International Journal of Environmental Science and Technology (2019) 16:5251–5258
https://doi.org/10.1007/s13762-019-02262-1

ORIGINAL PAPER

Determination of radiation dose from patients undergoing Tc-99m Sestamibi nuclear cardiac imaging

O. Günay[1,2] · M. Sarıhan[1] · O. Yarar[1] · M. Abuqbeitah[3] · M. Demir[3] · K. Sönmezoğlu[3] · E. Abamor[4] · Ö. E. Kara[4] · N. İpek Işıkcı[5] · S. Aközcan[6] · F. Kulalı[7] · H. Öztürk[1] · D. Yaşar[8] · Ö. Gündoğdu[2]

Received: 16 August 2018 / Revised: 28 January 2019 / Accepted: 5 February 2019 / Published online: 12 February 2019

Abstract

To date, myocardial perfusion (MP) has been utilized to assess the adequacy of blood flow to the myocardium in order to determine the ischemic heart diseases. With the advent of SPECT/CT, MP became the most common investigation in the field of nuclear cardiology with more accuracy and details. Thallium-201 and Technetium-99m (Tc-99m) have been early used in cardiac nuclear imaging. Half-life of Tc-99m is 6 h, and its energy is 140 keV, while the half-life of Tl-201 is as longer as 73 h, its X-ray energies range between 69 and 81 kV in addition to gamma rays of 135 keV and 167 keV. The purpose of the present study was to explore the radiation dose rates emitted from the patients following Tc-99m sestamibi injection. To achieve that, the radiation emanated to the environment was measured at different distances from patients and various time intervals for 20 patients using GM counter. The mean radioactivity administered to the patients was 391.1 MBq (10.6 mCi), with a range between 276.8 MBq to maximum of 515.4 MBq. Radiation dose rate was found 9.07 μSv h^{-1} at 1 m distance from the patient's chest level after 7.6 min, then decayed to 7.93 μSv h^{-1} after 36.5 min, and 7.83 μSv h^{-1} later to 66.4 min. It was concluded that 1 m distance from the patients sounds sensibly adequate to maintain the occupational dose within the safe limit following Tc-99m sestamibi injection, while verification of public dose rate ≤ 1 μSv h^{-1} at 1 m distance from the patient prolongs to 14 h following Tc-99m injection.

Keywords Radiation dose rate · Tc-99m · Hospital management

Introduction

People are usually exposed to artificial and natural radiation sources in their life span (Akkurt et al, 2015; Çetin et al. 2016; Demir et al. 2017; Günay 2018; Kara et al. 2017a; 2016a; Mavi and Akkurt 2010; Seçkiner et al. 2017). Accordingly, determination of radiation level is a prerequisite for justification of practice and radiation protection in the public health (Kara et al. 2017b). Over the past, many studies have been carried out to determine both occupational and natural radiation doses (Aközcan et al. 2014; Günay et al. 2018). Moreover, the concept of radiation dosimetry has gained greater concern with the widespread use of radioactive substances in the medical domain (Kara et al. 2016b; Çelen and Evcin 2018a; Çelen and Evcin 2018b).

Editorial responsibility: iskender AKKURT.

