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Effective dose to patients from single photon emission computed tomography and computed tomography during myocardial perfusion imaging

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Abstract

Rationale: Radiation dose to patients from imaging modalities is measured or calculated to assess the risk of the procedure and compare it to the benefits. Periodic review of image acquisition methods and radiation dose used are essential part of the optimization in medical imaging. The aim of this study was to estimate patient radiation dose from single photon emission computed tomography (SPECT) myocardial perfusion imaging (MPI) using computed tomography (CT) images for attenuation correction.

Method: SPECT and CT image acquisition parameters such as, administered activity (AA), CT dose index ($CTDI_{vol}$) and dose-length product (DLP) of 415 patients who have undergone SPECT MPI using CT attenuation correction were reviewed. Effective dose (ED) for the SPECT part, CT part and the total ED for the procedure were calculated. AA, $CTDI_{vol}$ and ED values were compared between patient gender, body mass index, imaging scanner model and imaging centers. Statistical analyses were carried out using t-test and one-way analysis of variance at $p < 0.05$ level of significance.

Results: The range of AA used for MPI was found to be 1206 to 1964 MBq per patient regardless of their gender. The resulting mean ED value of 8.8 mSv for males was significantly lower ($p=0.002$) than 10.4 mSv for females in SPECT. The range of $CTDI_{vol}$ was 1.12 to 3.97 mGy resulting in mean ED of 0.8 mSv for males, significantly lower ($p<0.001$) than 1.1 mSv for females in CT. The average combined ED for male and female patients were 9.6 and 11.5 mSv respectively. Positive correlation was found between AA and patient body mass index ($r=0.48$;

$p<0.001$), indicating patient size related AA. However, CTDIvol was found to depend only on the scanner model regardless of body mass index.

Conclusion: The ED from SPECT-CT MPI studies was found to be around 11 mSv with 10 mSv from the SPECT part of the study. The extra risk to the patients from CT imaging for attenuation corrections is small compared to the benefits incurred in accurate diagnosis.

Key Words

Myocardial perfusion imaging, SPECT-CT, Administered activity, CT dose index, effective dose.

Introduction

The use of Single Photon Emission Computed Tomography (SPECT), in conjunction X-ray Computed Tomography (CT) for the purpose of attenuation correction (AC), is common in myocardial perfusion imaging (MPI). (*1-3*) The AC using CT images has been proven to provide better image quality and more accurate diagnosis of coronary artery disease. The CT imaging delivers higher photon flux resulting better image quality, but at higher patient doses, compared to the 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 dose values for SPECT and/or CT component(s) of MPI and have also recommended establishing Diagnostic Reference Levels as a means of optimizing each component of the imaging procedure. (*6-9*) In terms of patient dose estimation, contribution from SPECT part of the imaging is derived from the administered activity (AA) of the radiopharmaceutical while the CT contribution is established from the Dose-Length-Product (DLP) and the Volume CT Dose Index ($CTDI_{vol}$) of the scan. In order 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 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, while in CT the X-ray tube voltage (kVp), tube-current (mA) and the scan length affect the patient dose. (*4*) Hence, studies involving patient dose measurements are important for establishing best practices and adhering to the optimisation 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 is to estimate patient radiation dose from the CT part, the SPECT part and the total in SPECT-CT MPI.

Materials and Methods

Clinical Centers and Imaging

This retrospective study was carried out by reviewing the imaging data of 415 randomly selected patients who were referred to MPI studies using 7 different SPECT-CT scanners at four 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 carried out MPI studies routinely. The data collection was carried out on five GE (General Electric, Milwaukee, WI, USA; 4 x GE Discovery 670 and 1 x GE Infinia Hawkeye) SPECT-CT and two Siemens (Siemens Medical, Germany.) scanners, each of them is equipped with a multi-slice CT scanner (Table 1). All centers used $^{99}Tc^{m}$ tetrofosmin (Myoview, GE Healthcare, Milwaukee, WI, USA.) as the radiopharmaceutical, followed a 2-day stress first imaging protocol, used low energy high resolution collimators and acquired the CT images for AC only. SPECT images from GE scanners were of 64 x 64 matrix while the images from Siemens scanners were of 128 x 128 matrix. All SPECT images from GE scanners were reconstructed using ordered subset expectation maximization algorithm and the images from Siemens scanners were reconstructed using 3D-FLASH algorithm. All CT images were acquired with 512 x 512 matrix and 5 mm slice thickness without any automatic exposure controls or dose modulation.

