Original Article

Comparison between the use of one and two CT scans for attenuation correction of rest-stress myocardial perfusion SPECT with Tc-99m sestamibi

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Abstract

Background: The standard protocol is to use separate computed tomography (CT) scans acquired during rest and stress for attenuation correction (AC) of myocardial perfusion (MP) single photon emission computed tomography (SPECT) imaging. Recently, there have been attempts to reduce the radiation dose by using one CT instead of two CTs.

Objective: To compare between the use of one and two CTs for AC of rest-stress MP SPECT with Tc-99m sestamibi in quantification of MP and left ventricle (LV) function.

Materials and Methods: Gated rest-stress MP SPECT images of 107 patients were reprocessed using 3 different AC methods: 1) rest CT for AC of rest SPECT and stress CT for AC of stress SPECT (2CT); 2) rest CT for AC of both rest and stress SPECT (1CT-rest); and 3) stress CT for AC of both rest and stress SPECT (1CT-stress). SPECT images obtained from 2CT and 1CT were used for quantification of MP values and LV function values. The values from 2CT and 1CT were compared.

Results: The MP values of 2CT and 1CT showed a strong correlation (r≥0.712) and they did not differ significantly (p=0.106 to 0.931). In contrast, the LV function values of 2CT and 1CT exhibited a very strong correlation (r≥0.960), but they differ significantly (p=<0.001 to 0.004).

Conclusion: The use of one and two CTs for AC in rest-stress MP SPECT with Tc-99m sestamibi can be interchanged for the quantification of MP, but not for the quantification of LV function.

Keywords: CT-based attenuation correction, Gated SPECT, Left ventricle function, Myocardial perfusion SPECT, Tc-99m sestamibi.

Introduction

Myocardial perfusion single photon emission computed tomography (MP SPECT) imaging has for several decades been one of the most widely used examinations in the diagnosis, risk stratification, and evaluation of treatment efficacy in patients with a suspected or known coronary artery disease (CAD) [1-6]. This perfusion imaging uses an intravenously administered radiopharmaceutical, such as technetium-99m (Tc-99m) sestamibi, to depict the distribution of blood flow in the myocardium. Myocardial perfusion SPECT imaging at rest and during cardiovascular stress allows differentiation between myocardial ischemia (limitations in blood flow) and infarction (absence of blood flow) [7, 8]. In addition to regional perfusion, acquiring MP SPECT data with electrocardiographic (ECG) gating (gated MP SPECT), allows measurement of cardiac function index such as left ventricle volume, ejection fraction (EF), and regional wall motion and thickening. Gated MP SPECT, with the ability to evaluate both myocardial perfusion and cardiac function, has become a routine protocol, and it expands the clinical utility of myocardial perfusion SPECT [7, 9-13].

Although gated MP SPECT is a valuable diagnostic tool, soft-tissue attenuation in the abdomen, breasts, diaphragm, and lateral chest wall causes attenuation artifacts, with an attendant decrease in the interpretive confidence of the reader and the diagnostic accuracy of the examination [14-16]. Computed tomography-based attenuation correction (CTAC) is a methodology that applies an attenuation map derived from computed tomography (CT) to SPECT in order to compensate for this degradation. Attenuation correction (AC) produces qualitative and quantitative data that can more accurately represent relative myocardial per¬ fusion and improve the performance of myocardial perfusion SPECT interpretation, especially the specificity of myocardial ischemia [7, 17-20].

Common gated rest-stress MP SPECT requires two scans taken at rest and after exercise or pharmacologic stress. For accurate CTAC, it is standard to acquire separate CT scans during rest and stress, causing additional radiation exposure to the patient. Recently, there have been attempts to reduce the radiation dose from MP SPECT while maintaining diagnostic accuracy [21, 22], and it has been proposed that one CT may be sufficient for AC of both rest and stress SPECT to reproduce accurate quantification of myocardial perfusion. The effectiveness of using one CT for this purpose has been evaluated previously [23-26]; however, few studies have been performed of the efficacy of using one CT for AC of gated rest-stress MP SPECT in quantification of the left ventricle (LV) function.

The aim of this study was to compare the use of one and two CTs for AC of gated rest-stress MP SPECT imaging with Tc-99m sestamibi in quantification of myocardial perfusion and LV function.

Materials and methods

Study population

This study retrospectively analyzed the data of 107 patients who underwent gated rest-stress MP SPECT/CT imaging with Tc-99m sestamibi between March 2020 and December 2021. The image data from patients who were unable to complete gated rest-stress myocardial perfusion (MP) SPECT/CT imaging, including rest SPECT, rest CT, stress SPECT, and stress CT scans, as well as patients with a significant liver, gall bladder, and bowel activity, which led to interference in myocardial uptake as observed in SPECT images, were excluded from this study. Table 1 shows the demographics of the study population. The proportion of male and female patients was approximately equal. This study was approved by the research ethics committee of Rajavithi Hospital (#221/2564).

Table 1. *Demographics of the study population (n = 107).*

Patient characteristics	Forum program
Male sex	52 (48.6%)
Age (years)	63 ± 12
Body-mass index (m^2/kg)	25.8 ± 5.4
Abnormal MP SPECT (ischemia or infarction)[a]	38 (35.51%)

Data are mean ± standard deviation (SD) or number, with percentages in parentheses.
[a]The interpretation results reported by nuclear medicine radiologists.

Gated MP SPECT data acquisition

All 107 patients were imaged with the dual-headed detector SPECT system, NM/CT 870 DR (GE Healthcare), using a standard one-day rest/stress imaging protocol with CT acquired for AC both at rest and during stress. Firstly, SPECT and CT data were acquired at rest (rest SPECT and rest CT) and the data were acquired 3 hours later. The imaging protocol of one-day rest/stress MP SPECT/CT is shown in Figure 1.