✉ O. Günay
osman.gunay@okan.edu.tr

1 Vocational School of Health Services, Istanbul Okan University, Istanbul, Turkey

2 Faculty of Technology, Kocaeli University, Kocaeli, Turkey

3 Department of Nuclear Medicine, Cerrahpasa Faculty of Medicine, Istanbul University-Cerrahpasa, Istanbul, Turkey

4 Istanbul Okan University Hospital, Istanbul, Turkey

5 Faculty of Engineering and Architecture, Nisantasi University, Istanbul, Turkey

6 Faculty of Art and Science, Kirklareli University, Kirklareli, Turkey

7 Vocational School of Health Services, Usküdar University, Istanbul, Turkey

8 Faculty of Art and Science, Ahi Evran University, Kirşehir, Turkey

Cardiovascular diseases are the most common causes of death around the world. Many health organizations declared that coronary artery disease (CAD) has a rising incidence in developing countries despite the exerted efforts to reduce the rate. Nuclear cardiology plays a substantial role in the detection and diagnosis of several cardiovascular disorders. In particular, the introduction of photoemission tomography (SPECT) has improved the diagnosis and prognosis of many cardiac conditions such as: CAD, infarct diagnosis, size, prognosis and risk assessment, evaluation of ventricular function, congestive heart failure, determination of stunning myocardial hibernation and evaluation of viability. In nuclear cardiology, radionuclides of Tl-201 and Tc-99m sestamibi are the most frequently used in myocardial perfusion imaging. Tc-99m-labeled legends has become the preferential agent in the myocardial imaging due to its superior physical properties compared to Thallium-201. For instance, the shorter half-life of Tc-99m (6 h) and the optimum efficiency in the interaction with the detector's crystal enabled more injections load and enhanced image quality. Simultaneously, Gated SPECT using technetium further helped to assess the ventricular functional parameters such as ventricular volume, ejection fraction, adjacent wall motion, and thickness (Germano et al. 1995). Tc-99m sestamibi is routinely applied in the form of two separate injections as stress and rest modes and a lot of investigators indicated the usefulness of nitroglycerin administration in evaluating viability (Maurea et al. 1995; Batista et al. 1999).

On the other hand, the radiation exposure hazards were beyond the radiation protection rules recommended by several global organizations. The International Commission on Radiological Protection (ICRP) recommended dose rate of 20 $\mu Sv\ h^{-1}$ at 1 m for discharging patients following radionuclide therapy (Abuqbeitah et al. 2017). These principles also regulate the safe use of radioactive materials in order to minimize the exposure risk to patients, caregivers, general public and environment. Thus, it is indeed important to explore the radiation intensity emitted from the patient and the expected dose rate after radiopharmaceutical injection in nuclear medicine.

The main purpose of this study was to determine the radiation dose rate in patients with cardiac diseases after radiopharmaceutical Tc-99m sestamibi venous injection into the body at different distances along the time.

Materials and methods

This study was conducted at the Hospital of Okan University in Istanbul including 20 patients (7 males and 13 females). The participants were randomly selected with an average age of 56.45 years (range: 34–81 years). The patients have average weight of 78 kg, minimum of 50 kg, and maximum weight up to 100 kg. The minimum injected dose to the patients was 276.8 MBq (7.5 mCi), and the maximum activity was 515.4 MBq (13.9 mCi) with a mean of 391.1 MBq (10.6 mCi). Informed consent was obtained from all individual participants included in the study according to the approval of Istanbul Okan University, Research Ethics Committee.

In the present study, exposure rate due to radiation emitted from the patient was measured at twelve different locations for all of the patients (Günay and Abamor 2018). Firstly, head-level measurements were made at only four distances as 30 cm (0.3 m anterior), 60 cm (0.6 m anterior), 100 cm

