Original Article

Radiation Exposure to the Personnel Performing Myocardial Blood Flow Quantification Study Using ^{13}N-ammonia Positron Emission Tomography/Computed Tomography

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Abstract

Purpose: The present study aimed to evaluate radiation exposure to staff performing coronary flow reserve (CFR) measurement using ^{13}N-ammonia. **Materials and Methods:** The radiation exposure rate during the administration of ^{13}N-ammonia for the rest and stress part of the study was noted using an ionization chamber-based calibrated survey monitor. The radiation exposure to persons involved in dispensing radioactivity (D1), administering radioactivity (D2) and monitoring the patient during pharmacological stress (D3) were measured using an energy compensated Si-diode personal pocket dosimeter. **Results:** The average dose received by individuals with dosimeters D1, D2, and D3 was 1.28 ± 0.79 μSv, 1.56 ± 0.51 μSv, and 0.88 ± 0.97 μSv per injection, respectively, during the rest of study and 1.56 ± 0.96 μSv, 2.64 ± 1.22 μSv, and 2.2 ± 1.7 μSv per injection, respectively, during stress study. The average exposure rate during the administration of ^{13}N-ammonia at 0.5 m and 1.5 m from the injection site was found to be 259 μSv/h and 53.4 μSv/h, respectively, during the rest study and 301 μSv/h and 67.25 μSv/h, respectively, during stress study. **Conclusion:** The exposure to the staff performing CFR study with ^{13}N-ammonia was well within prescribed limits by the International Commission on Radiological Protection 103. The CFR measurement with ^{13}N-ammonia positron emission tomography/computed tomography can be included in routine workups of cardiac patients without the fear of radiation exposure.

Keywords: *13N-ammonia, coronary flow reserve, myocardial blood flow, radiation exposure*

Introduction

The role of positron emission tomography (PET) in the management of cardiac patients has increased in recent times.[1-4] The routinely used PET myocardial perfusion imaging (MPI) studies reveal the difference in myocardial blood supply in stenosed and normal arteries. However, the MPI study can appear normal in patients with a less severe degree of stenosis due to the roll-off phenomenon.[5,6] The quantification of myocardial blood flow (MBF) or coronary flow reserve (CFR) due to pharmacologic vasodilation can help in the identification of coronary functional abnormalities at an early stage before the clinical manifestation of coronary artery disease (CAD).[7] These factors, along with the increased availability of PET scanners worldwide, have scaled the use of cardiac PET quantification from research to clinical applications.[8,9]

Quantifying MBF/CFR using PET radiotracers like ^{13}N-ammonia as an adjunct to MPI studies improves the stratification of patients for major adverse cardiac events and the selection of patients for intervention or medical therapy.[10] It has led to the increased belief of physicians in PET imaging and, hence, increased numbers of patients undergoing PET quantification studies. However, the high specific gamma-ray constant of PET radionuclides due to highly penetrating gamma-ray photons of energy 511 keV raises the concern of radiation exposure to staff members and physicians.[9,11] The measurement of CFR using ^{13}N-ammonia requires the administration of radiotracer twice and continuous monitoring of the patient's blood pressure (BP) and electrocardiogram (ECG) during the stress part of the study. It further increases the radiation exposure concern as compared to MPI studies. Radiation exposure is always harmful and may lead to stochastic

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and deterministic effects.[11,12] However, the International Commission on Radiation Protection (ICRP) has given certain guidelines and protection principles to keep the exposure to staff within prescribed limits.[12] A number of studies have been done to see the exposure to staff during routinely done ^{18}F-fluorodeoxyglucose (FDG) whole-body studies.[13-17] Measuring CFR using ^{13}N-ammonia is a relatively new procedure, and radiation exposure to staff has not been thoroughly explored.[9] The present study aimed to measure the radiation exposure to the staff performing the CFR study with ^{13}N-ammonia and evaluate if the exposure is within prescribed limits.

Materials and Methods

This prospective study was conducted from November 2017 to April 2018 at the PET/computed tomography (CT) center. A total of 25 patients with ischemic heart diseases were referred for CFR measurements using ^{13}N-ammonia were included in the study. Patients with left ventricular ejection fraction <35% on echocardiography reports and those unable to lie still for 30–40 min were excluded from the study. Informed written consent was obtained from all the included patients.

Patient preparation

All patients were ensured too fast for 6 h. Patients were instructed not to take tea/coffee, nitrates, calcium channel blockers 1 day before, and beta-blockers 2 days before the test. Two intravenous cannulas were placed in both arms, one each for radiopharmaceutical administration and vasodilator administration. Thirteen ECG electrodes were placed at respective positions on the patient's body.

