Additional value of systolic wall thickening in myocardial stunning evaluated by stress-rest gated perfusion SPECT

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Aim and patients. **The aim of the present study is to evaluate the additional value of systolic wall thickening to myocardial perfusion in diagnosing myocardial stunning in patients with angiography proven coronary artery disease. We selected 91 ischemic patients (82 males; mean age 59.7 ± 10.3) with CAD documented by angiography. Ischemia was defined as a summed difference score ≥5. All patients underwent a 2-day gated perfusion SPECT protocol. The patients received a dose of 740 MBq of ^{99m}Tc-tetrofosmin after stress and at rest. Treadmill maximal exercise tests were performed on all patients.**

Results. **The post-stress LVEF was significantly lower than rest LVEF (48.1% ± 10.3% vs 50.3% ± 10.7%; $P = .0001$). The wall thickening summed difference score was 4.44 ± 4.13 ($P = .0001$). At a multivariate regression analysis, only WT-SDS as independent variable was significantly correlated with myocardial ischemia (SDS). We also divided patients according to SDS in those with mild (SDS < 8) and severe (SDS ≥ 8) ischemia. WT-SDS, but not ΔLVEF, was significantly different between groups.**

Conclusions. **WT-SDS, more than the depression in the global function (ΔLVEF) of the left ventricle, correlates with the degree of ischemia and better identifies, when present, the stunning phenomenon. (J Nucl Cardiol 2019;26:833–40.)**

Key Words: Coronary artery disease • ischemic heart disease • myocardial stunning • cardiac single-photon emission computed tomography

Abbreviations

CAD	Coronary artery disease
SPECT	Single-photon emission computed tomography
LVEF	Left ventricular ejection fraction
SSS	Summed stress score
SRS	Summed rest score
SDS	Summed difference score
WT-SSS	Wall thickening summed stress score
WT-SRS	Wall thickening summed rest score
WT-SDS	Wall thickening summed difference score
ESV	End-systolic volume
EDV	End-diastolic volume

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INTRODUCTION

Several studies have demonstrated the impact and clinical role of ECG-gated-SPECT in the diagnosis, prognosis, and risk stratification of patients with suspected or known coronary artery disease.[1–5] Gated-SPECT images, acquired after the injection of ^{99m}Tc-tetrofosmin, give the opportunity to accurately assess both regional myocardial perfusion and function with a single evaluation,[6] improving the prognostic information regarding the extent of the myocardial perfusion abnormality.[1,3–5,7–9]

^{99m}Tc-tetrofosmin does not redistribute significantly, therefore post-stress images acquisition, after the injection of the radiopharmaceutical at peak exercise, provides information regarding peak stress perfusion, coupled with myocardial function at the time of acquisition. Since regional transient systolic dysfunction may persist from 30 to 240 minutes after stress test, images acquired within the first hour after the injection have the potential to detect post-stress wall motion and systolic wall thickening abnormality, or myocardial ''stunning''.[10–12]

Post-ischemic stunning is known to be an important marker for severe and extensive coronary artery disease, and ECG-gated-SPECT affords the opportunity to further evaluate its frequency and clinical relevance.

Myocardial stunning can be defined as a transient reduction in global systolic function (a reduction of LVEF% of at least 5% between rest and post-stress) or a transient reduction in wall thickening summed difference score.[7,13] The different values of these two parameters in diagnosing severe myocardial ischemia causing myocardial stunning are not well established, and are the aim of the present study.

Quantitative wall motion and wall thickening assessment with interpretation software provides quantitative methods for evaluation of the degree of wall motion and wall thickening of each segment of the left ventricle, that might augment the visual analysis of ventricular function from GSPECT data.[14] Direct quantification of segmental rest-stress motion and thickening changes may significantly improve accuracy of GSPECT in diagnosing severe multivessel CAD.[15]

Moreover, in addition to post-stress decreases in global LV function, wall motion abnormalities present post-stress have been described and may be easier to detect compared to abnormalities in global post-stress function.[11–13,16–19]

The aim of this study was to evaluate the additional value of the systolic wall thickening in detecting left ventricular stunning and in characterizing myocardial ischemia, in patients with coronary artery disease (CAD).

MATERIALS AND METHODS

Patients Population

In a population of 2064 consecutive patients who underwent stress/rest gated-SPECT studies ordered by referring physician for suspected or known coronary artery disease, we selected 91 ischemic patients (82 males; mean age 59.7 ± 10.3), with CAD documented by angiography. Ischemia was defined as a difference summed score ≥5. All patients underwent a 2-day protocol. The patients received a dose of 740 MBq of ^{99m}Tc-tetrofosmin after stress and at rest. Treadmill maximal exercise tests were performed on all patients. In 74/91 (81.3%) patients, anti-anginal medications, beta-blockers, and calcium channel-blockers were discontinued 48 to 72 hours before the radionuclide study. Coronary angiography was performed within three months of the stress perfusion study in all patients, without an intervening cardiac event. A ≥70% lumen stenosis was considered significant.

