The evolution of diastolic dysfunction in the hypertensive disease

Harry Pavlopoulos*, Julia Grapsa, Ellie Stefanadi, Vasileios Kamperidis, Elena Philippou, David Dawson, and Petros Nihoyannopoulos

Cardiology Department, National Heart and Lung Institute (NHLI), Imperial College of Medicine and Technology, Hammersmith Hospital, Du Cane Rd, W12 OHS London, UK

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Aims To investigate the effects of cardiac remodelling on left ventricular (LV) diastolic function, as evaluated by tissue Doppler and blood-pool indices, with respect to loading as expressed by wall stress. Cardiac remodelling is the major pathophysiological result of increased blood pressure and manifests as changes in the size, shape, and function of the heart.

Methods and Results We evaluated 90 hypertensive patients and 30 healthy volunteers. The hypertensive patients were divided into three groups: (i) HTN-N: normal remodelling (n = 30), (ii) HTN-CR: concentric remodelling (n = 30), and (iii) HTN-CH: concentric hypertrophy (n = 30). Mitral annular early diastolic (Ea) velocities were recorded. Filling pressures (E/Ea), relative wall thickness, LV mass index, DT, isovolumic relaxation time (IVRT), E/A ratio, and longitudinal wall stress (LWS) were also measured. Diastolic dysfunction (DD) was diagnosed based on published criteria. Progressive and increased incidence of DD with advancement of LV remodelling and an increase in LV mass was noted. Wall stress-loading was higher in the HTN-N group and lower in the HTN-CR and HTN-CH groups, despite the more deteriorated diastolic function in the latter groups. DD appeared early, even in the HTN-N group, which had a 36.6% incidence of DD compared to a 13% age-related incidence in the control group (P < 0.05). When the control group was used to define the reference values for septal Ea with the cut-off set as 2SD below the mean, the HTN-N, HTN-CR, and HTN-CH groups had abnormal diastolic function at 16.6, 26.6, and 56.6% incidence rates, respectively. Septal (Ea) was correlated with LVMI (r = −0.55), RWT (r = −0.56), Age (r = −0.52), BMI (r = −0.31), SBP (r = −0.54), PP (r = −0.55), and MAP (r = −0.39), all at P < 0.05. The correlations of blood-pool indices (DT, IVRT, and E/A) with the above parameters were less than that of tissue Doppler imaging (Septal and mean Ea). In a multivariate model, LVMI (β = −0.25), SBP (β = −0.26), and age (β = −0.24) R² = 0.49 were found to be independent predictors of DD.

Conclusions DD appears early in hypertensive disease, before the onset of abnormal remodelling or LV hypertrophy. With progression of the remodelling process and the advance of LVH, diastolic function progressively deteriorates. Tissue Doppler indices are better correlated with clinical and echocardiographic parameters of LV remodelling compared to blood-pool indices.

Introduction

Hypertension constitutes one of the most common causes of diastolic dysfunction (DD) and is a major contributor to the pathogenesis of a large proportion of heart failure cases in a population-based sample.1 Impaired diastolic function identifies hypertensive patients at increased cardiovascular risk, independently of left ventricular (LV) mass and ambulatory BP.2 It is also well known that DD is usually associated with left ventricular hypertrophy (LVH), which is characterized by a disproportionate involvement of non-myocyte elements.3 Previous studies have shown that DD may precede the development of LVH in hypertensive disease,4 with interstitial myocardial fibrosis5-7 and loading8 being among the most commonly accepted causes.

Cardiac remodelling, the major pathophysiological result of increased blood pressure, clinically manifests as changes in the size, shape, and function of the heart,9 and has been described as normal, concentric remodelling, or concentric hypertrophy.

* Corresponding author. Tel: +44 208 743 0121; fax: +44 208 3834392. E-mail address: drpavlo@yahoo.com
In the LIFE study, isovolumic relaxation time (IVRT), an indicator of DD, was prolonged in all the geometric patterns of cardiac remodelling and was independently correlated with LVM. However, tissue Doppler indices have a linear relation with the progression of diastolic abnormalities, and are more robust parameters for the detection of DD. Furthermore, the role of longitudinal wall stress (LWS) and loading/LWS using tissue Doppler (Septal and mean Ea) in addition to the blood-pool indices DT, IVRT, and E/A.