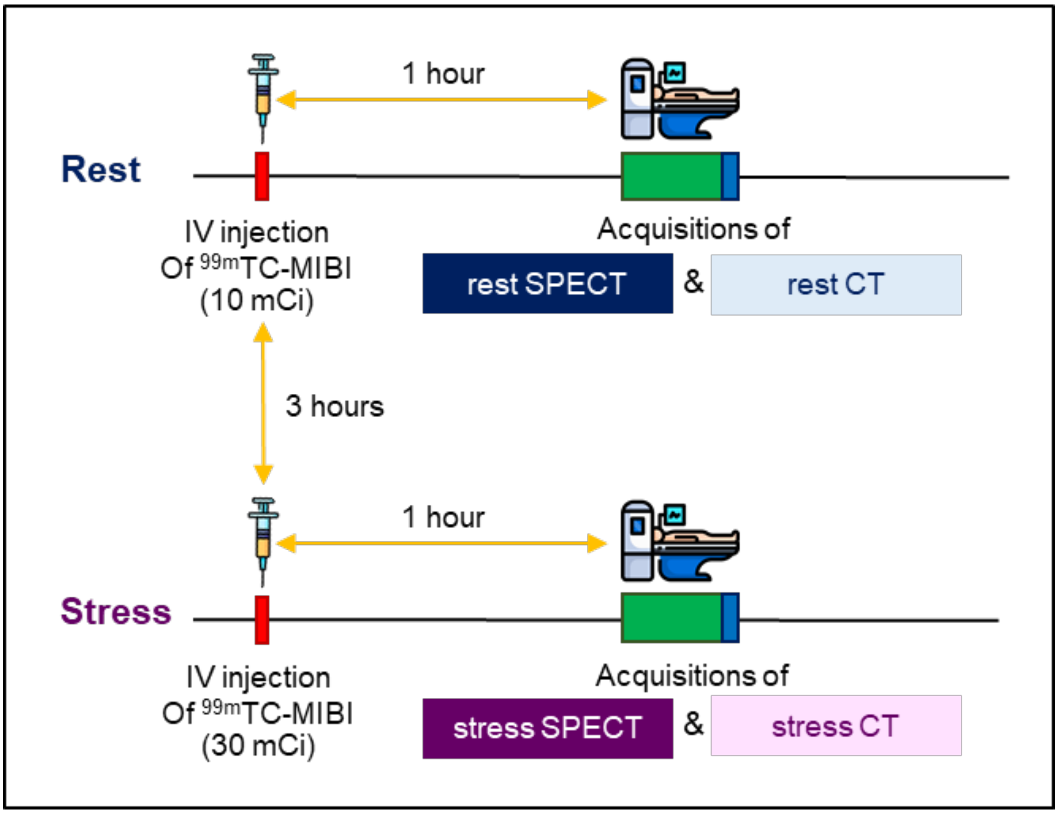

Figure 1. *Imaging protocol of one-day rest/stress MP SPECT/CT.*

At rest, patients were intravenously injected with 10 mCi of Tc-99m sestamibi, and gated MP SPECT imaging was performed 1 hour after injection. Two SPECT detectors coupled with low energy high resolution sensitivity (LEHRS) parallel-hole collimators were positioned at 90° to each other (L mode) and were rotated 180° from the right anterior oblique (RAO) 45° to the left posterior oblique (LPO) 45° with a view angle of 3°. Matrix sizes were set at 64 × 64 with the zoom factor of 1.5 and data were acquired for 20 seconds at each view. The energy windows were set at 140 keV ± 10% for the main window and 120 keV ± 5% for the scatter window. The gated data were acquired with 8 frames per R-R intervals. CT acquisition for AC was performed immediately after the SPECT acquisition with free breathing. The CT data was acquired at 120 kV, 20 mA and a slice thickness of 5 mm.

Stress tests were started at 3 hours after injection of Tc-99m sestamibi with patients in a resting condition. Pharmacological stress with adenosine was used in 90% of the patients and exercise stress was used for the remainder. The 30 mCi dose (3 times greater than the rest activity) of Tc-99m sestamibi was intravenously injected into the patients under the stress condition. The stress SPECT data was acquired before CT acquisition. The patient positioning and acquisition protocols of stress SPECT and CT were similar to those of the rest protocols, except for the time per view of SPECT acquisition. The time per view of SPECT acquisition for stress SPECT (15 seconds) was shorter than that of rest SPECT (20 seconds) in order to minimize the effects of cardiac and respiratory motions on the MP SPECT images during stress. All patients were scanned in a supine position with feet first, arms raised on the armrest, both at rest and under stress, to maintain the same positioning between acquisitions.

Image reconstruction & Quantitative analysis

The SPECT data (gated and non-gated) and CT data for both rest and stress (rest SPECT, rest CT, stress SPECT and stress CT) were used for SPECT image reconstruction with CTAC and quantitative analysis. The rest and stress SPECT images were reconstructed using ordered subset-expectation maximization (OS-EM) with 2 iterations and 10 subsets on a Xeleris workstation (GE Healthcare). Left ventricular activity was masked from liver, gall bladder and bowel activities. Scatter correction was based on the subtraction of projection data, with no method for motion correction. Butterworth filter was applied to reconstruct images with cut-off frequency of 0.45 and 0.548 cycles/cm and order of 10 and 12.6 for rest SPECT and stress SPECT, respectively.

CTAC was performed during SPECT image reconstruction. A single radiological technologist with expertise in gated MP SPECT analysis (> 20 years of experience) processed all gated MP SPECT studies with different CTAC methods (Figure 2) in order to investigate this research aim. The standard CTAC method was to use rest CT for AC of rest SPECT and stress CT for AC of stress SPECT, noted as 2CT (Figure 2a). The alternative method was to use rest CT for AC of both rest and stress SPECT, noted as 1CT-rest (Figure 2b). Another alternative method was to use stress CT for AC of both rest and stress SPECT noted as 1CT-stress (Figure 2c). The software for image reconstruction automatically performed image registration between SPECT and CT images for CTAC, and the alignment of the SPECT and CT images was visually confirmed and adjusted in the axial, sagittal, and coronal planes for every patient.

