Comparison of Personnel Radiation Dosimetry from Myocardial Perfusion Scintigraphy: Technetium-99m-Sestamibi Versus Thallium-201

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The whole-body and hand radiation doses to our technical staff were retrospectively compared for three distinct 4-mo periods when either ^{201}Tl or ^{99m}Tc-sestamibi were exclusively used for stress myocardial perfusion imaging. During the initial 4-mo period when ^{99m}Tc-sestamibi replaced ^{201}Tl, the mean whole-body film badge readings increased from 100 to 450 μSv/mo ($p < 0.001$) for nuclear medicine technologists ($n = 10$) and from 240 to 560 μSv/mo ($p < 0.05$) for radiopharmacy technologists ($n = 2$). Mean TLD readings to the hands also increased, although the differences were not statistically significant for the nuclear medicine technologists. Noninvasive cardiology staff were monitored with film badges and the mean whole-body film badge reading, when ^{99m}Tc-sestamibi was the imaging agent, was 360 μSv per month. Radiation reduction methods that decreased radiation exposure to staff were utilized. The most effective included the use of a lead face shield and lead lined storage container in the noninvasive imaging area, handling spills by shielding instead of decontamination and methods to reduce time spent in close proximity to the patient.

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Until recently, patients with known or suspected cardiovascular disease were assessed for myocardial perfusion using a ^{201}Tl stress treadmill test. For years, research has been directed at developing an agent with optimal imaging properties (*1,2*). The choice of imaging agent for myocardial perfusion imaging in clinical practice is challenging. One such agent, ^{99m}Tc-sestamibi, was approved by the FDA in 1991 for myocardial perfusion imaging. The characteristics of ^{99m}Tc-sestamibi and ^{201}Tl should be considered (Table 1) as well as the clinical indications in selecting the imaging agent (*3–5*).

Another characteristic to be considered is the external radiation exposure to the technical staff. At a minimum, one would expect that the increase in activity from 111 MBq (3 mCi) of ^{201}Tl to 1110 MBq (30 mCi) of ^{99m}Tc would increase the relative exposure to the technologists and radiopharmacy staff by a factor of 1.7. This estimate is based on the ratio of the specific gamma constants of ^{201}Tl (115 μGy-m^2/GBq-hr) and ^{99m}Tc (19.6 μGy-m^2/GBq-hr). This estimate does not take into account the difference in attenuation and radionuclide distribution between ^{201}Tl and ^{99m}Tc in soft tissue. The mass absorption coefficients of ^{201}Tl and ^{99m}Tc are similar for water (0.0253 cm^2/g and 0.0278 cm^2/g, respectively) (*6*).

This paper presents our retrospective radiation dosimetry data compiled over three distinct 4-mo periods between January 1991 and May 1992 when either ^{201}Tl or ^{99m}Tc-sestamibi were exclusively used for myocardial perfusion imaging. Dosimeter badges consisting of a small piece of x-ray film and thermoluminescent dosimeter chips were used to monitor radiation doses to personnel. Badge readings are reported in units of dose equivalent (sievert or rem). The generic term "dose" throughout this manuscript refers to the dose equivalent reported on the dosimeter badges.

METHODS

Radiation dosimetry to the technical staff was monitored with: (a) film badges for whole-body and (b) thermoluminescent dosimeters (TLD) for hand/finger dose equivalent. The badges (film and TLD) were changed monthly. The film and TLD service is a commercial laboratory accredited by the National Institute of Standards and Technology through the National Voluntary Laboratory Accreditation Program. The whole-body film badges were worn anteriorly between the neck and waist; the ring TLDs were worn consistently on the same finger and hand each month.

Monthly badge reports were reviewed retrospectively over the following 4-mo periods: January through April 1991, when ^{201}Tl was exclusively used (Period I); August through November 1991, when ^{99m}Tc-sestamibi was exclusively used (Period II); and February through May 1992, when ^{99m}Tc-sestamibi was exclusively used and after a radiation reduction policy was implemented (Period III). The average number of patient studies per day was 11.5 in Period I, 12 in Period II and 13.5 in Period III.

