

The left ventricular dyssynchrony in patients with diastolic dysfunction

Disincronía ventricular izquierda en pacientes con disfunción diastólica

Alev Cinar^{1*}, Kursat Okuyucu^{2,3}, and Derya Cayir^{1,2}

¹Department of Nuclear Medicine, Etlik City Hospital; ²Department of Nuclear Medicine, University of Health Sciences; ³Department of Nuclear Medicine, Gülhane Training and Research Hospital. Ankara, Turkey

Abstract

Objective: The purpose of this study was to assess left ventricle (LV) filling curve variables and LV volumes derived from gated myocardial perfusion imaging (gMPI) scans of patients with diastolic dysfunction. **Methods:** Two hundred patients without perfusion defects on gMPI were retrospectively examined. According to peak filling rate values (≤ 2 or > 2), the 200 patients divided equally ($n = 100$) into two subgroups. **Results:** The summed stress scores were significantly higher in patients with diastolic dysfunction ($p = 0.018$). The end-systolic ($p < 0.001$) and end-diastolic ($p < 0.001$) volumes of the LV were significantly higher, and ejection fraction ($p < 0.001$) was significantly depressed in patients with diastolic dysfunction. **Conclusions:** The functional and structural changes of the LV seem to affect both consecutive events of diastolic filling relatively and the synchronization of the onset of mechanical contraction of LV simultaneously or consecutively.

Keywords: Diastolic dysfunction. left ventricle dyssynchrony. SPECT. Tc-99m MIBI. Phase analysis.

Resumen

Objetivo: El propósito de este estudio fue evaluar las variables de la curva de llenado del VI y los volúmenes del VI derivados de exploraciones gMPI de pacientes con disfunción diastólica. **Métodos:** Se evaluaron retrospectivamente 200 pacientes sin defecto de perfusión en las gMPI. Según los valores de la tasa de llenado máxima (≤ 2 o > 2), 200 pacientes se dividieron equitativamente ($n = 100$) en dos subgrupos. **Resultados:** Las puntuaciones de estrés sumadas fueron significativamente mayores en los pacientes con disfunción diastólica ($p = 0.018$). Los volúmenes telesistólicos ($p < 0.001$) y telediastólicos ($p < 0.001$) del VI fueron significativamente mayores, y la fracción de eyección ($p < 0.001$) se redujo significativamente en los pacientes con disfunción diastólica. **Conclusiones:** Los cambios funcionales y estructurales del VI parecen afectar relativamente tanto a los eventos consecutivos de llenado diastólico como a la sincronización del inicio de la contracción mecánica del VI de manera simultánea o consecutiva.

Palabras clave: Disfunción diastólica. Disincronía del ventrículo izquierdo. SPECT. Tc-99m MIBI. Análisis de fase.

*Correspondence:

Alev Cinar

E-mail: alevcnr@gmail.com

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Introduction

Electrocardiography (ECG)-gated myocardial perfusion imaging (gMPI) is the most widely used nuclear imaging modality for the diagnosis and management of coronary artery disease (CAD), since it allows simultaneous evaluation of the left ventricular volumes, synchronization of the onset of mechanical contraction of the left ventricle (LV) and regional ventricular systolic and diastolic functions at post-stress gated examination in addition to assessment of regional myocardial perfusion.¹ The 16-phase gMPI allows for the automatic generation of time-volume curve (TVC) and a filling rate curve, which is the first derivative of TVC for the analysis of diastolic filling.² The peak filling rate (PFR) and time to peak filling (TTPF) are derived from LV volume curve and both are the most commonly reported parameters for assessing diastolic functions.²⁻⁴ Diastolic dysfunction of LV is usually the result of impaired LV relaxation and increased LV chamber stiffness, which increases cardiac filling pressures, and its presence can be detected by gMPI. Detection of diastolic dysfunction is significant because heart failure can occur in the setting of preserved systolic function and ejection fraction (EF).

