, hemangioma scintigraphy, osseous hemangioma scintigraphy, whole-body tumor imaging, and sentinel lymph node scintigraphy. The 6-year average absorbed doses of 2 technologists working as radiation attendants in SPECT recordings were found to be 1478 ± 386 μSv.

In group V, 2 technologists performed thyroid scintigraphy and thyroid uptake measurement across 6 years showing an average AOD of 1710 ± 154 μSv.

In group VI, the 6-year average absorbed dose of 2 technologists who performed bone mineral density measurements (DEXA) was found to be 334 ± 220.

The number of scans was determined year by year and the highest number of scintigraphy performed in 6 years was SPECT/CT with a total of 47 364 scans and average annual procedures of 7474 ± 1740. The lowest frequency was a result of thyroid scintigraphy and thyroid uptake measurements with a total of 4264 exams and average annual procedures of 710 ± 154. During the 6 years, the total number of 18F-FDG PET/CT scans was 38 261 and the annual procedures mean was 6377 ± 1610 (Table 4).

Pertaining to the dose per scintigraphic examination, the highest dose/exam was found to be 4.67 ± 1.75 μSv in PET/CT scan and

Table 1. Annual Occupational Doses (AOD) of Technologists Working in PET/CT

	AOD (μSv)						
Technologist No	**2021**	**2020**	**2019**	**2018**	**2017**	**2016**	**Mean ± SD**
1	4190	4400	5410	4140	4160	4010	4385 ± 517
2	4230	4221	5380	5100	4100	4270	4550 ± 544
3	4552	5088	4560	4850	4850	4876	4796 ± 206
4	4740	3070	5060	4450	4450	4310	4346 ± 681
5	4800	4440	5480	4620	4620	4890	4808 ± 365
6	4580	4540	4950	4740	4740	4460	4668 ± 177
Mean ± SD							4592 ± 200

PET/CT, positron emission tomography/computed tomography; SD, standard deviation.

Table 2. Annual Occupational Doses (AOD) of Technologists Working in PET/MRI

Technologist No	AOD (μSv) 2021	2020	2019	2018	2017	2016	Mean ± SD
1	1410	2760	1310	1500	1646	1430	1676 ± 542
2	1460	1260	1640	1531	1253	-	1429 ± 170
3	1100	1260	1180	1238	1195	1160	1188 ± 57
Mean ± SD							1431 ± 243

PET/MRI, positron emission tomography/magnetic resonance imaging; SD, standard deviation.

Table 4. The Number of Annually Performed Procedures

Study Name	2021	2020	2019	2018	2017	2016	Mean ±SD
PET/BT	3293	6005	7407	7148	7588	6820	3538 ± 968
PET/MR	1289	1085	1033	1100	1214	950	1111 ± 123
SPECT/CT	5289	6613	10144	9081	8375	7862	7474 ± 1740
SPECT	5106	3666	4026	4860	5424	6300	4897 ± 906
thyroid	1640	1446	1714	1757	1845	1862	1710 ± 154
DEXA	2635	4034	7204	7424	7002	8620	6152 ± 2298

DEXA, dual-energy x-ray absorptiometry; PET, positron emission tomography; SD, standard deviation; SPECT, single-photon emission computerized tomography.

subsequently decreased to 3.64 ± 0.76 μSv in PET/MR, 0.98 ± 0.07 μSv in SPECT/CT, 0.63 ± 0.24 μSv in SPECT, 0.59 ± 0.06 μSv in thyroid, and the lowest value was 0.052 ± 0.025 μSv in DEXA scans (Table 5).

Statistical evaluation between groups was done using Mann–Whitney *U* test. When the 6 groups were compared in pairs, only the doses of technologists working in group II PET/MR and group IV SPECT. There was no significant difference between the technologists working in group SPECT (P = .1). A highly significant difference was found between the other groups (P < .01-.00001).

Discussion

Radiopharmaceuticals labeled with 99mTc, 18F, and 68Ga are mostly used in diagnostic examinations in nuclear medicine centers. The preparation of these radiopharmaceuticals, their application to the patient, and the shooting are within the scope of the technologists. Technologists are exposed to radiation during these practices and the absorbed radiation doses are measured with dosimeters they wear on their collars in 2-month periods. In this study, it was aimed to determine the radiation doses of technologists for a period of 6 years and to evaluate the results in terms of radiation safety. Annual absorbed dose values during diagnostic examinations were 4.6 ± 2 mSv in PET/CT scans, 1.431 ± 0.243 mSv in PET/MR scans, 2.008 ± 0.3 mSv in SPECT/CT scans, 1.478 ± 0.386 mSv in SPECT scans, 1.710 ± 0.154 in thyroid scintigraphy and uptake measurements, 0.334 ± 0.221 mSv in DEXA recordings.

The annual permissible whole-body radiation dose has been determined as 100 mSv in 5 consecutive years, with an average of 20 mSv per year. However, the International Atomic Energy Agency (IAEA) recommended that the average annual dose for radiation workers in nuclear medicine centers was <5 mSv.[6] Whereas, the maximum annual dose to those under the age of 18 and intern students was recommended as 6 mSv. However, significant efforts have been made to safely manage radiation exposure of medical caregivers. In this context, ALARA (as low as reasonably achievable) principles have been introduced by the International Committee on Radiation Protection (ICRP) to justify medical radiation practices and to keep radiation exposure as low as possible. Therefore, radiation protection rules have been authorized

Table 3. Annual Occupational Doses (AOD) of Technologists Working in SPECT/CT

Technologist No	AOD (μSv) 2021	2020	2019	2018	2017	2016	Mean ± SD
1	1700	2280	3180	2484	2183	2530	2392 ± 487
2	-	1680	2280	1888	2158	2246	2050 ± 258
3	1870	1780	1820	1573	1285	1280	1601 ± 267
4	1590	1610	2180	2150	2307	2100	1989 ± 309
Mean ± SD							2008 ± 324

SD, standard deviation; SPECT/CT, single-photon emission computerized tomography/computerized tomography.

