EVALUATION FOR THE EFFECT OF ARRHYTHMIA AND GATING ERRORS IN THE GATED MYOCARDIAL SPECT PERFUSION AND FUNCTION

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Abstract: Gated myocardial perfusion SPECT (G-SPECT) is considered as one of the best techniques for the combined evaluation of the myocardial perfusion and the left ventricular ejection fraction (*LVEF*) within a single study. Sufficient count density in the ciné frames is necessary for best myocardial perfusion images quality and G-SPECT synchronized with the subject's electro cardio gram (ECG) to identify the temporal phases of the cardiac cycle. The variation in the cardiac cycle duration may cause fluctuation of the adjacent frames count which compromises the quality of perfusion image and decreases the left ventrecle ejection fraction (LV*EF)* accuracy. This study investigates the changes that occur in cardiac perfusion imaging and the *LVEF* accuracy due to the variation in the cardiac cycle duration due to arryhthmia or any gating errors (G.E). This study was performed on fifty-two patients classified into two groups: 35 non-arrhythmic patients (group 1) and 17 arrhythmic patients (group 2). Each patient had two consecutive stress G-SPECT acquisitions: one of them was taken with time-dependent projections (stress SEC), and the other with accepted beats projections (stress AB). *LVEF* was calculated for both acquisitions, and compared with echocardiogram *EF*, and their perfusion images were compared with the non-gated SPECT perfusion images (stress N.G). results: In arrhythmic patients all the myocardial perfusion and function assessed from G-SPECT showed significant changes when compared with non-gated SPECT and echo; non-arrhythmic patients had non-significant changes in contrast and square of different arteries, but other values showed significant differences. Non-gated SPECT and AB-gated SPECT is better than (SEC-gated SPECT in the evaluation of the myocardial perfusion or the *LVEF*, especially for arrhythmic patients.

Key words: G-SPECT, myocardial perfusion, arrhythmia, rejected heart beat, gating errors, flickering artifact, accepted heart beat.

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INTRODUCTION

G-SPECT is a nuclear medicine technique where patient's (ECG) is used as a guidance during the process. Global and regional ventricular function is most commonly assessed by measuring ejection fraction (*EF*). The ejection fraction, as the name implies, is the percentage of blood in the left (or right) ventricle that is ejected during contraction of the heart, which is evaluated by ECG-gated myocardial single photon emission tomography (G-SPECT) [3]. Cardiac parameters of particular interest in clinical decision include perfusion, wall motion, myocardial mass, ejection fraction and left ventricular volumes [1]. The accuracy of the *EF* can be affected by the presence of gating errors, because gating errors cause alteration of the systolic count increases [11]. Premature ventricular contractions (PVCs) and premature atrial contractions (PACs) are the most common cause of irregular heart rhythms (arrhythmias) that effect on myocardial perfusion and function measurements with G-SPECT [4]. Low R wave voltage decreases trigger sensitivity, which may result in gating errors leading to arrhythmia-like effects, even there is no real arrhythmia [7].

Determination of left ventricular ejection fraction (*LVEF*) in patients with atrial fibrillation (AF) must use electrocardiogram gating for accurate quantification of *LVEF* and requires a fairly constant R-R interval. Nichols *et al*. performed experiments to assess the impact of AF on *LVEF* by simulating the effects of AF (by altering counts in selected R-wave intervals) at the time of image processing in patients with sinus rhythm. *LVEF* was quantitated using both Quantitative Gated SPECT™ (QGS) and Emory Cardiac Toolbox™ (ECT) software. Although the mean change in *LVEF* between sinus rhythm and simulated AF was very small (QGS 0±3%, ECT –1±7%), the maximum change in *LVEF* in individual patients was substantial (QGS –18%, ECT +28%). These investigators also found that myocardial wall thickening was more prone to error than wall motion or myocardial perfusion in the presence of AF [10]. The impact of gating on single-photon emission computed tomography perfusion images in patients with atrial fibrillation was discussed by Sciagrá and colleagues [12, 14], who acquired gated and non-gated SPECT images simultaneously in 44 patients with AF. When the summed difference score was categorized according to severity class (normal, mild, moderate, severe), the severity class category changed in 39% of patients between the gated and non-gated images.