The variation of regional myocardial counts during the cardiac cycle are proportional to the wall thickness of the same region due to the partial volume effect and the approximate regional wall thickening curve over the LV is used to calculate a regional phase analysis.⁵ Phase analysis is used to extract amplitude and phase from the regional left ventricular count changes throughout the cardiac cycle, and this count-based technique from gMPI provides information about LV regional discordance in contractility, which is a measure of LV dyssynchrony.⁵ Actually, the normal myocardium of the LV contracts in a coordinated way so that most of the myocardial segments are nearly in the same phase. Phase analysis is an automatic, reproducible, and simple tool to implement. Hence, it is easy to apply to all gMPI studies and is already included in the latest versions of the main processing programs available in nuclear cardiology.⁶ The main indication for the use of this technique is the prognostic evaluation of patients who will undergo cardiac resynchronization therapy (CRT) and to establish the feasibility of an optimum placement site for the electrodes.^{7,8} Phase standard deviation and phase

histogram bandwidth (HB) are two quantitative indices to assess LV global mechanical dyssynchrony.^{9,10}

With phase analysis, gMPI has an important role in the diagnosis and management of patients with left ventricular systolic dysfunction.¹¹ However, its status in the presence of diastolic dysfunction of the LV without ischemia is still not clear. We assumed that the parameters of synchronization of the onset of LV mechanical contraction might be negatively affected in the presence of diastolic dysfunction of the LV due to similar underlying etiopathological factors. Therefore, the purpose of this study was to assess the left ventricular filling curve variables and left ventricular volumes derived from gMPI scans of the patients with diastolic dysfunction.

Methods

This was a retrospective study conducted with 200 patients (111 women [55%] and 89 men [45%], mean age 60 years [range 29-82 years]) who were referred to our department for stress-rest gMPI for suspected CAD. The patients in this study were referred to rule out CAD and were found to have a low likelihood of CAD on the basis of testing. Of the patients included in our study, 17 (8.5%) were diagnosed with diabetes mellitus (DM), and 17 (8.5%) had hypertension (HT). Patients diagnosed with DM were using oral antidiabetics. In cases diagnosed with HT, patients who did not use beta blockers and calcium channel blockers were included in the study. One hundred and fifty of the patients (75%) had hyperlipidemia, and 137 patients (68.5%) had a family history of CAD. 132 (66 %) of the patients were smokers of approximately one pack a day (Table 1).

None of the patients had a history of previous surgery. Patients with a body mass index over 18 were excluded from the study group. 17 (8.5%) of the patients were using inhaler therapy due to a diagnosis of asthma bronchitis.

All patients had no perfusion defects on their gMPI scans (summed stress score [SSS] < 4). The patients were divided into two subgroups according to diastolic function of the LV derived from gMPI scans. Patients in Group 1 (n = 100) had diastolic dysfunction (PFR ≤ 2), and patients in Group 2 (n = 100) normal diastolic function (PFR > 2).

Patients with perfusion defects on their scans (SSS > 4), bundle branch block, atrial fibrillation, treatment of beta blocker or calcium antagonists at the time of the study, submaximal stress test (< 85% of

Table 1. Comorbidities of the patients

Comorbidities	Female n (%)	Male n (%)	Total n (%)
Diabetes mellitus	10 (9)	7 (7.8)	17 (8.5)
Hypertension	12 (10.8)	5 (5.6)	17 (8.5)
Hyperlipidemia	81 (73)	69 (77.5)	150 (75)
Smoker	54 (48.6)	78 (87.6)	132 (66)
Family history	73 (65.7)	64 (72)	137 (68.5)

the maximal age-predicted heart rate), and dilated LV were excluded from the study. The hospital Ethics Committee approved the study protocol.

Stress protocol

All patients underwent an exercise stress test. Symptom-limited treadmill exercise test according to the standard Bruce protocol (stepwise increments of velocity and slope every 3 min) with continuous 12-lead ECG assessment was chosen on the basis of the patient's ability to exercise until reaching at least 85% of the maximal age-predicted heart rate.

Acquisition protocol

According to our 2-day stress-rest gMPI clinical protocol, each patient underwent stress gMPI for the 1st day. A standard dose of 222-296 MBq (6-8 mCi) Tc-99m MIBI (Cardio-single-photon emission computed tomography [SPECT], Medi-Radiopharma, Budapest, Hungary) was injected intravenously when the patients reached maximum exercise. All acquisitions were initiated 30 ± 10 min while the patients were in supine position with arms placed over the head.

