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Value of M-Mode Apical Systolic Excursion to Assess Subclinical Left Ventricular Dysfunction in Relation To 2D Speckle Tracking Echocardiography in Hypertensive Patients

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ABSTRACT

Background: Regardless of the early stages of their condition, hypertensive people exhibit diastolic and subclinical systolic dysfunction.

Objective: This study aimed to evaluate the accuracy of M-Mode Apical Systolic Excursion (MMASE) to identify subclinical systolic dysfunction in hypertensive sufferers in comparison to left ventricular global longitudinal systolic strain (LV GLS) determined by 2D-Speckle tracking echocardiography (2D-STE).

Patients and methods: In this case-control survey; demographics, clinical information, conventional echocardiography, tissue doppler imaging (TDI), and 2D-STE were examined in 56 hypertensive individuals with normal ejection fraction (EF), vs 28 healthy people. In order to determine MMASE. M-Mode vector was applied through the left ventricle's apex in an apical four-chamber view, and the endocardial excursion between end diastole and end systole was measured.

Results: MMASE and LV GLS revealed a strong positive correlation (P< 0.001). After implementing the ROC curve in comparison to the gold standard LV GLS, we said that MMASE has a cut off value for identification of subclinical systolic dysfunction below 0.6 cm.

Conclusion: In patients with hypertension, MMASE is a helpful M-mode assessment in the early diagnosis of subclinical LV systolic malfunction validated by a decrease in global LV longitudinal systolic strain.

Keywords: Hypertension, Speckle tracking, Subclinical systolic dysfunction, MMASE.

INTRODUCTION

Due to its widespread occurrence, hypertension is seen as a public health issue. It is characterised by systolic blood pressure in-office readings of ≥140 mmHg and/or diastolic readings of ≥ 90 mmHg [(1)].

The endothelium lining of blood arteries is damaged by hypertension, which raises the possibility of atherosclerotic disease. All of the direct and indirect consequences of persistent hypertension, such as systolic or diastolic heart failure, arrhythmias, and ischemic heart disorders, are a part of hypertensive heart diseases [(2)].

2D transthoracic echocardiography detects the reduction of left ventricular systolic function in late stages of the disease course, so early detection is of paramount importance [(3)].

Multiple evidence showed that LV EF is not sensitive enough to identify systolic impairment in its initial stages. However, despite having normal LVEF, numerous individuals with various clinical disorders have longitudinal systolic malfunction of the left ventricle, according to numerous investigations employing 2D-STE.

As a result, it has been recommended that systolic assessment of the left ventricle utilising LV GLS to be used as a gold benchmark for evaluating LV systolic performance globally. However, this requires skilled echocardiographic analysis [(4)].

M-mode measurements can be used to assess deformation of many LV regions [(5,6)]. We aimed to prove that MMASE is an easy way to assess LV GLS and find subclinical systolic impairment.

PATIENTS AND METHODS

56 hypertension sufferers, and 28 age-matched healthy controls made up this prospective case-control study. Patients were volunteers recruited from members of the local community, and referred to Menoufia University Hospitals´ clinics and echocardiography laboratory. This study was conducted from June 2021 to August 2022.

Inclusion criteria: Age ≥18 years old. Arterial hypertension [(1)]. Preserved LV EF > 50%.

Exclusion criteria:

Ischemic heart diseases. Significant valvular heart diseases. LV ejection fraction less than 50%. Bad echogenic window. Arrhythmia as atrial fibrillation. Conduction abnormalities as LBBB. Diabetes mellitus. Cardiomyopathies as: restrictive, hypertrophic and dilated types. Pericardial diseases. Congenital heart diseases.

Data collection:

This was accomplished using a questionnaire that asked about medical records, a physical assessment, and evidence from transthoracic echocardiography.

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Conventional transthoracic echocardiography of left ventricle

Employing GE Vivid E9 machine , a harmonic M5S variable frequency (1.7–4 MHz) phased-array transducer, and a single lead ECG signaling, as recommended by the American Society of Echocardiography[7], conventional echocardiographic measurements, doppler studies, and TDI were carried out**.**

Once early diastolic filling (E) and late diastolic filling (A) velocities were evaluated, the E/A ratio was computed using transmitral pulsed-wave Doppler [8]**.**

The first negative (e') wave velocity was measured using TDI, with the pulsed-wave doppler sample volume positioned at the lateral and septal mitral annuli, then E/e' ratios were obtained after estimating the mean e' velocity [9]**.**

In close proximity to both lateral and septal LV walls, M-mode vector was positioned through the mitral annulus. MAPSE, also known as the lateral and septal mitral annulus excursions throughout systole was evaluated from the lowest level (end-diastolic) to the maximum (end-systolic) (Figure 1).