J. Kenneth and his group have also studied the gated SPECT myocardial perfusion imaging quality assurance with inspected gating errors which cause intermittent count losses due to improper ECG placement or transient arrhythmias [12]. These gating errors can affect MPI measurements, which are related to myocardial wall thickening calculations.

The problem of false-positive SPECT results in the setting of AF patients with significant signs of myocardial ischemia. A positive SPECT outcome was less often correlated with significant coronary artery disease in those patients who subsequently underwent coronary angiography. Furthermore, a negative SPECT outcome did not exclude significant coronary artery disease in either group (AF *vs*. control).

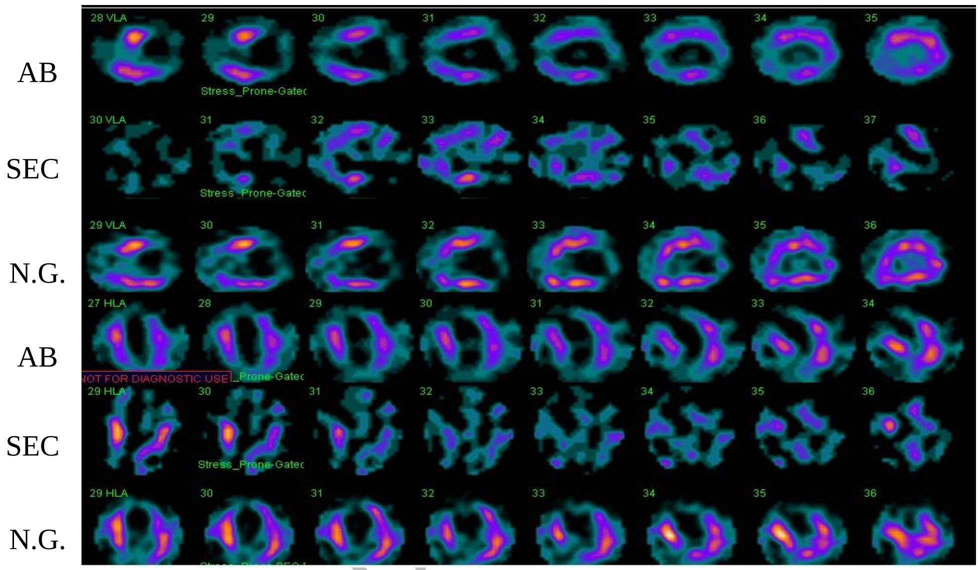

Fig. 1. Comparison between the perfusion images of the stress (AB), stress (SEC), and stress nongated SPECT (stress N.G.).

MATERIALS AND METHODS

PATIENT POPULATION AND STUDY PROTOCOL

52 patients (aged 60±13 years, mean±SD, 85% men) classified into two groups (35 non-arrhythmic patients – group 1, and 17 arrhythmic patients – group 2) were investigated by echocardiography and ^{99m}Tc Sesta-MIBI gated and non-gated myocardial perfusion SPECT. All patients were informed about the details of the research and accepted to participate in it. Echocardiographic studies were performed to evaluate *LVEF* and measurement of myocardial wall thickness for assessment of LV hypertrophy. Non-gated myocardial perfusion SPECT was

performed to assess myocardial perfusion and gated myocardial perfusion SPECT (G-SPECT) was performed to assess myocardial perfusion and LV function, and to measure myocardial wall thickness.

The patients were investigated by stress SPECT and G-SPECT myocardial perfusion acquisitions. The first G-SPECT depended on the number of the accepted heart beats (25 accepted heart beats per projection) and the second depended on time (25 seconds per projection). All myocardial perfusion acquisitions for each patient were analyzed by the quantitative algorithm (Cedars Sinai Medical Center) software and some parameters were calculated, like the total count, contrast, *SSS*, and *PD* for stress (AB) acquisition, and we compared them with the stress (SEC) acquisition parameters to determine the differences in perfusion images quality referenced by the non-gated stress (N.G.) parameters and the accuracy of the *EF* referenced by the patient echocardiography.