Positron emission tomography/computed tomography acquisition

All the patients underwent PET/CT cardiac perfusion studies using a hybrid PET/CT scanner (Discovery 710, GE Healthcare, Milwaukee, USA) and ^{13}N-ammonia as PET myocardial perfusion radiopharmaceutical. A low-dose CT acquisition (140 kV, 20 mA) was done with the heart in the field of view, followed by two dynamic PET acquisitions after on-table administration of ^{13}N-ammonia. The PET acquisitions consisted of two phases: the rest phase followed by the stress phase after the induction of pharmaceutical stress. The stress agent used was adenosine injection I. P., which acts as a vasodilator for coronary arteries. The administration rate was 140 μg/kg/min infusion for 6 min.

Exposure and exposure rate measurements

The personal pocket dosimeter RADOS RAD60 (LAURUS Systems, Inc., USA) with an energy-compensated Si-diode detector and an inbuilt alarm was used for exposure measurements during the CFR measurement procedure. Three personnel wore three pocket dosimeters, performing different parts of the procedure. Dosimeter D1 was worn by the person dispensing activity from the mother vial in the hot laboratory to the acquisition room. Dosimeter D2 was worn by the person administering the activity to the patient (both "rest" and "stress" study). Dosimeter D3 was worn by the physician who monitored the patient's BP, ECG, heart rate, etc. The exposure readings in all three pocket dosimeters were noted.

Dose rate measurements

An ionization chamber-based calibrated RAM ION DigiLog (Rotem Industries Ltd., Israel) portable survey monitor was used to measure exposure rates. The background exposure rate of the imaging room was measured just before the start of ^{13}N-ammonia administration. The exposure rates were measured at 0.5 m (E1) and 1.5 m (E2) distance from the injection site with a gun monitor during activity administration.

The whole-body occupational exposure to the staff performing CFR per year was estimated based on the radiation dose received per procedure. Considering three CFR procedures per week and 52 working weeks in a year, whole-body occupational exposure in a year (μSv/year) can be estimated as mean radiation dose per procedure (μSv) × 3 procedures per week × 52 working weeks in a year similar to previously reported studies.[18,19]

Results

A total of 25 patients (13 males), aged 48.32 ± 12.78 (range 15–68) years, underwent a CFR measurement procedure using ^{13}N-ammonia. Of these 25 patients, 8/25 had CAD, 6/25 were morbidly obese, 5/25 had systemic lupus, and 6/25 had type 2 diabetes.

The mean ^{13}N-ammonia activity administered to the patient for the rest study was 10.82 ± 2.80 mCi and for the stress study was 13.48 ± 5.22 mCi.

The average dose received by the individual with dosimeter D1 during the rest study was 1.28 ± 0.79 μSv per injection and during the stress study was 1.56 ± 0.96 μSv per injection. The average dose received by the individual with dosimeter D2 during rest and stress studies was 1.56 ± 0.51 μSv and 2.64 ± 1.22 μSv per injection, respectively. The average dose for the physician with dosimeter D3 during the rest study was 0.88 ± 0.97 μSv per injection and during the stress study was 2.2 ± 1.7 μSv per injection [Table 1].

The average dose in the complete procedure ("rest" + "stress" study) and the estimated whole-body occupational exposure in a year to the individuals with dosimeters D1, D2, and D3 for 3 CFR procedures in a week are tabulated in Table 1.

The average exposure rate during the administration of ^{13}N-ammonia in the rest study was 259 μSv/h and 53.4 μSv/h at 0.5-m and 1.5-m distances, respectively. During the stress study, the exposure rate was 301 μSv/h and 67.25 μSv/h at 0.5 m and 1.5 m from the injection site [Table 2].

Table 1: Effective dose for ^{13}N-ammonia rest study for dosimeter D1, D2, D3

Effective dose (μSv) Staff members	Mean±SD		Mean effective dose per procedure (μSv) (stress + rest)	Estimated effective dose for whole procedure per year (mSv/year) (stress + rest)
	Rest study	Stress study		
Person dispensing activity (D1)	1.28±0.79	1.56±0.961	2.84	0.443
Person administrating activity (D2)	1.56±0.5	2.64±1.22	4.2	0.655
Person monitoring patient (D3)	0.88±0.97	2.2±1.75	3.08	0.48

SD: Standard deviation

Table 2: Exposure rate measurements at 0.5 and 1.5 m from the patient

Distance from patient's injection site (m)	Exposure rate (μSv/h), mean±SD	
	Rest	Stress
0.5	259±119.6	301±115.1
1.5	53.4±22.3	67.25±29.3