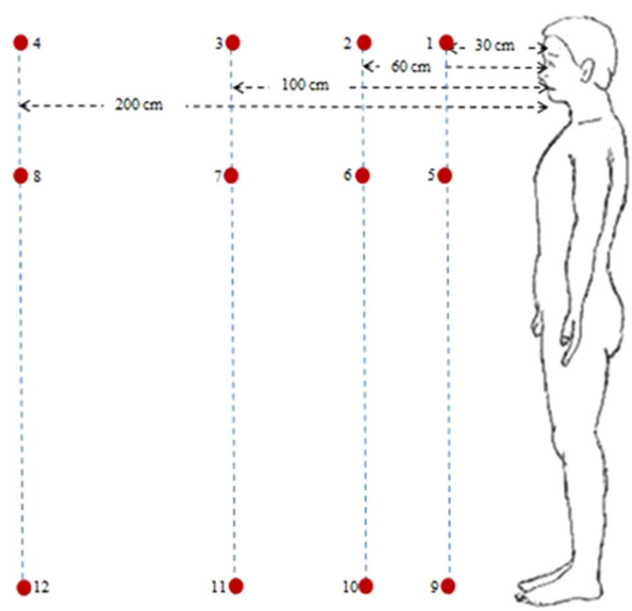

Fig. 1 Measurement regions; (1):30 cm anterior from head, (2): 60 cm anterior from head, (3): 100 cm anterior from head, (4): 200 cm anterior from head, (5): 30 cm anterior from chest, (6): 60 cm anterior from chest, (7): 100 cm anterior from chest, (8):200 cm anterior from chest, (9):30 cm anterior from foot, (10): 60 cm anterior from foot, (11):100 cm anterior from foot, (12): 200 cm anterior from foot

(1 m anterior), and 200 cm (2 m anterior) far a way from the patient's head. Chest-level and foot-level measurements were also acquired at the same distance points of 30 cm (0.3 m anterior), 60 cm (0.6 m anterior), 100 cm (1 m anterior), and 200 cm (2 m anterior) from the patient's chest and foot level (Fig. 1). All records were made at multiple time marks starting from an average of 7.6(range 1–15) min, 36.5(range 23–47) min and ending at 66.4(range 53–90) min after injection.

The radiation dose rates were measured using GM counter (Inspector Nuclear Radiation Monitor Deluxe Dose Rate CPT.5250-0047). Calibration (GM counter) was done by TAEK (Turkish Atom Energy Association) in June 2018.

Results and discussion

The mean dose rates and normalized mean dose rates measured at different distances from the head level at varied times are shown in Table 1. The mean dose rate measured at 100 cm distance from the patients' head level and 7.6 (range 1–15) min after injection was 8.81 (range 5.8–21.64) μSv h^{-1}. Then, the mean dose rate decayed down to 7.72 μSv h^{-1}(range 4.32–16.26) after 36.5 (range 23–47) min, whereas the measured mean dose rate after 66.4 (range 53–90) min was relatively lower as 7.51(4.76–11.43) μSv h^{-1} at 100 cm.

The mean dose rates and the normalized mean dose rates measured at different distances from the chest level

Table 1 Mean dose rates and normalized dose rate for different distance from head

Distance from patient (cm)	Time after the injection (min)	Mean dose rate μSv h^{-1} (range)	Normalized mean dose rate (μSv h^{-1} MBq^{-1})
30	7.6	54.26 (19.31–87.00)	0.139
	36.5	42.21 (14.84–85.5)	0.107
	66.4	34.46 (11.87–63.41)	0.088
60	7.6	20.11 (12.88–29.12)	0.051
	36.5	16.32 (11.12–23.71)	0.041
	66.4	14.92 (9.26–25.95)	0.038
100	7.6	8.81 (5.8–21.64)	0.022
	36.5	7.72 (4.32–16.26)	0.019
	66.4	7.51 (4.76–11.43)	0.019
200	7.6	4.15 (2.8–6.3)	0.011
	36.5	4.02 (1.1–14.71)	0.011
	66.4	3.96 (2.43–6.79)	0.010

Table 2 Mean dose rates and normalized dose rates at different distances from chest

Distance from patient (cm)	Time after the injection (min)	Mean dose rate μSv h^{-1} (range)	Normalized mean dose rate (μSv h^{-1} MBq^{-1})
30	7.6	73.47 (35.02–136.13)	0.019
	36.5	59.06 (32.2–94.13)	0.151
	66.4	50.57 (21.14–83.17)	0.129
60	7.6	22.34 (12.25–32.87)	0.057
	36.5	18.29 (11.58–26.46)	0.046
	66.4	17.94 (7.72–34.85)	0.046
100	7.6	9.07 (5.54–11.47)	0.023
	36.5	7.93 (5.18–11.53)	0.020
	66.4	7.83 (4.13–13.41)	0.020
200 cm	7.6	4.28 (2.67–6.71)	0.011
	36.5	4.12 (2.21–6.73)	0.011
	66.4	4.08 (2.24–7.83)	0.011

