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Original article

ARTERIAL HYPERTENSION: LEFT VENTRICULAR GEOMETRY AND DIASTOLIC DYSFUNCTION

Andrey Ivanov, Emil Manov, Stefan Naydenov, Nikolay Runev
Department of Internal Diseases "Prof. St. Kirkovich", Medical University of Sofia, Bulgaria.

ABSTRACT

Echocardiography is an established method for assessing left ventricular structure and function in patients with arterial hypertension (AH).

Purpose. The study aims to investigate left ventricular geometry and diastolic dysfunction in patients with arterial hypertension and to assess gender-related differences in the established data.

Material/methods. A total of 278 individuals were studied, including 30 healthy controls (16 women and 14 men) and 248 patients with arterial hypertension (139 women and 109 men). The echocardiographic examination included M-Mode and B-Mode echocardiography, pulsed-wave spectral Doppler, and pulsed-wave tissue Doppler imaging.

Results. Using the criteria of left ventricular mass index (LVMI) > 115 g/m^2 in men and LVMI > 95 g/m^2 in women for defining left ventricular hypertrophy (LVH), we found LVH in 147 of the hypertensive patients (59.27%). In our patients, LVH was more common in women. LVH was found in 97 women (69.78% of the women with AH) and 50 men (45.87% of the men with AH). One hundred and six (106) patients (42.74%) had no diastolic dysfunction. Grade 1 diastolic dysfunction was found in 95 patients (38.31%), grade 2 in 43 patients (17.34%), and grade 3 in 4 patients (1.61%).

Conclusion. In the studied patients with arterial hypertension, a number of echocardiographic indices were found which differed significantly from those in the individuals from the control group. Regular echocardiographic assessment is essential for guiding therapy and reducing the risk in these patients.

Keywords: left ventricular mass, left ventricular hypertrophy, diastolic dysfunction,

INTRODUCTION

Arterial hypertension (HTN) is associated with structural changes in the left ventricle with alterations in its geometry and the development of diastolic dysfunction [1,2]. Echocardiography is a well-established method for assessing these changes. However, literature reports on the prevalence of left ventricular hypertrophy (LVH), left ventricular geometry patterns, and diastolic dysfunction in patients with HTN vary widely. Some studies estimate the prevalence of LVH in HTN in the range of approximately 29% to 70%, and nearly 100% prevalence was reported in patients with severe hypertension or hypertension-related complications [3-11]. Similarly, estimates of diastolic dysfunction prevalence in hypertensive patients also show considerable variability [12].

This study aimed to evaluate left ventricular geometry and diastolic dysfunction in patients with HTN and to analyze gender-related differences in echocardiographic parameters.

MATERIALS AND METHODS

Our study included patients with HTN and preserved left ventricular ejection fraction, along with a control group of healthy individuals. The exclusion criteria were intraventricular block, atrioventricular block, atrial fibrillation, moderate or severe valvular regurgitation, valvular stenosis, reduced ejection fraction, and suboptimal echocardiographic image.

All participants were informed about the study, and written informed consent was obtained before inclusion. A total of 278 subjects were studied, including 30 healthy controls (16 women and 14 men, representing 53% and 47% of the control group, respectively) and 248 patients with HTN (139 women and 109 men, representing 56% and 44% of the hypertensive group, respectively). The mean age was 48.40 ± 13.51 years in the control group and 59.63 ± 13.29 years in the hypertensive group.

Echocardiographic examination

The echocardiographic examination included M-mode and B-mode echocardiography, pulsed-wave spectral Doppler, and pulsed-wave tissue Doppler imaging.

Assessment of left ventricular geometry

For the aims of the study, the thickness of the interventricular septum, the thickness of the posterior wall of the left ventricle, and the left ventricular end-diastolic dimension were measured. These parameters were obtained using M-mode echocardiography, with the scan line positioned based on the parasternal long-axis B-mode echocardiographic image. Measurements of the interventricular septum and posterior wall thickness were performed according to the American Society of Echocardiography's "leading edge to leading edge" method [13,14].

For left ventricular (LV) mass calculation, we used the Devereux formula, i.e., LV mass = 0.80 × {1.04 × [(IVSD + LVEDD + PWD)^3 – (LVEDD)^3]} + 0.6 g [15], where PWD is the posterior wall dimension, IVSD is the interventricular septum dimension, and LVEDD is the left ventricular end-diastolic dimension.

The left ventricular mass index (LVMI) was calculated using the formula "LVMI = LVM/BSA", where LVM is the left ventricular mass, and BSA is the body surface area.

For relative wall thickness (RWT) calculation, we used two formulas:

- **RWT1** = (PWD + IVSD) / LVEDD and
- **RWT2** = (2 × PWD) / LVEDD.

Classification criteria

- **Left ventricular hypertrophy:** It was defined according to the European Association of Cardiovascular Imaging (EACVI) and the American Society of Echocardiography (ASE) criteria [16,17]:
- **Men:** LVMI > 115 g/m²
- **Women:** LVMI > 95 g/m²

- **Relative wall thickness**

- Based on **RWT1**, an RWT value > 0.43 was used as the cut-off.
- Based on **RWT2**, an RWT value > 0.42 was used as the cut-off.