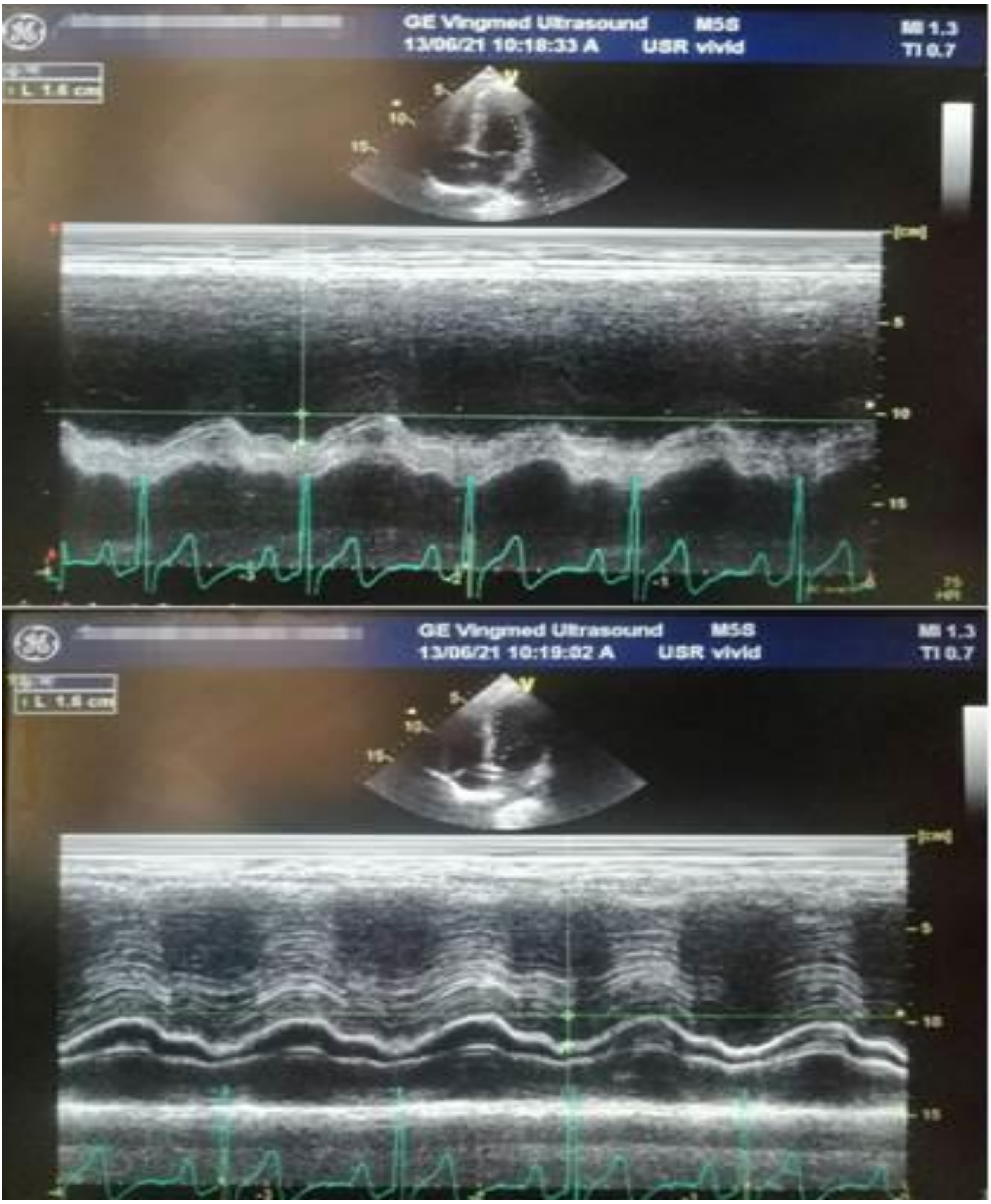


Figure (1): Measurements of lateral MAPSE (above), septal MAPSE (below).

In the apical four chamber view, with the left ventricle centred in the scanning sector and the M-mode cursor positioned through the apex, the MMASE was calculated by subtracting the distance between the apical lines at end-systole and end-diastole (Figure 2).

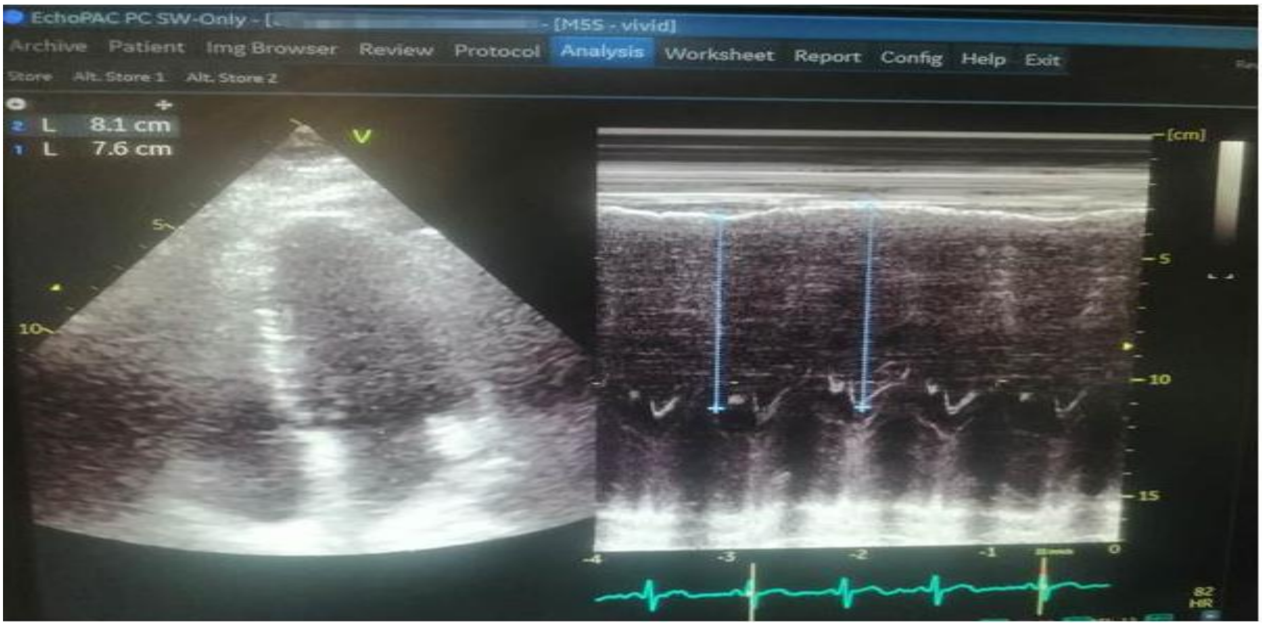


Figure (2): M-mode apical systolic excursion.

2D speckle tracking echocardiography

Utilizing the Echopac programme, LV longitudinal systolic strain measurement was performed (Vingmed model 1.8.1.X of General Electrics). All strain images from apical four, three, and two chamber views were acquired at a rate of 60–94 frames per second throughout ECG recording. For off-line assessment, there were three consecutive cardiac cycles captured and saved. The area of focus was manually adjusted using the three-point-and-click technique. The global Bull's eye then displayed a design with 17 segments and a mean LV GLS% [12] (Figure 3).

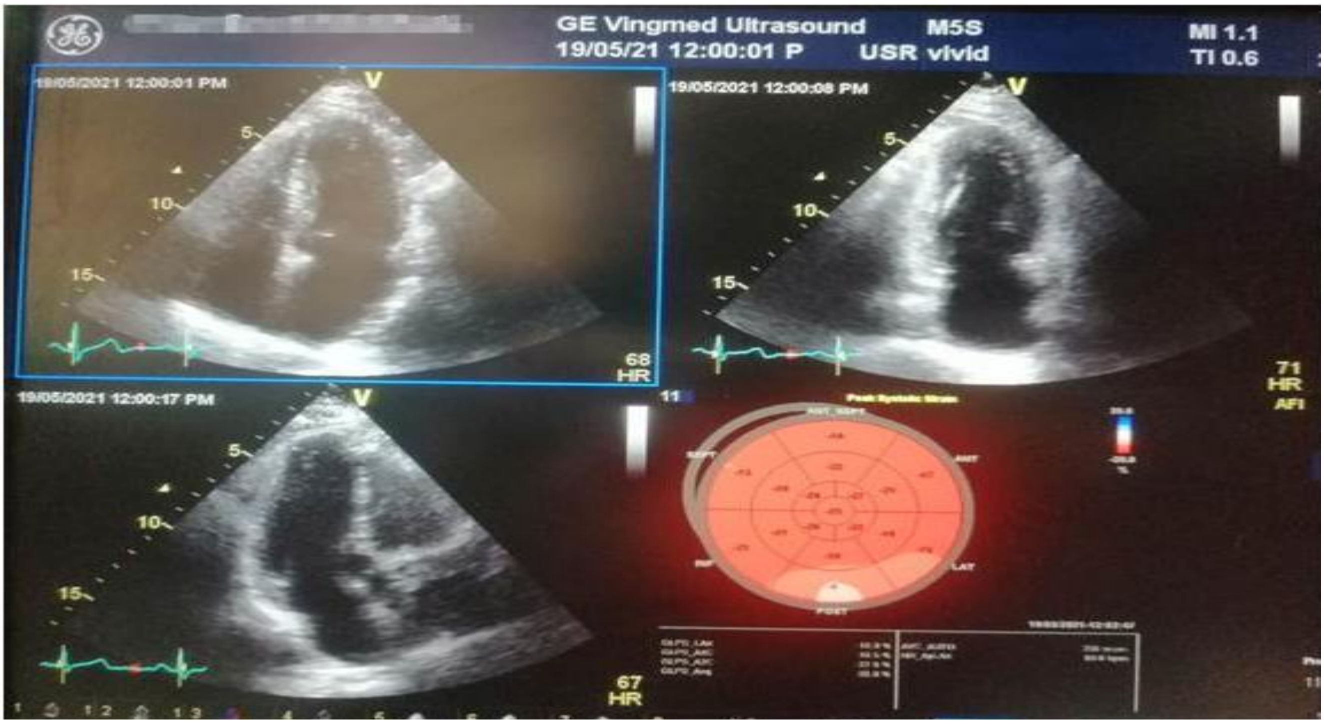


Figure (3): A hypertension patient's LV GLS was assessed, and a bull's eye.

