Effective Dose to Patients from SPECT and CT During Myocardial Perfusion Imaging

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Radiation dose to patients from imaging modalities is measured or calculated to assess the risk of the procedure and compare it with the benefits. Periodic review of image acquisition methods and the radiation dose used are an essential part of optimization in medical imaging. The aim of this study was to estimate patient radiation dose from SPECT myocardial perfusion imaging (MPI) using CT images for attenuation correction. **Methods:** SPECT and CT image acquisition parameters such as administered activity (AA), CT dose index ($CTDI_{vol}$), and dose–length product for 415 patients who had undergone SPECT MPI using CT attenuation correction were reviewed. Effective dose (ED) for the SPECT part, the CT part and the total ED for the procedure were calculated. AA, $CTDI_{vol}$, and ED values were compared between the 2 sexes and between body mass indexes (BMIs), imaging scanner models, and imaging centers. Statistical analyses were performed using *t* tests and 1-way ANOVA at $P < 0.05$ level of significance. **Results:** The range of AAs used for MPI was found to be 1,206–1,964 MBq per patient regardless of sex. The resulting mean ED of 8.8 mSv for men was significantly lower ($P = 0.002$) than the 10.4 mSv for women for SPECT. The range of $CTDI_{vol}$ was 1.12–3.97 mGy, resulting in an mean ED of 0.8 mSv for men, significantly lower ($P < 0.001$) than the 1.1 mSv for women for CT. The average combined EDs for male and female patients were 9.6 and 11.5 mSv, respectively. A positive correlation was found between AA and patient BMI ($r = 0.48$; $P < 0.001$), indicating patient size–related AAs. However, $CTDI_{vol}$ was found to depend only on the scanner model, regardless of BMI. **Conclusion:** The ED from SPECT/CT MPI studies was around 11 mSv, with 10 mSv being from the SPECT part of the study. The extra risk to the patients from CT imaging for attenuation correction is small compared with the benefit incurred from accurate diagnosis.

Key Words: myocardial perfusion imaging; SPECT/CT; administered activity; CT dose index; effective dose

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The use of SPECT, in conjunction with CT for the purpose of attenuation correction (AC), is common in myocardial perfusion imaging (MPI) (*1–3*). AC using CT images has been proven to provide better image quality and a more accurate diagnosis of coronary artery disease. CT imaging delivers a higher photon flux resulting in better image quality but at higher patient doses than are delivered by traditional transmission scans (*4*). The risk–benefit analysis of using CT for attenuation correction in SPECT MPI should include the radiation detriment caused by the additional radiation dose to the patient (*5*). Some studies have reported patient radiation doses for the SPECT or CT component of MPI and have recommended establishing diagnostic reference levels as a means of optimizing each component of the imaging procedure (*6–9*). In terms of patient dose estimation, the contribution from the SPECT part of the imaging is derived from the administered activity (AA) of the radiopharmaceutical, whereas the CT contribution is established from the dose–length product and the volume CT dose index ($CTDI_{vol}$) of the scan. To compare patient doses from different modalities and to assess the total risk to the patient, effective dose (ED) has been used (*10–12*).

The patient doses reported in the literature for routine SPECT/CT imaging procedures show wide variations caused by several image acquisition parameters and patient attributes. Similar variations in patient doses have been reported for MPI studies using SPECT/CT units (*1–4,13,14*). For SPECT, the type of tracer, AA, imaging protocol, and patient size influence the patient dose, whereas in CT the x-ray tube voltage (kVp), tube current (mA), and scan length affect the patient dose (*4*). Hence, studies involving patient dose measurements are important for establishing best practices and adhering to the optimization principle of radiation protection. Repeated patient dose measurements from different imaging centers, countries, and regions have contributed to optimizing imaging procedures and establishing diagnostic reference levels. The aim of this study was to estimate the patient radiation dose from the CT part, the SPECT part, and the total SPECT/CT MPI scan.

