Original Article

Echocardiographic Assessment of Left Ventricle Diastolic Dysfunction Using Transmitral Doppler Acceleration Rate of Mitral Inflow E-Wave

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Abstract

Background: Diastolic dysfunction (DD) has a high prevalence in the community. Although it often remains asymptomatic, it can be a significant cause of morbidity and mortality. The assessment of the left ventricular diastolic function (DF) should be an integral part of a routine examination, particularly in patients presenting with dyspnea or heart failure. **Patients and Methods:** A cross-sectional study started from June 2018 to February 2019. The study was conducted in four medical institutions in Baghdad. Mitral inflow for the assessment of left ventricular DF depending on guideline 2016 was performed. **Results:** Left ventricular ejection fraction (EF) was higher in a group with normal DF than in the group with DD ($P = 0.0001$). Mean E/A ratio was higher among patients 2.15 ± 0.48 than in the control Group 1.30 ± 0.50 the difference between them was significant ($P = 0.0001$). Mean acceleration time (AT) was longer in individual with normal DF (88.23 ± 13.85) than that of patients with LVDD (72.89 ± 8.88), while the acceleration rate in LVDD group (1364.38 ± 277.31) was higher than that in normal LVDF (859.12 ± 275.95). There was a significant difference ($P = 0.0001$) between the two groups. **Conclusion:** AT and rate were significantly correlated with DD in normal EF group, but both of them have no relation to the grading of DD.

Keywords: Acceleration rate, diastolic dysfunction, echocardiograph, E-wave

Introduction

Diastolic dysfunction (DD) study is an important concept for the high prevalence of predominantly DD in individual aged more than 65 years. The prevalence is 16% in the general population,[1] increased to 50% in type 2 diabetes mellitus (DM), 60% in patients with coronary artery disease (CAD), and 70% in patients with both CAD and DM.[2,3] Evaluation of diastolic function (DF) consists of assessing myocardial relaxation, filling pressures, and Left ventricular (LV) compliance.[4] The assessment of left ventricular (LV) DF has to be included in a routine examination.[5]

Transmitral Doppler echocardiography has been routinely used to identify left ventricular DD in patients.[6] However, problems related to the complexity of interpreting the transmitral flow profile still exist, and some of the better-established clinical indices may need to be re-evaluated for their relevance.[7]

Differentiation between normal and abnormal DF is complicated by overlap between Doppler indices values in healthy individuals and those with DD.[8] Furthermore, normal aging is associated with a number of changes in the heart and vascular system, especially slowing LV relaxation which may lead to DD. Therefore, filling patterns in the elderly resemble those observed in mild DD in younger patients (40–60 years), thus age should be taken into consideration when evaluating DF variables.[9,10]

Sattarzadeh was the first who assess the utility of the acceleration rate (AR) and time of the E wave of mitral inflow as a primary diagnostic modality for assessing DF.[11] Echocardiography has played a central role in the evaluation of LV DF over the past two decades.

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The aim of the study was to assess the utility of the AR and time of the E-wave of mitral inflow as a primary diagnostic method for assessing left ventricle DF.

Patients and Methods

Study design

This was cross-sectional study.

Duration of study

The study started from January 2018 to February 2019.

Study setting

The study was conducted in four medical institutions. Those were Baghdad Teaching Hospital, Al-Yarmouk Teaching Hospital, Iben-Alnafees Teaching Hospital, and Iraqi Center for Cardiac Disease which approved the study protocol.

Data collection

Sociodemographic data were collected by a questionnaire designed for the purpose of the study.

Echo studies

Standard transthoracic echocardiography

Complete M-mode, two-dimensional, and Doppler echocardiogram were performed by two experienced cardiologists according to the standardized protocol of the American Society of Echocardiography, using the machine (VIVID E9, GE-Ving Med, Horten, Norway) equipped with a 3.5 MHz transducer. The Modified Simpson method was utilized; LV ejection fraction (EF) was measured at the apical four and two-chamber views.

To assure quality control we use the same type of machine and the same method for the echo study.

Assessment of LV diastolic function

using mitral inflow for the assessment of LVDD in the current study depending on guideline 2016, from the apical 4-chamber view with pulsed wave Doppler by placing a 1–2 mm sample volume between the tips of the mitral leaflets during diastole. From the mitral inflow profile, the E and A-wave velocity, A-wave duration, and E/A velocity ratio were measured.