Based on the results obtained, patients were classified into four groups:

1. **Normal geometry (NG):** Normal LV mass index (LVMI) and relative wall thickness (RWT).
2. **Concentric remodeling (CR):** Normal LVMI, RWT above the normal limit.
3. **Eccentric hypertrophy (ECH):** LVMI above the normal limit, normal RWT.
4. **Concentric hypertrophy (CH):** LVMI and RWT above normal limits.

Pulsed-wave spectral Doppler

The pulsed-wave Doppler examination was performed by first registering mitral blood flow. The Doppler sample volume was positioned at the tip level of the mitral valve leaflets in the apical view to measure mitral blood flow velocity. The isovolumetric relaxation time was then measured from the end of the systolic aortic flow to the beginning of the diastolic mitral flow (after repositioning the sample volume in the left ventricular outflow tract between the mitral and aortic valves).

Pulsed-wave tissue Doppler imaging

The examination was performed at the lateral and medial mitral annulus. The mean values of the following parameters were calculated from these two zones:

- **Systolic velocity (S´)**
- **Early diastolic velocity (E´)**
- **Late diastolic velocity (A´)**

In the respective groups based on LV geometry, gender, and diastolic dysfunction, the indices **E´** and **E/E´** (representing left ventricular diastolic function) were assessed [18].

Diastolic dysfunction assessment

Diastolic dysfunction (DD) was evaluated based on the recommendations of the American Society of Echocardiography and the European Association of Cardiovascular Imaging [19].

Statistical analysis

Statistical analysis was performed using SPSS 21.0 for Windows. Data were presented as absolute values, relative frequencies (percentages), and mean values ± standard deviation (mean ± SD). The normality of distribution was assessed using the Kolmogorov-Smirnov and Shapiro-Wilk tests. Group comparisons were conducted using ANOVA (Analysis of Variance) to assess variation in studied parameters. If data followed a normal distribution, the independent samples T-test was used. For non-normally distributed data, the Mann-Whitney U test was applied. A critical significance level of $\alpha = 0.05$ was used, with the null hypothesis rejected for P-values < α.

RESULTS

Anthropometric data

Patients with HTN had significantly greater body mass and BMI (weight [kg] / height^2 [m^2]) compared with controls (P < 0.05 for both variables). The anthropometric characteristics of patients with HTN and controls are presented in Table 1:

- **Patients with HTN:**
- Body mass: 83.03 ± 15.02 kg
- Body mass index (BMI): 29.05 ± 4.41
- Body surface area (BSA): 1.93 ± 0.20 m²

- **Controls:**
- Body mass: 76.57 ± 12.29 kg
- BMI: 27.25 ± 3.41
- BSA: 1.86 ± 0.19 m²

Table 1. Basic characteristics.

Parameter	Control group n = 30	HTN patients			
		Total n = 248	Women n = 139	Men n = 109	P (M/W)*
Age (years)	48.40 ± 13.51	59.63 ± 13.29	60.44 ± 12.85	58.59 ± 13.81	NS
Weight (kg)	76.57 ± 12.29	83.03 ± 15.02	79.09 ± 14.54	88.05 ± 14.14	< 0.001

BMI	27.25 ± 3.41	29.05 ± 4.41	29.23 ± 4.88	28.82 ± 3.73	NS
BSA (m^2)	1.86 ± 0.19	1.93 ± 0.20	1.85 ± 0.18	2.03 ± 0.18	< 0.001
LV EDD (mm)	48.63 ± 3.54	50.57 ± 3.63	49.30 ± 3.30	52.18 ± 3.40	< 0.05
IVS (mm)	10.10 ± 0.53	11.52 ± 1.50	11.14 ± 1.44	12.03 ± 1.33	< 0.001
LVPW (mm)	9.58 ± 0.70	10.95 ± 1.31	10.62 ± 1.19	11.37 ± 1.34	< 0.001
LV mass (g)	171.10 ± 30.39	219.90 ± 50.96	201.35 ± 42.51	243.55 ± 51.20	< 0.001
LVMI (g/m^2)	91.70 ± 10.59	113.75 ± 22.88	108.79 ± 21.49	120.09 ± 23.13	< 0.001
RWT1	0.4061 ± 0.0283	0.4460 ± 0.0570	0.4429 ± 0.0563	0.4500 ± 0.0579	NS
RWT2	0.3951 ± 0.0284	0.4343 ± 0.0557	0.4321 ± 0.0540	0.4372 ± 0.0580	NS

Table legend: *BMI, body mass index; BSA, body surface area; LV EDD, left ventricular end-diastolic dimension; IVS, interventricular septum dimension; LVPW, left ventricular posterior wall dimension; LV mass, left ventricular mass; LMVI, left ventricular mass index; RWT1, relative wall thickness using the first formula; RWT2, relative wall thickness using the second formula*

** M/W – men vs. women.*

According to the body mass index, patients with arterial hypertension were classified as:

- Normal weight (BMI 18.5–24.9): N = 38 (15.32%)
- Overweight (BMI 25–29.9): N = 131 (52.82%)
- Obesity (BMI e” 30): N = 79 (31.85%)

Among the studied patients percentage distribution of cases with normal weight, overweight, and obesity by gender was as follows:

- Women:
• Normal weight: N = 24 (17.27%)
• Overweight: N = 67 (48.20%)
• Obesity: N = 48 (34.53%)
- Men:
• Normal weight: N = 14 (12.84%)
• Overweight: N = 64 (58.72%)
• Obesity: N = 31 (28.44%)

Compared to controls, BSA was slightly larger in hypertensive patients (controls – 1.86 ± 0.19 m^2, hypertensives – 1.93 ± 0.20 m^2), but the difference was not significant (P = NS).