### Methods

#### Study subjects

The study population consisted of 90 patients with essential hypertension. Participants were recruited from the hypertension outpatient clinic as well as the echocardiography department. Thirty healthy volunteers were also recruited as a control group. The hypertensive patients were divided into three groups: (i) HTN-N: normal remodelling (n = 30), (ii) HTN-CR: concentric remodelling (n = 30), and (iii) concentric hypertrophy (n = 30).

All patients originally had ≥ Grade 1 essential hypertension (systolic >140 mmHg and/or diastolic >90 mmHg), with a history of hypertension for more than 1 year. All were receiving medical treatment. Patients were excluded if they were not in sinus rhythm, or if they had a history of coronary artery disease (CAD), regional wall motion abnormalities, mitral or aortic stenosis, congenital disease, cardiomyopathy, mitral or aortic regurgitation, pericardial disease, or cor pulmonale. The control group consisted of normotensive volunteers, as determined by their BP measurements and disease, or cor pulmonale. The control group consisted of normoten-sion. Participants were recruited from the hypertension outpatient clinic as well as the echocardiography department. Thirty healthy volunteers were also recruited as a control group. The hypertensive patients were divided into three groups: (i) HTN-N: normal remodelling (n = 30), (ii) HTN-CR: concentric remodelling (n = 30), and (iii) concentric hypertrophy (n = 30).

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All subjects were evaluated for global DD; evaluations were based on known conventional echocardiographic criteria and newer tissue Doppler parameters. The diagnosis of DD was initially based on E/A < 1.0 and DT > 220 ms, E/A < 0.5, and DT > 280 ms, followed by IVRT > 92 ms, IVRT > 100 ms, IVRT > 105 ms, and pulmonary S/D > 1.5 or S/D > 2.5, respectively, and supplemented by septal Ea < 9 cm/s, septal Ea < 7 cm/s, septal Ea < 6 cm/s, and E/Ea mean > 15. The Valsalva manoeuvre, pulmonic venous' recordings, and annular tissue Doppler tracings were also used for diagnosis of pseudo normal type of DD.

As single blood-pool echo-Doppler indices correlate poorly with the pressure-derived indices of LV diastolic function, a combination of indices (≥2) was taken into account for the final diagnosis. The study was approved by the Local Research Ethics Committee.

#### Echocardiography

Standard two-dimensional and Doppler echocardiography was used to study all subjects. We used a Toshiba Apico model SSA-770A, with a phased array transducer (2.8-4.5 MHz). Parasternal and apical projections were obtained according to the recommendations of the American Society of Echocardiography (ASE). The LV ejection fraction was measured using the Simpson’s modified biplane method. LV mass was estimated using the area-length formula described in the ASE document on LV quantification. The formula LVMass/BSA, where BSA (body surface area), was used to estimate LV mass index. Relative wall thickness (RWT) was estimated using the formula RWT = 2 × posterior wall thickness/LVEDD, where LVEDD is left ventricular end-diastolic diameter.

Remodelling patterns were defined as follows: normal: RWT ≤ 0.42 and LVM < 95 and LVM < 115; concentric remodelling: RWT > 0.42 and LVM < 95 and LVM < 115; concentric hypertrophy: RWT > 0.42 and LVM > 95 and LVM > 115.

Pulsed-wave Doppler of transmural LV inflow was performed in the apical four-chamber view, with the sample volume placed at the level of the mitral valve tips. Global LV diastolic function measurements, including peak velocities of E and A wave and their ratio E/A, deceleration time of E wave (DT), and IVRT were determined.

Pulsed wave tissue Doppler recordings from the septal and lateral sites were also recorded from the apical four-chamber view. A pulsed sample volume of 5 mm was placed over the mitral annulus and the average peak diastolic velocities (Ea) during early filling over three consecutive cardiac cycles were measured. Mean Ea were estimated by averaging the septal and lateral values. LV filling pressures were estimated by calculating the E/Ea mean ratio. Longitudinal (Meridional) end-systolic wall stress (LWS) was calculated according to the formula: LWS = BP × R/2WT(1 + WT/R), where R is the end-systolic radius, WT the wall thickness, and BP the systolic blood pressure.

The formula \( PP = SBP - DBP \) was used to estimate pulse pressure (PP). The formula \( MAP = DBP + 1/3( SBP - DBP ) \) was used to estimate mean arterial pressure (MAP).