The study protocol was approved by the Local Ethics Committee. Each patient provided informed consent.

Study Protocol

Images were acquired 45 to 60 minutes after the injection. Both stress and rest acquisitions were performed using a dual head digital camera at 90° geometry equipped with high-resolution collimators. Stress/rest gated-SPECT images were acquired with the patients in supine position for a total of 64 projections, 3° interval, every 40 seconds, over a 180° elliptical orbit. A matrix size of 64 × 64 × 16 byte and a 38 cm roving detector mask were employed. At each projection, a total of eight frames of the cardiac cycle were used for reconstruction. Transaxial stress and rest slices of 6 mm thickness were reconstructed with a Butterworth back-projection filter, with a critical frequency of 0.40 and order of 10. The transaxial slices were reoriented along cardiac planes. LVEF and volumes were calculated using a completely automated algorithm, previously described and validated.[20–23] The algorithm operates in three-dimensional space and uses a gated short axis image sets. It segments the left ventricle; estimates and displays the endocardial surface, the epicardial surface and the valve plane for every gating interval; calculates the endocardial volumes; isolates the intervals corresponding to end-diastole and end-systole and derives the related LVEF. The LVEF variation (ΔLVEF) was calculated using the following formula: (post-stress LVEF − rest LVEF). In the present study, extracardiac activity was evaluated on the reconstructed images, and in case of excessive extracardiac activity, an acquisition was restarted after at least 30 minutes.

Image Analysis

The gated images were all normalized to the region of highest activity on the end-systolic image set. Regional myocardial perfusion was assessed on the summed images. Two readers who were blinded to the clinical, stress, and angiographic data reviewed the images. The studies were scored using a 20-segment model scored on a 5-point scale (0 = normal, 4 = no uptake). A perfusion defect with a score ≥3 was considered significant, and a segment score improved by at least one grade was considered reversible. The summed difference score (SDS) is the difference between the summed scores obtained during exercise (SSS) and at rest (SRS). Wall thickening was also scored on a four-point scale (0 = normal, 1 = mildly impaired, 2 = moderately impaired, 3 = severely impaired to absent thickening) based on the visual assessment of myocardial wall brightening from diastole to systole in the same 20 segments. The SSS, SRS, SDS, the stress and rest summed wall thickening scores (WT-SSS, WT-SRS), and the difference of systolic wall thickening between post-stress and rest test (WT-SDS) were calculated in each patient by adding the 20 segmental perfusion and thickening scores. For this study, we selected only patients with SDS ≥ 5, classified as ischemic.

Statistical Analysis

Statistical analysis was performed using SPSS ver. 24.0 software. Univariate tests were done using the Spearman rank correlation to correlate clinical, stress test, and scan data with the ΔLVEF and WT-SDS for all ischemic patients. Multivariate regression analysis was performed using the variables that were significant by univariate analysis. Regression analysis was performed using either ΔLVEF, or WT-SDS as independent variables, to find which is the parameter with the strongest correlation with ischemia (SDS) and with other clinical parameters.

The comparison between rest and post-stress scan parameters in the whole ischemic group was performed using paired *t* test. The chi-square test was used for comparisons of proportions.

Finally we, divided patients in two groups according to the presence of mild (SDS < 8) or severe (SDS ≥ 8) ischemia. We calculated mean ΔLVEF values and mean WT-SDS values and we compared the results using a *t* test.

P values <.05 were considered statistically significant for all the analyses performed.

RESULTS

Clinical, Stress Test, and Angiographic Characteristics

Clinical, stress test and angiographic characteristics of patients are shown in Table 1.

10% of patients had diabetes and 54% a history of or a previous myocardial infarction.

During stress test 21% of patients had typical angina and 46% showed a significant ST depression on ECG.

Table 1. Clinical, stress test, and angiography characteristics of study population (*N* = 91)

	***N* (%)**
Clinical	
Mean age (SD) (years)	59.7 ± 10.3
Male	82 (90.1)
Hypertension	48 (52.7)
History of smoking or active smoker	54 (59.4)
Hypercholesterolemia	48 (52.7)
Diabetes mellitus	9 (9.9)
Family history of premature coronary artery disease	46 (50.5)
History of myocardial infarction	49 (53.9)
Stress Test	
Drugs withdrawal (beta-blockers, calcium-antagonists and nitrates)	74 (81.3)
ST depression	42 (46.2)
Typical Angina	19 (20.9)
Rate pressure product (heart rate × systolic blood pressure)	26241 ± 6393
Coronary angiography	
One vessel disease	34 (37.4)
Two vessel disease	41 (45.1)
Three vessel disease	15 (16.5)
Four vessel disease	1 (1.1)

All patients had coronary artery disease documented by coronary angiography. 62.7% of the patients had multivessel coronary disease.