SPECT AND G-SPECT ACQUISITION

Gated SPECT was performed using a single-head gamma-camera (Symbia E, Siemens) equipped with high-resolution collimators and using a 15% window centered on the 140-keV photopeak of ^{99m}Tc. SPECT images were acquired in step-and-shoot mode using an 180º elliptic orbit, a 64X64 matrix, and 32 projections at 25 seconds per projection, then another acquisition was performed by 25 accepted heart beats per projection, and a non-gated acquisition as a reference. Acquisition parameters that cannot be modified are the number of projections, the rotation arc, the relative angle, the orbit type, and the patient orientation. Other variables, such as (in this study) the way of acquiring the projections, can be customized by the user, provided that the gantry motions and positions remain unchanged. We have chosen for gated SPECT an 8-frame acquisition. SPECT images were reconstructed using filtered back projection and realigned along the heart axis. In accord with our standard protocol and because most γ-cameras do not allow for attenuation correction, no attenuation correction was performed.

DATA ANALYSIS

The gated SPECT studies were processed automatically using the quantitative gated SPECT algorithm (Cedars Sinai Medical Center). Butterworth (cutoff 0.40, power 10.0) prefilters were applied for stress studies. The influence of arrhythmia on the perfusion images quality and the gated data was numerically analyzed, taking into account the total count, contrast *C*, summed stress score *SSS*, perfusion defect *PD*, and the shape of the reconstructed left ventricular volume curve, and count curve in the R-R interval according to the established criteria for quality control of gated studies [8].

The contrast was defined as:

$$C = \frac{A_{\text{Myo}} - A_{\text{Cavity}}}{A_{\text{Myo}} + A_{\text{Cavity}}} \times 100 \quad (1)$$

where A_{Myo} and A_{Cavity} are the mean number of counts of the LV wall and the LV cavity, respectively.

RESULTS

MYOCARDIAL PERFUSION ANALYSIS

Myocardial perfusion analysis for non-arrhythmic patients (group 1) evaluated by stress G-SPECT AB, time-dependent, and non-gated stress, illustrated in Table 1 for the average, standard deviation, and *P*-value for global summed stress scour (*SSS*), square for left anterior descending (*LAD*), left circumflex artery (*LCX*) and right coronary artery (*RCA*), perfusion defect (*PD*) for global and different arteries, and contrast.

In non-arrhythmic patients we found that there were non-significant changes between square of different arteries for stress G-SPECT time- and accepted beats-dependent compared with stress non-gated SPECT, but *SSS*, *PD* and total counts of stress G-SPECT time- and accepted beats-dependent for the same patient showed significant changes compared with stress non-gated SPECT.

The contrast of non-arrhythmic patients from stresses G-SPECT time- and accepted beats-dependent showed non-significant changes when compared with stress non-gated SPECT.

Table 1

Values of myocardial perfusion data (square, perfusion defects, contrast and total counts) for non-arrhythmic patients

Coronary arteries		Non-arrhythmic patients							
		Accepted beats stress			Time stress			Non gated stress	
		Average	St.dev	*P*-value	Average	St.dev	*P*-value	Average	St.dev
Square	*SSS*	12.74	8.38	0.0000	12.74	7.74	0.999	13.20	7.56
	LAD	4	4.16	0.0158	4.10	3.81	0.494	3.94	3.91
	LCX	3.23	3.36	0.1137	2.94	3.33	0.117	3	3.21
	RCA	5.43	3.07	0.0406	5.64	3.09	0.328	6.23	3.32
Perfusion	*PD*								
	LAD	28.44%	22.35	0.047	34.19%	25.30	0.002	29.56%	24.90

	LCX	22.09%	14.83	0.001	19.20%	16.09	0.018	18.48%	15.75
	RCA	43.94%	21.03	0.019	46.22%	23.05	0.006	49.52%	24.23
Contrast (%)		38.010%	8.576	0.818	36.51%	7.928	0.498	39.317%	8.272
T. Counts (disintegration /s)		2173.71	1550.0	0.0	2668.25	1688	0.0	2876.17	1926

Myocardial perfusion analysis for arrhythmic patients (group 2) evaluated by stress G-SPECT AB- and time-dependent and non-gated stress is illustrated in Table 2: the average, standard deviation and *P*-value for global summed stress scour (*SSS)*, square for left anterior descending artery (*LAD*), left circumflex artery (*LCX*) and right coronary artery (*RCA*), perfusion defect (*PD*) for global and different arteries, and contrast.