MATERIALS AND METHODS

Clinical Centers and Imaging

This retrospective study was performed by reviewing the imaging data of 415 randomly selected patients who were referred for

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TABLE 1
Equipment Design Parameters Used at Each Imaging Center Included in Study

Imaging center	Scanner	Image reconstruction	SPECT image matrix	No. of CT slices
C1	GE Discovery 670	OSEM	64 × 64	16
C2	GE Discovery 670	OSEM	64 × 64	16
	Siemens Symbia	3D-FLASH	128 × 128	16
C3	GE Discovery 670	OSEM	64 × 64	16
C4	GE Discovery 670	OSEM	64 × 64	16
	GE Hawkeye	OSEM	64 × 64	4
	Siemens Intevo	3D-FLASH	128 × 128	16

GE = GE Healthcare; OSEM = ordered-subset expectation maximization; 3D-FLASH = 3-dimensional fast low-angle-shot.

MPI studies using 7 different SPECT/CT scanners at 4 different nuclear medicine imaging centers (named C1–C4). The institutional review board approved this retrospective study and waived the requirement to obtain informed consent. All centers are part of the public hospital system and performed MPI studies routinely. The data collection was performed on 5 GE Healthcare scanners (4 Discovery 670 and 1 Infinia Hawkeye) and 2 Siemens scanners, each equipped with a multislice CT scanner (Table 1). All centers used ^{99m}Tc-tetrofosmin (Myoview; GE Healthcare) as the radiopharmaceutical, followed a 2-d stress first imaging protocol, used low-energy high-resolution collimators, and acquired the CT images for attenuation correction only. The SPECT images from the GE Healthcare scanners were of a 64 × 64 matrix, whereas the images from the Siemens scanners were of a 128 × 128 matrix. All SPECT images from GE Healthcare scanners were reconstructed using ordered-subset expectation maximization, and the images from the Siemens scanners were reconstructed using 3-dimensional fast low-angle shot. All CT images were acquired with a 512 × 512 matrix and a 5-mm slice thickness without any automatic exposure control or dose modulation.

Data Collection

Patient demographics such as age, sex, height, and weight were recorded from each of the patient image files. Body mass index (BMI) was calculated as weight (kg) divided by square of the height (m). For SPECT dosimetry, the scanner model, collimator type, image matrix size, AA for the stress study, AA for the rest study, acquisition time per view, image reconstruction method, and number of views were recorded. The EDs for the stress and rest studies were calculated from the AAs using sex-specific conversion factors already published (*15,16*). The total ED for SPECT was calculated by adding the ED for the stress study to that for the rest study. For CT dosimetry, the kVp, mA, $CTDI_{vol}$, dose–length product, image matrix size, and slice thickness were noted. The dose–length products were converted to ED values using the sex-specific conversion factors from the literature (*4*). The total patient dose for SPECT/CT MPI was calculated as the sum of ED SPECT and ED CT values. All $CTDI_{vol}$ measurements were made using the 32-cm-diameter dosimetry phantom, and the accuracy of $CTDI_{vol}$ and dose–length product for all scanners was tested as part of routine quality assurance programs.

Statistical Analysis

Patients were grouped on the basis of sex, and each sex was analyzed separately. The EDs for SPECT were statistically tested for any dependence on scanner type, imaging center, and image matrix size. The EDs for stress and rest tests were compared using paired *t* tests. Any correlation between EDs from the SPECT part of the study and BMI was investigated for each sex separately. The EDs for CT were tested for any dependence on scanner type, kV, and patient BMI. The total EDs were investigated for any correlation with patient BMI. All statistical analyses were performed using Statistical Package for Social Sciences (version 17), with the significance level set at a *P* value of less than 0.05. The Student *t* test and 1-way ANOVA were used as appropriate for all statistical tests. When statistically significant differences were not observed between male and female patients, the subjects were pooled for sex-neutral analysis.

RESULTS

This study was performed on 415 patients (268 men and 147 women) from 4 imaging centers. Patient characteristics such as age, height, weight, and BMI are listed in Table 2. The image acquisition parameters used in SPECT and CT are detailed in Table 3. A wide range of AAs was observed for the SPECT part of MPI, with a maximum-to-minimum ratio of around 4 for AA for both rest and stress studies among the 4 centers. Similar variation was observed for $CTDI_{vol}$, with a maximum-to-minimum ratio of 3.5. Statistically significant differences were not observed ($P > 0.380$) in AA between male and female patients for either the stress test or the rest test, image matrix size, or scanner model within each center in all 4 imaging centers. Paired *t* testing did not find any significant difference ($P = 0.864$) in AA between the stress and rest tests for either sex. When different imaging centers were compared, significant differences in total AA were observed, with the mean AA for each center ranging from 1,206 to 1,964 MBq ($P < 0.001$) for the stress and rest studies combined. The $CTDI_{vol}$ also