Scan Variables

Concerning the gated-SPECT parameters (Table 2), the SSS was 17.4 ± 7.5 and the summed difference score was 8.19 ± 2.9 ($P = .0001$). As regards functional parameters, the post-stress LVEF was significantly lower than rest LVEF (48.1% ± 10.3% vs 50.3% ± 10.7%; $P = .0001$), while the post-stress ESV and the post-stress EDV were similar to the rest values. The WT-summed difference score was: 4.44 ± 4.13 ($P = .0001$). The ΔLVEF was −2.2 ± 4.8 (95% CI [−3.2, −1.2]), ranging from −15 to 8. Only three patients showed a ΔLVEF >5% (7%, 8%, 8%): the SDS mean value was 7.3.

Univariate and Multivariate Analysis

Univariate analysis was performed using the ΔLVEF as the independent variable, and the following dependent variables were analyzed as both continuous and dichotomous factors: post-stress and rest LVEF and ventricular volumes, summed stress defect severity score, summed rest defect severity score, summed defect reversibility score, the stress and rest summed wall thickening score, the difference of systolic wall thickening between post-stress and rest test and all clinical and stress test parameters reported in Table 1. The variables that correlated significantly were rest LVEF ($P = .002$), wall thickening summed difference score ($P = .002$) and family history of CAD ($P = .004$). When multivariate regression analysis was performed, none parameter was significant.

Using the WT-SDS as the independent variable, the univariate analysis showed as significant the following parameters: post-stress EF ($P = .047$), ΔLVEF ($P = .002$), SDS ($P = .002$), WT-SSS ($P = .02$), WT-SRS ($P = .005$), family history of CAD ($P = .038$), history of myocardial infarction ($P = .018$), rate pressure product ($P = .029$). When multivariate regression analysis was performed, only post-stress EF ($P = .048$), ΔLVEF ($P = .019$), SDS ($P = .006$), WT-SSS ($P = .014$), and WT-SRS ($P = .001$) were significant (Table 3).

Correlation Between WT-SDS and ΔLVEF and SDS

Grouping patients into those with mild ischemia (SDS < 8) and into those with severe ischemia (SDS ≥ 8), ΔLVEF was non significantly different between groups (−1.29 ± 4.59 vs −3.08 ± 4.85; $P =$ NS), while WT-SDS was significantly lower in the first group (3.18 ± 3.8 vs 5.67 ± 4.11; $P = .003$). Figure 1A shows the good inverse linear correlation between WT-SDS and ΔLVEF (RHO = −0.33, $P = .002$). According to the equation shown into the figure, a threshold of 11.8 for WT-SDS has to be present before a significant drop (≥5%) in ΔLVEF is observed. Figure 1B

Table 2. Perfusion and function parameters obtained by gated-SPECT in all ischemic patients

	Minimum	Maximum	Mean	SD	95% CI	*P* value
Post-stress LVEF (%)	15	71	48.1	10.3	46.0; 50.1	.0001
Rest LVEF (%)	18	71	50.3	10.7	48.1; 52.5	
Post-stress EDV (mL)	54	296	113.3	44.4	104.1; 122.6	NS
Rest EDV (mL)	55	282	115	42.8	106.9; 124.7	
Post-stress ESV (mL)	24	251	61.4	38.0	53.5; 69.3	NS
Rest ESV (mL)	19	225	60.8	38.0	52.9; 68.7	
SSS	5	39	17.4	7.5	15.9; 19.0	.0001
SRS	0	31	9.26	7.25	7.7; 10.8	
SDS	5	18	8.19	2.9	7.6; 8.8	
WT-SSS	0	41	12.4	8.1	10.8; 14.1	.0001
WT-SRS	0	38	8.13	8.5	6.4; 9.9	
WT-SDS	−4	16	4.44	4.13	3.6; 5.3	
ΔLVEF	−15	8	−2.2	4.8	−3.2; −1.2	

