Short Communications

Evaluation of Annual Staff Doses and Radiation Shielding Efficiencies of Thyroid Shield and Lead Apron during Preparation and Administration of ^{131}I, ^{81}Kr, and ^{99m}Tc-Labeled Radiopharmaceuticals

Abstract

Nuclear medicine technicians would receive unavoidable exposures during the preparation and administration of radiopharmaceuticals. Based on the staff dose monitoring, the dose reduction efficiencies of the radiation protection shields and the need to implement additional strategies to reduce the staff doses could be evaluated. In this study, medical staff doses during the preparation and administration of Tc-99 m, I-131, and Kr-81 radiopharmaceuticals were evaluated. The dose reduction efficiencies of the lead apron and thyroid shield were also investigated. GR-207 thermoluminescent dosimeter (TLD) chips were used for quantifying the medical staff doses. The occupational dose magnitudes were determined in five organs at risk including eye lens, thyroid, fingers, chest, and gonads. TLDs were located under and over the protective shields for evaluating the dose reduction efficiencies of the lead apron and thyroid shield. The occupational doses were normalized to the activities used in the working shifts. During preparation and injection of Tc-99 m radiopharmaceutical, the average annual doses were higher in the chest (4.49 mGy) and eye lenses (4 mGy). For I-131 radiopharmaceutical, the average annual doses of the point-finger (15.8 mGy) and eye lenses (1.23 mGy) were significantly higher than other organs. During the preparation and administration of Kr-81, the average annual doses of the point-finger (0.65 mGy) and chest (0.44 mGy) were higher. The significant dose reductions were achieved using the lead apron and thyroid shield. The radiation protection shields and minimum contact with the radioactive sources, including patients, are recommended to reduce the staff doses.

Keywords: *Annual staff doses, lead apron, nuclear medicine, occupational dose, thermoluminescent dosimeter, thyroid shield*

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Introduction

Preparation and administration of radiopharmaceuticals and patient positioning are the most common sources of occupational exposure to ionizing radiation in nuclear medicine centers.[1] Long-term health effects associated with ionizing radiation including cancer and genetic mutations are well established.[2] Thus, the guidelines on limits of exposure and radiation protection requirements for professionals and the general public were legislated.[3]

Nuclear medicine staffs occupationally receive some of the highest radiation doses from man-made radiation sources.[4-6] Therefore, the radiation protection equipment and protective methods must be taken into account to reduce the staff doses.[7] Lead aprons, thyroid shields, syringe and vial shields, protective radiation barriers, and radiation attenuation gloves are common protection equipment that have been claimed to have good results for dose reduction. However, their applications in the nuclear medicine examinations are controversial, because of the characteristic X-rays generated in high atomic number materials, the penetration of gamma rays, and the weight of protective shields which reduces the staff's desire to use them.[8,9]

Lead aprons are typically used in nuclear medicine procedures, despite favorable and unfavorable arguments regarding their use.

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The shielding efficiency of the lead apron depends on its ingredients, radiant photon energy, etc.[10,11]

These aprons are routinely graded based on X-ray energies. These X-ray energies are lower than those that are used in nuclear medicine procedures. Thus, unknown levels of protection would result. Lightweight aprons make this more complicated. For Tc-99 m, the efficiency comparison of lead and lightweight aprons shows that lightweight aprons typically offer fewer protections.[10]

Tc-99 m (with the photon energy of 140 keV) and radioiodine (I-131, with gamma energy of 364 keV and mean beta energy of 192 keV) are the most used radionuclides for nuclear medicine examinations. Other isotopes have become more prominent with technological advancement. In Fog and Collins study,[12] the radiation protection efficiency of the lead apron was evaluated for Tc-99 m and F-18 radioisotopes. Despite the considerable dose reduction for Tc-99 m, minimal protection was observed against F-18. Therefore, the radiation protection efficiency of the apron is not clear for nuclear medicine examinations.

Nuclear medicine technicians would receive unavoidable exposures during the preparation and administration of radiopharmaceuticals.[13] Reversible and irreversible genotoxic effects and biological effects of moderate and high doses of ionizing radiation (>100 mGy) have been reported. Nonetheless, there is still considerable debate regarding the biological effects of low-dose exposures (<100 mGy). Long-term exposure to low-level radiation and associated biological effects are the potential hazards for nuclear medicine staff.[14] Thus, they are subjected to routine monitoring of professional radiation exposures. Based on the staff radiation dose monitoring, the dose reduction efficiencies of the radiation protection shields and the need to implement additional strategies to reduce the staff doses could be evaluated.