Data Collection

Patient demographics such as age, gender, height and weight were recorded from each of the patient image files. The body mass index (BMI) was calculated as weight (in kg) divided by square of the height (in m). For the SPECT dosimetry, the scanner model, collimator type, image matrix size, AA for the stress study and AA for the rest study, acquisition time per view, image reconstruction method and the number of views were recorded. The ED values for stress study and rest study were calculated from the AA values using gender specific conversion factors already published (*15,16*). The total ED for SPECT (ED SPECT) was calculated by adding the ED for the stress study to that for the rest study. For the CT dosimetry, the kVp, mA, $CTDI_{vol}$, DLP, image matrix size and slice thickness were noted. The DLP values were converted to ED (ED CT) values using the gender 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 DLP for all scanners were tested as part of routine quality assurance programs.

Statistical Analysis

Patients were grouped based on gender and each gender was analyzed separately. The ED values for SPECT were statistically tested for any dependence on scanner type, imaging center and image matrix size. The ED values for stress and rest tests were compared using paired t-test. Any correlation between ED values from the SPECT part of the study and BMI was investigated for each gender separately. The ED values for CT were tested for any dependence on scanner type, kV and patient BMI. The total ED values were investigated for any correlation with patient BMI. All statistical analyses were carried out using Statistical Package for Social Sciences (SPSS Version 17) with significance level set at $p < 0.05$. Student t-test and One-way Analysis of Variance (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 gender neutral analysis.

Results

This study was carried out on 415 patients (268 males; 147 females) from 4 imaging centers. Patient characteristics such as age, height, weight and BMI obtained are listed in Table 2. The image acquisition parameters used in SPECT and CT are detailed in Table 3. A wide range of AA values were observed for the SPECT part of MPI with maximum-to-minimum ratio of AA around 4 for both rest and stress studies among the four centers. Similar variation was observed for $CTDI_{vol}$ with maximum-to-minimum ratio of 3.5. Statistically significant differences were not observed ($p > 0.380$) in AA between male and female patients for both the stress test and the rest test, image matrix size or scanner model within each center in all 4 imaging centers. Paired t-test did not result in any significant difference ($p = 0.864$) in AA between stress test and rest test for both genders. When different imaging centers were compared, significant differences in total AA were observed with mean AA for each center ranging from 1206 to 1964 MBq ($p < 0.001$) for stress and rest studies combined. The $CTDI_{vol}$ also showed significant differences ($p < 0.001$) among the imaging centers, with mean values of different centers in the range of 1.4 to 3.8 mGy

(Table 4). Although the ED SPECT values differed between male and female patients, when comparing ED SPECT between the four centers, gender of the patient was ignored.

The overall mean value from all four centers was found to be 1616 ± 411 MBq of AA for SPECT and 2.3 ± 1.1 mGy of $CTDI_{vol}$ for CT. Within each imaging center, no significant differences ($p > 0.56$) were observed in AA between different SPECT-CT scanners. The $CTDI_{vol}$ values were found to be specific to each scanner without any regard to patient age, size or gender. Table 5 illustrates the ED values for male and female patients for the two imaging modalities separately and the total ED for the SPECT-CT MPI study. The ED values for female patients were significantly higher than those for the male patients even though the AA and $CTDI_{vol}$ were not significantly different. The SPECT contribution to the total ED was found to be about 10 times higher than the ED from CT. However, the ED from SPECT and total ED were found to show statistically significant ($p < 0.001$) positive correlations with BMI while ED from CT did not show any correlation with BMI (Figures 1 to 3). The image matrix size of SPECT did not have any influence on AA or ED values.