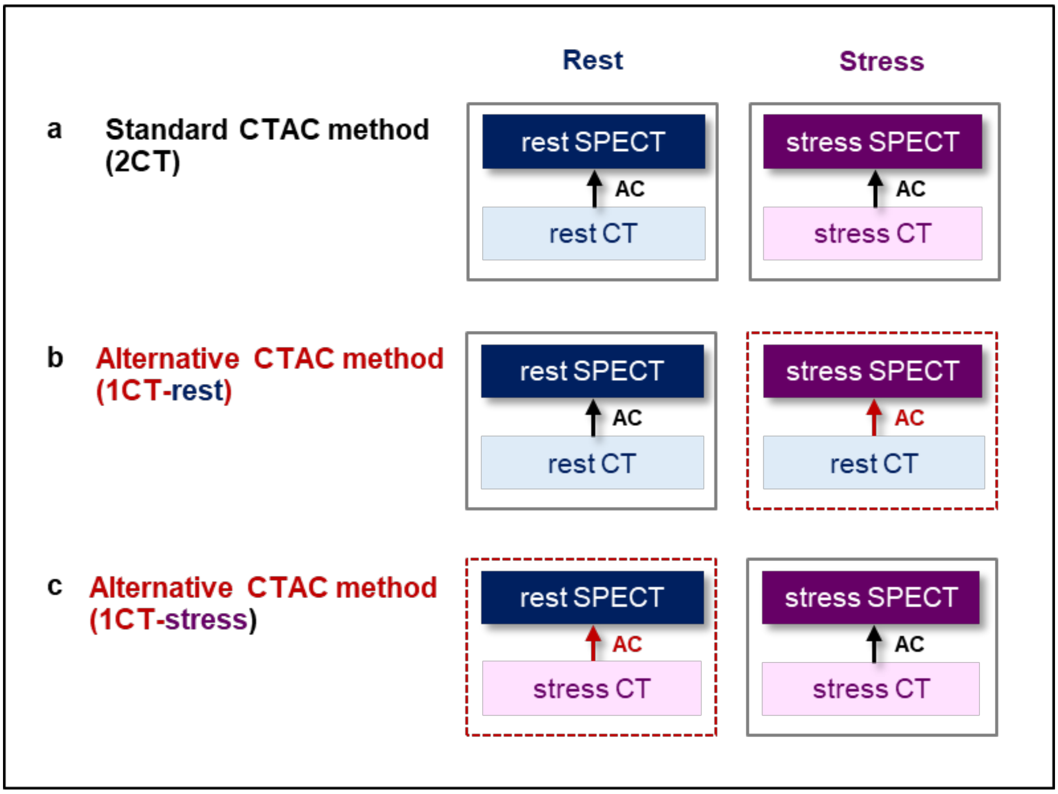

Figure 2. *SPECT image reconstruction with different CTAC methods: (a) standard CTAC method (2CT): using rest CT for AC of rest SPECT and stress CT for AC of stress SPECT; (b) alternative CTAC method (1CT-rest): using rest CT for AC of both rest and stress SPECT; and (c) alternative CTAC method (1CT-stress): using stress CT for AC of both rest and stress SPECT.*

We used Quantitative Perfusion SPECT (QPS) and Myometrix software for the quantitative analysis of gated MP SPECT imaging because these methods are routinely used in our hospital. The reconstructed MP SPECT images with different CTAC methods from non-gated data were used for quantification of myocardial perfusion values, including summed rest score (SRS), summed stress score (SSS) summed difference score (SDS), rest total perfusion deficit (rest TPD), stress total perfusion deficit (stress TPD) and transient ischemic dilation ratio (TID) [8, 27]. The MP SPECT images were automatically compared with a normalized database with QPS software to produce sum scores according to anatomic regions on a 17-segment American Heart Association polar map. The SRS and SSS were calculated as the sum of the individual scores from the 17 segments of the polar map obtained during rest and stress. The SDS was calculated by subtracting the SRS from the SSS (SDS = SSS-SRS). These values indicate the severity of myocardial ischemia. TPD was calculated based on both the extent and severity of ischemia. The TID, which is the ratio of the stress LV volume to rest LV volume, was quantified using Myometrix software; this value is one of the markers of severe myocardial ischemia.

The reconstructed MP SPECT images obtained from different CTAC methods from gated data were used for quantification of LV function values, including rest end diastolic volume (EDV), stress EDV, rest end systolic volume (ESV), stress ESV, rest ejection fraction (EF), and stress EF using Myometrix software. The percentage of EF was calculated as follows: EDV-ESV/EDV*100 [13]. The EF is clinically used as an index for evaluation of the cardiac function.

Statistical analysis

All quantitative values were represented as mean ± standard deviation (SD). Pearson's correlation was used to test the correlation between quantitative values obtained from 2CT and 1CT. An arbitrary classification for Pearson's correlation was: ≥0.800, very strong; 0.600-0.799, strong; 0.400-0.599, moderate; 0.200-0.399, weak; and <0.200, very weak. The quantitative values between 2CT and 1CT were compared using paired t-test, and $p < 0.05$ was considered statistically significant.

Results

Table 2 summarizes the findings, with mean ± SD of all quantitative values, and the correlation and the comparison of quantitative values of 2CT and 1CT. There was a very strong correlation between myocardial perfusion values obtained from 2CT and 1CT for SRS of 2CT and 1CT-stress, SSS of 2CT and 1CT-rest, SDS of 2CT and 1CT-stress, Rest TPD of 2CT and 1CT-stress, Stress TPD of 2CT and 1CT-rest, TID of 2CT and 1CT-stress, and TID of the 2CT and 1CT-rest ($r \geq 0.915$), as shown in Table 2. The correlation coefficient of SDS between 2CT and 1CT-rest ($r = 0.712$), which indicated a strong correlation, was lower than that of other myocardial perfusion values. This corresponded to the 3D scatter plots in Figure 3 in which the variability in the SDS from 2CT and 1CT-rest was seen to be the highest (Figure 3d) among other myocardial perfusion values (Figure 3a, 3b, 3c, 3e, 3f, 3g and 3h). However, the comparison results showed that there was no significant difference between myocardial perfusion values from 2CT and 1CT, as shown in the last column of Table 2.

Table 2. *Correlation and comparison of quantitative values obtained from 2CT and 1CT.*

Quantitative Values (2CT vs. 1CT)	Mean ± Standard Deviation (2CT vs. 1CT)	Correlation Coefficient (r)	Difference (p value)
Myocardial Perfusion Values			
SRS_{2CT} vs. $SRS_{1CT\text{-}stress}$	3.7 ± 8.3 vs. 3.7 ± 8.4	0.991[a]	0.931
SSS_{2CT} vs. $SSS_{1CT\text{-}rest}$	6.9 ± 9.1 vs. 7.0 ± 9.2	0.974[a]	0.647
SDS_{2CT} vs. $SDS_{1CT\text{-}stress}$	3.1 ± 2.6 vs. 3.1 ± 2.8	0.920[a]	0.931
SDS_{2CT} vs. $SDS_{1CT\text{-}rest}$	3.1 ± 2.6 vs. 3.2 ± 2.9	0.712[b]	0.647
Rest TPD_{2CT} vs. Rest $TPD_{1CT\text{-}stress}$	6.2 ± 9.5 vs. 6.2 ± 9.1	0.980[a]	0.918
Stress TPD_{2CT} vs. Stress $TPD_{1CT\text{-}rest}$	7.7 ± 9.6 vs. 7.7 ± 9.7	0.986[a]	0.680
TID_{2CT} vs. $TID_{1CT\text{-}stress}$	1.1 ± 0.1 vs. 1.1 ± 0.1	0.915[a]	0.571
TID_{2CT} vs. $TID_{1CT\text{-}rest}$	1.1 ± 0.1 vs. 1.1 ± 0.1	0.924[a]	0.106
LV Function Values			
Rest EDV_{2CT} vs. Rest $EDV_{1CT\text{-}stress}$ (mL)	82.7 ± 52.2 vs. 89.4 ± 50.1	0.982[a]	<0.001*
Stress EDV_{2CT} vs. Stress $EDV_{1CT\text{-}rest}$ (mL)	89.1 ± 54.4 vs. 92.9 ± 54.5	0.987[a]	<0.001*
Rest ESV_{2CT} vs. Rest $ESV_{1CT\text{-}stress}$ (mL)	41.6 ± 46.6 vs. 45.3 ± 47.1	0.973[a]	0.001*
Stress ESV_{2CT} vs. Stress $ESV_{1CT\text{-}rest}$ (mL)	45.7 ± 48.0 vs. 48.7 ± 49.9	0.979[a]	0.023*
Rest EF_{2CT} vs. Rest $EF_{1CT\text{-}stress}$ (%)	58.7 ± 17.7 vs. 57.7 ± 17.8	0.960[a]	0.031*
Stress EF_{2CT} vs. Stress $EF_{1CT\text{-}rest}$ (%)	57.0 ± 16.9 vs. 6.1 ± 17.4	0.983[a]	0.004*