Doppler tissue imaging was used to measure (e') and (A) velocities by placing a 1–2 mm sample volume at the septal and lateral mitral annulus.

Left atrial (LA) volume indexed to body surface area as the primary measure of LA size in evaluating DF was calculated from the area-length method from the apical four-chamber and two-chamber views at end-systole. LA volume index >34 mL/m^2 is considered abnormal. LV DF was determined using standard echocardiographic parameters including E/A velocity ratio, and mitral E/e' ratio. The AR of E wave of mitral inflow (AR) as our parameters was measured in all patients.

The acceleration rate of E

AR and time of E were measured in all patients. The AR of E (cm/sec^2) was represented by the slope of the line between an anchored point and a crosshair. This linear measurement was made on the velocity spectrum. The acceleration time (AT) of E was measured from the onset to the peak of E. These recordings were shown on a strip chart with a sweep speed of 100 mm/s to determine correct temporal observations. Measurements were performed offline by an independent observer who had no knowledge of Pulse Wave Doppler or Tissue Doppler findings. At least, three measurements were taken of each parameter and these were averaged.

Classification

all subjects included in the study were divided according to the EF into two groups, the cutoff point was EF of 54% for females and 52% for males: A group with a low EF; and a group with normal EF. In reference to the following four criteria:

- Average E/e >14
- Septal velocity <7 cm/s or Lateral velocity <10 cm/s
- TR velocity >2.8 m/s
- LA volume index >34 ml/m^2.

The group with normal EF was subdivided according to Nagueh *et al*. in 2016 into three subgroups: Normal DF; Indeterminate; and DD.[12]

This study faced time limitations and the availability of the same machine for the study.

Statistical issue

Data were entered into a personal computer; the SPSS software program version 23.0 (IBM Corp, USA) statistical package was used for data grouping tabulation and analysis. All values were expressed as mean ± standard deviation the correlation between AR and AT of E wave and LV DF grade was measured using the Spearman correlation coefficient. Multivariate logistic regression analysis was performed to adjust the age and gender effect. The receiver operating characteristic (ROC) curve was used to determine the sensitivity and specificity of AR of E wave in diagnosing LV DD and elevated left ventricle diastolic pressure (LVDP). ROC curve was performed in randomly selected two-thirds of the population (derivation group), then the derived cutoff was evaluated in the rest of the population (Test group).

Ethical issue

Verbal consent was taken from all participants after an explanation of the nature of the work to them. Required permission from higher authorities was obtained.

Results

The total number of participants in this study was 240 individuals. Among them, 138 (57.5%) had normal echo studies. Patients who had DD formed 79 (32.9%). The remaining 23 (9.6%) patients were indeterminant (those had got only 50% of the criteria of DD positive, so they were not normal nor they were considered patients with DD). Mean age 48.8 ± 13.8. Female constitute 60.4% of the sample, with 1.5:1 female-to-male ratio. The mean body mass index was 27.7 ± 4.4.

Table 1 represented some Echo measurements in patients with left ventricular DD in comparison with those with normal DF. LV-EF was higher in a group with normal DF than in the group with DD ($P = 0.0001$). The mean E/A ratio was higher among patients 2.15 ± 0.48 than in the control Group 1.30 ± 0.50 the difference between them was significant ($P = 0.0001$).

There was a significant difference ($P = 0.0001$) between Mean E/é ratio in the patients 8.20 ± 7.04 and control 4.04 ± 4.55. Mean AT was longer in an individual with normal DF (88.23 ± 13.85) than that of patients with LVDD (72.89 ± 8.88), while the AR in the LVDD group (1364.38 ± 277.31) was higher than that in normal LVDF (859.12 ± 275.95). There was a significant difference ($P = 0.0001$) between the two groups. The LA volume index was found to be higher in patients with LVDD than in those with normal LVDF ($P = 0.0001$).

In Table 2, DD with Normal ejection fraction (NEF) was highest 17 (65.4%) in the middle age group (45–64) years, in females 15 (57.7%), and in overweight 14 (53.9%).