Table 3 Mean dose rates and normalized dose rates at different distances from foot

Distance from patient (cm)	Time after the injection (min)	Mean dose rate μSv h^{-1} (range)	Normalized mean dose rate (μSv h^{-1} MBq^{-1})
30	7.6	16.82 (2.51–66.02)	0.043
	36.5	15.12 (3.58–38.14)	0.038
	66.4	14.61 (3.76–74.26)	0.037
60	7.6	13.78 (3.16–21.87)	0.035
	36.5	12.21 (1.59–25.17)	0.031
	66.4	10.35 (4.46–19.62)	0.026
100	7.6	8.43 (3.04–14.23)	0.021
	36.5	7.01 (2.41–15.72)	0.018
	66.4	6.87 (2.84–19.53)	0.017
200	7.6	4.02 (2.16–8.68)	0.010
	36.5	3.98 (2.31–24.36)	0.010
	66.4	3.95 (2.09–7.53)	0.010

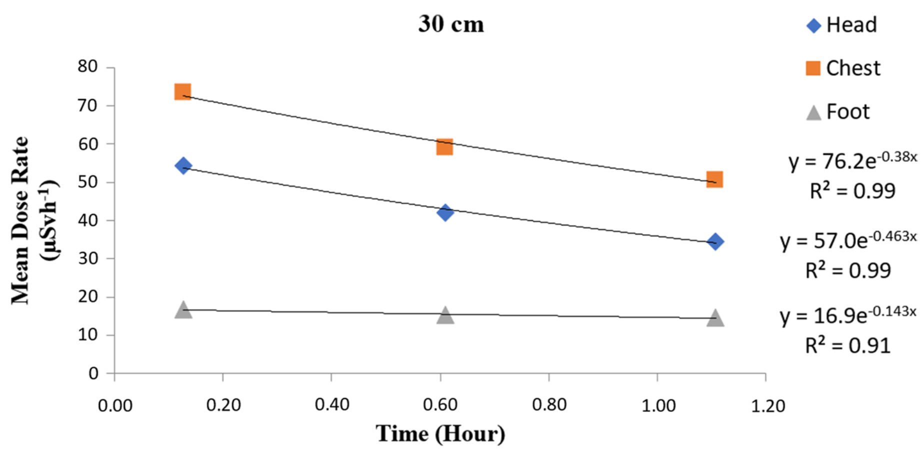

Fig. 2 Mean dose rates over time at 30 cm from the head, chest, and foot of the patients

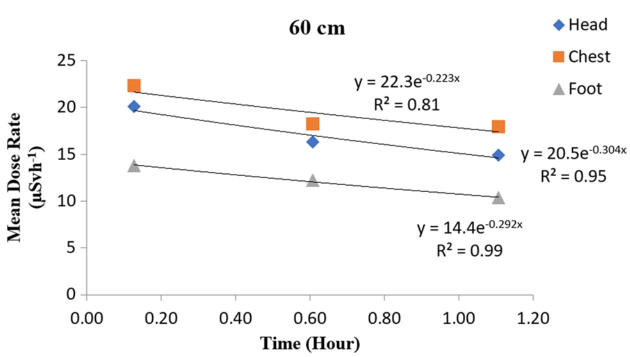

Fig. 3 Mean dose rates decay by time at 60 cm from the head, chest, and foot of the patients

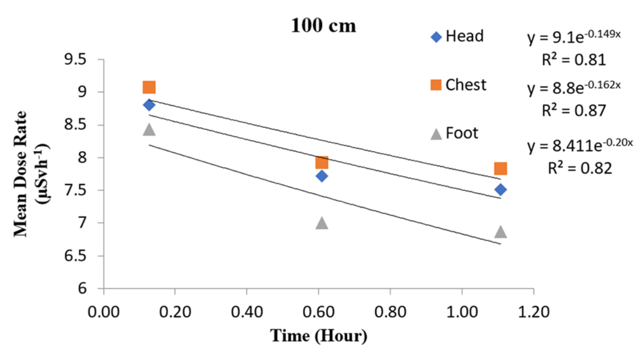

Fig. 4 Mean dose rates decrease by time at 100 cm from the head, chest, and foot of the patient