P values for the comparisons between rest and stress values
LVEF, Left ventricular ejection fraction; *EDV*, end-diastolic volume (mL); *ESV*, end-systolic volume (mL); *SSS*, summed stress score; *SRS*, summed rest score; *SDS*, summed difference score (SSS − SRS); *WT-SSS*, wall thickening summed stress score; *WT-SRS*, wall thickening summed rest score; *WT-SDS*, wall thickening summed difference score (WT-SSS − WT-SRS).ΔLVEF: it is calculated using the following formula: (post-stress LVEF − rest LVEF)

Table 3. Multivariate regression analysis using WT-SDS as independent variable

Parameter	*F* coefficient	*P* value
Post-stress LVEF	1.798	.048
DLVEF	2.085	.019
SDS	2.393	.006
WT-SSS	2.158	.014
WT-SRS	2.949	.001
Family history of premature coronary artery disease	1.301	.221
History of myocardial infarction	1.553	.105
Rate pressure product	1.224	.272

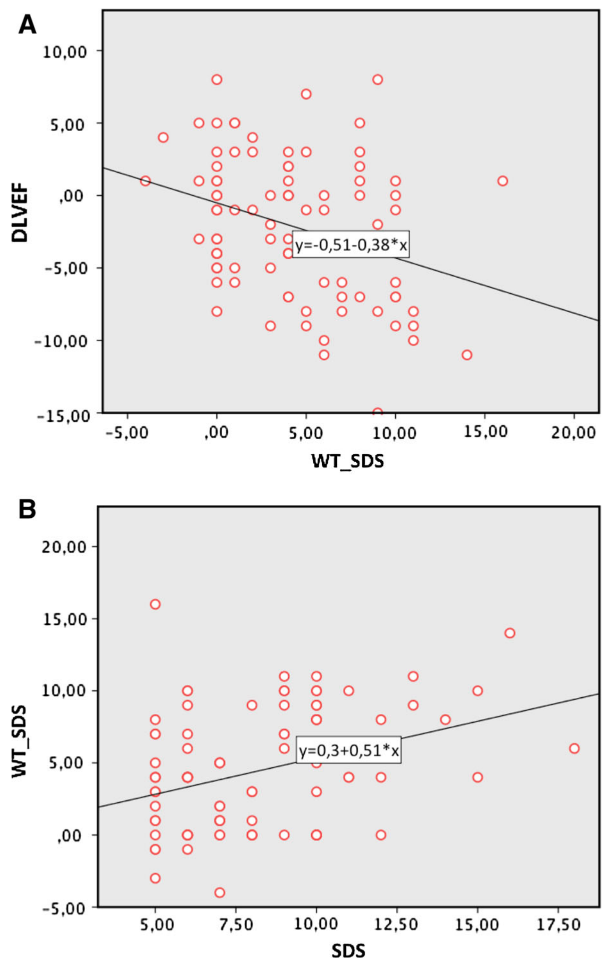


Figure 1. A This figure shows the good inverse linear correlation between WT-SDS and ΔLVEF (RHO = −0.33, $P = .002$). **B** This figure shows a good linear correlation between SDS and WT-SDS (RHO = 0.32, $P = .002$).