TABLE 2
Patient Demographics of Study

Demographic	Mean ± SD	Range	Skewness
Age	60 ± 11	29–88	−0.048
Height (m)	1.64 ± 0.99	1.34–1.90	−0.189
Weight (kg)	88 ± 20	39–172	+0.742
BMI (kg/m^2)	32.6 ± 7.2	17.4–70.7	+1.134

TABLE 3
Image Acquisition Parameters for SPECT and CT Images

Modality	Parameter	Mean ± SD	Range	Skewness
SPECT	Stress study	813 ± 211	297–1,183	−0.719
AA (MBq)	Rest study	803 ± 200	305–1,180	−0.778
CT	kVp	—	120–140	—
	mA	—	10–50	—
	$CTDI_{vol}$ (mGy)	2.3 ± 1.1	1.12–3.97	+0.718

showed significant differences ($P < 0.001$) among imaging centers, with the mean values for different centers ranging from 1.4 to 3.8 mGy (Table 4). Although the SPECT EDs differed between male and female patients, when the SPECT ED was compared among the 4 centers, the sex of the patient was ignored.

The overall mean value from all 4 centers was 1,616 ± 411 MBq for AA for SPECT and 2.3 ± 1.1 mGy for $CTDI_{vol}$ for CT. Within each imaging center, no significant differences ($P > 0.56$) were observed in AA among the different SPECT/CT scanners. The $CTDI_{vol}$ values were found to be specific to each scanner, without regard to patient age, size, or sex. Table 5 illustrates the EDs for male and female patients for the 2 imaging modalities separately and the total ED for the SPECT/CT MPI study. The EDs for female patients were significantly higher than those for male patients even though AA and $CTDI_{vol}$ did not significantly differ. The SPECT contribution to the total ED was about 10 times higher than the ED from CT. However, the ED from SPECT and the total ED showed statistically significant ($P < 0.001$) positive correlations with BMI whereas the ED from CT did not show any correlation with BMI (Figs. 1–3). The image matrix size of SPECT did not have any influence on AAs or EDs.

DISCUSSION

The EDs, of around 10 mSv from SPECT and about 1 mSv from CT, leading to a total radiation dose of 11 mSv for SPECT/CT MPI, from this study do not differ significantly from values reported and recommended in the literature (*1–5,10–12*). However, these values are much smaller than those previously reported (1–15 mSv from CT and 6–37 mSv from SPECT) for routine SPECT/CT studies (*14*). The increase in total ED, and hence the risk of developing radiation-induced cancer, by the introduction of CT for attenuation correction is small compared with the risk involved in the 2-d stress/rest SPECT protocol. Therefore, the benefits of using CT images for attenuation correction, leading to better image quality and a more accurate diagnosis of coronary artery disease, outweigh the extra risk introduced by CT (*17–20*). The differences in EDs from SPECT and CT between male and female patients result mainly from the differences in the conversion factors used to calculate the ED. The major contribution for these differences in conversion factors comes from the involvement of breast tissue in female patients (*15*). Since no significant differences in AA or $CTDI_{vol}$ were observed between the 2 sexes, we can report that female patients are presented with slightly elevated risk from the same imaging procedure. More stringent radiation dose optimization steps need to be followed when female patients are referred for SPECT/CT MPI studies.

The current study also found that the AA for the SPECT part of MPI depended mostly on the protocol followed by each imaging center. When different scanner models were used within 1 imaging center, the AAs did not depend on the scanner model or the image matrix size, indicating that imaging centers have protocols for calculating AA based only on patient characteristics. The positive correlation found between AA and BMI reassures clinicians that imaging procedures are performed with suitable protocols. This practice can be considered as following the personalized AA model for MPI, which has been advocated as a method of radiation dose optimization (*11*). In contrast, the $CTDI_{vol}$ values were observed to be fixed for a particular scanner model regardless of patient characteristics. This practice may lead to overexposure of small patients and image degradation of large patients. It was also observed that the scanner manufacturers have set constant parameters for acquiring attenuation correction images on CT, as reported in the literature. This may be because the nuclear medicine technologists who perform MPI studies may not have had any formal training in CT imaging, which is relatively new in nuclear medicine. This issue can be overcome by including CT imaging as part of the undergraduate curriculum of nuclear medicine technology or offering remedial courses