The increasing concern regarding the radiation safety of the patients and nuclear medicine technologists accompanied the recent substantial growth in nuclear medicine. Therefore, an attempt to estimate occupational radiation exposure during nuclear medicine procedures is of interest. In this study, medical staff doses were evaluated for the preparation and administration of Tc-99 m, I-131, and Kr-81 radiopharmaceuticals. The dose reduction efficiencies of the lead apron and thyroid shield were also investigated.

Materials and Methods

GR-207 thermoluminescent dosimeter (TLD) chips (PTW, Freiberg, Germany) were used for quantifying the medical staff doses.[15] TLDs were annealed before use to achieve better stability in sensitivity and lower fading. The annealing was performed at 400°C for 1 h followed by fast cooling and subsequent annealing at 80°C for 24 h. Natural variations in the response of materials and physical mass of manufactured TL chips cause a considerable variation in response of dosimeters. Element correction coefficient was used to unify their responses. TLDs were calibrated using Cs-137 standard source, located in the local atomic energy laboratory. TLD calibration was performed for doses of zero to 4 cGy in Plexiglas slab phantom (depth of 0.5 cm and the source to axis distance of 200 cm). The photo-multiplier tube responses (nC) of the TLD reader were converted to delivered doses using the calibration curve. The dose magnitudes absorbed by TLDs were quantified using the light telemetry reader (LTM, Fimel, France).

Medical staff doses were evaluated during nuclear medicine examinations. In these procedures, the most commonly used radionuclides, including Tc-99 m, I-131, and Kr-81 were prepared and administered. The occupational dose magnitudes were determined in five organs at risk (OAR) including eye lens, thyroid, fingers, chest, and gonads. The average occupational doses were measured for a month (from 7 am to 2 pm) and dose monitoring was repeated three times. TLDs were read at the end of each working shift. Ten TLDs were used for each measurement and the background dose was separately measured using two TLDs. OAR doses were determined on both left and right sides as are shown in Figure 1.

Two sets of TLDs were located under and over the protective shields for evaluating the dose reduction efficiencies of the lead apron and thyroid shield. In nuclear medicine departments, lead glasses and radiation attenuation gloves were not commonly used due to their relatively high weights and uncomfortable handling in busy shifts. Therefore, the dose magnitudes of the point-fingers and eye lenses were only measured without shielding. The mean values of the dose measurements were considered.

Two occupationally exposed technicians were monitored to eliminate the effect of staff experiences and their working speeds. For each radiopharmaceutical, the occupational

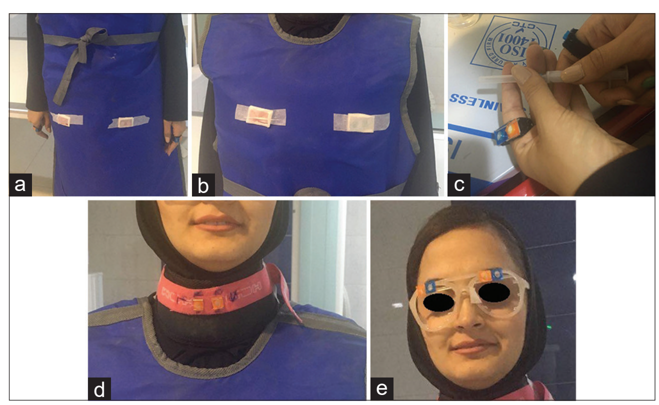

Figure 1: (a) Dosimeter positions for the measurement of gonad doses. (b) Dosimeter positions for the measurement of chest doses. (c) Dosimeter positions for the measurement of finger doses. (d) Dosimeter positions for the measurement of thyroid doses. (e) Dosimeter positions for the measurement of eye lens doses

doses with and without the radiation protection shields were normalized to the activity used in the working shift. For Tc-99 m, I-131, and Kr-81 radiopharmaceuticals, the amount of activities used were 2231 mci, 45 mci, and 5 mci, respectively. In each working shift, five lung perfusion scans were routinely performed. The mean annual doses were determined for 50 weeks with one working day per week. The ionizing radiation doses were measured in mGy. The data analysis was performed using Microsoft Excel software (ver. 2013, Microsoft, Redmond, WA, USA).