Table 2

Values of myocardial perfusion data (square, perfusion defects, contrast and total counts) for arrhythmic patients

Coronary arteries		Arrhythmic patients							
		Accepted beats stress			Time stress			Non gated stress	
		Average	St.dev	*P*-value	Average	St.dev	*P*-value	Average	St.dev
Square	*SSS*	11.53	6.34	0.0036	11.07	5.56	0.010	16.15	6.41
	LAD	4.53	3.84	0.0177	4.46	3.10	0.042	7.69	3.98
	LCX	2.30	2.17	0.055	2.07	2.05	0.046	4.69	2.99
	RCA	4.46	2.40	0.019	4.30	2.46	0.016	7.92	2.84
Perfusion defects	*LAD*	37.47%	23.98	0.010	42.06%	21.45	0.002	41.44%	27.49
	LCX	19.68%	18.66	0.028	17.88%	16.64	0.060	20.46%	18.05
	RCA	42.83%	15.65	0.001	38.89%	17.44	0.001	39.48%	21.57
Contrast (%)		35.12%	7.43	0.0174	36.26%	6.24	0.0438	44.12%	7.43
T. Count (dis./s)		2704.30	2386.0	0.0	2697.84	2516.6	0.0	3293.53	3755.5

All the data from myocardial perfusion imaging (squares, perfusion defect, contrast and total counts) for arrhythmic patients (group 2), evaluated by stress G-SPECT, showed significant changes when compared with stress non-gated SPECT.

W-SHAPE CURVE

In our study, we plotted a w-shaped curve that describes the relationship between the R-R interval for 8 frames (1-8) on X-axis and the count on Y-axis. In non-arrhythmic and arrhythmic patients we found that, in the time-dependent acquisition, the count changed roughly during the heart beats R-R interval (Fig. 2).

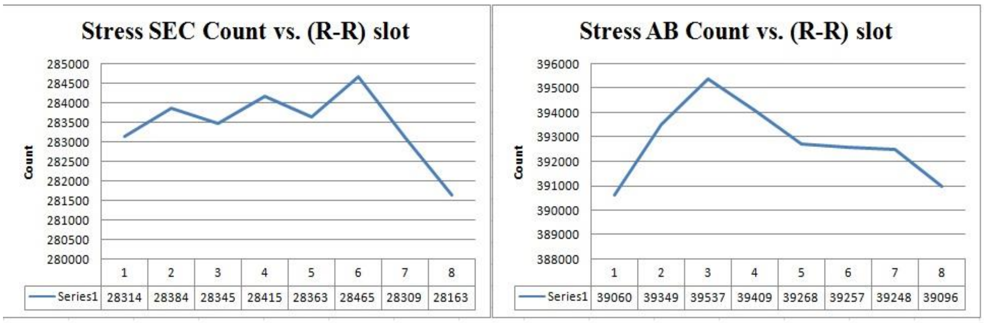

Fig. 2. The w-shape of count *vs*. R-R interval plot (8 frames, 1-8) for a non-arrhythmic patient evaluated by stress G-SPECT accepted beat- and time-dependent.

Nevertheless in the AB acquisitions there was a uniform curve, in which the count increased gradually from the end diastole frame to the end systole frame then the count decreased again gradually from the end systole to the end diastole, as shown in Fig. 3.

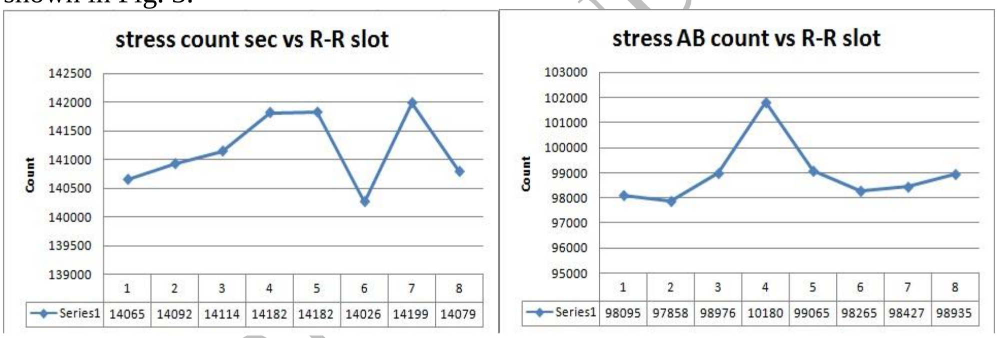

Fig. 3. The w-shape of count *vs*. R-R interval plot (8 frames, 1-8) for an arrhythmic patient evaluated by stress G-SPECT accepted beat- and time-dependent.