A pool of ten nuclear medicine technologists rotated through noninvasive cardiology and had 14, 16 and 15 badge reports in Periods I, II and III, respectively. Nuclear medicine technologists rotating through noninvasive cardiology were assigned exclusively to stress myocardial perfusion procedures. The badge readings recorded dose equivalent solely from exposure to ^{201}Tl (Period I) or ^{99m}Tc-sestamibi (Periods II and III). The same injection

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TABLE 1
Comparison of Myocardial Perfusion Imaging Agents

	^{201}Tl-chloride	^{99m}Tc-sestamibi
Photon energy	68–80 keV	140 keV
Half-life	73 hr	6 hr
Patient dose activity	111 MBq	1110 MBq
Dosimetry		
Total body	57 μGy/MBq	4.5 μGy/MBq
Critical organ	324 μGy/MBq	49 Gy/MBq
Availability	Off-site preparation and delivery	On-site preparation of lyophilized kit
Cost	$50–$100/patient	Depends on workload ($300/kit)
Myocardial pharmacokinetics	Redistribution	Slow clearance
Clinical protocol	1. Stress (74 MBq)	1. Rest (222–259 MBq)
	2. Redistribution (37 MBq)	2. Stress (814–851 MBq)

apparatus and technique, SPECT imaging equipment and exercise protocols were utilized in all three periods. The average imaging time per patient (rest and stress studies) decreased from 80 min with ^{201}Tl (Period I) to 51 min for ^{99m}Tc (Periods II and III).

The protocol during Period I was as follows: the patient exercised first on the treadmill using the Bruce Protocol (*7*). At peak stress, the patient was injected with 74 MBq (2 mCi) ^{201}Tl and imaged 5 min later. Three to 5 hr poststress dose, the patients were reinjected with 37 MBq (1.0 mCi) ^{201}Tl and imaged 15 min later. During Periods II and III, the resting injection of 222–259 MBq (6–7 mCi) ^{99m}Tc-sestamibi was administered first and the patient imaged an hour later. Later the same day, the patient exercised and at peak stress was injected with 814–851 MBq (22–23 mCi) ^{99m}Tc-sestamibi. The patients were imaged 30–120 min after the stress injection. All patients waited in rooms separate from the nuclear medicine and noninvasive cardiology technologists when not being imaged.

Monthly badge reports on two radiopharmacy technologists were also retrospectively compared during the same three periods. During Period I, injections were prepared from multi-dose vials of ^{201}Tl. During Periods II and III, preparation of ^{99m}Tc-sestamibi injections required an extra generator elution and two kit formulations each day. The two radiopharmacy technologists had eight badge reports during each period.

The diversity of radioactive products handled in the radiopharmacy was not controlled for in this study. The number of patient procedures closely approximates the number of radiopharmaceutical products prepared and dispensed by the radiopharmacy technologists. The number of procedures performed during each time period were retrospectively compared for 14 of our most common nuclear medicine procedures. Each procedure involved greater than 37 MBq (1 mCi) per patient. Radioiodine procedures for thyroid therapies were also included in this analysis.

Prior to Period III in November 1991, the noninvasive cardiology staff (including treadmill operators and exercise physiologists) directly involved with the ^{99m}Tc-sestamibi procedures were assigned whole-body film badges which were worn anteriorly on the chest. Eight cardiology staff members had a total of 30 badge reports during Period III (two film badges were lost).

Statistical Analysis

The results are presented as mean ± standard deviation. Some nuclear medicine technologists had more than one monthly badge report from nuclear cardiology during each period. The mean monthly dose equivalent per period was used for those technologists in determining whether there was a statistically significant change between periods.

Statistical significance was determined by comparing the change in reported dose equivalent to each technologist between Periods I and II and Periods II and III employing paired t-tests. A p value < 0.05 was considered statistically significant. Nominal p values between 0.05 and 0.1, though not significant, are included for completeness.

A comparison between observed and expected random error in the number of imaging procedures performed between Periods I and II and Periods II and III was used to assess statistical significance. Differences greater than two standard deviations of random error were considered to be statistically significant.