Table 5. Average Annual Occupational Doses (AOD) Per Procedure for Medical Imaging Technologists

Study Name	Average AOD Per Procedure (μSv) 2021	2020	2019	2018	2017	2016	Mean ± SD
PET/BT	8.22	4.28	4.16	3.90	3.54	3.93	4.67 ± 1.75
PET/MR	3.07	4.86	3.99	3.88	3.37	2.72	3.64 ± 0.76
SPECT/BT	0.97	1.11	0.93	0.89	0.94	1.03	0.98 ± 0.07
SPECT	0.43	0.91	0.93	0.67	0.47	0.40	0.63 ± 0.24
Tiroit	0.58	0.66	0.64	0.52	0.56	0.59	0.59 ± 0.06
DEXA	0.02	0.04	0.09	0.07	0.04	0.04	0.052 ± 0.025

DEXA, dual-energy x-ray absorptiometry; PET, positron emission tomography; SD, standard deviation; SPECT, single-photon emission computerized tomography.

to reduce radiation dose and related side effects. Accordingly, unnecessary radiation exposure should be avoided, the workload time should be kept reasonable, and leaded shields (leaded apron, thyroid shield, etc.) should be used in medical radiation investigations. In this study, AODs were analyzed in 6 groups of scintigraphic exams involving 19 technologists. The lowest AOD was 1178 ± 491 μSv/year (1.178 ± 0.491 mSv/year) for DEXA staff and the highest was 4385 ± 200 μSv/year (4.385 ± 2 mSv/year) for PET/CT staff.

The energies of radiopharmaceuticals used in PET/CT scans are close to 511 keV, which is approximately 3 times higher than the energy of 99 mTc used in SPECT/CT scans which increases the absorbed doses of technologists working in PET/CT ward. Based on this study, the dose per procedure in PET/CT (18F FDG) scans was found to be approximately 7 times higher than SPECT/CT. Similarly, the technologist dose per examination in PET/CT scans was 2.11 times higher than SPECT. This is due to probably the advanced technology in SPECT/CT systems that allow the operators to set up and start the procedure from the control panel, while the technologists stand closely near the patients in SPECT scans. Likewise, Pant et al[7] evaluated PET/CT radiation doses and reported 3.24 μSv per scan in PET/CT and Peet et al[3] reported a technician radiation dose of 0.0-3.2 μSv per procedure. Moreover, Seirstad et al[8] reported that technologists received annual doses of 20-25 nSv per procedure and a total of 2-3 mSv annually. Fathy et al[9] determined the technician doses per examination in several nuclear medicine procedures showing 6.1 μSv absorbed dose per procedure in bone scintigraphy, 4.1 μSv in 131I whole-body scan, and 11.1 μSv in PET/CT. Moreover, the annual absorbed doses of 5 PET/CT working technologists were investigated, demonstrating annual absorbed dose of 7.82 mSv for an employee who injected 555 MBq 18F-FDG and carried out the scan.[10] At present, the amount of 18F-FDG activity applied to the patient in PET/CT scans was reduced by approximately 1/3. About 296-370 MBq (8-10 mCi) 18F-FDG is injected for PET/CT scan at Cerrahpaşa Nuclear Medicine Center which leads to a significant reduction in radiation exposure. On the basis of this study, the imaging technologist receives an average dose of 4.67 ± 1.75 μSv/patient during injection, patient entrance to the scanning room, and positioning of the patient in PET/CT. Accordingly, it has been estimated that a PET/CT technician is almost exposed to an annual radiation dose of 4.6 ± 2 mSv with a workload of 240 days in a year and10 patients/day. This was found to be lower than the results reported in our previous publication (7.82 mSv per year) and still, less than 5 mSv/year as recommended by IAEA. Also, this dose level is deemed within a safe limit and can be further reduced by implementing the necessary radiation protection rules.

According to the significance evaluation of the radiation dose exposure between the groups, there was no significant difference between the effective doses of PET/MR and SPECT technologists. However, when the other groups were compared in pairs, a significant difference was found in all of them.

In this study, the radiation doses of technologists were determined during diagnostic examinations with a 6-year research in a large-capacity nuclear medicine center. A significant level of maturity has been reached in terms of the number of examinations performed during the 6 consecutive years of study. However, the complete isolation of some technologists from patients treated with radionuclide may not have been achieved. This situation can be evaluated separately in terms of radiation dose exposure.

Consequently, it has been determined that the radiation dose that technologists are exposed to in PET/CT is the greatest of the other diagnostic applications in nuclear medicine. From a radiation safety standpoint, it would be appropriate to limit the technologists' daily load to 10 patients per day in PET/CT by taking full duties of preparation, injection of radiopharmaceuticals, positioning the patient, and discharging the patient after finishing the scans.

Ethics Committee Approval: Ethical committee approval was received from the Ethics Committee of Istanbul University-Cerrahpaşa Cerrahpaşa Medical Faculty (Date: February 22, 2022, approval No: 32).

Informed Consent: Written informed consent was obtained from all participants who participated in this study.

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