Ethical Consideration:

The Academic and Ethical Committee of Menoufia University gave their approval to the research. Each participant signed a written informed consent form to participate in the research. On performing this experimental study, the World Medical Association's code of ethics known as the Declaration of Helsinki was fulfilled.

Statistical Analysis

The IBM Statistical Package for Social Sciences (SPSS), 21st version, IBM, United States, was used to analyse the data. The evaluation of the two groups with quantitative factors was performed using an unpaired student t-test. The quality of the relationship between two quantitative variables was evaluated using correlation analysis (using Spearman's approach). Categorical data were contrasted using the applicable Fisher exact analysis or Chi-square testing while numerical data were analyzed using the Mann-Whitney U testing. ROC curve was utilised to assess how well various tests performed at differentiating between various groups. The quantitative and qualitative statistics were given as numbers and percentages, the quantitative with parametric distributions as averages, standard deviations, and ranges, and the quantitative data with non-parametric distribution as median and interquartile range (IQR). The degree and orientation of the linear link between two parameters is defined by the correlation coefficient, which is represented by the symbol "r".

RESULTS

As shown in table (1), a mean age in hypertensive cases was 50.72 ± 7.33 years and 47.57 ± 8.36 years in control group. The results showed that controls were selected properly and matched for age, and gender compared to cases.

Table (1): Analysis of the examined participants' demographic characteristics

Variables		Hypertensive group (n=56)	Control group (n=28)	Test value	P-value
Age (years)	Mean± SD	50.72 ± 7.33	47.57 ± 8.36	Z_{MWU} =1.79	0.074
	Range	30.0- 61.0	26.0- 60.0		
Gender	Male	25 (44.6%)	15 (53.6%)	X^2= 0.597	0.440
	Female	31 (55.4%)	13 (46.4%)		

SD: Standard deviation ZMWU: Mann-Whitney U test, X2: Chi-Square test.

As shown in table (2), the mean duration of hypertension in the studied cases was 8.66 ± 3.38 years and ranged from 3 years to 18 years. The mean SBP in hypertensive cases was 133.81 ± 9.18 mm/Hg while the mean DBP was 83.70 ± 6.71 mm/Hg.

Table (2): Distribution of the study participants based on blood pressure measurements and hypertension duration

Variable		Hypertensive group (n=56)
Duration of hypertension (years)	Mean± SD	8.66 ± 3.38
	Range	3.0- 18.0
SBP (mm/Hg)	Mean± SD	133.81 ± 9.18
DBP (mm/Hg)	Mean± SD	83.70 ± 6.71

SBP: Systolic blood pressure, DBP: Diastolic blood pressure.

Table (3) demonstrated that LA diameter was noticeably larger in the studied patients than controls (p<0.001). Furthermore, the study patients had significantly larger dimensions of IVSD, PWD, and LV mass than the controls (p< 0.001, and < 0.05) respectively (Figures 4-7).

Table (3): Comparison of conventional electrocardiographic variables between the groups

Variable	Hypertensive group (n=56)		Control group (n=28)		Test value	P-value
	Mean	SD	Mean	SD		
LA diameter (cm)	4.0	0.4	3.6	0.4	3.891	**<0.001****
IVSD (cm)	1.2	0.1	1.0	0.1	5.783	**<0.001****
PWD (cm)	1.0	0.2	0.9	0.2	3.131	**0.002****
LV mass (g)	288.38	89.0	246.29	47.6	2.153	**0.031***
EF%	61.18	8.21	60.18	8.01	0.402	0.688
E (m/s)	0.76	0.19	0.76	0.21	0.240	0.811
A(m/s)	0.73	0.23	0.70	0.15	0.470	0.639
E/A	1.18	0.83	1.14	0.43	0.673	0.501

Peak late diastolic filling velocity is represented by A, and peak early diastolic filling velocity is represented by E. : *Significant, **: Highly significant, LA stands for left atrium, EF for ejection fraction IVSD: Interventricular septum thickness in diastole, PWD: Posterior wall thickness at end diastole.