Pearson's correlation was used to determine the correlation between quantitative values from 2CT and 1CT.
[a]very strong correlation (r in the range of 0.800-1.000); [b]strong correlation (r in the range of 0.600-0.799).
Paired t-test was used to determine the significance of the differences (p values) between quantitative values from the 2CT and 1CT.
**significant difference (p<0.05).*

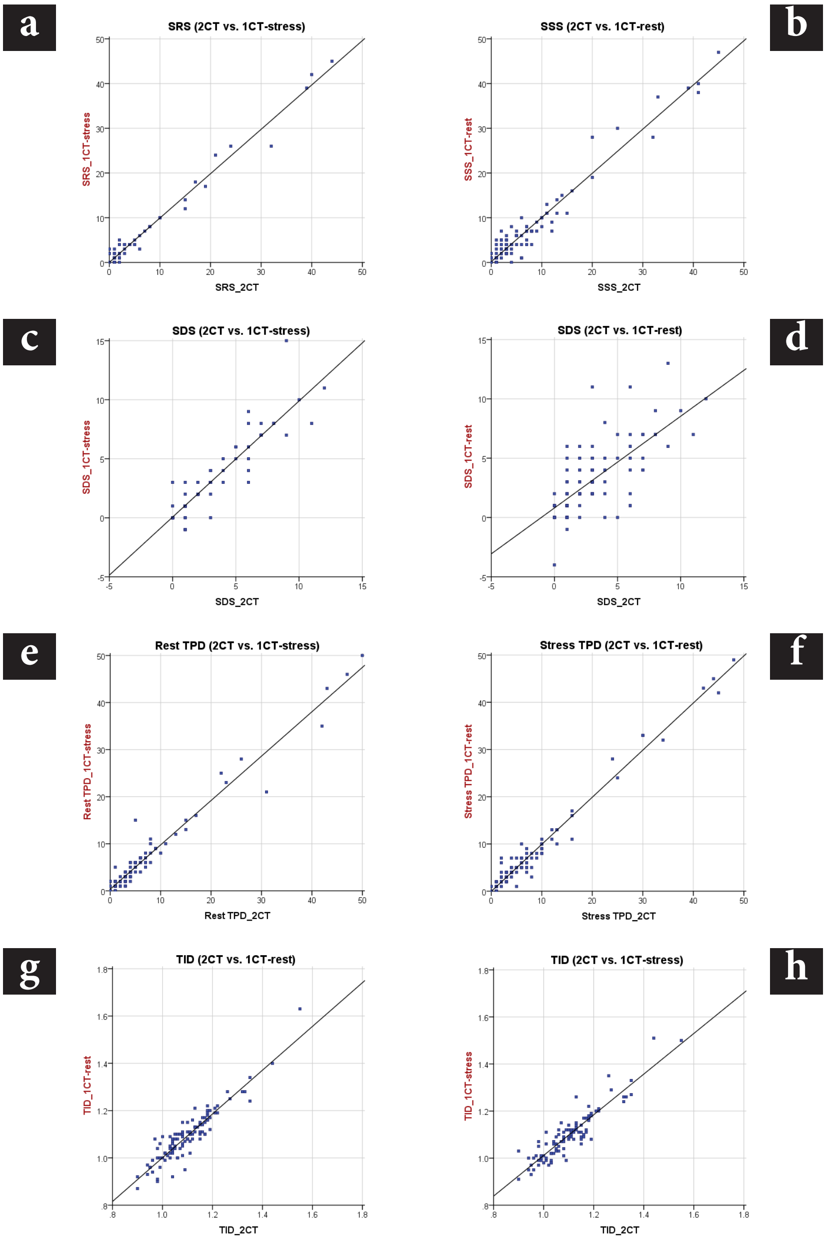

Figure 3. *Correlation between myocardial perfusion values from 2CT and 1CT: (a) SRS_{2CT} vs. $SRS_{1CT\text{-}stress}$; (b) SSS_{2CT} vs. $SSS_{1CT\text{-}rest}$; (c) SDS_{2CT} vs. $SDS_{1CT\text{-}stress}$; (d) SDS_{2CT} vs. $SDS_{1CT\text{-}rest}$; (e) Rest TPD_{2CT} vs. Rest $TPD_{1CT\text{-}stress}$; (f) Stress TPD_{2CT} vs. Stress $TPD_{1CT\text{-}rest}$; (g) TID_{2CT} vs. $TID_{1CT\text{-}stress}$; and (h) TID_{2CT} vs. $TID_{1CT\text{-}rest}$.*

The SDS was of interest in this study because it can be clinically used as an index for diagnosis of myocardial ischemia. The SDS was 3.1 ± 2.6 for 2CT and 3.1 ± 2.8 for 1CT-stress, and these values were not significantly different ($p = 0.931$). The SDS of 1CT-rest was 3.2 ± 2.9 and did not significantly differ from that of 2CT ($p = 0.647$). Figure 4 and 5 shows a comparison of 2CT and 1CT when the SDS values were classified into four groups: no ischemia (SDS 0-1); mild ischemia (SDS 2-4); moderate ischemia (SDS 5-6); and severe ischemia (SDS ≥ 7). There was concordance between diagnoses using SDS in 2CT and 1CT-stress in 91.7%, 91.3%, 58.3% and 100.0% of patients with no ischemia, mild ischemia, moderate ischemia, and severe ischemia respectively (Figure 4a). The overall concordance between diagnosis using SDS in 2CT and 1CT-stress was 88.8% (95 from 107 patients) while the discordance was 11.2% (12 from 107 patients) (Figure 4b). Figure 5a shows the concordance of diagnosis using SDS with 2CT and 1CT-rest: 75.0%, 71.7%, 33.3% and 69.2% in patients with no ischemia, mild ischemia, moderate ischemia, and severe ischemia respectively. The overall concordance of diagnosis using SDS with 2CT and 1CT-rest was 68.2% (73 from 107 patients) while the discordance was 31.8% (34 from 107 patients) (Figure 5b).