#### Statistical analysis

Data were analysed using SPSS 12 software (SPSS, Chicago, IL, USA). Continuous variables, expressed as mean ± SD, were compared using Student’s t-test for normally distributed independent groups. When deviation from normality was detected through the Kolmogorov-Smirnov test, comparison between groups was performed using the Mann–Whitney U-test. Linear regression was used to investigate the relationship between two parametric variables. Pearson’s correlation was used to evaluate univariate linear relations. Differences between groups were also tested for significance using analysis of variance (ANOVA), and the Scheffe F-test was used to perform subgroup analysis. Multivariate models for independent predictors in a general linear model were used. Septal annular Ea was regarded as an index of DD and was entered in the statistical model as a dependent variable.

#### Results

#### Characteristics of the study population

The study groups’ general echocardiographic parameters and clinical details are summarized in Tables 1 and 2. Men slightly outnumbered women in the control group, but there were no significant gender differences among the hypertensive sub-groups. Systolic BP, MAP, and PP were also similar among the hypertensive sub-groups, but were higher compared to the control group. Participants in the hypertensive sub-groups also had higher BMI than those in the control group. Hypertensive patients with concentric hypertrophy or remodelling appeared to have hypertension for longer (HTN years) than patients with normal remodel-ling. Patients with concentric hypertrophy had been pre-scribed more ACE inhibitors, Ca-Blockers, and diuretics compared to all the other hypertensive sub-groups.

#### Incidence of diastolic dysfunction in the study groups

There was a 13% incidence of age-related DD (n = 4) among the control group, a 36.6% (n = 11) incidence among
hypertensive patients with normal remodelling, a 60% (n = 18) incidence among those with concentric remodelling, and a 90% (n = 27) incidence among those with concentric hypertrophy (Table 2).

**Annular diastolic velocities (Ea) by tissue Doppler**

Septal and mean annular diastolic velocities (Ea) progressively decreased from the control group through the HTN-N, HTN-CR, and HTN-CH groups (Table 3, Figure 1). When the control group was used to define the reference values for Septal Ea with the cut-off set as 2SD below the mean, the HTN-N, HTN-CR, and HTN-CH groups had abnormal diastolic function at 16.6, 26.6, and 56.6% incidence rates, respectively.

**Filling pressures (E/Ea)**

Filling pressures progressively increased from the control group through the HTN-N, HTN-CR, and HTN-CH groups, although medical treatment likely prevented filling pressures from reaching higher levels (Table 3).

### Table 1: Clinical details of the study groups

<table>
<thead>
<tr>
<th></th>
<th>Control (n = 30)</th>
<th>HTN-N (n = 30)</th>
<th>HTN-CR (n = 30)</th>
<th>HTN-CH (n = 30)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medication</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACE inhibitors (%)</td>
<td>–</td>
<td>67*</td>
<td>52**</td>
<td>84***</td>
</tr>
<tr>
<td>B-blockers (%)</td>
<td>–</td>
<td>33*</td>
<td>32*</td>
<td>32*</td>
</tr>
<tr>
<td>Ca-blockers (%)</td>
<td>–</td>
<td>33*</td>
<td>40**</td>
<td>52***</td>
</tr>
<tr>
<td>Diuretics (%)</td>
<td>–</td>
<td>16*</td>
<td>24**</td>
<td>44**</td>
</tr>
<tr>
<td>A-blockers (%)</td>
<td>–</td>
<td>17*</td>
<td>4**</td>
<td>17**</td>
</tr>
<tr>
<td>Risk factors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smoking (%)</td>
<td>8</td>
<td>4*</td>
<td>4*</td>
<td>12.5*</td>
</tr>
<tr>
<td>Diabetes (%)</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Hypercholesterolaemia (%)</td>
<td>20</td>
<td>46</td>
<td>50*</td>
<td>54**</td>
</tr>
<tr>
<td>Family history CAD (%)</td>
<td>12</td>
<td>15</td>
<td>14</td>
<td>13</td>
</tr>
</tbody>
</table>

*P < 0.05 compared to control.
**P < 0.05 compared to HTN-N.
***P < 0.05 compared to HTN-CR.