Daily quality control of the gamma camera was performed routinely before the first study of the day in a routine fashion. The dedicated cardiac gamma camera (Discovery NM 530c, GE Healthcare, Chicago, Illinois, USA) equipped with a multiple pinhole collimator and 19 stationary cadmium-zinc-telluride detectors was used for acquisition of patients. Each detector contained 32 × 32 pixelated 5-mm thick (2.46 × 2.46 mm) elements. A window of 15% was centered on the 140 keV gamma peak, and the gating was done with 16 frames per RR interval. List mode files were acquired and stored. Images were reconstructed on

the same workstation as for the standard SPECT acquisition (Xeleris II, GE Healthcare, Haifa, Israel) using a new dedicated iterative algorithm. A Butterworth post-processing filter (frequency 0.37, order 7) was applied to the reconstructed slices. Images were reconstructed without scatter or attenuation correction. R–R acceptance window was set to 25%.

Data analysis

In a blinded manner, scintigraphic images were analyzed by two experienced observers in consensus. All systolic and diastolic measurements were obtained from stress-gMPI scans. Data from gated SPECT studies of all the patients were analyzed using quantitative gated SPECT and quantitative perfusion SPECT software (QGS, QPS, Cedars-Sinai Medical Center, Los Angeles, CA, USA). Myocardial segmentation was based on a 20-segment model, and SSSs were calculated based on 0-4 points in each segment (0, normal to 4, defect). EF, end-diastolic volume (EDV), and end-systolic volume (ESV) were automatically calculated by means of QGS software. The peak of the phase histogram (PP), standard deviation of the phase distribution (SD), phase HB, phase histogram skewness (HS), and phase histogram kurtosis (HK), which are the assessment parameters for LV dyssynchrony, were determined by using a commercially available software package (Emory Cardiac Toolbox, Emory University, Atlanta, GA, USA).¹² Diastolic function parameters of LV, such as PFR (defined as the greatest filling rate in early diastole) and TTPF (the interval between ES and PFR) were quantified using QGS software. LV filling rate/time curve was computed from the first derivative of the volume/time curve of LV. Since the filling was normalized to EDV, the unit for PFR was EDV/s and TTPF was expressed in milliseconds (ms).

Statistical analysis

Descriptive analysis was performed by examining the pertinent variables in the study population. Continuous variables were expressed as mean ± SD. An independent-samples t-test was used to compare the results of measurements between the groups. The relationship between two continuous variables within a group of subjects was evaluated by Pearson's correlation test. All p-values were two-tailed, with a value of < 0.05 set a priori and used as the level of

significance. Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) version 22.0 for Windows (SPSS Inc., Chicago, IL, USA).

Results

All of the patients were in a mild or moderate risk group for CAD. They did not have a history of bypass surgery or percutaneous coronary intervention. History of HT and DM were detected in 17 and 17 cases, respectively. Other patients were consulted to the Cardiology Department for a history of angina, palpitations, and dyspnea. In this study, we evaluated the phase analysis results of the patients with and without diastolic dysfunction. According to our results, the synchronization of mechanical contraction of LV in patients with diastolic dysfunction was detected as distorted. Besides, LV volumes were significantly higher, and EF was significantly lower in patients with diastolic dysfunction. Demographic data of the patients and the statistical comparison between the groups according to LV parameters of perfusion (SSS), volumes (ESV and EDV), systolic function (EF), diastolic function (PFR and TTPF), and dyssynchrony (PP, SD, HB, HS, HK) were represented in Table 2. Gender did not seem to have prominent effects on the results of the study groups, except that female patients were older and EF values were lesser than the male patients in Group 2. SSSs were significantly higher in patients with diastolic dysfunction, but these scores were lesser than 4 in all patients in the study group. Although the mean ventricular volumes were within normal limits for both groups, ESV and EDV were significantly higher in patients with diastolic dysfunction. Similarly, EF, as the systolic functional parameter of LV, was significantly depressed in patients with diastolic dysfunction. PFR in patients with diastolic dysfunction was significantly lesser than those of the normal group. The mean values for PFR (3.1 ± 0.7 EDV/s) and TTPF (164.8 ± 31.3 ms) in Group 2 were similar to those defined in the literature using gMPI and planar gated blood pool SPECT.^{2,13} TTPF results of 29 patients in Group 1 and 30 patients in Group 2 were higher than 180 ms.