Radiation Reduction Policy Implemented Prior to Period III

1. A lead acrylic face shield was placed in the noninvasive imaging area to be used by nuclear medicine technologists whenever they connect or disconnect the dose syringe from the injection apparatus.
2. A lead lined waste storage container was fabricated to store all the syringes, intravenous tubing, gauzes and contaminated items in the noninvasive imaging area.
3. The stress and rest ^{99m}Tc-sestamibi injections were distributed equally among the nuclear medicine technologists assigned to the nuclear cardiology rotation.
4. Technetium-99m-sestamibi volume was diluted to allow quicker injection preparation in a shielded 3-cc syringe.
5. Simultaneous use of adjacent drawing stations was avoided during kit preparation and dispensing of ^{99m}Tc-sestamibi. Two radiopharmaceutical preparation stations were located side by side, 1 meter apart, in the radiopharmacy. Each has a lead glass barrier on the counter top that shields the front of the radiopharmacy technologist. Radiation emanating from behind one barrier, however, may strike the technologist at the adjacent drawing station. Reconfiguration of the dispensing stations requires substantial remodeling of the radiopharmacy (a project planned for 1993).
6. The chemical affinity of sestamibi to surfaces and skin was well documented as well as difficulty with decontamination. Greater awareness of the chemical nature of sestamibi reduced the amount of personnel and area contamination during Period III. Technetium-99m-sestamibi spills were handled by shielding and radioactive decay rather than decontamination.
7. Operator consoles were repositioned as far from the treadmill as practical.

TABLE 2
Monthly Dose Equivalent to Nuclear Medicine Technologists

Time period	Dosimetry reports	Whole body (μSv)		Hand/Finger (μSv)	
I, ^{201}Tl	14	100 ± 100 (0–300)	$p < 0.001$	750 ± 550 (300–1900)	ns
II, ^{99m}Tc	16	450 ± 210 (200–1000)	ns	1390 ± 790 (400–2700)	ns
III*, ^{99m}Tc	15	310 ± 80 (200–500)		1030 ± 620 (200–2100)	

*Radiation reduction policy introduced prior to Period III.
Results are expressed as mean ± sd. Values in parentheses indicate the range. ns = not significant.

8. Patient histories were obtained by exercise physiologists prior to the rest injections.
9. Radiation protection instruction pertaining to time, distance and shielding was re-emphasized.

RESULTS

The mean monthly whole-body dose equivalent to nuclear medicine technologists increased from 100 μSv to 450 μSv ($p < 0.001$) when ^{99m}Tc-sestamibi replaced ^{201}Tl (Period I versus II, Table 2). The mean monthly hand dose equivalent increased from 750 μSv to 1390 μSv from Period I to Period II ($p < 0.1$). The mean monthly whole-body dose equivalent decreased from 450 μSv to 310 μSv from Period II to III after the radiation reduction policy was instituted ($p < 0.1$). The mean monthly dose equivalent to the hands also decreased from 1390 μSv to 1030 μSv from Period II to III, although the decrease was not statistically significant.

The mean monthly whole-body dose to the two radiopharmacy technologists increased from 240 μSv to 560 μSv ($p < 0.05$) when ^{99m}Tc-sestamibi replaced ^{201}Tl (Period I versus II, Table 3). The mean monthly dose equivalent to the hands increased from 4650 μSv to 9940 μSv from Period I to Period II ($p < 0.05$). Both the mean whole-body and hand doses decreased from Period II to III to 350 μSv and 9250 μSv, respectively, although neither decrease was statistically significant.

Of the 14 nuclear medicine procedures reviewed, five showed a significant difference in the number of procedures and thus the number of radioactive products dispensed between periods (Table 4). The number of pulmonary perfusion and pulmonary ventilation and brain imaging procedures increased significantly from Period I to II. Only renal scintigraphy decreased. The increase in whole-body and hand dose equivalents to radiopharmacy technologists cannot be attributed solely to the switch from ^{201}Tl to ^{99m}Tc-sestamibi (Periods I–II). The number of pulmonary ventilation and brain imaging procedures increased significantly from Period II to III. None of the 14 procedures decreased significantly from Period II to III.

During Period III, the mean monthly whole-body dose equivalent of eight noninvasive cardiology staff members was 360 ± 170 μSv (range 0–700 μSv).