Discussion

The ED values, 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 literature. (*1-5, 10-12*) However, these values are much smaller than ED values reported in ref. 14 (1-15 mSv from CT and 6-37 mSv from SPECT) for routine SPECT-CT studies. 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 to the risk involved in the 2-day stress/rest SPECT protocol. Therefore, the benefits of using CT images for attenuation correction, leading to better image quality and more accurate diagnosis of coronary artery disease, outweigh the extra risk introduced by CT. (*17-20*) The differences in ED values from SPECT and CT between male and female patients result mainly from the differences in the conversion factors used to calculate the ED value. The major contribution for these differences in conversion factors come from the involvement of breast tissue in female patients. (*15*) Since no significant differences in AA or $CTDI_{vol}$ were observed between the two genders, 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 to SPECT-CT MPI studies.

The current study also found that the AA for SPECT part of the MPI depended mostly on the protocol followed by each imaging center. When different scanner models were used within one imaging center, the AA values did not depend on the scanner model or the image matrix size, indicating that imaging centers have protocols for calculating AA only based on patient characteristics. The positive correlation found between AA and BMI reassures the clinicians that imaging procedures are carried out 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 optimisation. (*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 the CT, as reported in 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 can be overcome by including CT imaging as part of the undergraduate curriculum of nuclear medicine technology and/or offering remedial courses for practicing technologists. Once the technologists recognize how different image acquisition and reconstruction parameters affect image quality, they will be able to perform patient specific image acquisition. CT imaging has been incorporated in to the undergraduate curriculum of nuclear medicine technology at our institution over the last 3 years. Discontinuing the practice of using fixed acquisition parameters and using patient specific parameters with automatic exposure control and radiation dose modulation methods can reduce ED from CT. (*1, 13-14*) The scan length (and hence DLP) 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 by using lower x-ray tube voltage for the CT image acquisition. However, any changes in CT numbers of tissue due to lower x-ray tube voltage should be investigated. (*21*)

The wide range (1206 to 1964 MBq) of mean AA values found in this study, among the four centers, indicate that there is room for radiation dose optimisation in the SPECT part of MPI. The recommended value of AA for stress and rest MPI studies of 1850 MBq (*10*) is lower than some of the values found in this study. Among the four imaging centers, C2 used the lowest mean AA compared with all other centers. This center used two different SPECT-CT scanner models and two different image matrices but did not show any difference in mean AA used between the scanners. The image quality for the higher matrix images were maintained using longer acquisition time rather than increasing 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 compared to other centers are recommended. Further reduction in patient radiation doses can be achieved by adopting the recommendations by the American Society of Nuclear Cardiology and performing stress-only protocol or 1-day low dose stress imaging protocol. (*21*)

This study has some limitations. Firstly, 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. Secondly, the range scanner models used in this study comes from two 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 towards reducing the radiopharmaceutical dose, one-day 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 document in literature. However, investigation in to further image quality analysis on the effects of CT attenuation in SPECT MPI imaging is proposed for the future.

Conclusion

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

DISCLOSURE:

The author wishes to disclose no conflict of interest of any kind and declares that no financial support was sought or obtained for this study from any organization or individuals.