TABLE 4
Dosimetry Quantities, as Mean ± SD, from 4 Imaging Centers

Imaging center	N	AA stress (MBq)	AA rest (MBq)	$CTDI_{vol}$ (mGy)	ED SPECT (mSv)	ED CT (mSv)	ED total (mSv)
C1	118	1,000 ± 83	964 ± 81	1.6 ± 0.0	11.5 ± 1.2	0.6 ± 0.2	12.1 ± 1.3
C2	102	601 ± 136	605 ± 122	1.4 ± 0.2	7.0 ± 2.8	0.6 ± 0.2	7.6 ± 2.8
C3	101	758 ± 134	750 ± 120	3.8 ± 0.0	8.2 ± 1.5	1.2 ± 0.2	9.4 ± 1.6
C4	94	870 ± 90	872 ± 90	2.4 ± 1.1	10.4 ± 1.3	1.4 ± 1.0	11.8 ± 1.7
P		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

N = number of patients.

TABLE 5
ED (in mSv) from Various Components of SPECT/CT MPI Study and Total ED for Entire Procedure

Component	Male mean ± SD	Female mean ± SD	*P*
ED stress study	4.6 ± 1.1	5.0 ± 1.4	0.019
ED rest study	4.2 ± 1.1	5.4 ± 1.4	<0.001
ED SPECT	8.8 ± 2.2	10.4 ± 2.8	0.002
ED CT	0.8 ± 0.4	1.1 ± 0.8	<0.001
ED total	9.6 ± 2.2	11.5 ± 3.0	<0.001

for practicing technologists. Once the technologists recognize how the various image acquisition and reconstruction parameters affect image quality, they will be able to perform patient-specific image acquisition. CT imaging has been incorporated into the undergraduate curriculum of nuclear medicine technology at our institution over the last 3 y. Discontinuing the practice of using fixed acquisition parameters and instead using patient-specific parameters with automatic exposure control and radiation dose modulation methods can reduce the ED from CT (*1,13,14*). The scan length (and hence dose–length product) for a CT scan generally depends on the region of interest, in MPI the myocardium. Restricting the scan length to the required region of interest will reduce the ED from CT imaging. Further dose reductions can be achieved using a lower x-ray tube voltage for the CT image acquisition. However, any changes in the CT numbers of the tissue due to a lower x-ray tube voltage should be investigated (*21*).

The wide range (1,206–1,964 MBq) of mean AAs found in this study, among the 4 centers, indicates that there is room for radiation dose optimization in the SPECT part of MPI. The recommended value of AA for stress and rest MPI studies—1,850 MBq (*10*)—is lower than some of the values found in this study. Among the 4 imaging centers, C2 used the lowest mean AA. This center used 2 different SPECT/CT scanner models and 2 different image matrices but did not show any difference in the mean AA used between the scanners. The image quality for the higher-matrix images was maintained by using a longer acquisition time rather than by increasing the AA. The center C1 used the largest mean AA on the single SPECT/CT scanner model that was available. Investigations into the reduction of AA in centers using higher amounts than other centers are recommended. A further reduction of patient radiation doses can be achieved by adopting the recommendations of the American Society of Nuclear Cardiology and performing stress-only protocol or 1-d low-dose stress imaging protocol (*21*).

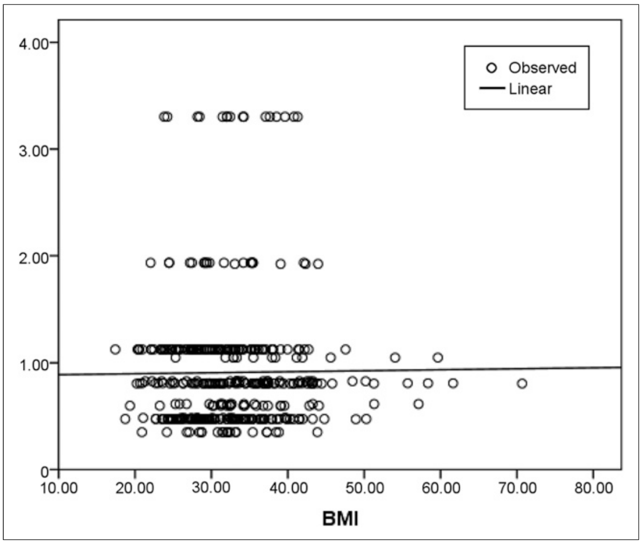

FIGURE 2. Correlation ($r = 0.00$; $P = 0.832$) of ED (mSv) from CT with BMI (kg m^{-2}).