EJECTION FRACTION (*EF*) ANALYSIS

Ejection fraction analysis for non-arrhythmic patients (group 1) and arrhythmic patients (group 2) evaluated by stress G-SPECT AB- and time-dependent compared with echocardiography is illustrated in Table 3 for the average, standard deviation, and *P*-value for left ventricle ejection fraction (*LVEF*).

Table 3

The average, standard deviation, and significance value *P* of *LVEF* of stress G-SPECT (AB and time-dependent) and echo

Ejection fraction (%)	Non-arrhythmic patients			Arrhythmic patients		
	Average	St. dev	*P*-value	Average	St. dev	*P*-value
EF ECHO	59.05%	8.91		51.15	13.52	
EF AB	57.89%	11.11	0.868	47	17.42	0.0153
EF Time	57.84%	11.94	0.617	42.23	19.92	0.000005

In cases of non-arrhythmic patients, there were no significant changes between *EF* of the cases calculated by cardiac sonography (*EF* echo) and those calculated by the QCS software for stress G-SPECT time-dependent acquisition (*EF* SEC), and significant changes between *EF* echo and stress G-SPECT accepted heart beat-dependent ejection fraction (*EF* AB).

The average *EF* echo was higher than *EF* AB and *EF* sec (Fig. 4).

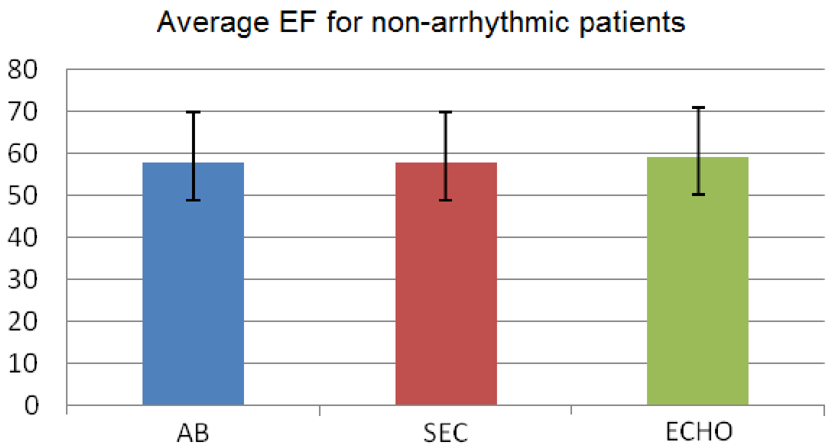

Fig. 4. Average ejection fraction (EF) for non-arrhythmic patients evaluated by stress G-SPECT (AB and time-dependent SEC) and echo (ECHO).

In cases of arrhythmic patients, there were significant changes between *EF* calculated by cardiac echo (*EF* echo) and those calculated by the QCS software for stress G-SPECT time-dependent acquisition (*EF* sec) (P = 0.000), and significant changes between *EF* echo and stress G-SPECT accepted heart beat-dependent ejection fraction (*EF* AB) (P = 0.0153).

The average ejection fraction of accepted heart beats acquisition (*EF* AB), time-dependent acquisition (*EF* sec), and *EF* echo showed that *EF* echo was always greater than *EF* AB and greater than *EF* sec but *EF* AB was closer to the *EF* echo than *EF* sec (Fig. 5).

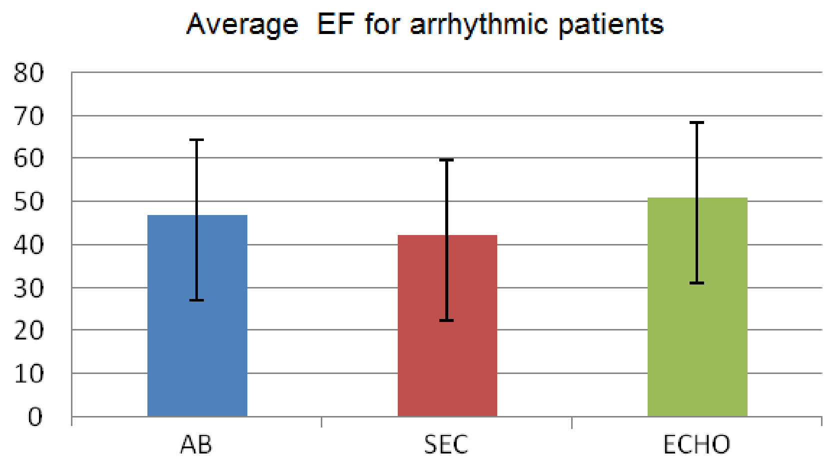

Fig. 5. Average ejection fraction (EF) for arrhythmic patients evaluated by stress G-SPECT (AB and time-dependent SEC) and echo (ECHO).