Left ventricular parameters

Data about the left ventricular (LV) parameters, including LV end-diastolic dimension, interventricular septal thickness, posterior wall thickness, LV mass, and relative wall thickness (RWT), are presented in Table 1.

Compared to hypertensive patients, the control group exhibited significantly smaller LV EDD (P < 0.05), thinner interventricular septum (P < 0.001), thinner posterior wall (P < 0.001), smaller LV mass (P < 0.001), lower LV mass index (P < 0.001), lower RWT1 (P < 0.001), and lower RWT2 (P < 0.001).

Left ventricular geometry

Left ventricular hypertrophy (LVH)

Using the criteria of LVMI > 115 g/m^2 in men and LVMI > 95 g/m^2 in women, left ventricular hypertrophy (LVH) was detected in 147 patients with HTN (59.27%), while 101 patients (40.73%) showed no evidence of LVH. LVH was more prevalent in women, affecting 97 out of 139 women with hypertension (69.78%). When applying an alternative LVH criterion for women (LVMI > 104 g/m^2), the LVH prevalence decreased to 54.06%. Among men, using the LVMI > 115 g/m^2 criterion, LVH was identified in 50 out of 109 hypertensive men (45.87%).

Left ventricular geometry based on RWT1

The results for left ventricular geometry based on RWT1 are presented in Table 2.

- **Normal geometry and concentric remodeling (RWT1):** Significant differences were observed in age (P < 0.05), LV EDD (P < 0.05), interventricular septal thickness (P < 0.001), LV posterior wall thickness (P < 0.001), LV mass (P < 0.05), LVMI (P < 0.05), RWT1 (P < 0.001), and E' (P < 0.05). The E/E' ratio did not show a significant difference between these groups.

- **Normal geometry and eccentric hypertrophy (RWT1):** No significant difference was found in relative LV wall thickness (P = NS). In the remaining parameters in Table 2, the differences were statistically significant (P < 0.01).

- **Normal geometry and concentric hypertrophy (RWT1):** Significant differences were found in all parameters (P < 0.001), except for LV end-diastolic dimension (NG: 49.90 ± 3.01 mm vs. CH: 49.96 ± 3.38 mm, P = NS).

- **Concentric remodeling and eccentric hypertrophy (RWT1):** Between the CR and ECH groups, no significant difference was observed in interventricular septum thickness and LV posterior wall thickness. Significant differences were found for age (P < 0.05), LV EDD (P < 0.001), LV mass (P < 0.01), LVMI (P < 0.001), RWT1 (P < 0.001), E' (P < 0.01), and E/E' (P < 0.01).

- **Concentric remodeling and concentric hypertrophy (RWT1):** A comparison of the results between the CR and CH groups reveals a significant difference across all indices, with the least significant difference observed in LV EDD (P < 0.01). For all other indices, the difference is highly significant (P < 0.001).

- **Eccentric hypertrophy and concentric hypertrophy (RWT1):** The significance of the differences in indices between patients with ECH and CH is presented in Table 2.

Table 2. Left ventricular geometry in patients with HTN based on RWT1.

Parameter	Left ventricular geometry (RWT1)				
	Normal geometry (N = 64) 25.81%	Concentric remodeling (N = 37) 14.92%	Eccentric hypertrophy (N = 69) 27.82%	Concentric hypertrophy (N = 78) 31.45%	P (ECH vs. CH)
Age (years)	49.89 ± 12.45	55.51 ± 11.04	61.01 ± 11.59	68.33 ± 9.88	< 0.001
LV EDD	49.90 ± 3.01	48.34 ± 2.77	53.08 ± 3.54	49.96 ± 3.38	< 0.001
IVS	10.34 ± 0.78	11.50 ± 0.85	11.15 ± 1.00	12.85 ± 1.56	< 0.001
LVPW	9.87 ± 0.79	10.94 ± 0.72	10.68 ± 0.94	12.07 ± 1.30	< 0.001
LV mass	186.04 ± 33.02	202.47 ± 31.95	228.20 ± 47.79	248.60 ± 54.29	< 0.05
LVMI	94.25 ± 11.39	99.24 ± 10.76	119.02 ± 16.14	131.98 ± 22.17	< 0.001
RWT1	0.4059 ± 0.0209	0.4653 ± 0.0264	0.4117 ± 0.0272	0.5001 ± 0.0596	< 0.001
E´ (cm/s)	9.52 ± 1.95	8.98 ± 3.25	7.16 ± 2.53	5.85 ± 1.59	< 0.001
E/E´	7.78 ± 1.85	8.03 ± 1.79	9.64 ± 3.72	11.66 ± 4.59	< 0.01

Left ventricular geometry based on RWT2

When RWT was calculated using the formula RWT=(2×PWD)/LVEDD, four patients previously classified as having normal geometry were reclassified into the concentric remodeling group, while five patients from the second group were reassigned to the normal geometry category. Consequently, the number of individuals with normal geometry increased by one. Additionally, there was a change in the distribution of patients with eccentric and concentric hypertrophy, with the number of patients with concentric hypertrophy increased and those with eccentric hypertrophy decreased (Table 3).