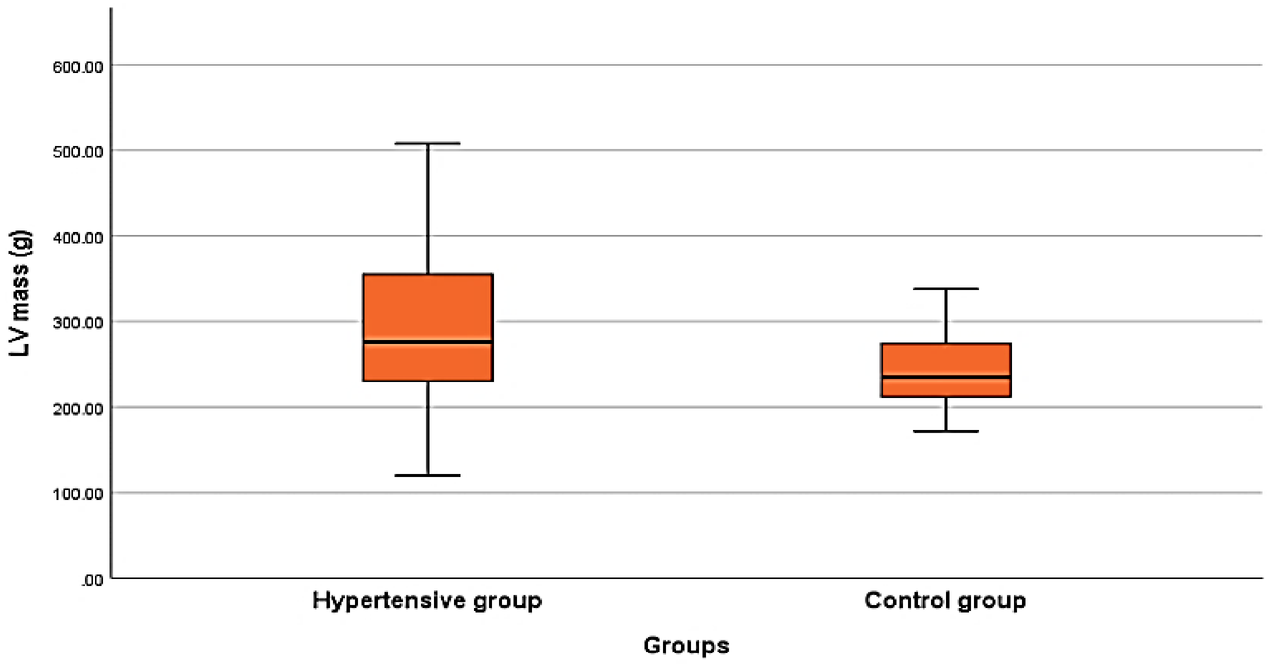


Figure (4): Comparative boxplot of the two research groups regarding LA diameter

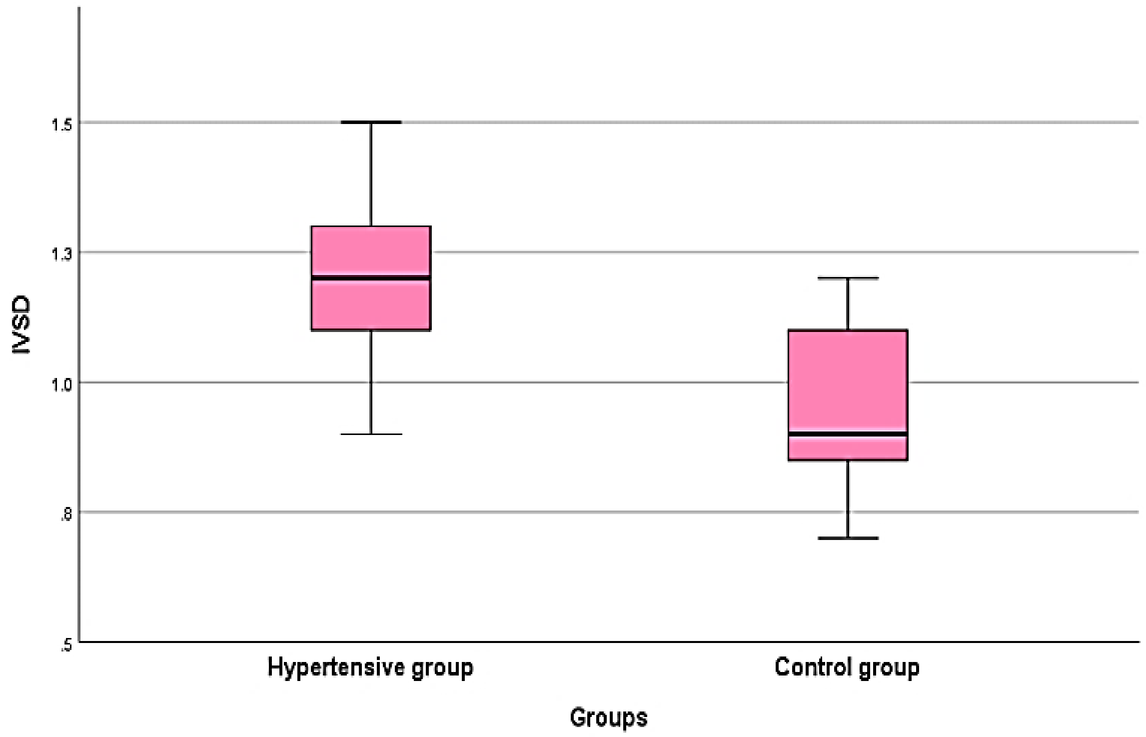


Figure (5): Comparative boxplot of the two research groups regarding IVSD.

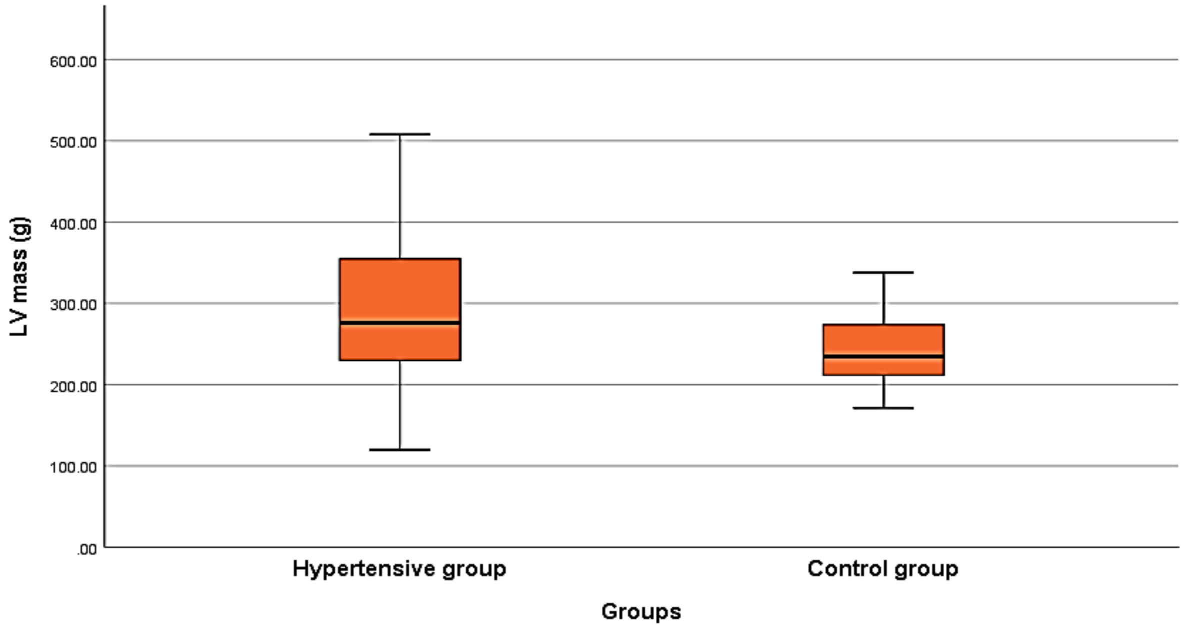


Figure (6): Comparative boxplot of the two research groups regarding LV mass

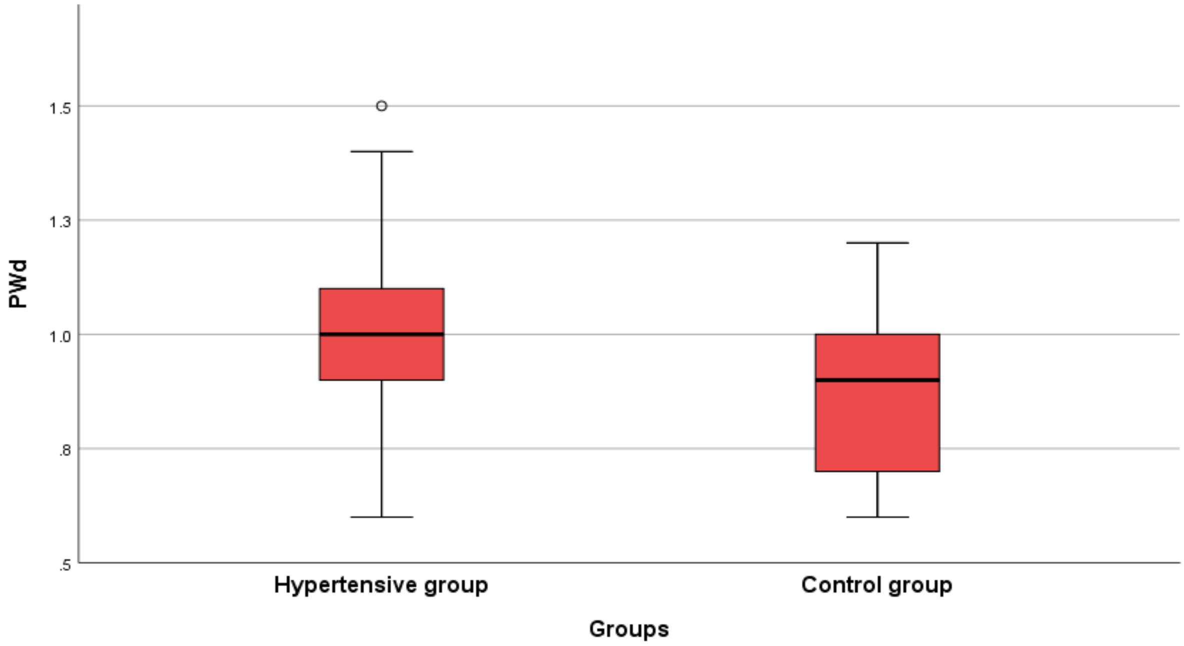


Figure (7): Comparative boxplot of the two research groups regarding PWD

As can be observed in table (4), hypertension sufferers had considerably lower septal and lateral early diastolic mitral annular velocities than controls (P value< 0.05). Contrarily, lateral and septal E/e' measurements in hypertension patients were significantly higher than in controls (p<0.05 & p<0.001, respectively) (Figures 8-11).