HB and SD, which are important parameters of the synchronization of mechanical contraction of LV, were higher in patients with diastolic dysfunction, and these differences were statistically significant. Therefore, the synchronization of mechanical contraction of LV was significantly depressed in Group 1.

Insignificant poor negative linear correlation was detected between the results of PFR and age of the patients ($r: -0.083$, $p = 0.242$). There was a significant difference between the groups according to beats per minute (BPM), and an insignificant poor positive linear correlation was detected between the results of PFR and BPM of the patients ($r: -0.073$, $p = 0.308$). On the other hand, a significant positive linear correlation was detected between the results of PFR and BPM of the patients in Group 1. The effect of age and BPM on PFR, both in the study population and patient groups separately, was illustrated by a scatter plot (Figs. 1 and 2).

Discussion

Unlike ventricular systolic function where single parameters are utilised to define myocardial performance, the assessment of diastolic function relies on the interpretation of multiple myocardial and blood-flow velocity parameters.

The echocardiographic assessment of diastolic function is therefore multifaceted and complex, requiring an algorithmic approach that incorporates parameters of myocardial relaxation/recoil, chamber compliance and function under variable loading conditions, and the intra-cavity pressures under which these processes occur.

The flow rate curve is the first derivative of the volume curve of the LV, which is obtained from gMPI by means of software. PFR is defined as the greatest filling rate in early diastole and corresponds to peak value of the first derivative of the diastolic portion of the time-activity curve.² Although clear-cut values have not yet been established for normal versus abnormal diastolic function due to insufficiency of large population-based criteria adjusted for age and sex,¹⁴ the threshold values usually accepted for PFR and TTPF are 1.70 EDV/s and 180 ms, respectively.² Since typical values for these parameters have been accepted < 180 ms for TTPF and > 2 EDV/s for PFR,³ we chose the threshold value for PFR as 2 EDV/s and subdivided our study population according to this value.

The results of TTPF in patients with diastolic dysfunction whose PFR results were < 2 were significantly lesser than those of normal group. Unlike PFR, TTPF does not seem to be a sensitive parameter for detecting disruption of early rapid filling of the ventricle in patients with diastolic dysfunction.

Table 2. Patient demography and statistical comparison of the results between the groups according to LV parameters of perfusion (SSS), volumes (ESV and EDV), systolic function (EF), diastolic function (PFR and TTPF), and dyssynchrony (PP, SD, HB, HS, HK)

Variables	Group 1			Group 2			Group 1 (n = 100)	Group 2 (n = 100)	p
	Male (n = 54)	Female (n = 46)	p	Male (n = 36)	Female (n = 64)	p			
SSS	1.57 ± 1.32	1.56 ± 1.42	0.974	0.92 ± 1.16	1.25 ± 1.28	0.200	1.57 ± 1.36	1.13 ± 1.24	0.018
EDV (mL)	90.67 ± 25.91	86.34 ± 31.53	0.454	74.44 ± 17.07	75.56 ± 16.53	0.746	88.68 ± 28.56	75.17 ± 16.65	< 0.001
ESV (mL)	38.63 ± 17.54	38.58 ± 27.49	0.993	24.0 ± 8.84	26.1 ± 9.3	0.288	38.61 ± 22.55	25.33 ± 9.14	< 0.001
EF (%)	58.55 ± 8.56	58.93 ± 10.04	0.839	69.14 ± 5.44	66.47 ± 6.81	0.046	58.73 ± 9.23	67.43 ± 6.45	< 0.001
PFR (EDV/s)	1.57 ± 0.35	1.39 ± 0.51	0.043	3.02 ± 0.5	2.93 ± 0.5	0.411	1.49 ± 0.44	2.96 ± 0.49	< 0.001
TTPF (ms)	151.66 ± 59.87	133.26 ± 67.14	0.151	165.64 ± 30.1	163.25 ± 32.53	0.718	143.2 ± 63.66	164.11 ± 31.54	0.004
PP	148.57 ± 22.96	156.22 ± 25.81	0.120	152.64 ± 1.12	150.52 ± 14.54	0.837	152.1 ± 24.49	151.28 ± 15.86	0.782
SD	28.09 ± 14.82	29.91 ± 13.92	0.529	22.28 ± 7.26	22.67 ± 9.78	0.525	28.93 ± 14.37	22.53 ± 8.91	< 0.001
HB	82.15 ± 47.25	91.4 ± 52.91	0.358	65.89 ± 18.71	67.73 ± 28.25	0.727	86.41 ± 49.89	67.07 ± 25.15	0.001
HS	3.17 ± 0.95	3.22 ± 0.84	0.778	3.4 ± 0.7	3.45 ± 0.67	0.757	3.19 ± 0.9	3.43 ± 0.7	0.036
HK	12.25 ± 8	12.77 ± 8.11	0.746	13.93 ± 7.18	14.06 ± 7.25	0.932	12.49 ± 8	14. ± 7.1	0.160
Age (years)	60 ± 9	62 ± 9	0.220	55 ± 11	61 ± 12	0.025	61 ± 9	59 ± 12	0.250
BPM	69 ± 12	72 ± 10	0.269	76 ± 7	74 ± 9	0.360	70 ± 11	75 ± 9	0.003