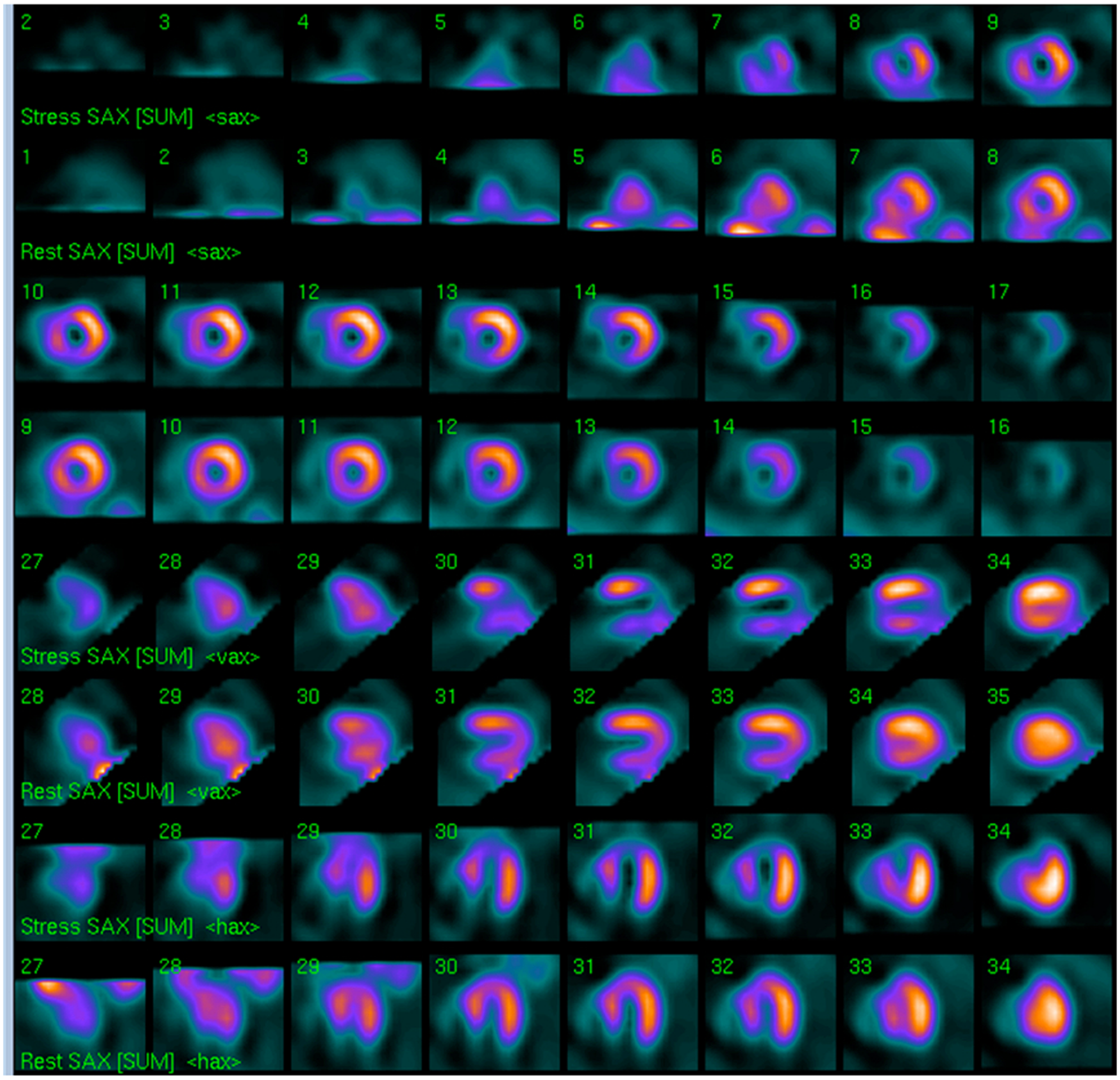
demonstrates the significant correlation between ischemia, represented by SDS, and regional wall thickening impairment.

Figure 2A, B show examples of SPECT images on perfusion and function of patients.

DISCUSSION

This study demonstrates that in a population of patients with moderate-severe ischemia (SDS = 8.19 ± 2.9), there is a significant reduction of post-stress LVEF compared to rest LVEF (−2.2 ± 4.8) 45 to 60 minutes after the injection of ^{99m}Tc-Tetrofosmin. In our study, ΔLVEF was employed as the independent variable similarly to previous authors.[24–28] In the study of Johnson et al.[27] in 22 (36%) of 61 patients with reversible perfusion defects, post-stress LVEF was >5% lower than at rest. Furthermore, the differences in segmental cordal shortening between rest and post-stress were significantly greater in the reversible perfusion defects territories than in non ischemic perfusion defects territories ($P < .0001$). By univariate analysis, the summed defects reversibility score and a left anterior descending coronary artery location of the scan defects were the only two variables that correlated significantly with the variation of LVEF. Verberne et al.,[28] in a subgroup of 100 ischemic patients, selected based on a threshold of SDS less restrictive than ours (≥3), found that stress-induced ischemia and greater difference in heart rate during scan acquisition at peak stress and rest were independent predictors of negative ΔLVEF. In a small group (n.30) of ischemic patients (SDS > 0), Ramakrishna et al.[24] demonstrated that SDS was the only variable statistically significantly associated with negative ΔLVEF. The magnitude of stress-induced ischemia (SDS) was only weakly correlated with ΔLVEF ($r = 0.26$, $P = .01$). Mut et al.,[29] aimed to determine whether early post exercise imaging (15 ± 5 minutes) was more likely to detect stunning than conventional imaging (60 ± 15 minutes) without adversely affecting image quality or perfusion information. 63 out of 229 (27%) patients were ischemic (SDS > 4). In this subgroup, there were 25 patients (39.7%) with at least 5% decrease in LVEF from rest to early stress, while only 16 (25.4%) from rest to late stress. When plotting the