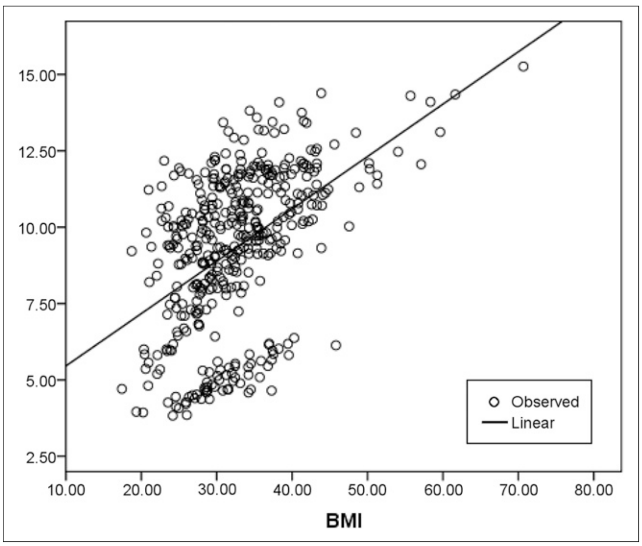

FIGURE 1. Correlation ($r = 0.48$; $P < 0.001$) of ED (mSv) from SPECT with BMI (kg m^{-2}).

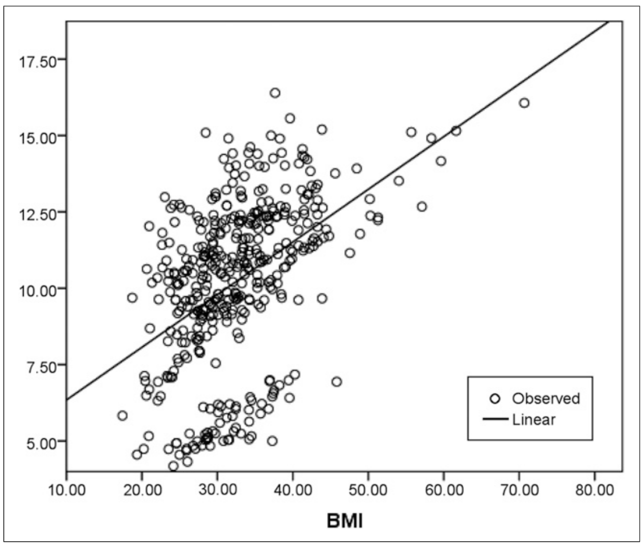

FIGURE 3. Correlation ($r = 0.46$; $P < 0.001$) of total ED (mSv) with BMI (kg m^{-2}).

This study had some limitations. First, the study did not compare the quality of images acquired using different scanners or at different imaging centers. Since all images were used for interpretation by physicians, they were assumed to be diagnostically acceptable. Second, the range of scanner models used in this study comes from 2 major SPECT/CT scanner manufacturers and hence the results may not extend to other scanner models. Future investigations into radiation dose reduction could be directed toward reducing the radiopharmaceutical dose; 1-d stress-rest study protocols and their benefits to patients are recommended. Image quality improvements due to attenuation correction using CT images in SPECT MPI are well documented in the literature. However, further image-quality analyses of the effects of CT attenuation on SPECT MPI imaging are proposed for the future.

CONCLUSION

This study found the ED from the SPECT and CT components of SPECT/CT MPI to be in the range of 10 and 1 mSv, respectively. We conclude that the excess risk from CT image acquisition for attenuation correction of SPECT images is small compared with the benefits presented by CT attenuation correction. The ED and the potential risk to female patients are slightly higher than those to male patients, given use of the same image acquisition parameters.

DISCLOSURE

No potential conflict of interest relevant to this article was reported.

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