Table 3 shows the distribution of patients with DD with NEF according to concomitant chronic disease. Hypertension was on the top of the list at a rate of (73.1%) followed by CAD (34.6%) and at last, came DM at a rate of (26.9%).

Table 4 reveals that AT decreased with increasing age group in those with normal DF ($P = 0.0001$), this was not obvious in patients with DD despite the significant differences in the mean of AT ($P = 0.0001$). In the case of AR, there was a significant difference between genders while it was not significant in mean AT. The difference in mean AT and AR was significant in patients with chronic diseases.

LVDF is significantly associated with concomitant chronic diseases: hypertension, DM, and ischemic CAD ($P = 0.0001$). This is represented in Table 5.

Table 6 shows the mean inflow of E wave was highest (0.993 ± 0.23) among patients with DD. The difference between the different groups was highly significant ($P = 0.0001$). While the mean inflow of A wave was highest among the indeterminate group (0.84 ± 0.22), this association was highly significant ($P = 0.0001$). The E/A ratio was also high in patients with DD (1.93 ± 0.34) and showed a significant difference among the LVDD ($P = 0.0001$).

The mean lateral E/é, septal E/é, and the mean E/é ratio were higher in LVDD (14.82 ± 6.78) (15.94 ± 8.41) (15.38 ± 7.42), respectively, and the relationship was highly significant ($P = 0.0001$).

The mean AT was higher (88 ± 14) among normal DF while the mean AR was higher (1375 ± 318) among LVDD. The relationship between LVDF and AT and rate were highly significant ($P = 0.0001$) ($P = 0.0001$), respectively.

Figure 1 shows that there was a fair and graded relationship between AR of E wave of mitral inflow and left ventricular DF grades (Spearman correlation coefficient $r_s = 0.67$, $P \leq 0.0001$).

Table 1: Initial echo cardiography data of study groups

	LV diastolic function, mean±SD		*P*
	DD	Normal DF	
LVEF	0.51±0.09	0.64±0.03	0.0001
Mean inflow of E wave	0.89±0.24	0.75±0.15	0.0001
Mean inflow of A wave	0.47±0.12	0.65±0.15	0.0001
E/A ratio	2.15±0.48	1.30±0.50	0.0001
Deceleration time	125.56±17.26	173.41±35.75	0.0001
Lateral E/é ratio	7.25±6.46	3.78±4.29	0.0001
Septal E/é ratio	9.10±7.89	4.33±5.08	0.0001
Mean E/é ratio	8.20±7.04	4.04±4.55	0.0001
AT	72.89±8.88	88.23±13.85	0.0001
AR	1364.38±277.31	859.12±275.95	0.0001
Left atrial volume index	45.24±10.58	26.18±8.90	0.0001

SD: Standard deviation, EF: Ejection fraction, AT: Acceleration time, DD: Diastolic dysfunction, LV: Left ventricular, AR: Acceleration rate, DF: Diastolic function

Table 2: Distribution of diastolic dysfunctions with normal ejection fraction according to age, gender, and body mass index groups (*n*=26)

	LVDD with normal EF, *n* (%)
Age group	53.3±13.8
18-44	5 (19.2)
45-64	17 (65.4)
65-more	4 (15.4)
Gender	
Male	11 (42.3)
Female	15 (57.7)
BMI group	28.3±3.3
Normal	4 (15.4)
Overweight	14 (53.9)
Obese	8 (30.7)

BMI: Body mass index, EF: Ejection fraction, DD: Diastolic dysfunction, LV: Left ventricular

Table 3: Distribution of diastolic dysfunctions with normal ejection fraction according to concomitant chronic diseases

	LVDD with normal EF, *n* (%)
HT	
Yes	19 (73.1)
No	7 (26.9)
DM	
Yes	7 (26.9)
No	19 (73.1)
CAD	
Yes	9 (34.6)
No	17 (65.4)

EF: Ejection fraction, DD: Diastolic dysfunction, LV: Left ventricular, CAD: Coronary artery disease, DM: Diabetes mellitus, HT: Hypertension

Based on logistic regression analysis, the ($P \leq 0.0001$) which indicates that AR of E wave could predict DD. ROC curve analysis is represented in Figure 2, it showed the AR of E wave

of mitral inflow area under curve about 0.91% and $P = 0.0001$. From ROC study, AR equal to 1126 as a cut off value would give a sensitivity of 91% and 84% specificity [Table 7].