A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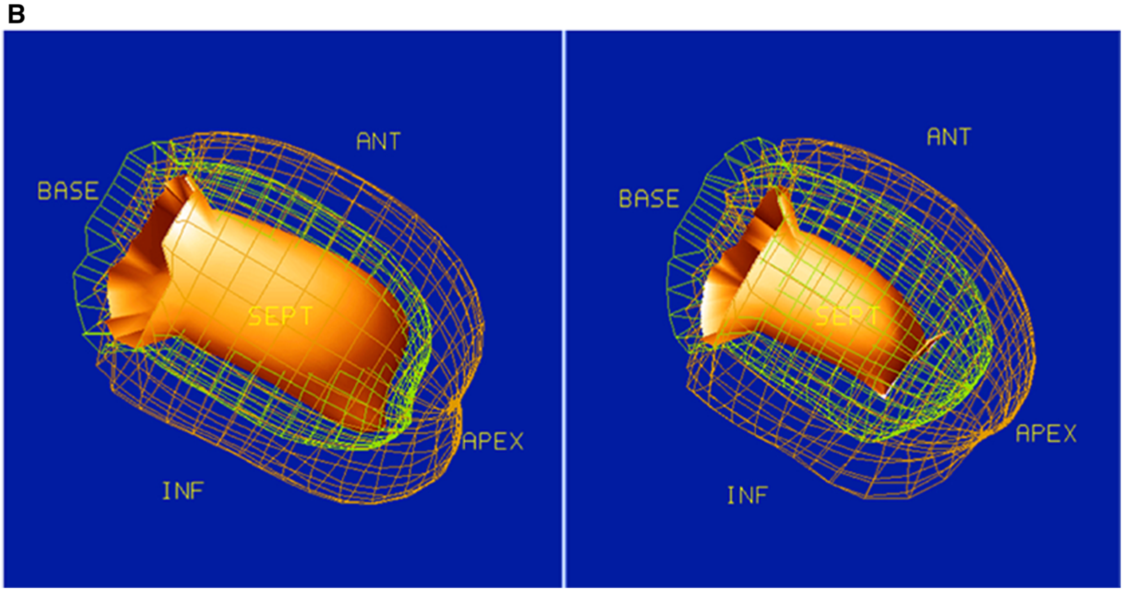
B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◀**Figure 2.** **A** Myocardial perfusion scintigraphy with ^{99m}Tc-tetrofosmin. SPECT perfusion shows partially reversible defect in the apex and the antero-septal regions of the left ventricle (SDS = 14). **B** Three-dimensional display images: the solid contoured image represents the left ventricular cavity at end-systole (ES) post-stress and at rest; the end-systolic volume is noticeably larger on the post-stress study; post-stress left ejection fraction was indeed significant lower (56% vs 77%). WT-SSS: 10.1; WT-SRS: 6.8.

relationship between SDS and ΔLVEF, a negative relationship between these variables was evident, which was more pronounced using early stress data as compared with late stress ($r = 0.23$ vs .08, $P =$ ns).

In contrast, Bavelaar-Croon et al.[25] and Vallejo et al.[26] found no significant differences in ΔLVEF and volumes between stress and rest in ischemic patients, but the number of ischemic patients was very limited (16 and 13 respectively).

We evaluated 91 CAD patients with moderate-severe ischemia, 63% of those had multivessel disease at angiography. After multivariate regression analysis, with the use of the univariate statistically significant parameters, no clinical, stress test, and scan parameter was significantly correlated to ΔLVEF. The failure of SDS to correlate is probably due to the late time of acquisition when LV dysfunction might have already recovered. Furthermore, many patients had a previous myocardial infarction (54%) and consequently a high summed rest score (9.26 ± 7.2). In fact, the correlation between the two parameters was not significant (RHO = −0.19), (figure not shown) due to the great data variability.

We found significant correlation between the systolic wall thickening summed difference score and both the amount of ischemia and ΔLVEF at multivariate regression analysis. When dividing patients according to the severity of ischemia (SDS < 8: mild ischemia; SDS ≥ 8: severe ischemia), mean WT-SDS values were significantly different between groups, while mean ΔLVEF values could not discriminate the two groups.

This finding supports our conclusion that systolic wall thickening provides more information on myocardial stunning than ΔLVEF alone, and it is a parameter with strong correlation with myocardial perfusion.

Transmural myocardial thickening occurs primarily in the endocardial layer because the epicardium contributes little to thickening. The subendocardium is also the site of stress-induced ischemia. The correlation between SDS and WT-SDS that we found in our study may be explained by the close relation between subendocardial myocardial blood flow and regional wall motion.[30]

NEW KNOWLEDGE GAINED

WT-SDS quantifies the stunning phenomenon and it is the independent parameter that shows the strongest correlation with both the degree of ischemia (SDS) and reversible systolic dysfunction (ΔLVEF). WT-SDS should be routinely evaluated in patients with suspected myocardial stunning who are candidates to revascularization.