Results

OAR doses received from administered radiopharmaceuticals are listed in Table 1. During preparation and injection of Tc-99 m radiopharmaceutical, the average annual doses received by NM technologists were higher in the chest (4.49 mGy) and eye lenses (4 mGy). For I-131 radiopharmaceutical, the average annual doses of the point-finger (15.8 mGy) and eye lenses (1.23 mGy) were significantly higher than other organs. During the preparation and administration of Kr-81, the average annual doses of the point-finger (0.65 mGy) and chest (0.44 mGy) were higher, but there were no significant differences for organ-absorbed doses. For each radiopharmaceutical, there are statistically significant differences between the OAR doses ($P < 0.0001$).

OAR doses received with and without lead shields are listed in Table 2. The effect of the lead apron to reduce the chest dose received from Tc-99 m is significant. If the lead apron is used, the dose received by the chest is almost three times smaller than that of the without shielding. There were the same reduction percentages in the radiation doses received by gonads, chest, and thyroids. The OAR doses were decreased by almost half when the lead apron is used during the preparation and administration of I-131. There were the same reduction percentages in the radiation doses received by gonads and thyroids. For Kr-81 radiopharmaceutical, the protective effect of the lead apron was slightly higher for gonads. There were the same reduction percentages in the radiation doses received by gonads and thyroids. For each radiopharmaceutical, the OAR doses were significantly reduced when a lead shield is used ($P < 0.05$).

Table 1: Organs at risk doses received from different radiopharmaceuticals

OAR	Number of TLD	The mean annual dose (mGy/year)		
		Tc-99m	I-131	Kr-81
Eye lens	4	4	1.23	0.26
Thyroids	4	3	0.60	0.16
Point-fingers	4	3.26	15.8	0.65
Chest	4	4.59	0.63	0.44
Gonads	4	2.19	0.17	0.11

OAR – Organs at risk, TLD – Thermoluminescence dosimeter

Discussion

Nuclear medicine technologists will be exposed to two main radiation sources. Their main occupational doses are received from the preparation and injection of radioactive substances. The second irradiation source is the radioactive patients who have been given radiopharmaceuticals. In the United Nations Scientific Committee on the Effects of Atomic Radiation reports and some independent studies, the average annual effective doses of nuclear medicine staff were mostly ranged from 0.75 to 1.6 mSv.[4-6,14,16-21] The higher magnitudes of 2.89, 3.16, and 3.50 mSv were, respectively, reported for Thailand, Syria, and Brazil during the period from 1990 to 1994.[16] Some Pakistani NM staff had also annual average effective doses of 6.26–6.95 mSv during the period from 2003 to 2007.[20]

In our study, staff doses also have considerable magnitudes, one of the reasons for which could be the high workload of our centers. Therefore, in this referral center, immediate action must be taken to reduce the staff doses. In the Hot-Lab area, staff doses could exceed the annual dose limit of 500 mSv if they continued the same work throughout the year with a constant schedule. Therefore, the necessary protection proceedings including holding retraining courses, the use of radiation protectors, the use of rotational working shifts, etc., are required to maintain staff doses within the permissible dose limits.

Brudecki *et al*.[22] study showed that the highest exposures were achieved in the Hot-Lab. For the nuclear medicine staff, maintaining the staff doses within the safe range is only possible through continuous monitoring of staff doses. In Mosley and Currie study,[23] it was reported that the chest would receive the highest radiation doses due to the poor protective effect of lead glass shielding in the radiopharmacy. Another reason for this dose enhancement is that the chest is inappropriately close to the source (staff mostly bent forward to inject radiopharmaceuticals). An increase in the chest dose during preparation and administration of Tc-99 m was reported, similar to our results.

The conventional lead aprons have 0.5 mm lead-equivalent thickness which has a significant protective effect for nuclear medicine staff, especially in the Hot-Lab area. In Sani *et al*.[24] and Huda and Boutcher[25] studies, the effect of the lead apron to reduce the personnel radiation exposure during the preparation and administration of the radiopharmaceuticals was also investigated. The results showed that the staff doses depend on the radionuclide types and their corresponding energy spectrums.

For the nuclear medicine staff that used lead aprons during preparation and administration of Tc-99 m and I-131 radiopharmaceuticals, the chest doses reduced, respectively, by 68% and 28%. In He *et al*. study,[11] the effectiveness of lead apron was evaluated for nuclear medicine procedures.