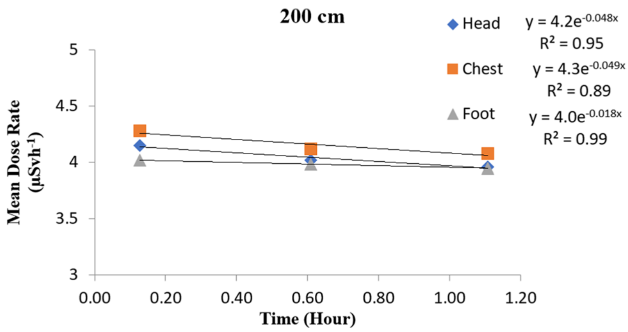

Fig. 5 Mean dose rates by time at 200 cm distance from the head, chest, and foot of the patients

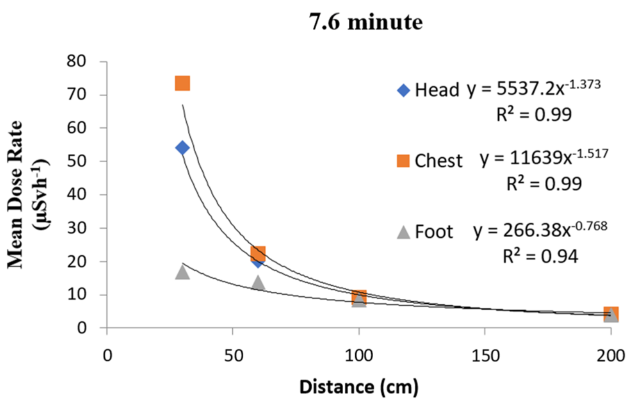

Fig. 6 Mean dose rates by distance from patients' head, chest and foot level after 7.6 min

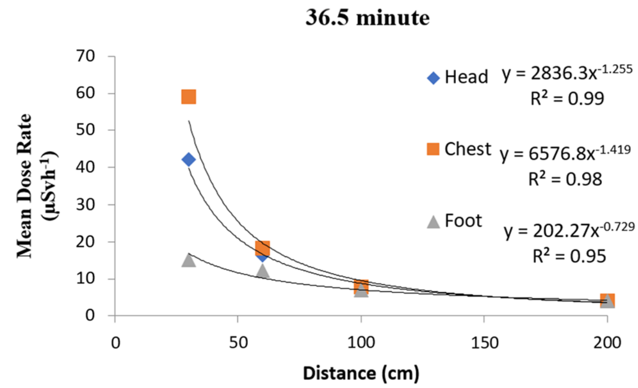

Fig. 7 Mean dose rates by distance from patients' head, chest and foot level after 36.5 min

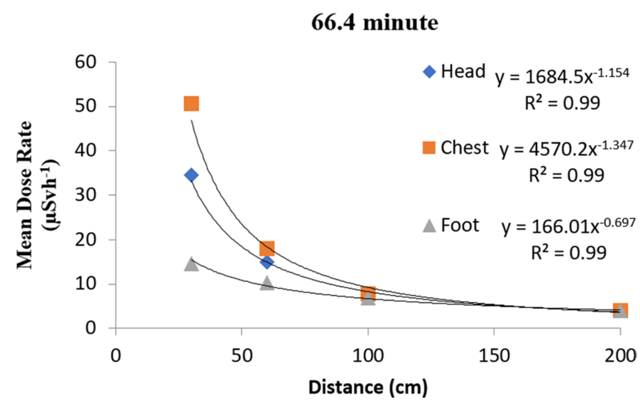

Fig. 8 Mean dose rates by distance from patients' head, chest and foot level after 66.4 min

through variable time points are summarized in Table 2. The mean dose rate measured after 7.6 (range 1–15) min at 100 cm distance from patient chest level was 9.07 (range 5.54–11.47) µSv h^{-1}. The mean dose rate measured following 36.5 (range 23–47) min at 100 cm distance from patients' chest level was 7.93(5.18–11.53) µSv h^{-1}. Ultimately, the mean dose rate registered after 66.4 (range 53–90) min at 100 cm distance from chest level was as low as 7.83 (range 4.13–13.41) µSv h^{-1}.

