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ORIGINAL ARTICLE

Radiation Doses to Staff in a Nuclear Medicine Department

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ABSTRACT

Objectives: *To measure external radiation doses and estimate internal radiation doses (due to the process of radionuclide injection) to staff members working in a nuclear medicine department over a 1-year period; to assess the possible radiation doses to staff members in order to determine whether classification of radiation workers is necessary.*

Methods: *Radiation doses to 4 nuclear medicine physicians, 8 radiographers, and 2 laboratory attendants were measured by digital pocket dosimeters.*

Results: *After correction for background natural radiation dose, the mean annual radiation dose to the physicians was 0.29 ± 0.21 mSv. This was lower than the mean annual radiation dose of 2.07 ± 0.97 mSv (p = 0.017) to the radiographers and 1.97 ± 0.05 mSv (p = 0.064) to the laboratory attendants, respectively. The mean radiation dose to the radiographers performing data acquisition and radionuclide injection (1.82 ± 1.08 mSv) was not different from that of the radiographers performing data acquisition only (2.53 ± 0.47 mSv) [p = 0.439]. An empirical formula was applied to compute the possible risk of receiving an internal dose in the process of radionuclide injection. The annual internal radiation dose to individual staff members performing radionuclide injection was estimated to be 0.01 mSv, which can be considered negligible in an estimation of total effective dose.*

Conclusions: *This 1-year study showed that effective radiation doses to nuclear medicine department staff members were within permissible levels, and that the classification of radiation workers is unlikely to be necessary in a typical nuclear medicine department in Hong Kong.*

Key Words: *Classification, Dosage, radiation, Effect, radiation, Maximum permissible exposure level, Nuclear medicine department, hospital, Radiation protection*

INTRODUCTION

A great deal of attention has been paid in recent years to radiation protection in nuclear medicine departments. According to the Radiation Ordinance, an effective dose limit of 20 mSv each year has been laid down for persons employed in radiation work. Although routine radiation monitoring programs using thermoluminescent dosimetry (TLD) are in place in all nuclear medicine departments to ensure that the dose limit is not exceeded, there have been no reports of actual measured radiation doses to nuclear medicine staff. Most nuclear medicine staff would have a monthly TLD return ‘below recordable level’, ie < 0.167 mSv. Moreover, staff may not be working for the entire month in the nuclear medicine department, so that the actual dose contributed by working in the nuclear medicine department cannot normally be measured. In our department, medical, radiographic, and technical staff working in nuclear medicine have been monitored continuously since mid-1999, using digital pocket dosimeters (The Bleeper Sv, Gothic Crellon Ltd., UK) with sensitivity of 1 mSv, in addition to TLD. Dosimeter readings were recorded weekly, and on the first and last day when the staff member was working in the department. Thus, the actual dose contributed by working in the nuclear medicine department could be measured.

The principal hazards in nuclear medicine are associated with external exposure; radiation doses from ingestion due to contamination are small.[1] In the literature, measurements of radiation doses to personnel involved in the practice of nuclear medicine have been expressed as doses per month,[2] doses per year,[3] or doses per procedure.[4-7] Internal irradiation was considered negligible,

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and was discounted in all studies. Because the internal dose cannot be measured, we have derived an empirical formula to estimate the possible internal dose to the staff involved in radionuclide injection.

We now report our experience with measured staff radiation doses, and estimated internal doses due to radionuclide injection, over the entire year 2000.