SSS: summed stress score; EDV: end-diastolic volume; ESV: end-systolic volume; EF: ejection fraction; PFR: peak filling rate; TTPF: time to peak filling rate; PP: peak phase; SD: standard deviation; HB: histogram bandwidth; HS: histogram skewness; HK: histogram kurtosis; BPM: beat per minute.

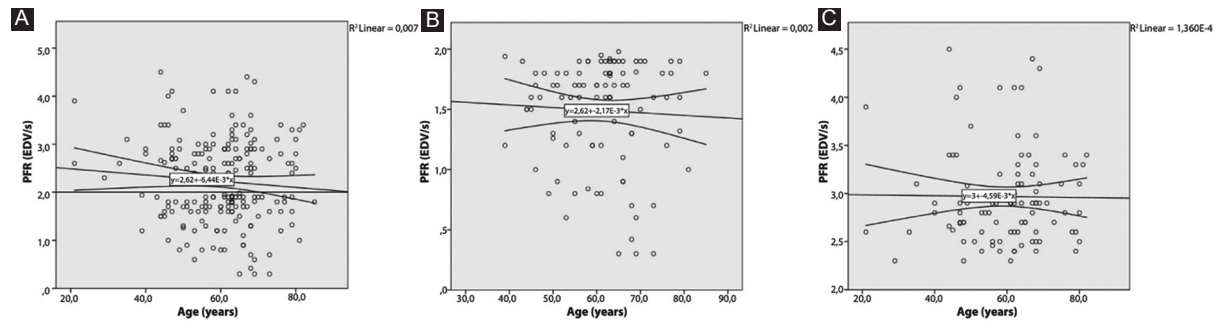


Figure 1. A: Scatter plot showing the effect of age on PFR results in the study population, **B:** group 1 ($r = -0.049$, $p = 0.632$) and **C:** group 2 ($r = -0.012$, $p = 0.908$) respectively.

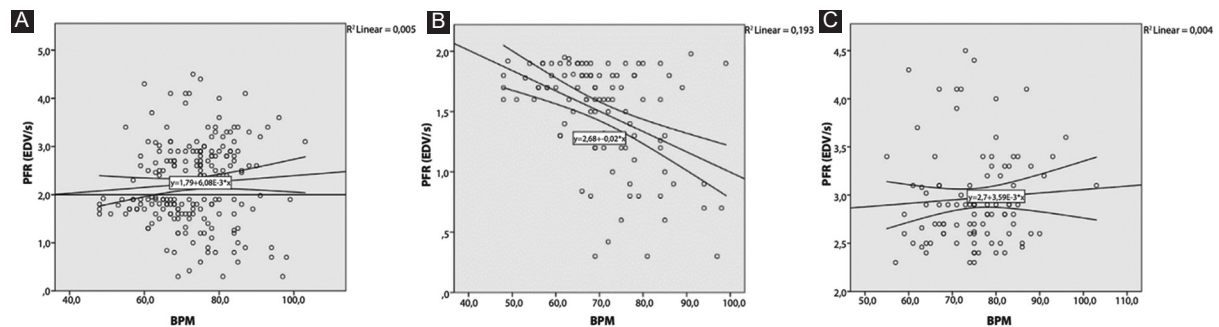


Figure 2. A: Scatter plot demonstrating the effect of BPM on PFR results in the study population, **B:** group 1 ($r = -0.439$, $p < 0.001$) and **C:** group 2 ($r = 0.064$, $p = 0.524$), respectively.

gMPI provides reproducibility and repeatability for the evaluation of left ventricular dyssynchrony using a phase analysis diagnostic tool which was introduced in 2005 by Chen et al.^{6,15} The main indication for the use of this technique is the prognostic evaluation of the patients who will undergo CRT. It determines if dyssynchrony is detectable by usual methods. If it translates into mechanical synchrony, these patients will receive some real benefit from the treatment.