a

SDS		1CT-stress				Concordance (%)
		No Ischemia	Mild Ischemia	Moderate Ischemia	Severe Ischemia	
2CT	No Ischemia	33	3	0	0	91.7
	Mild Ischemia	1	42	3	0	91.3
	Moderate Ischemia	0	3	7	2	58.3
	Severe Ischemia	0	0	0	13	100.0

b

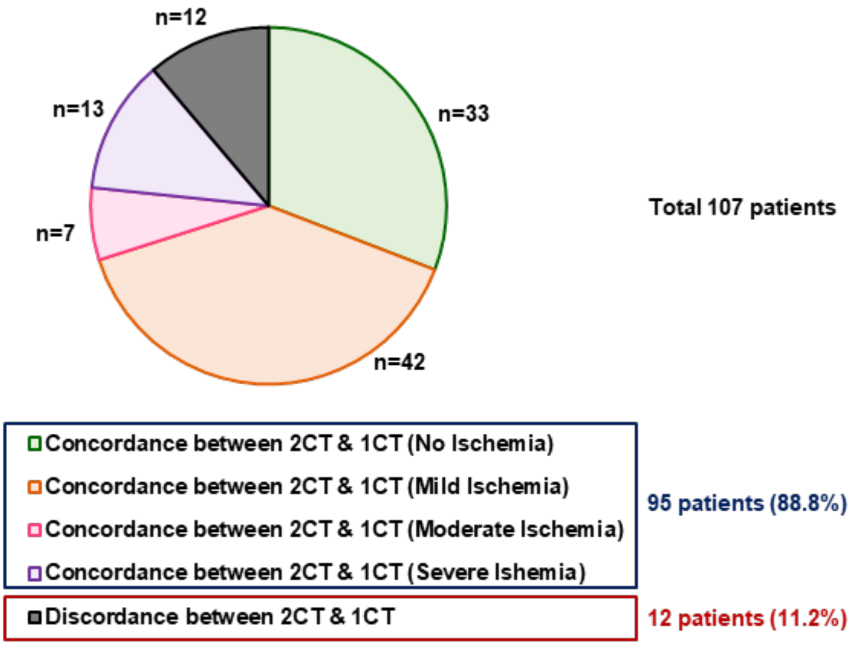

Figure 4. *(a) Concordance between 2CT and 1CT-stress for classification of SDS defined as no ischemia (0-1), mild ischemia (2-4), moderate ischemia (5-6), and severe ischemia (≥ 7) and (b) pie chart showing numbers of patients with concordance in each classification and discordance between 2CT and 1CT-stress.*

a

SDS		1CT-rest				Concordance (%)
		No Ischemia	Mild Ischemia	Moderate Ischemia	Severe Ischemia	
2CT	No Ischemia	27	7	2	0	75.0
	Mild Ischemia	3	33	8	2	71.7
	Moderate Ischemia	3	2	4	3	33.3
	Severe Ischemia	0	2	2	9	69.2

b

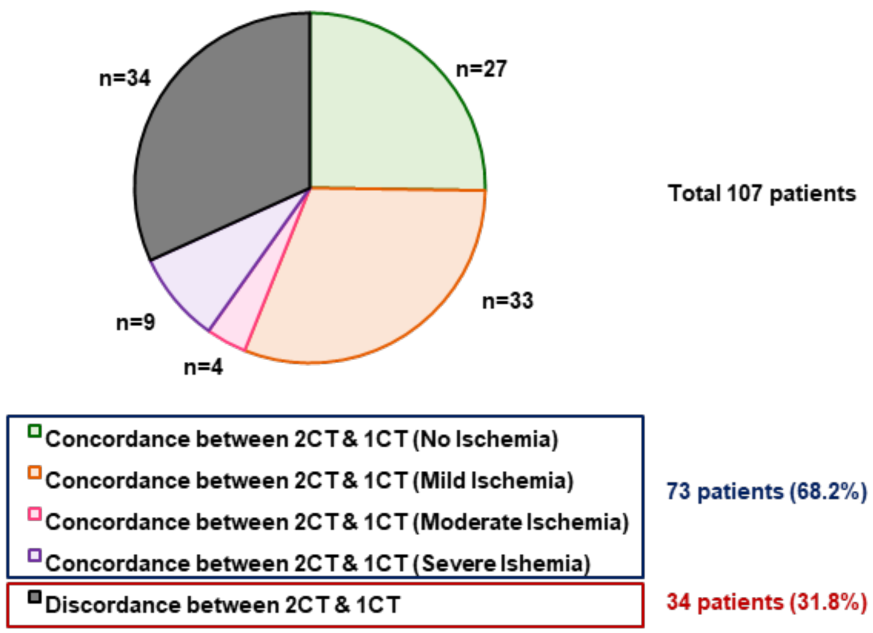

Figure 5. *(a) Concordance between 2CT and 1CT-rest for classification of SDS defined as no ischemia (0-1), mild ischemia (2-4), moderate ischemia (5-6), and severe ischemia (≥ 7) and (b) pie chart showing the number of patients with concordance in each classification and discordance between 2CT and 1CT-rest.*

Figure 6 depicts the correlation between LV function values in 2CT and 1CT. There was a very strong correlation between 2CT and 1CT for all LV function values ($r \geq 0.960$) (Table 2). However, there were significant differences between values for rest EDV, rest ESV, stress EDV, stress ESV, rest EF and stress EF in 2CT and 1CT, as shown in the last column of Table 2.