MATERIALS AND METHODS

Radiation doses to staff in the nuclear medicine department were monitored using digital pocket dosimeters. The department is staffed with 4 nuclear medicine physicians (M1, M2, M3, and M4), 5 radiographers, and 2 laboratory attendants (L1 and L2). Three of the 4 nuclear medicine physicians (M2, M3, and M4) regularly performed radionuclide injection using the butterfly technique with a syringe shield. Three radiographers (R1, R2, and R3) worked in the department throughout the year, while 5 radiographers (R4, R5, R6, R7, and R8) rotated between nuclear medicine and diagnostic radiology duties. R4, R5, R6, R7, and R8 worked in the department for 44, 135, 179, 229, and 138 days, respectively, during the year 2000. The department ordered unit doses, and preparation of radiopharmaceuticals was seldom carried out. On some occasions, dose preparation or quality control was performed by R1. All the other radiographers were involved in data acquisition and measurement of activity of radionuclides before injection; R2 and R3 also performed radionuclide injection in addition to other usual duties. The laboratory attendants assisted the doctors and radiographers in radionuclide injection, data acquisition, and handling and disposal of used syringes and injection kits. L1 worked in the department throughout the year, while L2 worked for 171 days. For measurement of the background natural radiation dose, the Reception Office was also monitored, using a digital pocket dosimeter. This room, with a 2 mm lead-equivalent glass window and 2 mm lead-lined wall and door, has the lowest background radiation activity in the department; patients and radioactive materials are not permitted inside the Reception Office.

During the process of radionuclide injection, radionuclide is transferred from a predispensed and shielded syringe into a vein of the patient through a butterfly injector, with or without a heparin block. As the entire process is performed in a closed system, spillage of radionuclide should not occur under normal circumstances. Rarely, spillage of radionuclide may occur, usually due to pressure built up from injecting through an obstructed heparin block. The local departmental radiation protection rules specify spills involving microcurie quantities as ‘minor’ and spills involving millicurie quantities as ‘major’. Of more than 3000 radionuclide injection processes performed in the year 2000, there were only a few incidents of minor spillage, giving a rate of less than 0.33%. However, a high degree of conservatism was applied to account for possible trivial spillage events that might have passed unnoticed, and an incidence of spillage of 2% was taken in making the estimation of possible internal dose to staff. According to the local rules, major spillage would have occurred if there was a spillage of over 5% of a bone dose (740 MBq), the most commonly used radiopharmaceutical in the department. As there had been no incident of major spillage, a maximum amount of spillage of 5% was taken for the internal dose estimation. As the operator is always required to wear protective clothing and disposable gloves during the process, there is only a small chance that the spilled activity will come into contact with an uncovered skin surface, which is essentially the face. Assuming that the face of the operator is 1 metre away from the injection site, the chance that the spilled activity may come into contact with the face is less than 3%. There are as yet no data to document the percentage of spillage activity that may be absorbed from the skin surface. As the skin is relatively impermeable to water, and most radionuclides are in non-lipophilic forms, the major risk is actually the transfer of spilled activity from the skin to the mouth. A nominal value of 2% for percentage absorption of spilled activity was used for estimation.

Based on the above values and the total activities of ^{99m}Tc, ^{201}Tl, ^{67}Ga, ^{111}In, and ^{131}I received for the year 2000, an empirical formula was developed to compute the possible risk of internal dose resulting from each of the radionuclides in the process of radionuclide injection:

Internal dose (mSv) = [Activity of radionuclide handled in MBq] x [incidence of spillage] x [amount of spillage] x [percentage of spilled activity in contact with uncovered skin] x [percentage absorption] / [annual limit of intake in MBq] x 20 mSv

The total estimated internal dose arising from the process of radionuclide injection was given by the summation of the internal doses contributed by each of the five radionuclides used in our department. The annual limits of intake for ^{99m}Tc, ^{201}Tl, ^{67}Ga, ^{111}In, and ^{131}I are

1000 MBq, 100 MBq, 80 MBq, 50 MBq, and 0.8 MBq, respectively.[8]

Kruskal-Wallis 1-way analysis of variance (ANOVA) by ranks was applied for comparing the annual radiation doses to different staff groups, with statistical significance at $p < 0.05$. Values were expressed as mean ± standard deviation (SD).

RESULTS

The workload of the department in the year 2000 was 3338 studies, including 443 myocardial perfusion studies using ^{99m}Tc tetrofosmin and a 2-day imaging protocol (925 MBq each for stress and rest studies). The total activities of ^{99m}Tc, ^{201}Tl, ^{67}Ga, ^{111}In, and ^{131}I received for the year 2000 were 2420, 35, 15.6, 0.6, and 0.4 GBq, respectively.