Table 3. Left ventricular geometry in patients with HTN based on RWT2.

Parameter	Left ventricular geometry (RWT2)				
	Normal geometry (N = 65) 26.21%	Concentric remodeling (N = 36) 14.52%	Eccentric hypertrophy (N = 58) 23.39%	Concentric hypertrophy (N = 89) 35.89%	P (ECH vs. CH)
Age (years)	50.20 ± 12.43	55.11 ± 11.35	60.10 ± 11.22	68.02 ± 10.25	< 0.001
LV EDD	50.02 ± 2.92	48.09 ± 2.79	53.22 ± 3.70	50.25 ± 3.35	< 0.001
IVS	10.45 ± 0.86	11.34 ± 0.93	11.23 ± 1.33	12.59 ± 1.49	< 0.001
LVPW	9.87 ± 0.78	10.95 ± 0.72	10.56 ± 0.95	11.98 ± 1.25	< 0.001
LV mass	188.05 ± 32.98	199.30 ± 33.48	229.16 ± 53.42	245.45 ± 50.63	NS (0.064)
LVMI	94.62 ± 11.26	98.71 ± 11.24	118.81 ± 19.74	130.52 ± 20.26	0.001
RWT2	0.3950 ± 0.0244	0.4558 ± .0246	0.3973 ± 0.0271	0.4784 ± 0.0580	< 0.001
E´ (cm/s)	9.34 ± 2.09	9.30 ± 3.15	7.31 ± 2.69	5.92 ± 1.55	0.001
E/E´	7.79 ± 1.83	8.01 ± 1.82	9.72 ± 4.05	11.36 ± 4.38	< 0.01

Statistical analysis of left ventricular geometry using RWT2 is shown below.

- **Normal geometry and concentric remodeling (RWT2):** Using this formula, we observed a significant difference between patients with normal geometry and those with concentric remodeling in terms of age ($P < 0.05$), LV EDD ($P < 0.01$), IVSD ($P < 0.001$), PWD ($P < 0.001$), and RWT2 ($P < 0.001$). There was no significant difference in LVM, LVMI, E´, and E/E´ (P = NS).
- **Normal geometry and eccentric hypertrophy (RWT2):** The only parameter that did not show a significant difference between these two groups was RWT2 (P = NS). However, all other parameters, i.e., age ($P < 0.001$), LV EDD ($P < 0.001$), IVSD ($P < 0.001$), PWD ($P < 0.001$),

LVM ($P < 0.001$), LVMI ($P < 0.001$), E¹ ($P < 0.001$), and E/E¹ ($P < 0.01$), showed statistically significant differences.

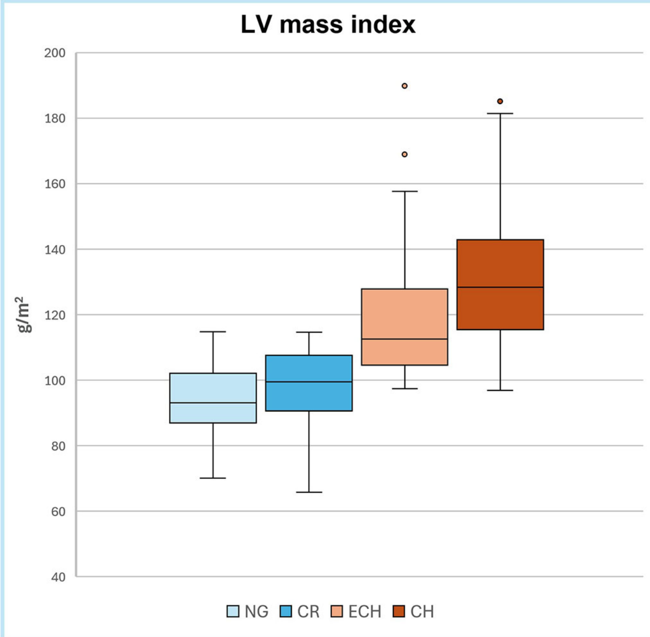
• **Normal geometry and concentric hypertrophy (RWT2):** In our patients with these two types of left ventricular geometry, there was no significant difference in end-diastolic left ventricular diameter (P = NS). However, all other parameters showed highly significant differences ($P < 0.001$).

• **Concentric remodeling and eccentric hypertrophy (RWT2):** Using this formula, we found no significant difference in IVS thickness between these two groups (P = NS). However, significant differences were observed in age ($P < 0.05$), LV EDD ($P < 0.001$), PWD ($P < 0.05$), LVM ($P < 0.01$), LVMI ($P < 0.001$), RWT2 ($P < 0.001$), E' ($P < 0.01$), and E/E' ($P < 0.05$).

• **Concentric remodeling and concentric hypertrophy (RWT2):** All parameters presented in Table 3 showed significant differences between the two groups: age ($P < 0.001$), LV EDD ($P = 0.001$), IVSD ($P < 0.001$), PWD ($P < 0.001$), LVM ($P < 0.001$), LVMI ($P < 0.001$), RWT2 ($P < 0.05$), E¹ ($P < 0.001$), and E/E¹ ($P < 0.001$).

• **Eccentric vs. concentric hypertrophy (RWT2):** When comparing groups with eccentric and concentric left ventricular (LV) hypertrophy using this formula, significant differences are observed in almost all parameters, except for left ventricular mass. While the left ventricular mass was higher in patients with concentric hypertrophy, the difference did not reach statistical significance ($P = 0.064$) (Table 3). Figure 1 illustrates the left ventricular mass index in patients with HTN.