Table (4): Comparison of tissue Doppler parameters between the studied groups

Variable	Hypertensive group (n=56)		Control group(n=28)		Test value	P-value
	Mean	SD	Mean	SD		
Septal e`(m/s)	0.08	0.02	0.10	0.03	2.130	**0.033***
Septal E/e`	10.96	2.13	9.31	2.36	2.673	**0.008****
Lateral e`(m/s)	0.12	0.04	0.13	0.04	1.986	**0.047***
Lateral E/e`	7.33	2.45	5.34	1.95	1.830	**0.0003****

E: Peak early diastolic filling velocity, e`: Early diastolic mitral annular velocity, *: Significant, **: Highly significant.

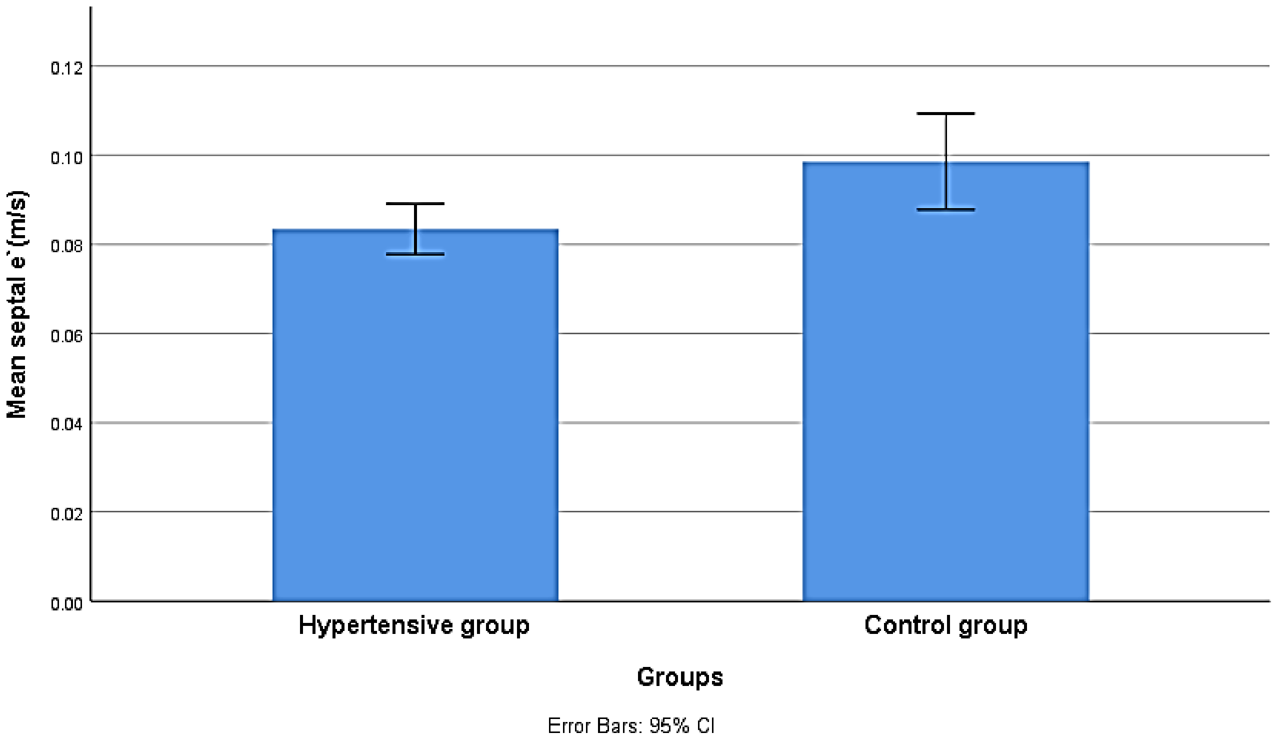


Figure (8): Contrast of the two research groups regarding Septal e`(m/s)

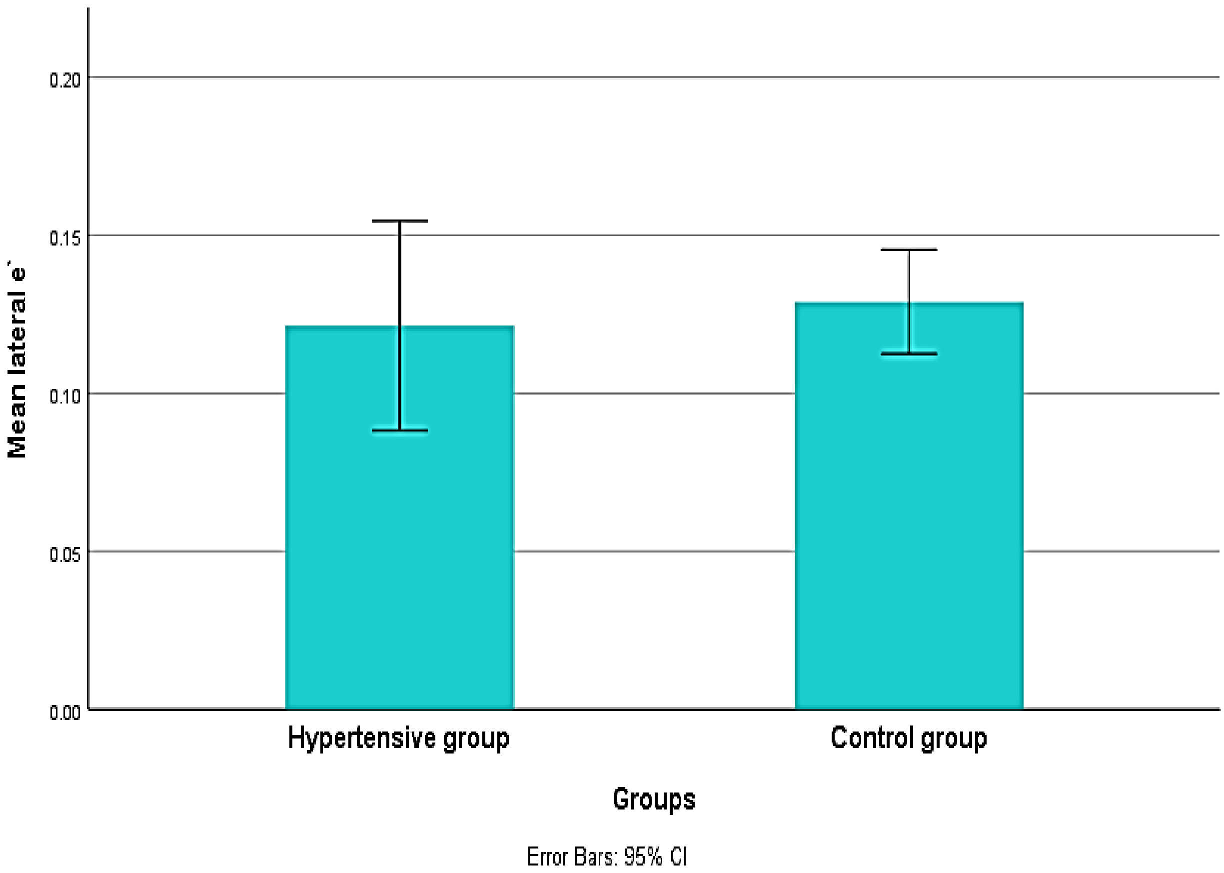


Figure (9): Lateral e' between the two groups of participants (m/s).