STUDY LIMITATIONS

While most GSPECT measurements of LVEF in the literature have been derived from images acquired using 8-frame gating, 16-frame gating is becoming increasingly popular. Sixteen-frame gating requires additional data storage and processing time, and could result in images with unacceptably low-counts. However, it can also provide more accurate estimates of LVEF, since there is more precise end-systolic imaging. Using a 2-day protocol with the same tracer activity is less practical compared to single day protocol, but avoids the risk that different doses might result in different signal to noise ratio, influencing LVEF value.

Attenuation correction was not used (nor was prone imaging) since it would have added more heterogeneity due to the good row image quality.

CONCLUSIONS

Stress-rest gated myocardial perfusion SPECT provides valuable data on myocardial ischemia and wall motion abnormalities. WT-SDS is strongly correlated with the degree of ischemia (SDS) and ΔLVEF. While both WT-SDS and ΔLVEF indicate the presence of myocardial stunning, WT-SDS shows greater correlation with the severity of ischemia, and it is altered even in the absence of a major reduction in post-stress LVEF (ΔLVEF < 5%). For these reasons, we conclude that WT-SDS should be considered as the best parameter to identify myocardial stunning.

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Disclosure

Alberto Bestetti, Besart Cuko, Adriano Decarli, Alessio Galli, Federico Lombardi have nothing to disclose.