Fig. 1. Left ventricular mass index in patients with HTN (classification using RWT2). **NG**, normal LV geometry; **CR**, concentric remodeling; **ECH**, eccentric hypertrophy; **CH**, concentric hypertrophy.



Left ventricular geometry in patients with HTN by gender

Analysis of LV geometry in both sexes indicates a higher prevalence of LV hypertrophy in women. The prevalence of both types of LVH (eccentric and concentric) is higher in women when assessed using both methods of RWT calculation (Table 4).

Table 4. Left ventricular geometry in patients with HTN by gender (using both RWT calculation methods).

LV geometry	Women (N = 139)		Men (N = 109)	
	RWT1	RWT2	RWT1	RWT2
NG	N = 27 (19.42 %)	N = 27 (19.42 %)	N = 37 (33.94 %)	N = 38 (34.86 %)
CR	N = 15 (10.79 %)	N = 15 (10.79 %)	N = 22 (20.18 %)	N = 21 (19.27 %)
ECH	N = 46 (33.09 %)	N = 39 (28.06 %)	N = 23 (21.10 %)	N = 19 (17.43 %)
CH	N = 51 (36.69 %)	N = 58 (41.73 %)	N = 27 (24.77 %)	N = 31 (28.44 %)

Diastolic dysfunction

Among hypertensive patients, 106 (42.74%) had no diastolic dysfunction (DD). In the remaining patients, the distribution by DD severity was as follows:

- **Grade 1 DD:** 95 patients (38.31%)
- **Grade 2 DD:** 43 patients (17.34%)
- **Grade 3 DD:** 4 patients (1.61%)

Table 5 represents data concerning age, LV morphological parameters, E´ velocity, and E/E´ ratio across different degrees of DD. Patients with more severe DD are older and have greater LV wall thickness, greater LV mass, and larger relative LV wall thickness, along with poorer LV functional parameters.

Table 5. Age, morphological, and functional LV parameters across groups by diastolic dysfunction severity.

Parameter	Control group (N = 30)	Diastolic dysfunction (HTN patients)				P (Gr. 1 vs. 2)
		No DD (N = 106) 42.74%	Grade 1 (N = 95) 38.31%	Grade 2 (N = 43) 17.34%	Grade 3 (N = 4) 1.61%	
Age (years)	48.40 ± 13.51	52.08 ± 12.74	63.40 ± 10.14	68.60 ± 11.05	73.25 ± 7.18	< 0.01
LV EDD	48.63 ± 3.54	49.56 ± 2.97	51.12 ± 3.49	51.83 ± 4.69	50.75 ± 4.34	NS
IVS	10.10 ± 0.53	10.74 ± 0.98	11.78 ± 1.15	12.70 ± 1.95	13.87 ± 2.32	< 0.05
LVPW	9.58 ± 0.70	10.21 ± 0.88	11.17 ± 0.85	12.10 ± 1.78	12.68 ± 1.81	< 0.01
LV mass	171.10 ± 30.39	192.47 ± 33.61	228.98 ± 42.04	262.36 ± 64.82	274.43 ± 32.78	< 0.01
LVMI	91.70 ± 10.59	99.35 ± 14.41	121.13 ± 19.63	130.87 ± 26.17	136.14 ± 15.94	< 0.05
RWT1	0.4061 ± 0.0283	0.4240 ± 0.0361	0.4504 ± 0.0409	0.4827 ± 0.0875	0.5309 ± 0.1259	< 0.05
RWT2	0.3951 ± 0.0284	0.4128 ± 0.0360	0.4387 ± 0.0402	0.4710 ± 0.0855	0.5070 ± 0.1187	< 0.05
E´ (cm/s)	11.42 ± 2.05	10.14 ± 2.04	5.97 ± 1.17	5.44 ± 1.06	3.80 ± 0.18	< 0.05
E/E´	6.63 ± 1.27	7.50 ± 1.34	8.91 ± 1.83	14.74 ± 3.74	23.43 ± 2.92	< 0.001

Diastolic dysfunction in patients with HTN by gender

The prevalence of diastolic dysfunction among men and women is detailed in Table 6 and illustrated in Figure 2.

Women:

• **No DD:** 56 patients (40.29%)

• **Grade 1 DD:** 57 patients (41.01% of all women; 68.67% of women with DD)

• **Grade 2 DD:** 23 patients (16.55% of all women; 27.71% of women with DD)

• **Grade 3 DD:** 3 patients (2.16% of all women; 3.61% of women with DD)

Men:

• **No DD:** 50 (45.87%)

• **Grade 1 DD:** 38 patients (34.86% of all men; 64.41% of men with DD)

• **Grade 2 DD:** 20 patients (18.35% of all men; 33.90% of men with DD)

• **Grade 3 DD:** 1 patient (0.92% of all men; 1.69% of men with DD)

Table 6. Diastolic dysfunction in patients with HTN by gender.