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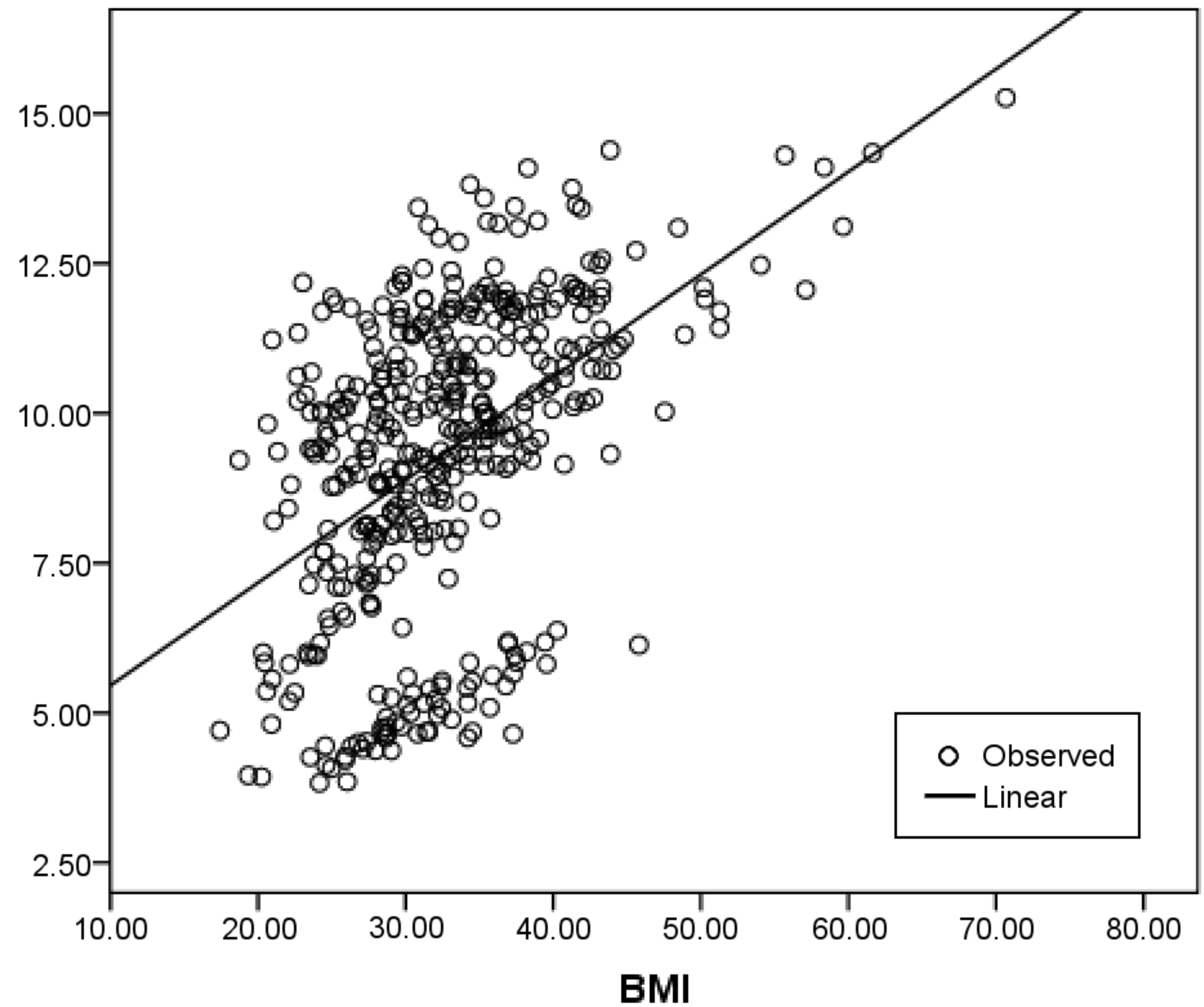

Figure 1. The correlation ($r = 0.48$; $p < 0.001$) of effective dose (ED in mSv) from SPECT with body mass index (BMI in kg m^{-2})