The mean dose rates and normalized mean dose rates obtained at different distances from the foot level and variable times are reported in Table 3. The mean dose rate measured after 7.6 (range 1–15) min at 100 cm from the patients' foot level was 8.43 (range 3.04–14.23) µSv h^{-1}, and decayed to average dose rate of 7.01 (range 2.41–15.72) µSv h^{-1} after 36.5(range 23–47) min from injection. The mean dose rate persists decaying until 6.87 (range 2.84–19.53) µSv h^{-1} after 66.4 (range 53–90) min at the same distance.

The mean dose rates noted at the mentioned distances of 30, 60, 100 and 200 cm from the patients markedly decreased with the spending time, as shown in Figs. 2, 3, 4 and 5 subsequently. Ordinarily, myocardium perfusion test implies accumulation of higher amount of radioactivity in the heart muscle; therefore, the normalized mean dose rates measured from the chest level at 30 cm 60 cm and 100 cm distances were greater than the head level. Nevertheless, the dose rate at the head level was as same as the chest level at the farthest distance 200 cm from the patients.

In contrast, Figs. 2, 3, 4 and 5 also addressed the power of correlation between the decayed dose rates across the time. It was majorly found a well to robust degree of association at all measurement levels including head, chest and foot level from the commencement of injection until late time points.

The measured mean dose rates at 7.6 min after injection decrease with the distance from the head, chest and foot level. There was also a strong correlation from the fitting of the dose rates to the distance from the patients at all levels as seen in Fig. 6.

The measured mean dose rate at 36.5 min after injection was further decreased due to not only the activity decay, but also the increased distance from the measurement levels (head, chest and foot) of the patient as shown in Fig. 7.

Eventually, the measured mean dose rate at the last time point of 66.4 min after injection showed symmetrical regression with respect to the distance level from the head, chest and foot of the patient. This regression is visualized on the sturdy correlation between the distance from the head, chest, foot level of the patients and the normalized mean dose rates, as demonstrated in Fig. 8.

In common, many studies described the biokinetics of different types of radionuclides where the mutual consequence posed to gradual decrease in the dose rate by time pass and distance from the patients (Demir et al. 2011; Quinn et al. 2012; Cronin et al. 1999; Bera et al. 2018; Fayad et al. 2015).

The occupational radiation dose or the maximum exposure rate in the hot area should be kept below 10 μSv h^{-1} (Demir 2015), while the maximum permissible dose rate for the public is extremely lower as 1 μSv h^{-1}. In this study, the dose rate at 1-m distance from the patient's chest level was 9.07 μSv h^{-1} after 7.6 min, 7.93 μSv h^{-1} after 36.5 min, and 7.83 μSv h^{-1} at the last measurement time of 66.4 min following injection of 391 MBq Tc-99m, while the dose rate at 2 meters from the patient's chest level was much lower to 4.28 μSv h^{-1} after 7.6 min, 4.12 μSv h^{-1} after 36.5 min, and 4.08 μSv h^{-1} at the end time point 66.4 min.

On the basis of the present study, the scintigraphy technologist and the radiation workers should stay at least 1 m away from the patient after 7 min from the injection. Unlikely, the distance should be much bigger and the time for the safest proximity to patients is considerably longer for public safe exposure. In other words, to verify the dose rate limit of the public as low as 1 μSv h^{-1}, it was emphasized through this study that the radiation dose rate less than 1 μSv h^{-1} at 1 m distance from the patient can be reached 14 h after Tc-99m injection. Hence, the companions and patient's family members should stay far away from the patient as much as possible after the commencement of Tc-99m injection to avoid unnecessary radiation exposure. Moreover, careful instructions must be conveyed to the treated patients regarding the acts in the abroad like public transportation, and special care has to be taken to avoid close contact to others in the first 14 h following the onset of the procedure in order to maintain the highest degree of the radiation safety.