Discussion

Chronic diseases

This study showed a significant relationship between DD with the chronic diseases understudy (hypertension, DM, CAD). We compared our results with Soldatos *et al*. in their case–control study of 55 individuals with type 2 DM (T2DM) and found that; DD is present in a significant proportion of the population with T2DM.[13] Similarly, Patil *et al*.'s study in 2013, found 54.3% of subjects from the case group had DD and 11 (11%) in the control group had DD ($P < 0.001$).[14]

Poulsen *et al*.'s findings support that moderate or severe LV DD and LA dilation in the early phase of T2DM are closely associated with intrinsic LV dysfunction. However, such LV DD and LA dilation are not closely related to vascular disease with arterial stiffening and abnormal ventriculoatrial coupling.[15] Another study revealed a high burden of DD in a cohort of type 2 DM population.[14] Long-standing hypertension serves as a stimulus for the development of left ventricular DD.[16] Abnormal diastolic filling of the left ventricle (LV), as evaluated by transthoracic echocardiography, is associated with a worse prognosis. DD is the first cardiac function to be impaired in ischemic heart disease.[17] It is possible that the pathophysiological process of subclinical atherosclerosis, usually not sufficient to reduce

Table 4: Acceleration time and acceleration rate according to age, gender, and chronic diseases

Variables	LVDF, mean±SD			
	AT		AR	
	Normal DF	DD	Normal DF	DD
Age group				
18-44	90.5±13.3	71.6±13.2	843.2±237.4	1340.6±92.9
45-64	86.6±13.7	74.2±9.4	849.3±276.6	1380.8±388.8
65-more	71.8±12.6	65.3±7.1	1214.0±567.3	1396.5±148.5
P	0.0001	0.0001	0.0001	0.0001
Gender				
Male	88.6±15.4	72.7±7.9	832.7±241.2	1419.4±220.0
Female	88.0±12.9	72.1±11.7	875.1±295.2	1343.3±378.6
P	0.282	0.210	0.0001	0.0001
HT				
Yes	79.3±19.4	71.1±8.0	1043.8±407.3	1449.1±195.9
No	90.2+11.5	75.9+14.4	818.3+219.8	1175.7+492.4
P	0.0002	0.001	0.0001	0.0001
DM				
Yes	73.2±14.2	74.3±4.2	1089.0±489.5	1318.9±181.7
No	89.8+12.9	71.6+11.5	835.2+234.2	1396.3+357.4
P	0.00001	0.059	0.0001	0.00001
CAD				
Yes	82.6±20.7	74.7±7.3	1016.3±547.4	1363.7±146.8
No	88.5+13.4	71.1+11.3	850.7+255.0	1381.7+383.5
P	0.0012	0.009	0.00001	0.018

DM: Diabetes mellitus, CAD: Coronary artery disease, HT: Hypertension, DD: Diastolic dysfunction, LV: Left ventricular, AR: Acceleration rate, AT: Acceleration time, DF: Diastolic function, SD: Standard deviation

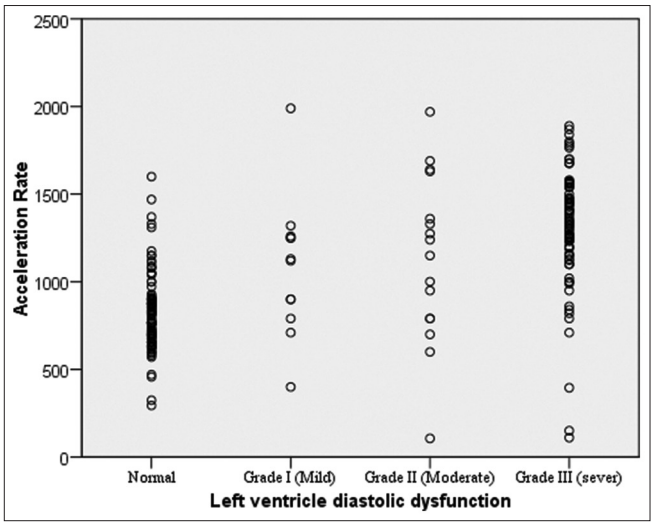

Figure 1: Acceleration rate of E wave of mitral inflow and left ventricular diastolic function grades. r: Correlation coefficient