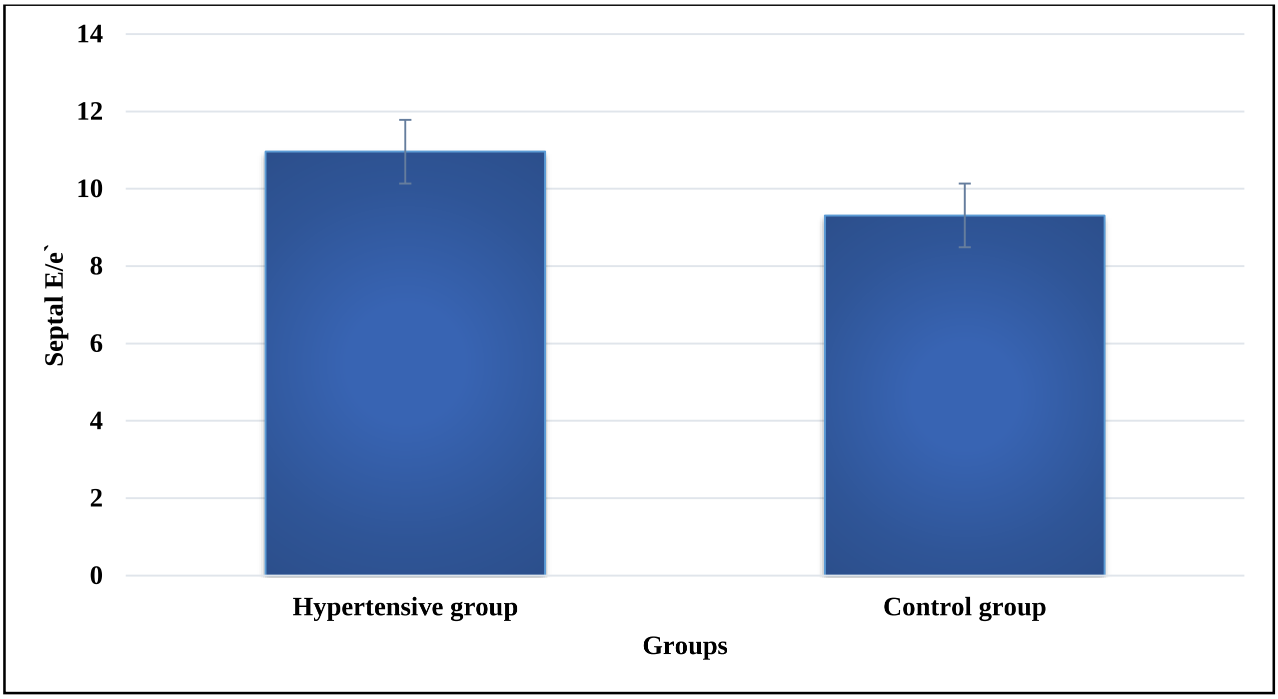


Figure (10): Variation of Septal E/e' between the control and hypertensive groups

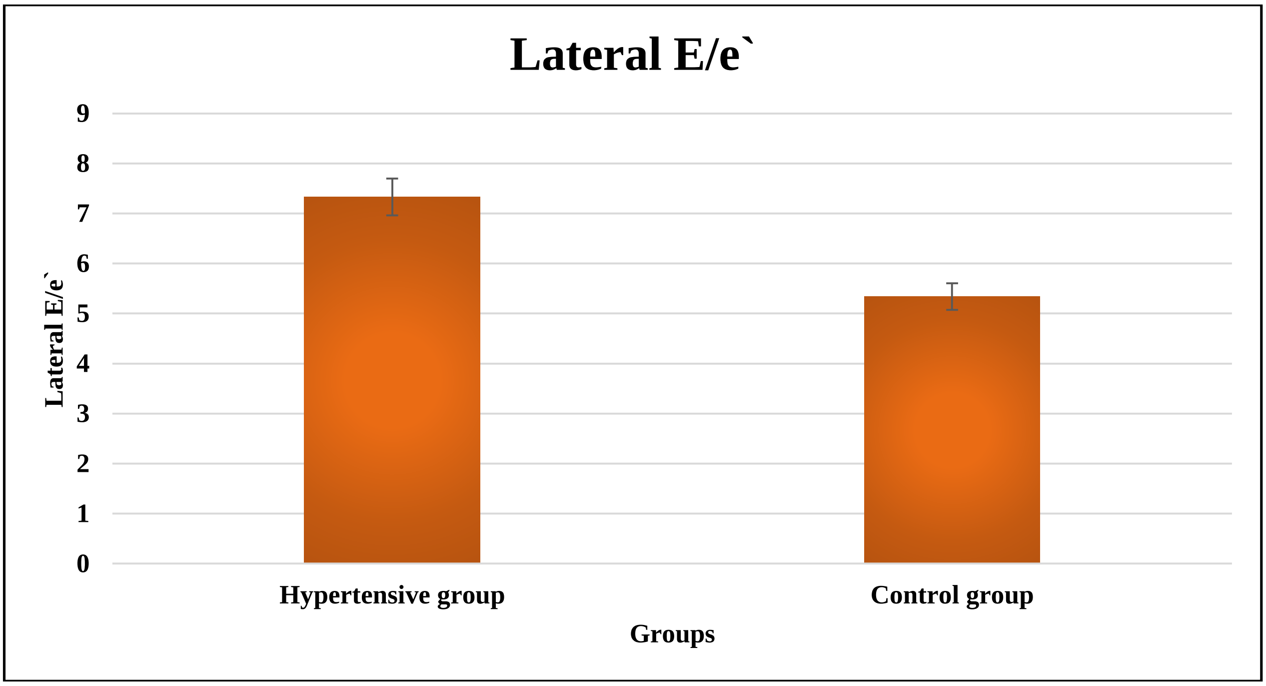


Figure (11): Contrast of the two research groups regarding lateral E/e`

Table (5) demonstrated that when contrasted to the control group**;** septal, lateral MAPSE and MMASE were considerably lower in hypertensive subjects (p<0.001) (Figures 12-14).

Table (5): Comparison of M-mode parameters between the studied groups

Variable	Hypertensive group (n=56)		Control group (n=28)		Test value	p-value
	Mean	SD	Mean	SD		
Septal MAPSE	1.4	0.2	1.6	0.2	3.677	**<0.001****
Lateral MAPSE	1.7	0.2	1.9	0.2	2.901	**0.004***
MMASE	0.69	0.17	0.92	0.10	5.261	**<0.001****

*: Significant, **: Highly significant.