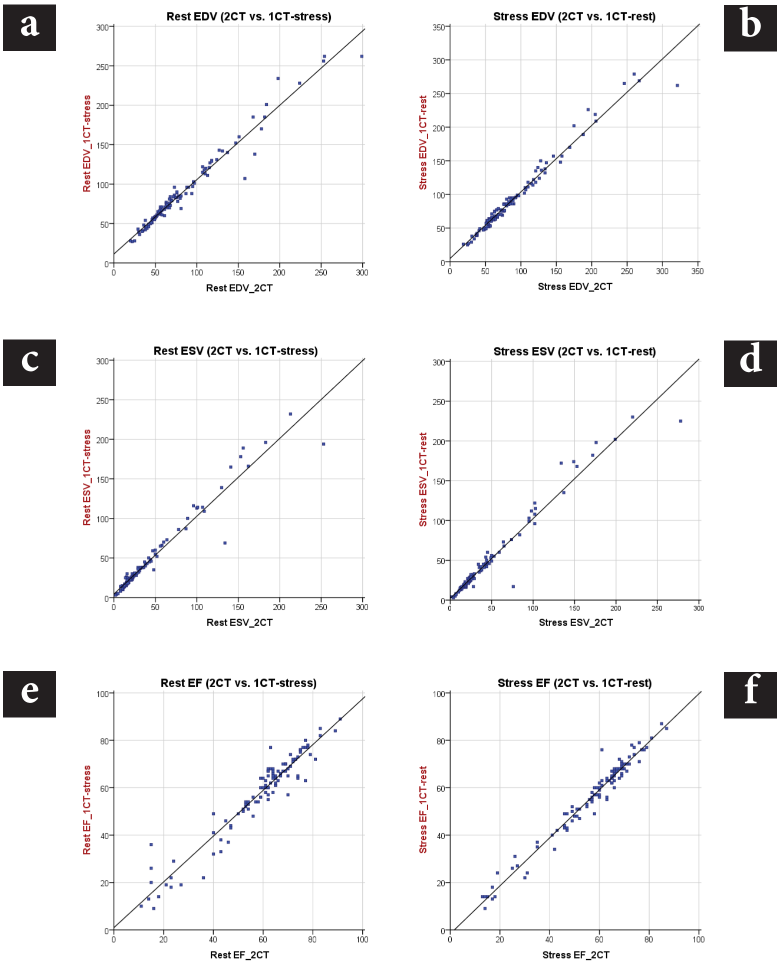

Figure 6. *Correlation between LV function values in 2CT and 1CT: (a) Rest EDV$_{2CT}$ vs. Rest EDV$_{1CT\text{-}stress}$; (b) Stress EDV$_{2CT}$ vs. Stress EDV$_{1CT\text{-}rest}$; (c) Rest ESV$_{2CT}$ vs. Rest ESV$_{1CT\text{-}stress}$; (d) Stress ESV$_{2CT}$ vs. Stress ESV$_{1CT\text{-}rest}$; (e) Rest EF$_{2CT}$ vs. Rest EF$_{1CT\text{-}stress}$; and (f) Stress EF$_{2CT}$ vs. Stress EF$_{1CT\text{-}rest}$.*

The EF was considered because it is clinically used as an index for interpretation of the cardiac function. The rest EF values, 58.7 ± 17.7 for 2CT and 57.7 ± 17.8 for 1CT, were significantly different ($p = 0.031$). The stress EF was 57.0 ± 16.9 for 2CT and 56.1 ± 17.4 for 1CT, and these differences were also statistically different ($p = 0.004$). Figures 7 and 8 show a comparison between 2CT and 1CT when the EF levels were categorized into three groups: reduced EF (EF 0-40%); borderline EF (EF 41-49%); and normal EF (EF ≥50%). There was concordance of interpretation using rest EF in 2CT and 1CT-stress in 87.5%, 50.0% and 97.6% of patients for reduced EF, borderline EF, and normal EF, respectively (Figure 7a). The overall concordance of rest EF interpretation was 93.5% (100 from 107 patients) while the discordance was 6.5% (7 from 107 patients) (Figure 7b). The comparison between stress EF in 2CT and 1CT when the EF values were categorized into the same three groups is shown in Figure 8a. There was concordance of interpretation using stress EF in 2CT and 1CT-rest in 100%, 66.7% and 95.0% of patients with reduced EF, borderline EF, and normal EF respectively. The overall concordance of stress EF interpretation was 92.5% (99 from 107 patients) while the discordance was 7.5% (8 from 107 patients) (Figure 8b).

a

Rest EF		1CT-stress			Concordance (%)
		Reduced EF	Borderline EF	Normal EF	
2CT	Reduced EF	14	2	0	87.5
	Borderline EF	3	3	0	50.0
	Normal EF	0	2	83	97.6

b

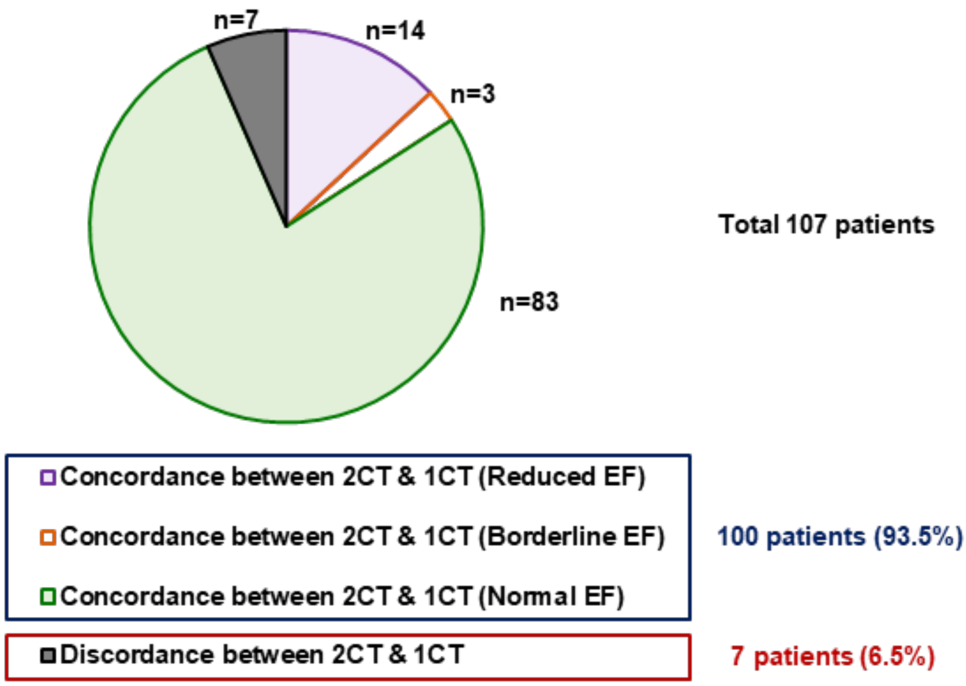

Figure 7. *(a) Concordance between 2CT and 1CT for interpretation of categories of EF defined as reduced rest EF (0-40%), borderline EF (41-49%) and normal EF (≥50%) and (b) pie chart showing the number of patients with concordance in each category and discordance between 2CT and 1CT of rest EF.*