DISCUSSION

The myocardial perfusion images and images quality analysis will depend on the analysis of summed stress score (*SSS*), perfusion defect (*PD*), contrast (*C*), the total count and the shape of R-R vs. count curve for arrhythmic and non-arrhythmic cases in this study [7, 14]. Nichols *et al*. [11] observed significant differences in the extent and severity of abnormalities in perfusion imaging; these differences were greatest in the case of arrhythmias, so they prefer non-gated SPECT to G-SPECT, but Lima *et al*. [9] and Hachamovitch *et al*. [6], recommended using G-SPECT because it has additional prognostic and diagnostic value over the perfusion data.

In the present study, we specifically addressed this issue by directly comparing perfusion data from stress G-SPECT time- and accepted beats-dependent compared with stress non-gated SPECT for non-arrhythmic and arrhythmic patients. In non-arrhythmic patients the direct comparison of stress G-SPECT time- and accepted beats-dependent compared with stress non-gated SPECT demonstrates non-significant changes in contrast and square of different arteries, but *SSS*, *PD* and total counts showed significant changes. In list mode G-SPECT, each individual count is stored in a memory bin, which contains information on the count's location in the XY detector plane and on the exact time of its arrival relative to the ECG signal. Cardiac function and perfusion assessment are unreliable when too many beats are rejected during acquisition [8].

In patients with high voltage of T-wave or low voltage of R-wave, the T-wave may trigger the gate in lieu of, or in addition to, the R-wave. These gate errors and tall, peaked P-waves give unreliable results of G-SPECT [3]. In arrhythmic patients the direct comparison of stress G-SPECT time- and accepted beats-dependent compared with stress non-gated SPECT demonstrated that all collected data from myocardial perfusion imaging (squares, perfusion defects, contrast and total counts) showed significant changes when compared with stress non-gated SPECT. In cases of arrhythmic patients, there were significant changes between *EF* of the cases calculated by echo and those calculated by the QCS software for stress G-SPECT time- and accepted heart beats-dependent, but in non-arrhythmic patients there were no significant changes between *EF* of the cases calculated by echo and those calculated by the QCS software for stress G-SPECT time-dependent acquisition.

Now, to know which G-SPECT is better in the perfusion images quality compared with non-gated stress, we computed a score to ease this step. We attributed to the higher value of the average compared parameter score 3, to the middle value score 2, and to the lower value score 1, as shown in Table 4.

For the accuracy of the *EF*, the scores of stress AB, stress SEC compared with *EF* echo, as shown in Table 5.

Table 4

The scores of stress AB, stress SEC, and stress N.G.

	Stress AB		Stress SEC		Stress N.G.	
	Arrhythmic	Non Arrhythmic	Arrhythmic	Non Arrhythmic	Arrhythmic	Non Arrhythmic
SSS	8	9	4	7	12	9
PD	6	5	5	7	7	6
Contrast (%)	2	2	1	1	3	3
T. Count (disintegration /s)	2	1	1	2	3	3
Sum	18	17	11	17	24	21

Table 5

The scores of the *EF* of stress AB, stress SEC and stress N.G.

	Stress AB		Stress SEC		Echo	
	Arrhythmic	Non Arrhythmic	Arrhythmic	Non Arrhythmic	Arrhythmic	Non Arrhythmic
EF	2	2	1	1	3	3

CONCLUSION

In arrhythmic and non-arrhythmic patients the direct comparison of non-gated and G-SPECT (AB and time-dependent) images demonstrate major differences in perfusion and *EF* results, leading to a clinically significant divergence in the severity of coronary arteries disease (CAD) and cardiac function, especially in arrhythmic cases. So, non-gated SPECT and AB-gated SPECT are better than SEC-gated SPECT in the evaluation of myocardial perfusion or *LVEF*, especially for arrhythmic patients.

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