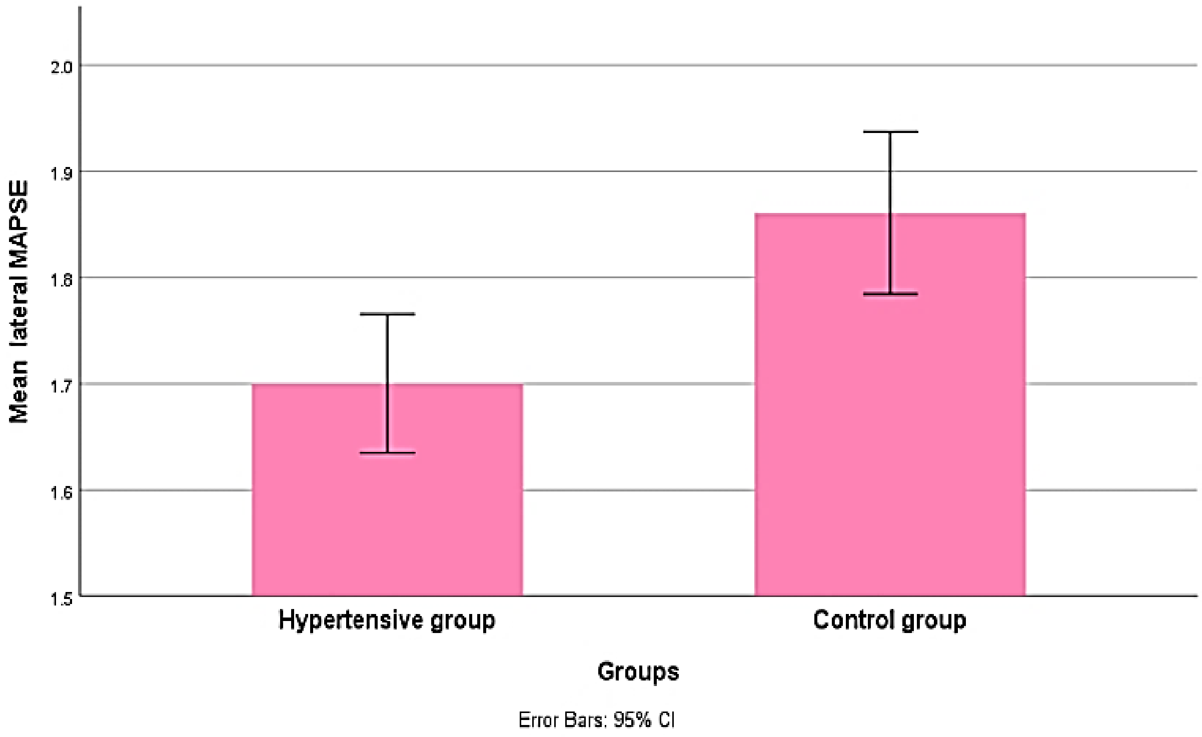


Figure (12): Contrast of the two research groups regarding septal MAPSE.

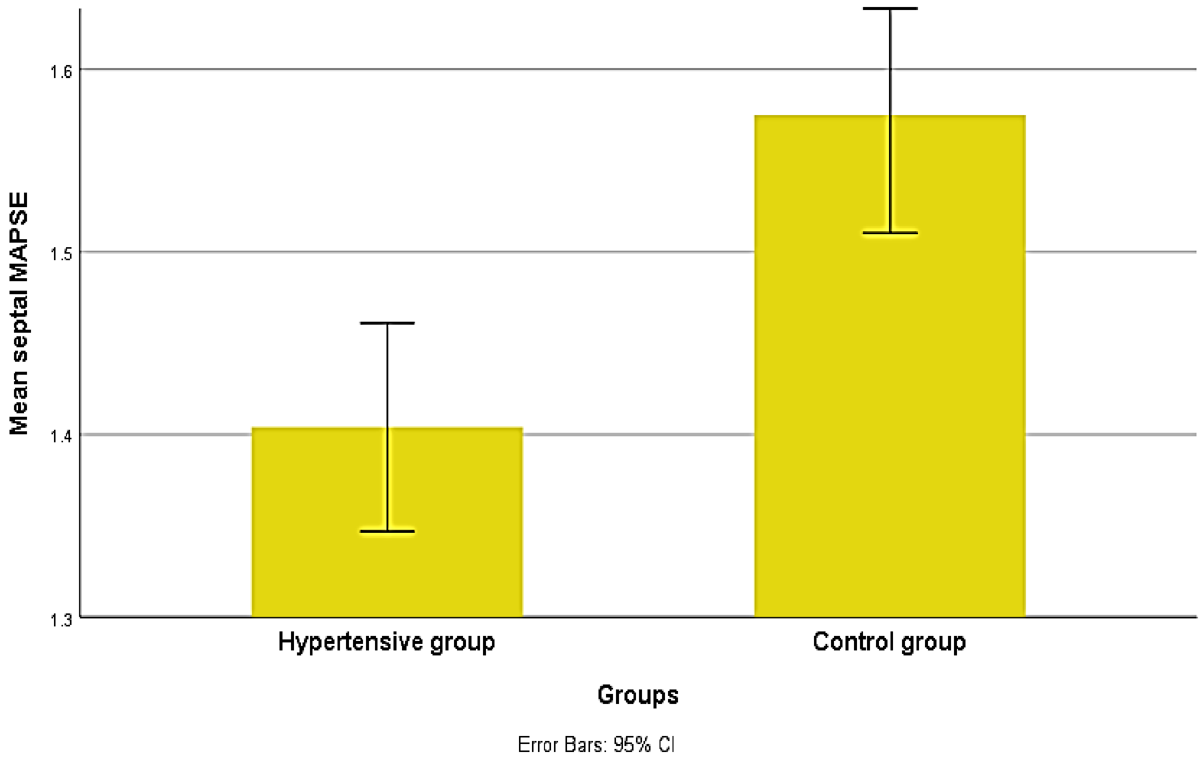


Figure (13): Contrast of the two research groups regarding lateral MAPSE

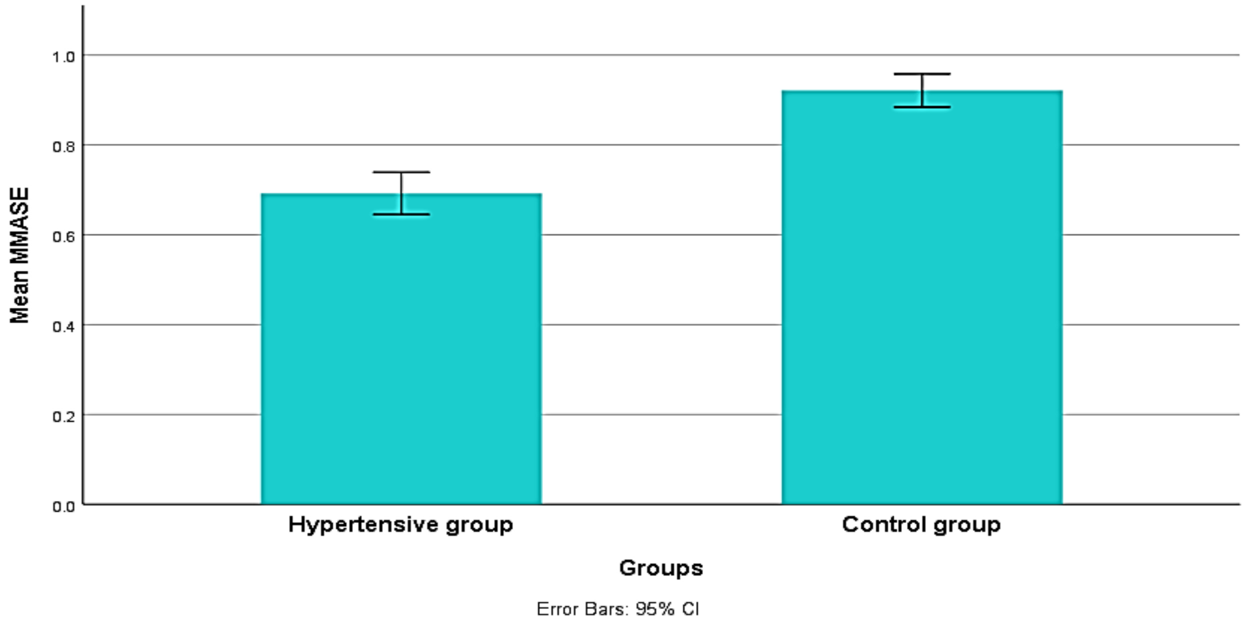


Figure (14): Contrast of the two research groups regarding MMASE.