An annual background natural radiation dose of 2.08 mSv was recorded in the Reception Office. Results of the measured radiation doses to staff are presented in Table 1. For staff with less than 366 days' monitoring during the study period, annual radiation doses were projected from measured radiation doses using the following formula:

[Projected annual radiation dose] = [Measured radiation dose in mSv] / [duration of monitoring in days] x [366 days]

All measured and projected annual radiation doses were then corrected for the background natural radiation dose.

The mean annual radiation dose to the physicians was 0.29 ± 0.21 mSv, significantly lower than the mean annual radiation dose to the radiographers of 2.07 ± 0.97 mSv ($p = 0.017$). The mean annual radiation dose to the physicians was also lower than the mean annual radiation dose to the laboratory attendants of 1.97 ± 0.05 mSv, and the difference approached statistical significance ($p = 0.064$). The mean annual doses to the radiographers and the laboratory attendants were not significantly different ($p = 0.296$). The mean radiation dose to the radiographers performing data acquisition and radionuclide injection (R2 and R3) – 1.82 ± 1.08 mSv — was not significantly different from that to the radiographers performing data acquisition only (R4, R5, R6, R7, and R8) — 2.53 ± 0.47 mSv ($p = 0.439$).

Based on the total activities of ^{99m}Tc, ^{201}Tl, ^{67}Ga, ^{111}In, and ^{131}I received for the year 2000, the total annual internal radiation dose to all staff performing radio-nuclide injection was estimated as 0.04 mSv. Since the duty of radionuclide injection was shared among 3 doctors (M2, M3, and M4) and 2 radiographers (R2 and R3), the estimated annual internal radiation to individual staff performing radionuclide injection would be around 0.01 mSv.

DISCUSSION

The results showed that the annual effective dose to nuclear medicine physicians, radiographers, and laboratory attendants were well within permissible levels. As the doses are below 3/10 of the annual limits, ie 6 mSv, classification of radiation workers in the nuclear medicine department is unnecessary.

Previous studies have shown that the major component of doses received by technologists is from the patient, rather than from handling syringes in radiopharmaceutical preparation and injection.[9] Our results are in total

Table 1. Results of annual radiation dose monitoring.

Staff	Duration of monitoring (days)	Background corrected annual dose (mSv)	Annual radiation dose (mSv) [mean ± SD]
M1	366	0.06	0.29 ± 0.21 (p = 0.017 vs R1-R8; p = 0.064 vs L1-L2)*
M2	366	0.38	
M3	366	0.18	
M4	366	0.53	
R1	366	0.24	[R1-R8] 2.07 ± 0.97 (p = 0.017 vs M1-M4; p = 0.296 vs L1-L2)*
R2	352	1.06	[R2-R8] 2.33 ± 0.68
R3	366	2.59	[R2-R3] 1.82 ± 1.08 (p = 0.439)*
R4	138	3.03	[R4-R8] 2.53 ± 0.47 (p = 0.439)*
R5	179	3.04	
R6	44	2.40	
R7	135	2.13	
R8	229	2.07	
L1	366	1.94	1.97 ± 0.05 (p = 0.064 vs M1-M4; p = 0.296 vs R1-R8)*
L2	171	2.01	

* Kruskal-Wallis 1-way ANOVA by ranks

agreement with these findings. In our study, the radiographers performing injection (R2 and R3) had (non-significantly) lower radiation doses than the other radiographers not performing injection. The fact that only experienced radiographers who work full-time in the nuclear medicine department were allowed to perform radionuclide injection during the study period may account for these lower doses, since experienced staff tend to be more alert to radiation protection measures. On the other hand, since they were assigned injection duty, they would spend a shorter time in data acquisition, and were exposed to the patients for a shorter time. Physicians only spent a short time with the patients during radionuclide injection. They received a significantly lower dose when compared with the radiographers and laboratory attendants, who spent most of the time inside the scan rooms.