### Table 2: General and echocardiographic characteristics of the study groups

<table>
<thead>
<tr>
<th></th>
<th>Control (n = 30)</th>
<th>HTN-N (n = 30)</th>
<th>HTN-CR (n = 30)</th>
<th>HTN-CH (n = 30)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DD</td>
<td>13% (4)</td>
<td>36.6% (11)*</td>
<td>60% (18)**</td>
<td>90% (27)*****</td>
</tr>
<tr>
<td>AGE (years)</td>
<td>48.5 ± 8</td>
<td>48.3 ± 5.4</td>
<td>53.5 ± 7.8**</td>
<td>52.7 ± 8.9**</td>
</tr>
<tr>
<td>Male</td>
<td>61% (18)</td>
<td>50% (15)*</td>
<td>47% (14)*</td>
<td>55% (16)*</td>
</tr>
<tr>
<td>WT (mm)</td>
<td>8.7 ± 1.1</td>
<td>9.3 ± 0.9</td>
<td>10.5 ± 0.8**</td>
<td>12.7 ± 1.4**</td>
</tr>
<tr>
<td>RWT</td>
<td>0.36 ± 0.05</td>
<td>0.38 ± 0.03</td>
<td>0.47 ± 0.04**</td>
<td>0.56 ± 0.09**</td>
</tr>
<tr>
<td>LVMi (g/m²)</td>
<td>89.1 ± 17.4</td>
<td>95.1 ± 15.2</td>
<td>104.2 ± 10.4**</td>
<td>136.5 ± 15.6**</td>
</tr>
<tr>
<td>BSA (m²)</td>
<td>1.93 ± 0.13</td>
<td>1.92 ± 0.23</td>
<td>1.90 ± 0.24</td>
<td>1.92 ± 0.21</td>
</tr>
<tr>
<td>BMI</td>
<td>25.8 ± 3.4</td>
<td>28.7 ± 4.4*</td>
<td>30.0 ± 5.3*</td>
<td>27.9 ± 3.5*</td>
</tr>
<tr>
<td>HTN (years)</td>
<td>–</td>
<td>8.2 ± 7.1*</td>
<td>9.2 ± 7.6**</td>
<td>9.5 ± 7.4**</td>
</tr>
<tr>
<td>SBP (mmHg)</td>
<td>122.4 ± 7.7</td>
<td>143.8 ± 18.9*</td>
<td>144.4 ± 18.1*</td>
<td>146.0 ± 19.9*</td>
</tr>
<tr>
<td>DBP (mmHg)</td>
<td>79.2 ± 4.1</td>
<td>84.0 ± 4.1</td>
<td>83.8 ± 10.2</td>
<td>81.3 ± 9.6</td>
</tr>
<tr>
<td>MAP (mmHg)</td>
<td>93.3 ± 4.9</td>
<td>103.6 ± 10.0*</td>
<td>104.3 ± 12.2*</td>
<td>102.3 ± 12.1</td>
</tr>
<tr>
<td>PP (mmHg)</td>
<td>43.4 ± 7.3</td>
<td>59.6 ± 15.9*</td>
<td>60.0 ± 15.8*</td>
<td>64.0 ± 17.0*</td>
</tr>
<tr>
<td>LVEDD (mm)</td>
<td>47.7 ± 6.4</td>
<td>48.2 ± 4.1</td>
<td>44.6 ± 5.7</td>
<td>45.0 ± 4.3</td>
</tr>
<tr>
<td>LVESD (mm)</td>
<td>30.6 ± 3.9</td>
<td>29.5 ± 3.8</td>
<td>28.5 ± 4.1</td>
<td>27.9 ± 4.2</td>
</tr>
<tr>
<td>LVEDDI (mm/m²)</td>
<td>24.7 ± 2.7</td>
<td>25.1 ± 2.9</td>
<td>23.4 ± 2.4</td>
<td>23.6 ± 2.7</td>
</tr>
<tr>
<td>EF (%)</td>
<td>66.2 ± 5.1</td>
<td>65.4 ± 7.5</td>
<td>67.1 ± 8.3</td>
<td>68.9 ± 9.4</td>
</tr>
<tr>
<td>DT (ms)</td>
<td>191.8 ± 33.2</td>
<td>216.9 ± 31.2*</td>
<td>219.2 ± 38.9*</td>
<td>235.1 ± 43.2**</td>
</tr>
<tr>
<td>IVRT (ms)</td>
<td>82.5 ± 25.2</td>
<td>102.9 ± 23.5*</td>
<td>123.6 ± 24.3*</td>
<td>126.5 ± 26.6*</td>
</tr>
<tr>
<td>E (cm/s)</td>
<td>66.0 ± 11.0</td>
<td>70.8 ± 11.8</td>
<td>64.6 ± 11.8</td>
<td>62.1 ± 16.8</td>
</tr>
<tr>
<td>A (cm/s)</td>
<td>53.1 ± 14.8</td>
<td>62.1 ± 17.1*</td>
<td>69.2 ± 17.0**</td>
<td>70.0 ± 18.2**</td>
</tr>
<tr>
<td>E/A</td>
<td>1.31 ± 0.38</td>
<td>1.20 ± 0.36*</td>
<td>0.97 ± 0.29**</td>
<td>0.88 ± 0.30**</td>
</tr>
<tr>
<td>LA (mm)</td>
<td>36.6 ± 3.7</td>
<td>40.2 ± 6.0*</td>
<td>41.1 ± 4.8*</td>
<td>44.2 ± 4.7**</td>
</tr>
<tr>
<td>HR (bpm)</td>
<td>68.1 ± 9.1</td>
<td>65.9 ± 16.2</td>
<td>67.0 ± 14.5</td>
<td>69.1 ± 15.1</td>
</tr>
</tbody>
</table>