Diastolic dysfunction	Women (N = 139)		Men (N = 109)	
	% of all women	% of women with DD	% of all men	% of men with DD
No DD	40.29%	-	45.87%	-
Grade 1	41.01%	68.67%	34.86%	64.41%
Grade 2	16.55%	27.71%	18.35%	33.90%
Grade 3	2.16%	3.61%	0.92%	1.69%

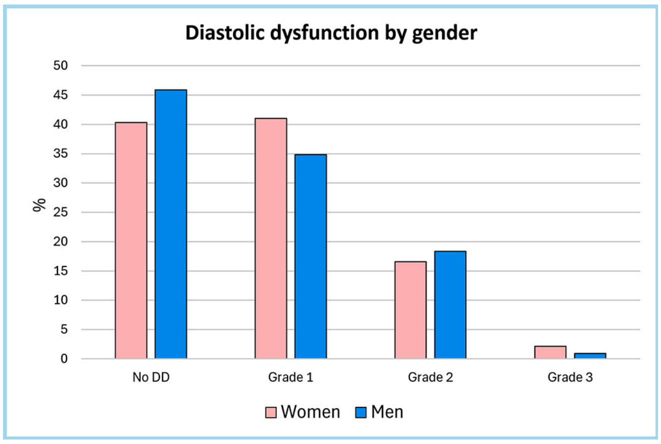


Fig. 2. Distribution of diastolic dysfunction severity by gender.
DD – diastolic dysfunction.

DISCUSSION

Anthropometric data

When reviewing the anthropometric data, a low proportion of patients with arterial hypertension and normal body weight was observed – 15.32% (N = 38). More than half of the hypertensive patients were overweight (131 patients, 52.82%), and 79 patients were obese (31.85%). These findings are consistent with the literature data demonstrating a high prevalence of obesity among patients with arterial hypertension [20,21]. Tu et al. reported data concerning the trends of obesity prevalence in hypertensive patients in the United States [22]. According to their data, over the period from 2001 to 2023, the prevalence of obesity in hypertensive patients increased from 35.4% to 55.4% [22]. In a study by Zhang et al. conducted among hypertensive patients aged 40 to 79 years in Southwest China, it was found that approximately 40% of them had obesity-related hypertension [23]. These results are not surprising, since obesity has a direct pathogenetic relationship with elevated blood pressure. Excess adipose tissue is associated with insulin resistance, increased leptin levels, increased activity of the sympathetic nervous system and the renin-angiotensin-aldosterone system, the presence of obstructive sleep apnea, as well as structural and functional changes in the kidneys [24].

In the studied control group, a relatively high prevalence of increased body mass index was also observed, with only 26.67% of healthy individuals being of normal weight, while 46.67% were overweight and 26.67% were obese. However, patients with arterial hypertension showed a more unfavorable distribution of BMI categories, with a lower proportion of individuals with normal weight (15.32% vs. 26.67% in controls) and a higher prevalence of obesity (31.85% vs. 26.67%). In the context of arterial hypertension, the differences in the prevalence of obesity have a great clinical significance, as obesity is more strongly associated with left ventricular hypertrophy, concentric remodeling, and diastolic dysfunction [25,26]. Furthermore, Russo et al. demonstrated that higher BMI is independently associated with impaired left ventricular diastolic function, regardless of left ventricular mass and other associated risk factors [27].

In hypertensive patients, obesity (BMI ≥ 30 kg/m²) was more frequently observed in women (34.53%) compared to men (28.44%), whereas overweight (BMI 25–29.9 kg/m²) was more common in men compared to women (58.72% vs. 48.20%, respectively). The body mass index observed in women with arterial hypertension (29.23 ± 4.88) was higher than in men (28.82 ± 3.73), although the difference was not statistically significant (P = NS). Such sex-related differences in the distribution of BMI categories are consistent with literature data, showing that obesity is more common in women [28,29]. According to the results of Zhang et al., for example, obesity-related hypertension was found in 31.4% of the hypertensive men, and in 44.9% of the hypertensive women [23].

Left ventricular hypertrophy

Echocardiographic assessment of LV hypertrophy is performed based on left ventricular mass indexed for body surface area (g/m^2) or height (g/m$^{2.7}$). In our study, we used left ventricular mass indexed for body surface area. In the literature, a number of cut-off values for the normal limit of LV mass index above which LV hypertrophy can be assumed are found. According to some literature data, for men these values range from LVMI > 114 g/m^2 to LVMI > 137 g/m^2, and for women from LVMI > 95 g/m^2 to LVMI > 116 g/m^2 [9,10,16,17,30-33]. In our study, we used the limits LVMI > 115 g/m^2 for men and LVMI > 95 g/m^2 for women.

The literature data concerning the prevalence of LVH in patients with arterial hypertension vary widely, from about 20% in patients with mild hypertension to almost 100% in those with severe HTN or HTN with complications [34]. Some studies illustrating the prevalence with which left ventricular hypertrophy is detected are those of: Zanchetti et al. – 29.9% [3], Adebayo et al. – 33.9% [4], De-la-Garza-Salazar et al. – 42.9% [5], Xu et al. – 44.1% [6], Ballo et al. – 39.8% [7], Huang et al. – 55.2% [8], Marchev S. – 57.9% [9], Eguchi et al. – 63% [10], Wachtell et al. – 70% [11]. In our study, left ventricular hypertrophy was found in 147 patients with arterial hypertension (59.27%), of whom ninety-seven were women (69.78% of women with HTN) and fifty were men (45.87% of men with HTN). In a study of 1699 patients, Casiglia et al. found a similar gender difference in the prevalence of LVH – 52.4% in women and 36.6% in men [35].