Conclusion

In this study, the dose rate of the emitted radiation from patients injected by Tc-99m sestamibi was determined taking into consideration different distances and multiple time marks. It was deduced that keeping 1 m far from the patients can be regarded an adequate distance to keep the occupational dose within the safe limit following Tc-99m injection. It was also emphasized that the permissible dose rate for the public ≤ 1 μSv h^{-1} at 1 m distance from the patient can be fulfilled 14 h after the start of Tc-99m injection.

Acknowledgements Authors would like to thank the Hospital of Istanbul Okan University for cooperation in this study.

Funding This research did not receive any specific grant from any funding agency in the public, commercial or not-for-profit sector.

Compliance with ethical standards

Conflict of interest All authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

Ethical approval All procedures performed in the current study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration. Istanbul Okan University, Research Ethics Committee, approved this study with Decision number: 94 (Date: 09.05.2018). Ethics Committee Members: Prof. Dr. Mithat Kıyak, Prof. Dr. Mazhar Semih Baskan, Prof. Dr. Dilek Öztürk, Prof. Dr. Dilek Sirvanlı Özen, Prof. Dr. Ali Tayfun Atay, Dr. Nermin Bölükbaşı, Dr. Nihat Özaydın, Dr. Kerime Derya Beydağ

Informed consent Informed consent was obtained from all individual participants included in the study.

References

Abuqbeitah M, Demir M, Uslu-Beşli L, Yeyin N, Sönmezoğlu K (2017) Blood clearance and occupational exposure for177Lu-DOTATATE compared to177Lu-PSMA radionuclide therapy. Radiat Environ Biophys. https://doi.org/10.1007/s00411-017-0721-6

Akkurt I, Uyanik NA, Günoğlu K (2015) Radiation dose Estimation: an in vitro Measurement for Isparta-Turkey. IJCESEN 1(1):1–4. https://doi.org/10.22399/ijcesen.194376

Aközcan S, Yılmaz M, Külahcı F (2014) Dose rate and seasonal variations of ^{238}U,^{232}Th, ^{226}Ra, ^{40}K and ^{137}Cs radionuclides in soils along Thrace, Turkey. J Radional Nucl Chem 299:95–101. https://doi.org/10.1007/s10967-013-2730-5

Batista JF, Pereztol O, Valdés JA, Sánchez E, Stusser R, Rochela LM, López D, Garcia EV (1999) Improved detection of myocardial perfusion reversibility by rest-nitroglycerin Tc-99m-MIBI: comparison with Tl-201 reinjection. J Nucl Cardiol 6(5):480–486

Bera G, Soret M, Maisonobe J A, Giron A, Garnier JM, Habert MO, Kas A (2018) Equivalent dose rate from patients after whole-body FDG-PET/CT. Méd Nucl 42(1):45–48. ISSN 0928-1258. https://doi.org/10.1016/j.mednuc.2017.11.003

Çelen YY, Evcin A (2018a) Differentiation of using flattening filter free energy in Vmat plans for prostate cancer. In: ITM web of conferences, vol 22, p 01049. EDP Sciences. https://doi.org/10.1051/itmconf/20182201049

Çelen YY, Evcin A (2018b) Comparison of different algorithms in the radiotherapy plans of breast cancer. In: ITM web of conferences, vol 22, p 01048. EDP Sciences. https://doi.org/10.1051/itmconf/20182201048

Çetin B, Öner F, Akkurt I (2016) Determination of natural radioactivity and associated radiological hazard in excavation field in Turkey (OluzHöyük). Acta Phys Pol A 130:475–478. https://doi.org/10.12693/APhysPolA.130.475