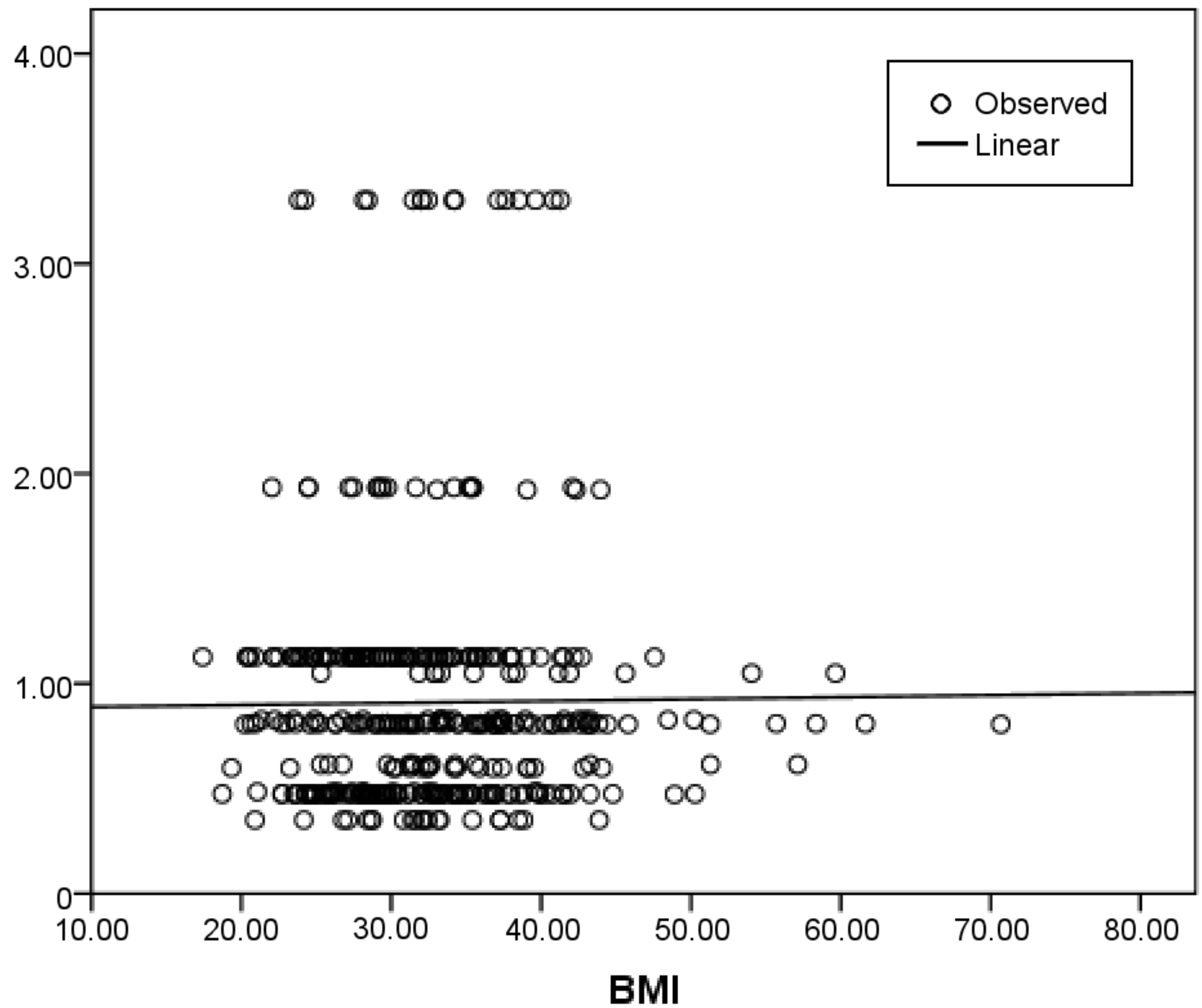

Figure 2. The correlation (r = 0.00; p = 0.832) of effective dose (ED in mSv) from CT with body mass index (BMI in kg m^{-2})