Left ventricular geometry

LV geometry classification is based on LV mass index (LVMI) and relative wall thickness (RWT), dividing patients into four categories, i.e., normal geometry (NG), concentric remodeling (CR), eccentric hypertrophy (ECH), and concentric hypertrophy (CH). Compared to eccentric LVH, concentric LVH is generally associated with worse outcomes, but eccentric LVH is also associated with serious complications. In patients with eccentric LVH, progression from heart failure with preserved ejection fraction (HFpEF) to HF with systolic dysfunction is possible [36].

Just as the criteria for LVH, thresholds for the assessment of LV geometry also differ, and cut-off values used for RWT can be found ranging from RWT > 0.42 to RWT > 0.47 [9,17,31,33,37].

In our study, we used two different RWT thresholds (calculated using the two different formulas): RWT1 > 0.43 and RWT2 > 0.42.

Using RWT1, normal geometry was found in 25.81% of patients, concentric remodeling in 14.92%, eccentric hypertrophy in 27.82%, and concentric hypertrophy in 31.45%. Using RWT2, the corresponding percentages were the following: normal geometry – 26.21%, concentric remodeling – 14.52%, eccentric hypertrophy – 23.39%, and concentric hypertrophy – 35.89%. In our patients, in both genders, the prevalence of concentric hypertrophy was higher than that of eccentric hypertrophy. When calculated using RWT2, the percentage of CH increased, and that of ECH decreased. For comparison, Table 7 presents literature data on LV geometry in hypertensive patients.

Table 7. Left ventricular geometry in HTN according to literature data.

Study	Year	Patients (n)	Normal geometry	Concentric remodeling	Eccentric hypertrophy	Concentric hypertrophy
Wachtell et al. [11]	2000	750	19%	11%	45%	25%
Zanchetti et al. [3]	2007	2545	51.50%	18.60%	14.40%	15.50%
Marchev S. [9]	2012	140	25.00%	17.10%	33.60%	24.30%
Adebayo et al. [4]	2013	1020	18.20%	47.80%	10.70%	23.20%
Ballo et al. [7]	2014	532	35.10%	25.00%	16.70%	23.10%
Santos et al. [38]	2016	3001	49%	51%		
Xu et al. [6]	2020	381	29.10%	26.80%	15.50%	28.60%
De-la-Garza-Salazar et al. [5]	2022	672	22.00%	35.10%	7.90%	35.00%
Tadic et al. [39]	2022	211	35.10%	25.10%	21.80%	18.00%
Phanzu et al. [40]	2023	220	14.50%	45%	-	40.50%
Huang et al. [8]	2023	125	28.80%	16.00%	36.00%	19.20%

The literature shows considerable variability in the distribution of left ventricular (LV) geometry types in patients with arterial hypertension, with the prevalence of normal geometry, concentric remodeling, and the two forms of left ventricular hypertrophy varying widely between studies.

In a study of Zanchetti et al. (2007), including over 2500 patients, normal geometry was frequent (51.5%), and the distribution between concentric remodeling, eccentric, and concentric hypertrophy was relatively balanced [3]. Santos et al. (2016), in a cohort of over 3000 patients, also reported an approximately equal distribution between normal and abnormal LV geometry (CR, ECH, CH) (49% and 51%) [38]. These findings suggest that, in some large cohorts, normal LV geometry is relatively common among hypertensive patients. However, this pattern is not consistently observed across different populations and study designs.

A substantial number of studies report a markedly lower prevalence of normal LV geometry, with pathological remodeling and hypertrophy representing the prevailing LV geometry. In the study by Ballo et al. (2014), normal geometry was found in about one-third of patients, while the rest showed remodeling and hypertrophy [7]. Some recent studies, such as those by Xu et al. (2020) and De-la-Garza-Salazar et al. (2022), reported a high prevalence of concentric remodeling and concentric hypertrophy, with normal geometry remaining relatively rare (between 22% and 29%) [5,6]. Marchev (2012) and Adebayo et al. (2013) also reported a low frequency of normal geometry (25% and 18.2%, respectively) [4,9], with concentric remodeling being the dominant geometric pattern according to Adebayo et al. (47.8%) [4]. In an earlier study of Wachtell et al. (2000), normal LV geometry was found in only 19% of hypertensive patients, whereas abnormal geometric patterns, especially eccentric hypertrophy (45%) and concentric hypertrophy (25%), were most frequent [11]. Phanzu et al. (2023) found a very low proportion of normal geometry (14.5%), with a predominance of concentric remodeling (45%) and concentric hypertrophy (40.5%) [40]. In the study by Huang et al. (2023), eccentric hypertrophy was the most common pattern (36%), while normal geometry was found in less than a third of patients [8].

Overall, the distribution of LV geometric patterns in our cohort is consistent with studies reporting a low prevalence of normal geometry and a predominance of remodeling and hypertrophy.