Table 5: Distribution of left ventricle diastolic function according to concomitant chronic diseases

	LVDF (normal EF)				*P*
	Normal DF (*n*=138), *n* (%)	Indeterminate (*n*=23), *n* (%)	DD (*n*=26), *n* (%)	Total (*n*=187), *n* (%)	
HT					
Yes	25 (18.1)	12 (52.2)	19 (73.1)	56 (29.9)	0.0001
No	113 (81.9)	11 (47.8)	7 (26.9)	131 (70.1)	
DM					
Yes	13 (9.4)	12 (52.2)	7 (26.9)	32 (17.1)	0.0001
No	125 (90.6)	11 (47.8)	19 (73.1)	155 (82.9)	
CAD					
Yes	7 (5.1)	3 (13.0)	9 (34.6)	19 (10.2)	0.0001
No	131 (94.9)	20 (87.0)	17 (65.4)	168 (89.8)	

DM: Diabetes mellitus, CAD: Coronary artery disease, HT: Hypertension, DD: Diastolic dysfunction, LV: Left ventricular, DF: Diastolic function, EF: Ejection fraction

Table 6: Distribution of patients with normal ejection fraction according left ventricle echo parameters of diastolic function

Echo data	LVDF (normal EF), mean±SD				*P*
	Normal DF (*n*=138)	Indeterminate (*n*=23)	DD (*n*=26)	Total (*n*=187)	
Mean inflow of E wave	0.745±152	0.755±0.25	0.993±0.23	0.781±0.198	0.0001
Mean inflow of A wave	0.65±0.15	0.84±0.22	0.53±0.16	0.65±0.18	0.0001
E/A ratio	1.3±0.50	0.95±0.36	1.93±0.34	1.34±0.54	0.0001
Deceleration time	173±36	148±52	132±16	165±39	0.0001
Lateral E/é ratio	3.78±4.29	7.36±4.51	14.82±6.78	8.65±5.19	0.001
Septal E/é ratio	4.33±5.08	8.86±6.05	15.94±8.41	9.71±6.51	0.001
Mean E/é ratio	4.04±4.55	8.11±4.84	15.38±7.42	9.17±5.60	0.001
AT	88±14	70±15	72±10	84±15	0.0001
AR	859±276	1080±393	1375±318	958±349	0.0001

SD: Standard deviation, DD: Diastolic dysfunction, LV: Left ventricular, DF: Diastolic function, AR: Acceleration rate, AT: Acceleration time, EF: Ejection fraction

Table 7: Cut off value of acceleration rate of E for specificity and sensitivity to detect moderate or severe diastolic dysfunction

AR	LVDF		Predictive value
	No DD	Moderate or severe DD	
<1126	121	6	NPV=95%
≥1126	17	63	PPV=79%
	Specificity=88%	Sensitivity=91%	

NPV: Negative predictive value., PPV: Positive predictive value, DD: Diastolic dysfunction, LV: Left ventricular, DF: Diastolic function, AR: Acceleration rate

systolic function, is able to alter the DD of the left ventricle. CAD is not independently associated with measures of DD on echocardiography among patients without prior CAD or LV dysfunction.[17]

Acceleration time and rate

A central parameter for the diagnosis of DD that is recommended by the European Society of Cardiology is the E/e' ratio, which requires tissue Doppler and mitral pulse wave Doppler measurements.[18] An E/e' ratio >14 is considered abnormal in humans.[12]

In the current study, when we examine the relationship of AT and AR with the VDF, there was a significant association between the presence of DD and these parameters. For that AT and AR can be considered useful parameters for expecting a DD in examined patients. We found in our study that AR had a good correlation with DD; the sensitivity rate was 87% in detecting DD in this study. Sattarzadeh *et al*. in their novel study in 2016 reported that by simple measurement of AR of E of mitral valve they might be able to identify patients with elevated LVDP and DD. This application could be clinically important and valuable because it might explain patients' symptoms in some conditions.[11] In our study, we found that the E/e ratio increased when there was a DD, so it can be utilized as a tool to assess and evaluate VDD. According to Schnellea, the E/e ratio is one of the parameters that is most widely used to assess DD in humans and has also been used in many murine studies.[19]