Diastolic dysfunction.
*P < 0.05 compared to control.
**P < 0.05 compared to HTN-N.
***P < 0.05 compared to HTN-CR.
Wall stress-loading

Wall stress was greater in the HTN-N group than in the other groups, and was progressively lower in the HTN-CR and HTN-CH groups below the control’s levels, (Table 3, Figure 2).

Correlations of diastolic dysfunction

Univariate correlations of septal Ea, mean Ea, filling pressures (E/Ea), DT, IVRT, and E/A with clinical and echocardiographic parameters are summarized in Table 4. Tissue Doppler indices of septal and mean Ea correlated better with clinical and echocardiographic parameters, than blood-pool indices of diastolic function (DT, IVRT, and E/A). LV remodelling based on RWT and LV mass index was highly correlated with tissue indices of DD. In Figure 2, the relation of LVMI with septal annular Ea is presented. Aging, systolic BP, and obesity also appeared to correlate with the presence of DD.

When significant univariate variables were analysed using a multivariate model, LVMI, Systolic BP, and age were found to be independent predictors of DD (septal Ea) (Table 4).

Discussion

The main finding of our study is that DD can be present early in the development of hypertensive disease, before any LV remodelling or significant changes in LV mass can be observed (HTN-N group). Loading (as measured by wall stress) is increased during these early stages, suggesting that it may be an important ‘co-parameter’ in the DD observed at this point. As LVH appears and increases, diastolic function progressively deteriorates, and at the same time wall stress decreases. Intrinsic structural abnormalities seem to be more significant than wall stress in these groups (HTN-CR and HTN-CH). Tissue Doppler indices (septal and mean Ea) correlate better with clinical and echocardiographic parameters than do blood-pool indices (DT, IVRT, and E/A).

Diastolic dysfunction and hypertrophy

Our findings agree with previous studies and show that DD may be evident before the presence of LVH in patients with systemic hypertension. However, wall stress-loading and tissue Doppler parameters were not taken into account in previous investigations. In another study, although early diastolic annular velocity (Ea) was lower in hypertensive patients without LVH, geometric patterns were not examined.

The HyperGEN study reported early abnormal LV relaxation in 18% of hypertensive subjects with normal LV geometry and in 31% of those who presented with concentric LV remodelling. In our study, the incidence of DD is higher among the hypertensive subgroups, but otherwise agrees with the findings of Zabalgoitia et al., who reported a high incidence of DD in hypertensive groups.

Our findings concerning the high incidence of DD in overt LVH confirm previous observations of the relation between impaired LV filling and increased LV mass. De Simone et al. found that LV mass that exceeds the compensatory needs for workload is associated with delayed LV relaxation independent of demographic, clinical, and haemodynamic confounders.
Exaggerated myocardial fibrosis, intrinsic myocyte impairment, microvascular ischaemia, and loading effects have been described as the principle causes of DD in systemic hypertension. Mechanical stress forces and humoral substances such as the components of the renin–angiotensin–aldosterone system, catecholamines, endothelin, nitric oxide, and growth factors have been implicated in mediating myocardial fibrosis. Furthermore, the role of myocardial fibrosis has also been documented by Brilla et al. who found that morphometrically determined interstitial and perivascular fibrosis, and not LVH, was responsible for abnormal myocardial diastolic stiffness in rats with genetic hypertension.