Left ventricular geometry by gender

Voors et al. studied untreated hypertensive patients aged between 60 and 75 years [41]. According to their results, 37% of men had normal LV geometry, 43% had concentric remodeling, 9% had eccentric LVH, and 11% had concentric LVH. In women, the corresponding figures were as follows: NG – 16%, CR – 76%, ECH – 4%, and CH – 5% [41]. In a study of 524 hypertensive patients, Appolinaire et al. found the following prevalence of different types of LV geometry: concentric remodeling (women – 14.7%, men – 15.7%), eccentric hypertrophy (women – 7.6%, men – 3.7%), concentric hypertrophy (women – 6%, men – 10.3%) [42]. In this study, 71.7% of women and 70.3% of men had normal LV geometry. Our data concerning the type of LVH in both sexes show a higher prevalence of concentric LVH in females. Using RWT1-based classification, concentric hypertrophy (CH) was present in 36.69% of hypertensive women and 24.77% of hypertensive men. Using RWT2-based classification, the corresponding proportions were 41.73% in women and 28.44% in men.

Diastolic dysfunction

Prevalence of diastolic dysfunction

The prevalence of diastolic dysfunction (DD) in hypertensive patients varies widely, with reported rates ranging from 18% to 84% [12]. Studies demonstrating this variability include: Dini et al. – 18% [43], Paudel et al. – 33.8% [44], Zanchetti et al. – 46% [3], Jaroch et al. –

59.3% [45], Sciarretta et al. – 66.3% [46], Santos et al. – 67% [38], Ballo et al. – 71.8% [7], Wachtell et al. – 84% [11]. Despite this variability, most studies have shown that diastolic dysfunction is a common finding in patients with hypertension and often develops early in the disease. Diastolic dysfunction is considered a major mechanism in the pathogenesis of heart failure with preserved ejection fraction (HFpEF), which is particularly common in patients with long-standing hypertension.

In our study, diastolic dysfunction was found in 57.26% of hypertensive patients, which places our results in the middle range of values reported in the literature. This prevalence is consistent with observations that more than half of hypertensive patients demonstrate impaired diastolic function.

Severity of diastolic dysfunction

Among our patients, 42.74% had no diastolic dysfunction, 38.31% had grade 1 DD, 17.34% had grade 2 DD, and 1.61% had grade 3 DD. For comparison, Table 8 represents literature data concerning the diastolic dysfunction grades in hypertensive patients.

Table 8. Diastolic dysfunction severity in hypertensive patients (literature data).

Study	Year	Patients (n)	No DD	Grade 1	Grade 2	Grade 3
Wachtell et al. [11]	2000	750	16%	69%	11%	4%
Mottram et al. [47]	2005	70	47.10%	40%	12.90%	-
Sciarretta et al. [46]	2009	1073	33.70%	56.80%	9.50%	-
Jaroch et al. [45]	2012	113	40.70%	48.70%	10.60%	-
Ballo et al. [7]	2014	532	28.20%	50.20%	16.70%	4.90%
Santos et al. [38]	2016	3001	33%	31%	36%	
Paudel et al. [44]	2023	68	66.10%	25.00%	7.40%	1.50%
Abubakar et al. [48]	2023	352	41.50%	42.60%	15.90%	-

The literature shows considerable variability not only in the prevalence but also in the severity of diastolic dysfunction in patients with hypertension. In most studies, patients without diastolic dysfunction or with mild diastolic dysfunction (grade 1) predominate, whereas advanced forms are significantly less common.

The proportion of patients without diastolic dysfunction varies widely – from 16% in the study by Wachtell et al. [11] to 66.1% in Paudel et al. [44], with intermediate values reported in other studies. Mild diastolic dysfunction (grade 1) is the most common type, with a prevalence of over 50% in some studies [7,11,46].

Diastolic dysfunction of moderate severity (grade 2) is found in a smaller proportion of patients (from 7.4% to 16.7% across the studies shown in Table 8). Severe diastolic dysfunction (grade 3) is the rarest, with a prevalence below 5% [7,11,44]. In the study by Santos et al., advanced forms of diastolic dysfunction (grades 2 and 3, analyzed together) reached 36%, indicating a significant severity of diastolic disorders in this cohort [38].

In our study, the distribution of the severity of diastolic dysfunction is comparable to the literature data, with grade 1 prevailing and advanced degrees being relatively rare. This confirms that in arterial hypertension, diastolic dysfunction most often manifests in its early stages, but in some patients it can progress to more severe forms.

Diastolic dysfunction by gender

Several echocardiographic studies have demonstrated significant sex differences in diastolic function among hypertensive populations. Zanchetti et al. found a higher prevalence of diastolic dysfunction in women (28.2%) than in men (22.8%) [3]. Abubakar et al. also reported more common DD in women [48]. In our study, diastolic dysfunction was found in 59.71% of women and in 54.13% of men. These findings suggest that female sex may be associated with a higher susceptibility to diastolic dysfunction in the setting of arterial hypertension.

CONCLUSION

Our study provides data on left ventricular hypertrophy and diastolic dysfunction in hypertensive patients. In patients with arterial hypertension, left ventricular hypertrophy and diastolic dysfunction were common findings. LVH was present in 59.27% of hypertensive patients and diastolic dysfunction in 57.26%, with both conditions more frequent in women. These findings emphasize that echocardiography should be routinely incorporated into the evaluation of hypertensive patients to detect remodeling and diastolic impairment early, tailor treatment intensity, and potentially prevent progression to heart failure with preserved ejection fraction.

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Address for correspondence:
Prof. Nikolay Runev, MD, PhD
Department of Internal Diseases "Prof. St. Kirkovich", Medical University of Sofia
1, St. Georgi Sofiiski Str., Sofia, Bulgaria.
E-mail: nrunev@abv.bg,