References

1. Hachamovitch R, Berman DS, Shaw LJ, Kiat H, Cohen I, Cabico JA, et al. Incremental prognostic value of myocardial perfusion single photon emission computed tomography for the prediction of cardiac death: Differential stratification for risk of cardiac death and myocardial infarction. Circulation 1998;97:535-43.
2. Shaw LJ, Hachamovitch R, Heller GV, Marwick TH, Travin MI, Iskandrian AE, et al. Non invasive strategies for the estimation of cardiac risk in stable chest pain patients: The Economics of Noninvasive Diagnosis (END) Study Group. Am J Cardiol 2000;86:1-7.
3. Nakajima K, Matsuo S, Okuda K, Wakabayashi H, Tsukamoto K, Nishimura T. Estimation of cardiac event risk by gated myocardial perfusion imaging and quantitative scoring methods based on a multi-center J-ACCESS database. Circ J 2011;75:2417-23.
4. Berman DS, Hachamovitch R, Kiat H, Cohen I, Cabico JA. Incremental value of prognostic testing in patients with known or suspected ischemic heart disease: A basis for optimal utilization of exercise technetium-99m sestamibi myocardial perfusion single-photon emission computed tomography. J Am Coll Cardiol 1995;26:639-47.
5. Hashimoto A, Nakata T, Wakabayashi T, Kusuoka H, Nishimura T. Incremental prognostic value of stress/rest gated perfusion SPECT in patients with coronary artery disease—subanalysis of the J-ACCESS study. Circ J 2009;73:2288-93.
6. Borges Neto S, Shaw LK. The added value of simultaneous myocardial perfusion and left ventricular function. Curr Opin Cardiol 1999;14:460-3.
7. Usui Y, Chikamori T, Nakajima K, Hida S, Yamashina A, Nishimura T, J-ACCESS investigators. Prognostic value of post-ischemic stunning as assessed by gated myocardial perfusion single-photon emission computed tomography: A subanalysis of the J-ACCESS study. Circ J 2010;74:1591-9.
8. Bestetti A, Triulzi A, Di Leo C, Tagliabue L, Strinchini A, Bax J. Enhanced prognostic stratification of CAD patients with low ejection fraction by stress-rest Tc99m tetrofosmin gated-spect. Acta Cardiol 2004;59:17-23.
9. Bestetti A, Bigi R, Terranova P, Lombardi F, Fiorentini C. Prognostic implications of stress-induced transient ischemic dilation of the left ventricle in patients with systolic dysfunction and fixed perfusion defects. Int J Cardiol 2010;140:323-7.
10. Hida S, Chikamori T, Tanaka H, Usui Y, Igarashi Y, Nagao T, et al. Diagnostic value of left ventricular function after stress and at rest in the detection of multivessel coronary artery disease as assessed by electrocardiogram-gated SPECT. J Nucl Cardiol 2007;14:68-74.
11. Emmett L, Iwanochko RM, Freeman MR, Barolet A, Lee DS, Husain M. Reversible regional wall motion abnormalities on exercise technetium-99m gated cardiac single photon emission computed tomography predict high-grade angiographic stenoses. J Am Coll Cardiol 2002;39:991-8.
12. Sharir T, Bacher-Stier C, Dhar S, Lewin HC, Miranda R, Friedman JD, et al. Identification of severe and extensive coronary artery disease by postexercise regional wall motion abnormalities in Tc-99m sestamibi gated single-photon emission computed tomography. Am J Cardiol 2000;86:1171-5.
13. Paul AK, Hasegawa S, Yoshioka J, Mu X, Maruyama K, Kusuoka H, et al. Characteristics of regional myocardial stunning after exercise in gated myocardial SPECT. J Nucl Cardiol 2002;9:388-94.
14. Xu Y, Hayes S, Ali I, Ruddy TD, Wells RG, Berman DS, et al. Automatic and visual reproducibility of perfusion and function measures for myocardial perfusion spect. J Nucl Cardiol 2010;17:1050-7.
15. Karimi-Ashtiani S, Arsanjani R, Fish M, Kavanagh P, Germano G, Berman D, et al. Direct quantification of left ventricular motion and thickening changes using rest-stress myocardial perfusion spect. J Nucl Med 2012;53:1392-400.
16. Lee DS, Yeo JS, Chung JK, Lee MM, Lee MC. Transient prolonged stunning induced by dipyridamole and shown on 1- and 24-hour poststress 99mTc-MIBI gated spect. J Nucl Med 2000;41:27-35.
17. Petix NR, Sestini S, Marcucci G, Coppola A, Arena A, Nassi F, et al. Can the reversible regional wall motion abnormalities on stress gated Tc-99m sestamibi SPECT predict a future cardiac event? J Nucl Cardiol 2005;12:20-31.
18. Mazzanti M, Cianci G, Carini G, Marini M, Gabrielli G, Silenzi C, et al. Post exercise regional and global myocardial stunning after gated SPECT in asymptomatic subjects with increased absolute cardiovascular risk (nidot project). J Nucl Cardiol 2003;10:S12.
19. Sharir T. Role of regional myocardial dysfunction by gated myocardial perfusion SPECT in the prognostic evaluation of patients with coronary artery disease. J Nucl Cardiol 2005;12:5-8.
20. Williams KA, Taillon LA. Left ventricular function in patients with coronary artery disease assessed by gated tomographic myocardial perfusion images: Comparison with assessment by contrast ventriculography and first-pass radionuclide angiography. J Am Coll Cardiol 1996;27:173-81.
21. Germano G, Kiat H, Kavanagh PB, Moriel M, Mazzanti M, Su HT. Automatic quantification of ejection fraction from gated myocardial perfusion SPECT. J Nucl Med 1995;36:2138-47.
22. Germano G, Jacob E, Kiat H, Kavanagh P, Berman DS. Quantitative LVEF and qualitative regional function from gated thallium 201 perfusion SPECT. J Nucl Med 1997;38:749-54.
23. Mazzanti M, Germano G, Kiat H, Friedman J, Berman DS. Fast tecnetium 99m-labelled sestamibi gated single-photon emission computed tomography for evaluation of myocardial function. J Nucl Cardiol 1996;3:143-9.
24. Ramakrishna G, Miller TD, Hodge DO, Connor MK, Gibbons RJ. Differences in left ventricular ejection fraction and volumes measured at rest and poststress by gated sestamibi SPECT. J Nucl Cardiol 2006;13:668-74.
25. Bavelaar-Croon CD, America YG, Atsma DE, Dibbets-Schneider P, Zwinderman AH, et al. Comparison of left ventricular function at rest and post-stress in patients with myocardial infarction: evaluation with gated SPECT. J Nucl Cardiol 2001;8:10-8.
26. Vallejo E, Dione DP, Sinusas AJ, Wackers FJ. Assessment of left ventricular ejection fraction with quantitative gated SPECT: Accuracy and correlation with first-pass radionuclide angiography. J Nucl Cardiol 2000;7:461-70.
27. Johnson LL, Verdesca SA, Aude WY, Xavier RC, Nott LT, Campanella MN, et al. Postischemic stunning can affect left ventricular ejection fraction and regional wall motion on poststress gated sestamibi tomograms. J Am Coll Cardiol 1997;30:1641-8.
28. Verberne HJ, Dijkgraaf MG, Somsen GA, van Eck-Smit BL. Stress related variations in left ventricular function as assessed with gated myocardial perfusion SPECT. J Nucl Cardiol 2003;10:456-63.
29. Mut F, Giubbini R, Vitola J, Lusa L, Sobic-Saranovic D, Peix A, et al. Detection of post-exercise stunning by early gated SPECT myocardial perfusion imaging: Results from the IAEA multi-center study. J Nucl Card 2014;21:1168-76.
30. Rahimtoola SH. Hibernating myocardium has reduced blood flow at rest that increases with low-dose dobutamine. Circulation 1996;94:3055-61.