For the LV to function effectively as a pump, it must not only be able to eject but also fill blood (diastolic function). Diastolic function has conventionally been assessed on the basis of the LV end-diastolic pressure-volume relation. Impaired relaxation may result in persistent pressure generation at end-diastole and may thus contribute to reduced LV distensibility. The invasive nature of the procedures for obtaining the LV end-diastolic pressure-volume relation, however, limits its clinical use for assessment of diastolic function. Furthermore, there is more to adequate diastolic performance of the LV than is apparent by examining the diastolic pressure-volume relation.

The myocardium depends on a continuous supply of oxygen due to its limited anaerobic capacity. When the coronary flow is unable to meet the demands of the myocardial tissue, myocardial ischemia results.

Prolonged ischemia can compromise the function and integrity of the myocardium, resulting in decreased cardiac output, arrhythmia, and/or death. The most common etiology of compromised coronary circulation is CAD, the details of which are beyond the scope of this discussion.

The build-up (and rupture) of plaques causes decreased coronary luminal diameter, resulting in a mismatch between oxygen demand and delivery. Certain medications such as nitroglycerin and calcium channel-blocking agents exist, which can contribute to relief from myocardial ischemia by dilating the large coronary arteries.

The mechanical contraction is measured at multiple points across the LV myocardium, and either a polar map or histogram visualizes its distribution. HB and SD, as important parameters of the synchronization of mechanical contraction of the LV are widened when the mechanical dyssynchrony of LV increases.¹⁶ Both parameters of the phase analysis were significantly higher in our patients with diastolic dysfunction. Diastolic filling and synchronization of the onset of mechanical contraction of LV are relatively consecutive events and therefore, functional and microstructural events affecting the diastolic filling are also

expected to affect the synchronization of the onset of mechanical contraction of LV.

Reversible or persistent perfusion defects were not detected on gMPI scans of all our study population. The patients with diastolic dysfunction may have undetectable coronary atherosclerosis affecting the functions of the LV, especially in early diastolic filling. It has been reported that in patients without anatomically significant coronary lesions, the development of post-stress LV diastolic dysfunction on gMPI associates with the presence of non-obstructive atherosclerosis on coronary angiography.¹⁷ On their multivariate analysis, the presence of non-obstructive atherosclerosis has been declared to be the only significant predictor ($p = 0.026$) of post-stress LV diastolic impairment independently from perfusion parameters.

The pressure decay due to untwisting and elastic recoil creating ventricular relaxation promotes rapid filling of the ventricles by reducing the LV pressure below that of the left atrial pressure during early diastole, which accounts for 60-80% of ventricular filling.¹⁸ Another power for ventricular relaxation comes from the hydrostatic pressure stored in the arcus aorta by the LV itself, and it is carried by coronary arteries in early rapid filling of the ventricles. Clinically insignificant coronary atherosclerosis also causes turbulent flow and alterations in calcium homeostasis, and the changes in the extracellular matrix causing increased LV stiffness and slowing of LV relaxation may lead to diastolic dysfunction.^{19,20} According to our data, functional and structural changes causing diastolic dysfunction seem to affect the synchronization of the onset of mechanical LV contraction simultaneously or consecutively.

Electrical synchrony may differ from the mechanical synchrony of LV.²¹ This theory is consistent with our findings in some respects, such that in addition to electrical changes, functional and microstructural changes causing the diastolic dysfunction seem to affect the coordinated action of pumping of LV.