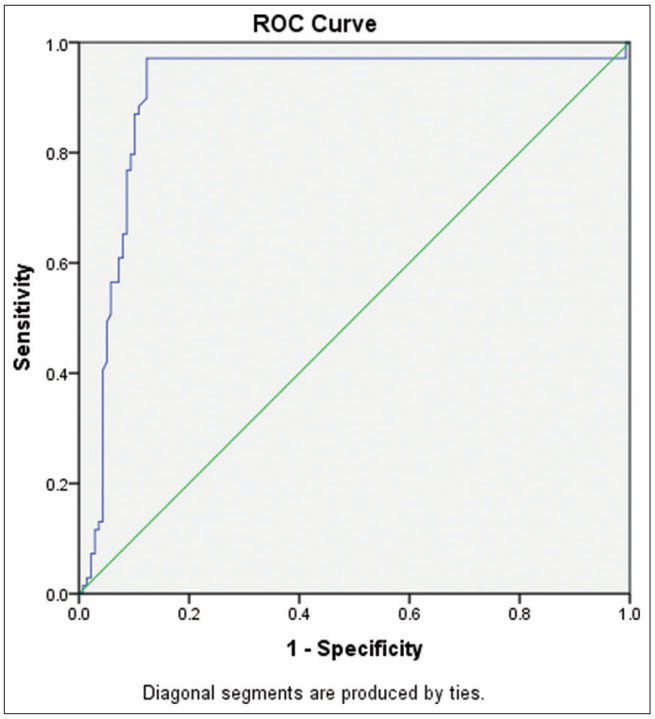

Figure 2: Receiver operating characteristics curve by using acceleration rate of E wave of mitral inflow to detect diastolic dysfunction. ROC: Receiver operating characteristic curve

Diastolic dysfunction

In our study, we found that 26 patients out of 187 patients with normal EF had DD in addition to 23 (12.3%) indeterminate. This is supported by Redfield *et al*.'s study in 2003, who stated that although the prevalence of systolic dysfunction increased with increasing severity of DD, most participants with DD had a normal EF. Indeed, moderate or severe isolated DD was as common as systolic dysfunction.[7]

The relationship between LV end-diastolic pressure and LA_S appears stronger in patients with depressed EF than in those with normal EF.[14] Furthermore, it is possible to use LA_S along

with LA pressure or its Doppler echocardiographic surrogate E/e' to calculate LA chamber stiffness.[20]

In patients with borderline increased E/e' (>8 and <14), the entire echocardiographic picture should be assessed, including LA size, and mitral filling pattern. This information is particularly helpful in establishing the diagnosis in patients with the clinical picture of heart failure when the LVEF is preserved. It provides prognostic information and can help guide therapy in patients with heart failure regardless of the EF.[21]

Conclusion and Recommendation

DD was reported in patients with normal EF. AT and rate were significantly correlated with DD in the normal EF group. Further research works are recommended to establish the prediction power of the AT and rate in expectation of DD. A population-based survey is needed to find our local cutoff values for different parameters used in classification.