a

Stress EF		1CT-rest			Concordance (%)
		Reduced EF	Borderline EF	Normal EF	
2CT	Reduced EF	145	0	0	100.0
	Borderline EF	2	8	2	66.7
	Normal EF	0	4	76	95.0

b

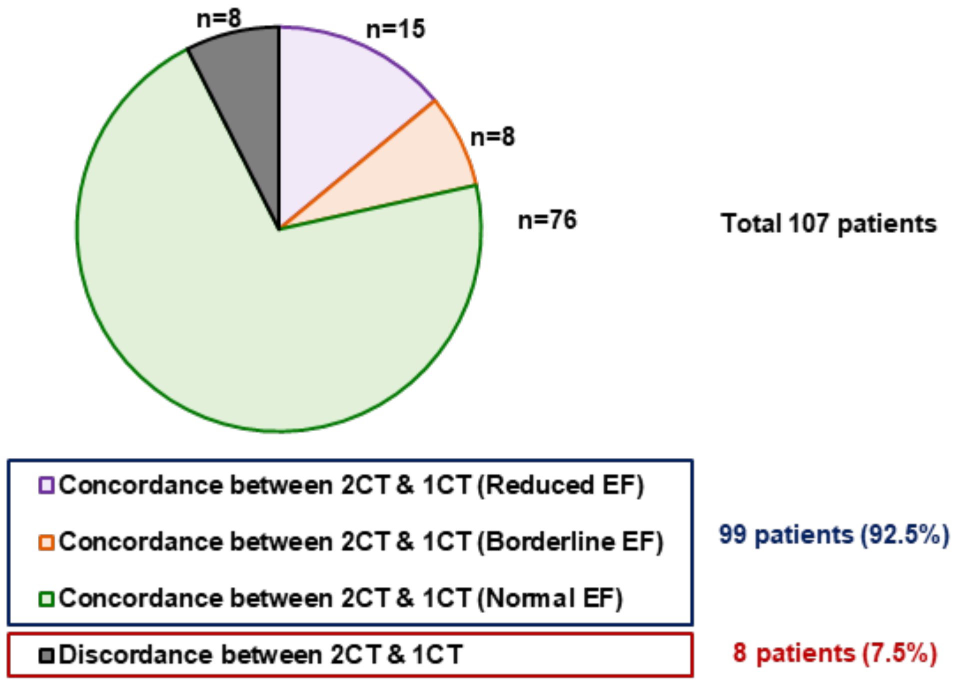

Figure 8. *(a) Concordance between 2CT and 1CT for interpretation of categories of stress EF defined as reduced EF (0-40%), borderline EF (41-49%) and normal EF (≥50%) and (b) pie chart showing the number of patients with concordance in each category and discordance between 2CT and 1CT of stress EF.*

Discussion

Four image acquisitions are required for conventional rest-stress MP SPECT imaging: rest SPECT, rest CT, stress SPECT and stress CT. The standard CTAC method (two CTs) is to use rest CT for AC of rest SPECT and stress CT for AC of stress SPECT. This study aimed to compare the use of two CT scans (2CT) and one CT scan (1CT-stress or 1CT-rest) for AC of gated rest-stress MP SPECT with Tc-99m sestamibi in quantification of myocardial perfusion and LV function values. This allowed us to evaluate the reliability of using just one CT for AC instead of two. Elimination of an extra CT for AC without affecting the myocardial perfusion and LV function values obtained from gated rest-stress MP SPECT could reduce patients' radiation exposure without having any impact on diagnostic results. Even though patients receive only a small amount of radiation exposure from CT for AC (0.4 mSv) [28], eliminating one CT for AC should be considered, in accordance with the principle of keeping radiation exposure as low as reasonably achievable (ALARA).

Several previous studies have examined the effectiveness of using one CT for AC of rest and stress MP SPECT in quantification of myocardial perfusion values such as SRS, SSS and SDS. Ahlman et al. [24] found that a single rest or stress CT was not sufficient for AC of both rest and stress MP SPECT; however, their study adopted a small number of patients (40) with abnormal perfusion only, and it included a mixture of patients who underwent thallium-201 (^{201}Tl)/ ^{99m}Tc (dual isotope) and ^{99m}Tc/^{99m}Tc (single isotope) one-day rest/stress protocols. The ^{99m}Tc emits gamma rays with single energy of 140 keV while ^{201}Tl emits smaller numbers of gamma rays at energies of 135 keV and 167 keV. The attenuation effects of ^{201}Tl and ^{99m}Tc may vary as a result of their different energies; therefore, it may be difficult to compare the use of one and two CTs for AC in a mixture of dual isotope and single isotope protocols.

Wells et al. [25] studied the use of a single CT, choosing stress CT for AC of both rest and stress MP SPECT. Their study included 154 patients who underwent one-day rest/stress MP SPECT with Tc-99m tetrofosmin, and they found that the use of stress CT for AC of both rest and stress SPECT images caused a significant increase in SRS and a rise in the variability of SDS compared with the use of two CTs. However, the variability in SDS between the use of one and two CTs was seen to be less than the inter-observer variability, suggesting that the differences resulting from one CT are unlikely to be clinically significant.

Fukami et al. [26] examined the effectiveness of the single CTAC method in gated stress-rest MP SPECT with ^{201}Tl-chloride (^{201}TlCl) in 106 patients. Like Wells et al., they chose stress CT (rather than rest CT) for AC comparison, with two CTs for AC. They concluded that there was no significant difference between SRS, SSS and SDS obtained by two CTs and a single CT.

Unlike Fukami et al., we studied gated stress-rest MP SPECT with Tc-99m sestamibi. The Tc-99m sestamibi MP SPECT provides significantly better image quality and higher specificity in detection of CAD than ^{201}TlCl MP SPECT [29]. In addition, we compared 3 different CTAC methods: 2CT, 1CT-rest and 1CT-stress. However, the results of Wells's study, Fukami's study and our study in comparing 2CT and 1CT-stress were similar. Our results showed that there was a strong correlation between SRS, SSS and SDS obtained by 2CT and 1CT with no significant differences. Therefore, 1CT and 2CT can be used interchangeably for the quantification of MP values. Because SDS can be clinically used to diagnose the degree of ischemia [8], we have conducted further studies regarding the diagnosis of myocardial ischemia using SDS values. In our study, the concordance of diagnostic results based on the SDS between 2CT and 1CT-stress was high: 91.7% for patients with no ischemia, 91.3% for patients with mild ischemia, 100% for patients with severe ischemia, and 88.8% for all patients except those with moderate ischemia, resulting in a diagnostic concordance of 58.3%. The concordance of diagnostic results based on the SDS from 2CT and 1CT-rest was quite high but lower than that achieved by 2CT and 1CT-stress: 75.0% for patients with no ischemia, 71.7% for patients with mild ischemia, 69.2% for patients with severe ischemia, and 68.2% for all patients except those with moderate ischemia, yielding a diagnostic concordance of 33.3%. These results suggest that using stress CT for AC is better than using rest CT for AC of both rest and stress SPECT.