It has been reported that there was a significant difference between men and woman according to LV volumes, EF, and PFR, such that both EDV and ESV were lower, EF and PFR were higher in women, but TTPF was similar in both sexes.² Besides, Chen et al.¹⁵ proposed higher values of phase analysis parameters in males compared to females in their study. They were later supported by the data published from the Indian and Japanese population.^{22,23} The explanations for this include the presence of greater body mass index and LV mass in males in comparison to females

and a concept based on electrophysiological studies showing that the large myocardial mass in males takes longer time to depolarize.²⁴

Although mean ventricular volumes and EFs were within normal limits in both groups, EDV and ESV were significantly higher, and EF was significantly depressed in patients with diastolic dysfunction. Increased LV end-diastolic pressure due to diastolic dysfunction induces higher left atrium afterload and hence mechanical stress on the atrium, leading to higher left atrium volumes in the early phase.^{25,26}

It has been stated that there was a significant decline in PFR with advancing age, whereas TTPF did not show any correlation with age.² The relationship between PFR and aging has also been reported in a previous radionuclide ventriculography study.²⁷

Since variations in heart rate preferentially affect diastolic time intervals, BPM can affect diastolic function measurements. The mean count of heartbeat in Group 2 was significantly higher than that of Group 1. This significant difference in BPM may have caused a minimal negative effect on categorizing the patients into two subgroups. The recorded ranges of PFR and TTPF did not seem to affect the results of the study. It has been urged that the ranges of PFR and TTPF observed early after maximal exercise imaging, which increases the possibility of varied BPM during the acquisition, were not substantially different from those reported in the studies acquired at rest and under more ideal conditions.²

Many studies have shown a high prevalence of LVDD in patients with HT even in the absence of alteration of LV systolic function, including newly diagnosed patients who are clinically asymptomatic.^{14,21,23} Left ventricular diastolic dysfunction has been shown to be associated with increased cardiovascular morbidity and mortality, as well as the development of heart failure, thus rendering its recognition important for the assessment of hypertensive persons. ECG-gated SPECT has been reported to be a useful method for evaluation of LV function. Since phase analysis is a count-based technique, it may be influenced by count density. If similar doses are injected, a larger heart would accumulate less myocardial count per unit volume, and lower counts per pixel may result in higher noise and potential measurement, leading to higher SD and bandwidth.²⁸ It has been shown that the phase parameters may be influenced by myocardial counts, frames per cardiac cycle, dose of radionuclide, stress versus rest study, and gender.²⁹ It has been reported that the dose-dependent differences

and differences in relation with stress type (physical or pharmacological) were not found.

In a study conducted by Nakajima et al., the diagnostic performance of four different software programs was compared for the purpose of phase analysis evaluation in 156 patients, including 122 patients with normal myocardial perfusion and 34 patients with heart failure detected by echocardiography.²³ Accordingly, it has been reported that all software programs can be used reliably for phase analysis. In another study, phase analysis was evaluated between software; phase parameters between these software were compared. Although a significant correlation was observed between them, no software was found to have superiority over the other.¹⁴

Study limitations are the retrospective design, and diastolic LV dysfunction assessed by gMPI has to be confirmed echocardiographically to reduce possible PFR overlapping between healthy individuals and those with diastolic dysfunction without echocardiographic correlation. In addition, if we took 1.7 EDV/s as cut-off value for PFR instead of 2 EDV/s, our results would be more evident.

The functional and structural changes in the LV due to pathological processes like atherosclerosis, DM, and HT seem to affect both the relatively consecutive events of early rapid diastolic filling and the synchronization of the onset of mechanical contraction of the LV simultaneously or consecutively. Since the number of patients with comorbidities of DM and HT in our study group was low, this information should be supported by studies with a larger number of patients.

Conclusions

The versatile gMPI provides multidirectional information regarding the ventricle function such as perfusion, systolic and diastolic functions, volumes, and synchronization of the mechanical contraction of LV in a single session. Thus, it deserves special praise among the other imaging methods for the heart.

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Conflicts of interest

The authors declare no conflicts of interest.

Ethical considerations

Protection of human subjects and animals. The authors declare that no experiments on humans or animals were performed for this research.

Confidentiality, informed consent, and ethical approval. The authors have obtained approval from the Ethics Committee for the analysis of routinely collected and anonymized clinical data; therefore, individual informed consent was not required. Relevant ethical recommendations have been followed.

Declaration on the use of artificial intelligence. The authors declare that no generative artificial intelligence was used in the writing or creation of the content of this manuscript.

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