DISCUSSION

In the third quarter of 1991 (during Period II), two nuclear medicine and both radiopharmacy technologists had whole-body dose equivalents in excess of 1250 μSv. Commitment to our ALARA program requires investigation and action to reduce unnecessary radiation exposure. The purpose of our radiation reduction policy was: (1) to minimize external exposure from the handling and injection of ^{99m}Tc-sestamibi and (2) to minimize external exposure from patient care during treadmill exercise and imaging. After implementation of the radiation reduction policy, our results showed that the whole-body dose decreased to a mean of 310 μSv per month for nuclear medicine technol-

TABLE 3
Monthly Dose Equivalent to Radiopharmacy Technologists

Time period	Dosimetry reports	Whole body (μSv)		Hand/Finger (μSv)	
I, ^{201}Tl	8	240 ± 130 (100–400)	$p < 0.05$*	4650 ± 4420 (400–10,300)	$p < 0.05$*
II, ^{99m}Tc	8	560 ± 340 (100–1100)	ns	9940 ± 8600 (300–22,200)	ns
III†, ^{99m}Tc	8	350 ± 180 (200–700)		9250 ± 5130 (1100–14,800)	

*The significance of these findings cannot be solely attributed to the change from ^{201}Tl to ^{99m}Tc-sestamibi due to the number of radioactive products handled in the radiopharmacy during these time periods. See Table 4.
†Radiation reduction policy introduced prior to Period III.
Results are expressed as mean ± sd. Values in parentheses indicate the range. ns = not significant.

TABLE 4
Number of Procedures Performed per Period*

Time period	Renal (370 MBq ^{99m}Tc-DTPA)	Pulmonary perfusion (56 MBq ^{99m}Tc-MAA)	Pulmonary ventilation (74 MBq ^{99m}Tc-DTPA aerosol)	Brain (740 MBq ^{99m}Tc-HMPAO)	Brain (222 MBq ^{123}I-Iodoamphetamine)
I	82	208	36	5	104
	$p < 0.01$	$p < 0.05$	$p < 0.01$	ns	$p < 0.05$
II	36	263	77	9	141
	ns	ns	$p < 0.05$	$p < 0.001$	ns
III†	47	276	103	95	132

*No significant difference between periods for the following procedures: biliary, diuresis renogram, technetium thyroid, bone, rest and stress MUGA, myocardial perfusion scintigraphy and ^{131}I thyroid therapy.
†Radiation reduction policy introduced prior to Period III.

ogists. The noninvasive cardiology staff, who do not handle or inject radiopharmaceuticals, were found to have a mean whole body dose equivalent of 360 μSv per month. This is slightly higher than the rate for nuclear medicine technologists and suggests that improved handling procedures during ^{99m}Tc-sestamibi injection preparation, administration and disposal reduced the whole-body as well as hand dosimeter readings in Period III. This finding is consistent with exposures reported in the literature related to patient handling during ^{99m}Tc imaging procedures (*8–11*). The mean monthly whole-body dose equivalent in Period III was also consistent with our other nuclear medicine rotations utilizing ^{99m}Tc imaging agents.

The radiation reduction policy appears to have been effective at lowering the whole-body dose equivalents of the radiopharmacy technologists, although their hand dose equivalents remained unchanged. With the increased number of radioactive products prepared and dispensed in Period III, the results suggest that good radiation safety techniques are effective at reducing external whole-body exposure.

The noninvasive cardiology staff, who do not handle or inject radiopharmaceuticals, were found to have a mean whole-body dose equivalent of 360 μSv per month. A portion of this radiation exposure occurs immediately postinjection of the exercise dose (851 MBq ^{99m}Tc-sestamibi) and during the "cool-down" period of 5–7 min postexercise. The exercise physiologists are in close proximity to the radioactive patient during EKG preparation and blood pressure measurement. The dose equivalent recorded by the treadmill operators is a result of the time spent and distance relative to the patient after the rest and stress injections.

In conclusion, we observed an increase in radiation dose to our nuclear medicine, radiopharmacy and noninvasive cardiology staff after we changed imaging agents: from ^{201}Tl to ^{99m}Tc-sestamibi. Since we initiated a radiation reduction policy, the mean whole-body and hand dose equivalents to nuclear medicine and radiopharmacy technologists have decreased to levels more consistent with our ALARA levels (10% of the maximum permissible exposure set by the Nuclear Regulatory Commission). The current whole-body and hand dose equivalents are, however, still above those observed when ^{201}Tl was used to assess myocardial perfusion. Since the change to ^{99m}Tc-sestamibi, noninvasive cardiology staff have been trained and classified as radiation workers. Until further study has been completed, pregnant technologists are no longer preferentially assigned to nuclear cardiology rotations. Efforts are continuing to further reduce the radiation dose to radiopharmacy and noninvasive cardiology staff.

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