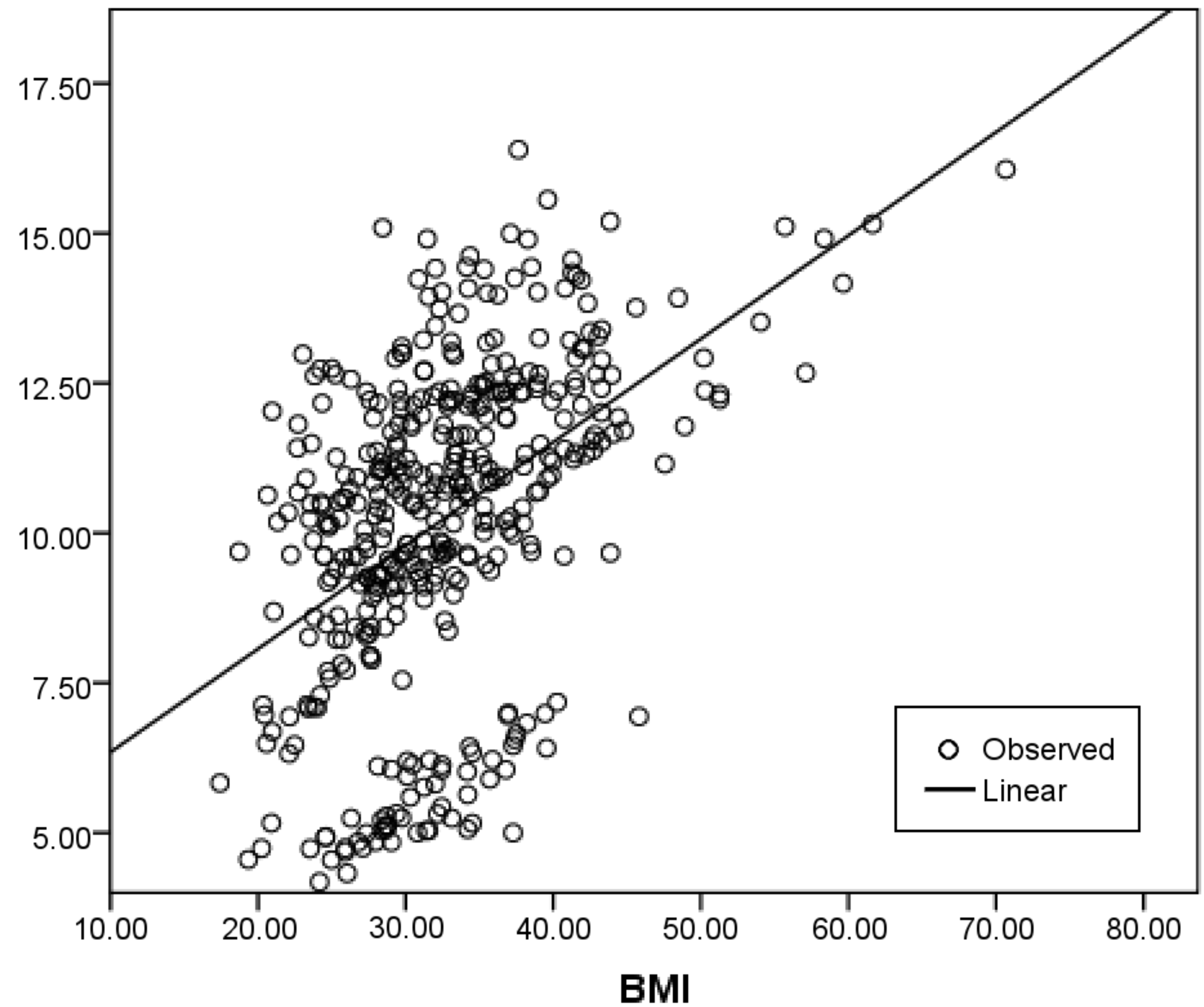

Figure 3. The correlation ($r = 0.46$; $p < 0.001$) of total effective dose (ED in mSv) with body mass index (BMI in kg m^{-2})

Imaging Center	Scanner	Image Reconstruction	SPECT Image Matrix	Number of CT Slices
C1	GE Discovery 670	OSEM	64 x 64	16
C2	GE Discovery 670	OSEM	64 x 64	16
	Siemens Symbia	3D-FLASH	128 x 128	16
C3	GE Discovery 670	OSEM	64 x 64	16
C4	GE Discovery 670	OSEM	64 x 64	16
	GE Hawkeye	OSEM	64 x 64	4
	Siemens Intevo	3D-FLASH	64 x 64	16

GE = General Electric; OSEM = Ordered Subset Expectation Maximization

Table 1. Equipment design parameters used at each imaging center included in the study.

	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

SD = Standard Deviation

Table 2. Patient demographics of the study.

Modality		Mean ± SD	Range	Skewness
SPECT AA (MBq)	Stress Study	813 ± 211	297 – 1183	- 0.719
	Rest Study	803 ± 200	305 – 1180	- 0.778
CT	kVp	-	120 – 140	-
	mA	-	10 – 50	-
	CTDIvol (mGy)	2.3 ± 1.1	1.12 – 3.97	+ 0.718

AA = Administered Activity; SD = Standard Deviation

Table 3. Image acquisition parameters for SPECT and CT images.

Imaging Center	N	AA Stress (MBq)	AA Rest (MBq)	$CTDI_{vol}$ (mGy)	ED SPECT (mSv)	ED CT (mSv)	ED Total (mSv)
C1	118	1000±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-value		< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

N=number of patients; AA = Administered Activity, $CTDI_{vol}$ = volume CT dose index

Table 4. Dosimetry quantities, as mean ± standard deviation, from the four imaging centers.

	Male Mean ± SD	Female Mean ± SD	p-value
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

SD = Standard Deviation; ED = Effective Dose (mSV)

Table 5. Effective dose (in mSv) from various components of the SPECT-CT MPI study and the total effective dose for the entire procedure.