Nuclear medicine studies based on data from the United Kingdom (UK) have reported radiation doses to technologists with a weighted average of 1.5 μSv per study for conventional procedures, and 5.5 μSv for cardiac methoxyisobutylisonitrile (MIBI) scintigraphy or tetrofosmin single photon emission computed tomography (SPECT) procedures.[6] On the other hand, an Italian study reported a measured dose per procedure of 0.2-0.4 μSv for conventional procedures, 1.0 mSv for radionuclide ventriculography, and 1.7 mSv for MIBI SPECT.[7] In the Italian study, procedures were performed with the technologist separated from the patient in a control room with a 2 mm lead-equivalent glass window. In addition, the distance from the patient to the lead glass window was 3 to 4 metres. These provisions were uncommon for a nuclear medicine department in the UK, where space is at a premium. In Hong Kong, most nuclear medicine departments do not have separate control rooms for technologists or radiographers, who sit quite close to the patient during data acquisition. Our setting therefore resembles that in use in the UK. Based on the UK published data and our annual workload, the total annual radiation dose to a radiographer, if the same radiographer is performing all studies, is calculated to be 6.78 mSv (Table 2). Since the department is equipped with 3 gamma cameras and a radiographer at any one time can only be engaged with 1 gamma camera, the estimated annual dose to the individual radiographer would be 2.26 mSv. The figure is in close agreement with our measured mean annual dose of 2.33 ± 0.68 mSv for the radiographers who perform data acquisition as their main duty (R2-R7). This also implies that the UK estimates of radiation dose to technologists per procedure may be applicable to radiographers in Hong Kong settings. A laboratory attendant in Hong Kong is also likely to receive a dose similar to a radiographer in Hong Kong. On the other hand, the highest radiation dose received by a physician is only 25.6% of the lowest radiation dose received by a radiographer performing data acquisition in the same department.

Table 2. Estimation of annual radiation dose to radiographer based on UK figures[6] of dose per procedure.

Type of procedure	Annual throughput in 2000	Dose per procedure[6]	Estimated annual dose
Conventional	2895	1.5 μSv	4343 μSv
Cardiac tetrofosmin	443	5.5 μSv	2437 μSv
Total	3338		6780 μSv

Number of gamma cameras = 3
Estimated annual dose per radiographer serving one gamma camera = 2260 μSv

The only study in the literature that measured the actual body burdens of radionuclide, using a whole body counter regularly over 3 years reported ^{99m}Tc at 0 to 3.7 kBq in medical staff and 0 to 11.1 kBq in radiographers on the day of counting.[10] Even assuming that the highest level of contamination was present on each and every working day, the annual internal radiation dose would only be 0.02 mSv for medical staff and 0.06 mSv for radiographers. The results of our internal dose estimation are therefore comparable with the results from this study. Given appropriate assumptions, the same formula can be applied to other work processes to estimate the internal dose to an individual or group of workers. Our estimates have confirmed that internal irradiation can be considered negligible in the estimation of the total effective dose in nuclear medicine staff.

One area that was not specifically addressed was the level of airborne activity and contamination and the doses to staff arising from Technegas ventilation scintigraphy. A UK study has estimated lung deposition as 12 kBq, nose deposition as 1 kBq, and hair contamination as 5kBq per test.[11] These figures are insignificant when compared with the annual limit of intake of 2000 MBq for ^{99m}Tc by inhalation. The estimated effective dose from all airborne sources is 0.32 mSv per Technegas ventilation test. The whole body effective dose – from both external and internal sources – to the operator performing a combined Technegas ventilation and ^{99m}Tc-macro-aggregated albumin (MAA) perfusion scan was 2.02 mSv per test, a figure not greatly different from the quoted figure of 1.5 mSv per conventional procedure.

CONCLUSION

Assessment of the possible radiation dose to staff may be important to determine whether classification of a radiation worker is needed before a staff member commences work in a nuclear medicine department. Simple assessment can be made for a radiographer by utilising the method described in Table 2. The estimated radiation dose to a physician can be assumed to be one quarter of the estimated radiation dose to a radiographer, while the estimated radiation dose to a laboratory attendant can be assumed to be the same as that to a radiographer working in the same department.

This 1-year study showed that appropriate training and experience in the specialty of nuclear medicine, as well as maintaining a high awareness of radiation safety, would contribute to maintaining effective radiation doses to staff in a nuclear medicine department well within the limits prescribed by law. Classification of radiation workers is unlikely to be required in a typical nuclear medicine department in Hong Kong.

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