Although the concordance of diagnostic results based on the SDS between 2CT and 1CT was relatively high, there are still some differences in diagnostic results among certain patients, especially those with moderate ischemia. The SDS was calculated from the SRS and SSS. Therefore, if the SRS and SSS obtained from 2CT and 1CT were different, it affected the SDS value and diagnostic results based on the SDS. When interpreting diagnostic results based on the SDS, if a patient falls into the category of moderate ischemia, which lies between mild ischemia and severe ischemia, even a slight difference in SDS values obtained from 2CT and 1CT can lead to divergent diagnostic results. However, the comparison of 1CT and 2CT for the diagnosis of myocardial ischemia from ^{99m}Tc-sestamibi rest-stress MP SPECT should be further investigated using visual inspection of SPECT images by nuclear medicine radiologists. Other myocardial perfusion values, such as rest TPD, stress TPD and TID, were included in our study, and no statistically significant difference was identified between myocardial perfusion values from 2CT and 1CT. These results suggest that 1CT can be used in place of 2CT in quantification of myocardial perfusion values from ^{99m}Tc-sestamibi rest-stress MP SPECT imaging. The use of stress CT for the 1CT approach revealed that the variability between SDS from 1CT and 2CT was less than that resulting from using rest CT.

In addition to the myocardial perfusion values, we also studied LV function values including rest EDV, rest ESV, stress EDV, stress ESV, rest EF and stress EF. Fukami et al. compared EF from 2CT and 1CT, and their results showed no significant differences. In contrast, our results revealed statistically significant differences in rest EF, stress EF and other LV function values obtained from 2CT and 1CT. However, the correlation between these LV function values obtained by 2CT and 1CT were very strong. The left ventricle EF was clinically used for assessment of the cardiac function [13]. In our study, the concordance of interpretation of LV function from rest EF between 2CT and 1CT was high: 87.5% for patients with reduced EF, 97.6% for patients with normal EF, and 93.5% for all patients except those with borderline EF, which yielded a concordance of interpretation of 50.0%. Regarding stress EF, the concordance of interpretation of the cardiac function between 2CT and 1CT was high: 100.0% for patients with reduced EF, 95.0% for patients with normal EF, and 92.5% for all patients except those with borderline EF, resulting in a concordance of interpretation of 66.7%. Even though interpreting the LV function from the EF values obtained from 1CT yielded similar results to those obtained from 2CT in more than 90% of patients, it can still lead to misinterpretations in patients with borderline EF values (41-49%).

Myocardial perfusion values were obtained from non-gated SPECT data while LV function values were derived from gated SPECT data. The LV function values from 2CT and 1CT were significantly different. The myocardial perfusion values from 2CT and 1CT were not significantly different, but these values obtained from 2CT and 1CT were not equal in all patients. This can be caused by a change in the distribution of attenuating tissues between SPECT and CT acquisitions in both rest and stress image sessions. Mis-registration of CT and SPECT images can cause an error in attenuation correction and influence regional tracer distribution on MP SPECT images [30]. This error may be due to changes in the patient position, the movement of arms, the movement of gas in the bowel, as well as the respiratory and cardiac motion during and between image acquisitions in rest-stress MP SPECT/CT imaging. Differences in the cardiac motion and the respiratory motion between patients who underwent exercise stress (resulting in an increased heart rate and contractility) and patients who underwent pharmacologic stress with adenosine (which causes vasodilation in coronary vessels) [31] may also result in a varying degree of mis-registration of SPECT and CT images. CT yields rapid acquisition while SPECT is slower, with free breathing. Stress and rest CT images may be acquired in different phases of the cardiac and respiratory cycles, and the aforementioned events may lead to a mismatch of attenuating tissues and errors in attenuation correction, which is applied at a single time point in the cardiac and respiratory cycles. It is, therefore, very important to set exactly the same patient positions and minimize the patient motion as much as possible during and between the image acquisitions, especially when using one CT for AC. In our study, automated fusion of SPECT and CT was used, and then alignment of the SPECT and CT images was visually confirmed. In case of misalignment between the images, the CT image was shifted to match the borders of the left ventricle in the SPECT image. Apart from attenuation, scatter is another factor affecting quantitative values obtained from MP SPECT images. The model-based and energy-window-based methods are widely-used scatter correction techniques in MP SPECT imaging [32, 33]. The first method uses an attenuation map from CT to define the scattering medium. With this method, the mis-registration of SPECT and CT images and error in attenuation correction will also lead to inaccurate scatter correction [25]. Instead of using transmission (CT) data, the energy-window-based technique uses scatter data acquired simultaneously with that of photopeak emission. In our study, we used energy-window-based scatter correction, which is likely to be more suitable for the use of one CT for AC in rest-stress MP SPECT imaging.

The main limitations of this study were that we processed gated rest-stress MP SPECT data retrospectively, and that the proportion of normal and abnormal patients were not equal. This study used image data from patients who underwent rest-stress MP SPECT/CT without separating patient data between those who underwent exercise stress and those who underwent pharmacological stress. We used automated quantitative values (rather than qualitative or visual interpretation) for the statistical analysis to eliminate inter-individual variability of MP SPECT interpretation; thus, visual interpretation, which is used in many institutions, was not included in this study.

Conclusion

The myocardial perfusion values from 2CT and 1CT were not significantly different and exhibited a strong correlation. When using stress CT for the 1CT approach, the variability in SDS from 1CT and 2CT was observed to be less than that resulting from using rest CT. However, the comparison of 1CT and 2CT for the diagnosis of myocardial ischemia from ^{99m}Tc-sestamibi rest-stress MP SPECT should be further investigated using visual inspection of SPECT images by nuclear medicine radiologists. The LV function values from 2CT and 1CT exhibited a very strong correlation but were significantly different. In conclusion, the use of one and two CTs for AC in rest-stress MP SPECT with Tc-99m sestamibi can be interchanged for the quantification of myocardial perfusion, but not for the quantification of LV function.

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