SD: Standard deviation

Discussion

The image quality and quantification offered by PET imaging due to its better sensitivity and spatial resolution have increased the popularity of PET imaging.[20,21] However, using positron emitters exposes the staff and patients to higher radiation exposure due to the high specific gamma-ray constant of PET radionuclides. The general principles for radiation protection, i.e., time, distance, and shielding, are applicable to keep radiation exposure in check. However, procedures like CFR require on-table administration of radioactivity and patient monitoring during stress, which makes it difficult to increase the distance from the patient, and other protection requirements are also fulfilled to a minimal extent. It necessitates monitoring radiation exposure received by the staff to ensure that the personnel dose does not exceed the prescribed annual dose limits given by ICRP. The present study estimated the radiation exposure received during the measurement of CFR using ^{13}N-ammonia.

The critical group that gets exposure from ^{13}N-ammonia during CFR study includes physicians monitoring the patient's vital signs (BP and heart rate) during infusion of pharmaceutical stress agent, and individuals involved in dispensing and administering radioactivity.

The radiation exposure in the present study to the person dispensing activity, person injecting activity, and physician monitoring the patient during the scan was 2.84 ± 1.75 μSv, 4.2 ± 1.73 μSv, and 3.08 ± 2.67 μSv, respectively, for one complete procedure including both rest and stress studies. In a similar study by Kristoffersen *et al*., exposure to staff during ^{13}N-ammonia perfusion scan ("rest" and "stress") was found to be 10.4 ± 0.6 μSv, 4.1 ± 0.5 μSv, and 2.2 ± 0.4 μSv to the person dispensing activity, person injecting activity, and the person monitoring the patient during scan, respectively.[9] The lower values in the present study may be due to the lower average activity administered compared to the study by Kristoffersen *et al*. The activity administered in their study has not been mentioned. They also calculated exposure to the index finger and wrist, which were not evaluated in the present study.

On comparing the radiation exposure during rest and stress studies, it was found that radiation workers got high exposure during the stress study compared with the rest study. Increased exposure in case of stress can be explained for two reasons. First, the average activity administered in the ^{13}N-ammonia stress study was high compared to the rest study, and second, the time spent by all individuals near the patient was more during the stress study.

The exposure rate at 0.5 m was higher than at 1.5 m from the injection site as the radiation exposure obeys the inverse square law. The obvious increase in exposure rate at 0.5 m and 1.5 m with an increase in administered activity was observed.

As per the ICRP (ICRP, Stockholm, Sweden), 20 mSv (20,000 μSv) per year is the effective occupational whole-body dose limit (ICRP).[12] Considering 52 weeks with 5 working days per week, the daily dose limit can be estimated to be 76.9 μSv. In the present study, it was found that the person dispensing activity (D1) got 3.69% of per day limit, whereas the person injecting activity (D2) got 5.46% of per day dose limit and the physician monitoring the patient during the scan (D3) got 4.0% of per day dose limit for one complete procedure including both rest and stress scans.

In a study by Schleipman *et al*.,[16] the effective dose to staff using ^{82}Rb was found to be 0.9 μSv per scan (rest or stress), which was much less compared to the present study. The difference in the effective dose was due to a shielded generator ^{82}Sr/^{82}Rb, a semiautomatic infusion system for injection. Furthermore, a 22 mm mobile plastic sheet equivalent to 1 mm lead was used as a shield while monitoring the patient, which was not used in the present study. In another study by Clarke *et al*.,[22] a mean dose of 5.5 μSv was reported for complete rest and stress procedures with ^{99m}Tc-MIBI or ^{99m}Tc-tetrofosmin. They also performed radioactivity dispensing, administration, and patient monitoring in their study.

On comparing the exposure received by staff in the present study with that received during routinely done FDG studies, the exposure received during dispensing and administration of 10 mCi of FDG was 3.34 μSv, as documented by Pant

and Senthamizhchelvan which was comparable to exposure during ^{13}N-ammonia administration, 2.84 μSv and 4.20 μSv for rest and stress injections, respectively.[11]

Conclusion

It was concluded that exposure to the staff performing CFR study with ^{13}N-ammonia was well within prescribed limits by ICRP 103 under section 5.10. If proper work practice is followed, CFR measurement with ^{13}N-ammonia PET/CT can be included in routine workup of cardiac patients without fearing radiation exposure.

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Conflicts of interest

There are no conflicts of interest.

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