Table 2: Organs at risk doses received with and without protective shields

Radiopharmaceutical	Eye lens	Thyroids	Point-fingers	Chest	Gonads
The mean annual dose received (mGy/year) without protective shields					
Tc-99m	4	3	3.26	4.59	2.19
I-131	1.23	0.60	15.8	0.63	0.17
Kr-81	0.26	0.16	0.65	0.44	0.11
The mean annual dose received (mGy/year) with protective shields					
Tc-99m	-	1.05	-	1.47	0.83
I-131	-	0.30	-	0.46	0.09
Kr-81	-	0.112	-	0.35	0.077
Percentage of dose reduction (%)					
Tc-99m	-	64	-	68	62
I-131	-	49	-	28	47
Kr-81	-	31	-	20	33
P					
Tc-99m	-	0.004	-	<0.001	<0.001
I-131	-	0.003	-	0.001	<0.001
Kr-81	-	0.008	-	0.047	<0.001

For each radiopharmaceutical, the levels of statistical significance of differences in the OAR doses with and without lead shields are also listed in the table. OAR – Organs at risk

In photon energy of 137 KeV, shielding efficiencies of the 0.5 mm lead apron and 0.5 mm lead sheet were 56.4% and 77.8%, respectively. In photon energy of 356 KeV, shielding efficiencies of the 0.5 mm lead apron and 0.5 mm lead sheet were 19.3% and 23.6%, respectively. These results were similar to our findings.

In Young's study,[10] dose rates and the effectiveness of lead aprons were evaluated in nuclear medicine examinations. The use of a lead apron was shown to reduce doses by 64.5% and 16% when shielding against Tc-99 m and I-131, respectively. These dose reductions are comparable to the values obtained in our study. There was also a significant dose reduction in the gonadal and thyroid area of the nuclear medicine staff that used lead protective shields during the preparation and administration of radiopharmaceuticals.

Krypton-81 (Kr-81 m) is one of the most commonly used radiopharmaceuticals in our department. The staff doses during lung perfusion imaging were measured, despite the low activity, short half-life, and low health risk of Kr-81 radionuclide. The average annual dose of the staff's fingers was 0.65 mGy, which was higher than the other organs. It' is because the staff's fingers are directly exposed during mask placement and the patients' noncooperation. During the preparation and administration of the radiopharmaceuticals, staff hands might receive significant radiation doses (particularly the fingers). The finger dose during preparation and administration of I-131 radionuclide was 15.8 mGy which is significantly higher than the other organs. In Nassef and Kinsara study,[6] the results show that the radiation doses to the fingers of nuclear medicine staff were ranged from 12.88 mSv to 31.7 mSv. Because nuclear medicine technologists did not use the syringe shield and have more contact with patients during the administration of I-131. For one working day per week, the finger dose is smaller than the recommended annual dose limit International Commission on Radiological Protection (ICRP). However, the high numbers of nuclear medicine procedures will perform daily at the nuclear medicine departments. The syringe and vial shields could reduce the finger doses by 98.5%.[26] Restricting the exposure time and appropriate shielding strategy could considerably reduce staff doses in nuclear medicine procedures.

From the results, it could be concluded that lead protective shields could offer a significant dose reduction in answer to if the lead protective shields are really helpful in nuclear medicine. The use of a lead apron, radiation attenuation gloves, and thyroid shield is recommended at least in the Hot-Lab area, although the use of lead protective shields is difficult and to some extent reduces the working speed. It is also recommended to provide appropriate protective shields (or at least a lead paravan) between patients and nuclear medicine staff.

Conclusion

In this study, the dose reduction shielding efficiencies of the lead apron and thyroid shield were investigated. From the results, it could be concluded that lead protective shields could offer a significant dose reduction in answer to if the lead protective shields are really helpful in nuclear medicine. Nuclear medicine staff doses were also evaluated for the preparation and administration of Tc-99 m, I-131, and Kr-81 radiopharmaceuticals. In our medical centers, staff doses have considerable magnitudes. The lead apron, thyroid shield, syringe shield, and minimum contact with the radioactive sources (especially in the Hot-Lab area) are recommended to reduce the staff doses. Adapted shields should be used whenever it is possible. For the nuclear medicine departments with a high workload, it is necessary to use rotating shifts, especially for the Hot-Lab. In addition to the conventional dosimetry methods, a more accurate survey is required for the Hot-Lab area.

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Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Conflicts of interest

There are no conflicts of interest.

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