The effect of wall stress-loading on diastolic function

No index of relaxation can be considered as an index of ‘intrinsic’ relaxation unless loading conditions (and other modulators) are held constant or are at least specified. Whether DD is caused directly by raised blood pressure or by structural changes related to LVH remains controversial, because blood pressure and LV wall thickness both wield an independent influence on LV diastolic function. It has been shown that the normal ventricle easily compensates for moderate afterload elevations, while greater elevations induce DD even in normal hearts. In contrast, load-dependent DD occurs in severely diseased hearts even with normal haemodynamic parameters.

Although our observational study design did not specifically address the pathophysiological role of wall stress in DD, our findings show that wall stress-afterload was higher in the early stages of LV remodelling (HTN-N group) than in later stages, suggesting that loading may play an important role in inducing DD at that stage. Given the fact that systolic BP was similar among hypertensive subgroups, wall stress-loading appeared to be lower in the later stages (HTN-CR, HTN-CH), because of the presence of a hypertrophic state. This is in accordance with Laplace’s law, which states that an afterload-induced increase in systolic wall stress is offset by an increase in wall thickness. At the same time, though, DD was exaggerated in the later stages (HTN-CR, HTN-CH), possibly mirroring the important role of underground structural fibrotic lesions.

Correlations and independent predictors

Our study confirms the well-established independent correlations of DD with both aging and LVMI. Moreover, Systolic BP also appears to play a crucial and independent role in the presence of DD, as a recent study has also shown.

We further highlight the close relation between DD and LVMI, showing the progressive decrease of septal annular early diastolic velocity with the advance of LVH (Figure 2).

It has been suggested that tissue Doppler lengthening velocity measurements, because of the absence of pseudonormalization, are superior to blood flow Doppler measurements as indicators of diastolic LV function. Although deceleration time (DT) appears to be the first detectable marker of DD, poor concordance among blood pool indices and DD has been shown. Furthermore, it has been reported that early diastolic mitral annulus velocity measured by TDI provides prognostic information incremental to clinical data and standard echocardiographic variables for risk stratification of hypertensive patients under treatment.

The value of TDI is confirmed in our study, where measurement of septal or mean Ea correlated better with all the clinical and echocardiographic parameters than with the blood-pool indices DT, IVRT, or E/A (Table 4).

Clinical significance

It is widely accepted that in essential hypertension, increased cardiac mass carries a higher likelihood for
future cardiovascular events. However, LV mass represents a continuum from normal to hypertrophy; thus, choosing a cut-off value may be arbitrary. In fact, data from the Framingham Heart Study indicates that cardiovascular events start to increase in subjects with LV masses considered to be at the upper normal limits. 37 Furthermore, concentric remodelling with normal LV mass is found to be an independent predictor of increased cardiovascular risk in hypertensive patients. 38 Given also the fact that DD identifies hypertensive patients at increased cardiovascular risk, 2 early identification of such patients based on tissue Doppler parameters, which can be found even in the range of normal remodelling and normal LV mass, may help to identify risk, guide therapy, and prevent target organ damage. Moreover, normalization of wall stress at early stages, further reducing systolic blood pressure, may be beneficial in the treatment of left ventricular diastolic dysfunction.

Limitations
The coexistence of CAD was not excluded in all the hypertensive patients, as not all the subjects had performed tests for detection of ischaemia. However, there was no evidence of wall motion abnormalities, abnormal ECG findings, or chest pain on exertion among the participants. Moreover, the risk factors for CAD were relatively low in the study group, making the presence of CAD less likely.

Furthermore, microvascular and subendocardial ischaemia seem to be integral constituents in hypertensive disease, especially with LVH, and even with normal coronary arteries. 39–41 Several studies have used lateral 42 or septal 43 mitral annulus to record early diastolic velocities, some reporting better diagnostic utility for the latter. 44 However, septal Ea can be affected by any right ventricular pathology. In our study, right ventricular function and size, as estimated by visual estimation, were normal in all the participants.

Previous studies have shown the detrimental effects of obesity on LV diastolic function. 45 As BMI was higher in our hypertensive patients. 46 Given also the fact that DD identifies hypertensive patients at increased cardiovascular risk, early identification of such patients based on tissue Doppler parameters, which can be found even in the range of normal remodelling and normal LV mass, may help to identify risk, guide therapy, and prevent target organ damage. Moreover, normalization of wall stress at early stages, further reducing systolic blood pressure, may be beneficial in the treatment of left ventricular diastolic dysfunction.

Tissue Doppler indices are better correlated with clinical and echocardiographic parameters of LV remodelling compared to blood-pool indices.

Conflict of Interest: none declared.

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