Cronin B, Marsden PK, O'Doherty MJ (1999) Are restrictions to behavior of patients required following fluorine-18 fluorodeoxyglucose positron emission tomographic studies? Eur J Nucl Med 26:121–128. https://doi.org/10.1007/s002590050367

Demir M (2015) Radiobiological effects, protection of the patient, protection of caregivers, protection of those around the patient and the environment. Nucl Med Semin 3:171–179. https://doi.org/10.4274/nts.0026

Demir M, Demir B, Sayman H, Sager S, Sabbir Ahmed A, Uslu I (2011) Radiation protection for accompanying person and radiation workers in PET/CT. Radiat Prot Dosim 147:528–532. https://doi.org/10.1093/rpd/ncq497

Demir N, Kıvrak A, Üstün M, Cesur A, Boztosun I (2017) experimental study for the energy levels of Europium by the Clinic LINAC. IJCESEN 3–1(2017):47–49

Fayad E, Maia S, Zilnus A (2015) Care continuity in post-scintigraphy period and radioactivity exposure of medical and technical staff. Med Nucl (Paris) 39:380–385

Germano G, Kiat H, Kavanagh PB, Moriel M, Mazzanti M, Su HT, van Train KF, Berman DS (1995) Automatic quantification of ejection fraction from gated myocardial perfusion SPET. J Nucl Med 36:2138–2147

Günay O (2018) Determination of natural radioactivity and radiological effects in some soil samples in Beykoz-Istanbul. Eur J Sci Technol 12:9–14. ISSN 2148-2683

Günay O, Abamor E (2018) Environmental radiation dose rate arising from patients of PET/CT. Int J Environ Sci Technol. https://doi.org/10.1007/s13762-018-2040-0

Günay O, Saç MM, Içhedef M, Taşköprü C (2018) Natural radioactivity analysis of soil samples from Ganos fault (GF). Int J Environ Sci Technol ISSN 1735-1472, Online ISSN 1735-2630. https://doi.org/10.1007/s13762-018-1793-9

Kara U, Kara Y, Akkurt I (2016a) A study on radiation in operating room in Suleyman Demirel University. Acta Phys Pol A 129(1):401–403. https://doi.org/10.12693/APhysPolA.129.401

Kara U, Tekin HO, Akkurt I (2016b) Computed tomography routine examinations and the related risk of cancer. Acta Phys Pol A 129(1):409–4011. https://doi.org/10.12693/APhysPolA.129.409

Kara U, Yildiz M, Akkurt I (2017a) Investigation of radiation exposure dose from nuclear medicine procedures (Tc-99m MAG-3). Acta Phys Pol A 132(3):883–885. https://doi.org/10.12693/APhysPolA.132.883

Kara U, Kaya A, Tekin HO, Akkurt I (2017b) Adult patient radiation doses with multislice computed tomography exam: MSCT Standard Protocols. Acta Phys Pol A 132(3):1126–1127. https://doi.org/10.12693/APhysPolA.132.1126

Maurea S, Cuocolo A, Soricelli A, Castelli L et al (1995) Enhanced detection of viable myocardium by technetium-99m-MIBI imaging after nitrate administration in chronic coronary artery disease. J Nucl Med 36:1945–1952

Mavi B, Akkurt I (2010) Natural radioactivity and radiation hazards in some building materials used in Isparta, Turkey. Radiat Phys Chem 79(9):933–939. https://doi.org/10.1016/j.radphyschem.2010.03.019

Quinn B, Holahan B, Aime J, Humm J, Germain JS, Dauer L (2012) Measured dose rate constant from oncology patients administered 18F for positron emission tomography. Med Phys 39:6071–60719. https://doi.org/10.1118/1.4749966

Seçkiner S, Akkurt I, Günoglu K (2017) Determination of 40 K concentration in gravel samples from Konyaaltı Beach. Antalya. Acta Phys Pol A 132(3-II):1095–1097. https://doi.org/10.12693/aphyspola.132.1095