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Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Fischer M, Baessler A, Hense HW, Hengstenberg C, Muscholl M, Holmer S, *et al.* Prevalence of left ventricular diastolic dysfunction in the community. Results from a Doppler echocardiographic-based survey of a population sample. Eur Heart J 2003;24:320-8.
2. Bell DS. Diabetic cardiomyopathy. Diabetes Care 2003;26:2949-51.
3. Poirier P, Garneau C, Bogaty P, Nadeau A, Marois L, Brochu C, *et al.* Impact of left ventricular diastolic dysfunction on maximal treadmill performance in normotensive subjects with well-controlled type 2 diabetes mellitus. Am J Cardiol 2000;85:473-7.
4. Lin G, Oh JK. Echocardiographic assessment of diastolic function and diagnosis of diastolic heart failure. In: Smiseth OA, Tendera M, editors. Diastolic Heart Failure. Ch. 10. London: Springer; 2008. p. 149-62.
5. Grant AD, Negishi K, Negishi T, Collier P, Kapadia SR, Thomas JD, *et al.* Grading diastolic function by echocardiography: Hemodynamic validation of existing guidelines. Cardiovasc Ultrasound 2015;13:28.
6. Tabata T, Thomas JD, Klein AL. Pulmonary venous flow by Doppler echocardiography: Revisited 12 years later. J Am Coll Cardiol 2003;41:1243-50.
7. Redfield MM, Jacobsen SJ, Burnett JC Jr., Mahoney DW, Bailey KR, Rodeheffer RJ. Burden of systolic and diastolic ventricular dysfunction in the community: Appreciating the scope of the heart failure epidemic. JAMA 2003;289:194-202.
8. Schirmer H, Lunde P, Rasmussen K. Mitral flow derived Doppler indices of left ventricular diastolic function in a general population; The Tromso study. Eur Heart J 2000;21:1376-86.
9. Caballero L, Kou S, Dulgheru R, Gonjilashvili N, Athanassopoulos GD, Barone D, *et al.* Echocardiographic reference ranges for normal cardiac Doppler data: Results from the NORRE study. Eur Heart J Cardiovasc Imaging 2015;16:1031-41.
10. Lang RM, Badano LP, Mor-Avi V, Afilalo J, Armstrong A, Ernande L, *et al.* Recommendations for cardiac chamber quantification by echocardiography in adults: An update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. J Am Soc Echocardiogr 2015;28:1-39.e14.
11. Sattarzadeh R, Tavoosi A, Jabbari M, Parsa AF, Geraiely B, Saadat M, *et al.* Erratum to: 'Acceleration rate of mitral inflow E wave: A novel transmitral Doppler index for assessing diastolic function'. Cardiovasc Ultrasound 2016;14:26.
12. Nagueh SF, Smiseth OA, Appleton CP, Byrd BF 3rd, Dokainish H, Edvardsen T, *et al.* Recommendations for the evaluation of left ventricular diastolic function by echocardiography: An update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. J Am Soc Echocardiogr 2016;29:277-314.
13. Soldatos G, Jandeleit-Dahm K, Thomson H, Formosa M, D'orsa K, Calkin AC, *et al.* Large artery biomechanics and diastolic dysfunctionin patients with Type 2 diabetes. Diabet Med 2011;28:54-60.
14. Patil VC, Patil HV, Shah KB, Vasani JD, Shetty P. Diastolic dysfunction in asymptomatic type 2 diabetes mellitus with normal systolic function. J Cardiovasc Dis Res 2011;2:213-22.
15. Poulsen MK, Henriksen JE, Dahl J, Johansen A, Gerke O, Vach W, *et al.* Left ventricular diastolic function in type 2 diabetes mellitus: Prevalence and association with myocardial and vascular disease. Circ Cardiovasc Imaging 2010;3:24-31.
16. Nakanishi K, Jin Z, Homma S, Elkind MS, Rundek T, Tugcu A, *et al.* Association of blood pressure control level with left ventricular morphology and function and with subclinical cerebrovascular disease. J Am Heart Assoc 2017;6:e006246.
17. Jamiel A, Ahmed AM, Farah I, Al-Mallah MH. Correlation between diastolic dysfunction and coronary artery disease on coronary computed tomography angiography. Heart Views 2016;17:13-8.
18. Paulus WJ, Tschöpe C, Sanderson JE, Rusconi C, Flachskampf FA, Rademakers FE, *et al.* How to diagnose diastolic heart failure: A consensus statement on the diagnosis of heart failure with normal left ventricular ejection fraction by the Heart Failure and Echocardiography Associations of the European Society of Cardiology. Eur Heart J 2007;28:2539-50.
19. Schnelle M, Catibog N, Zhang M, Nabeebaccus AA, Anderson G, Richards DA, *et al.* Echocardiographic evaluation of diastolic function in mouse models of heart disease. J Mol Cell Cardiol 2018;114:20-8.
20. Oh JK, Park SJ, Nagueh SF. Established and novel clinical applications of diastolic function assessment by echocardiography. Circ Cardiovasc Imaging 2011;4:444-55.
21. Little WC, Oh JK. Echocardiographic evaluation of diastolic function can be used to guide clinical care. Circulation 2009;120:802-9.