As shown in table (6), LV GLS was significantly lower in hypertensive participants than in control participants (p< 0.05) (Figure 15).

Table (6): Comparison of LV global longitudinal systolic strain between the studied groups

Variable	Hypertensive group (n=56)		Control group (n=28)		Test value	p-value
	Mean	SD	Mean	SD		
apical2	-17.68	4.18	-20.59	3.44	3.022	**0.003****
apical3	-17.39	4.20	-18.31	4.39	1.068	0.285
apical4	-17.85	4.06	-18.88	3.18	1.266	0.205
LV GLS	-17.72	3.31	-19.58	3.05	2.448	**0.017***

*: Significant, **: Highly significant.

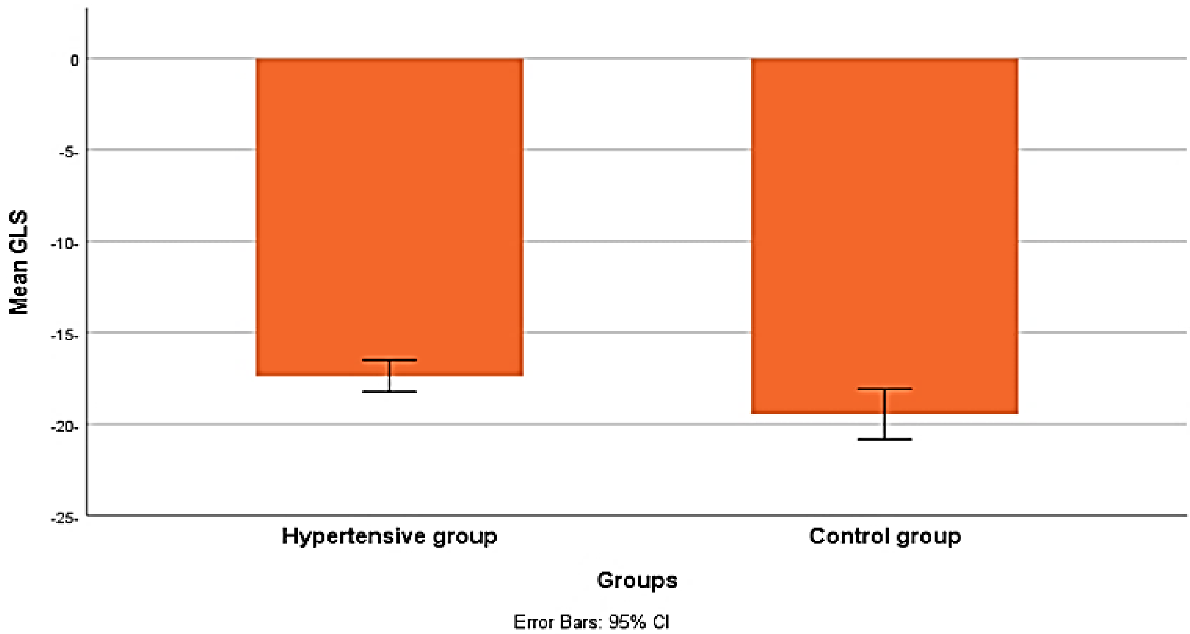


Figure (15): Contrast of the two research groups regarding LV GLS.

As shown in table (7), MMASE had a significant positive correlation with septal e` (m/s), septal MAPSE (r= 0.455, p=0.001), as well as LV GLS (r= 0.720, p<0.001), while there was statistically significant negative correlation between MMASE and IVSD (r= -0.413, p=0.003), and PWD (p<0.05) (Figures 16, 17).

Table (7): Correlation between M-mode apical systolic excursion and different parameters in the studied patients

	MMASE	
	R	**p- value**
LA diameter (cm)	-0.018	0.905
IVSD (cm)	-0.413	**0.003****
EF%	0.178	0.217
septal e`(m/s)	0.381	**0.006****
septal MAPSE(cm)	0.455	**0.001****
PWD (cm)	-0.166	**0.02***
LV GLS %	0.720	**0.000****

*: Significant, **: Highly significant.

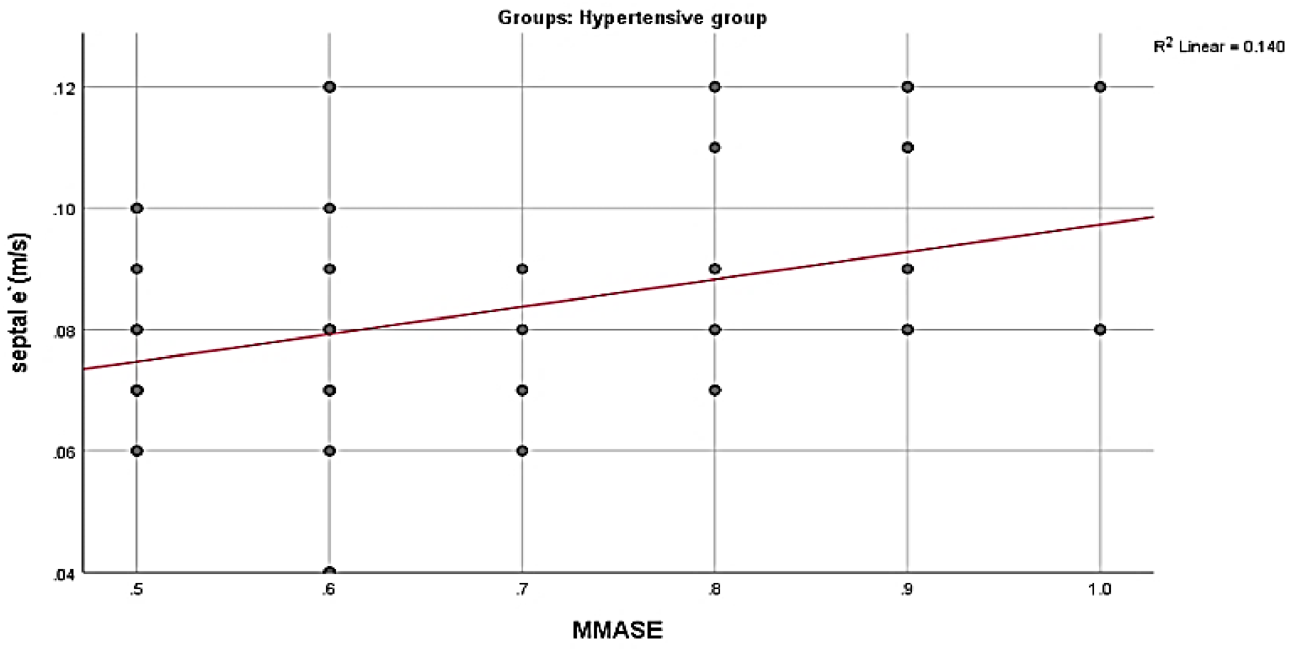


Figure (16): Scatter plot showing positive correlation between MMASE and septal e' in hypertensive group.

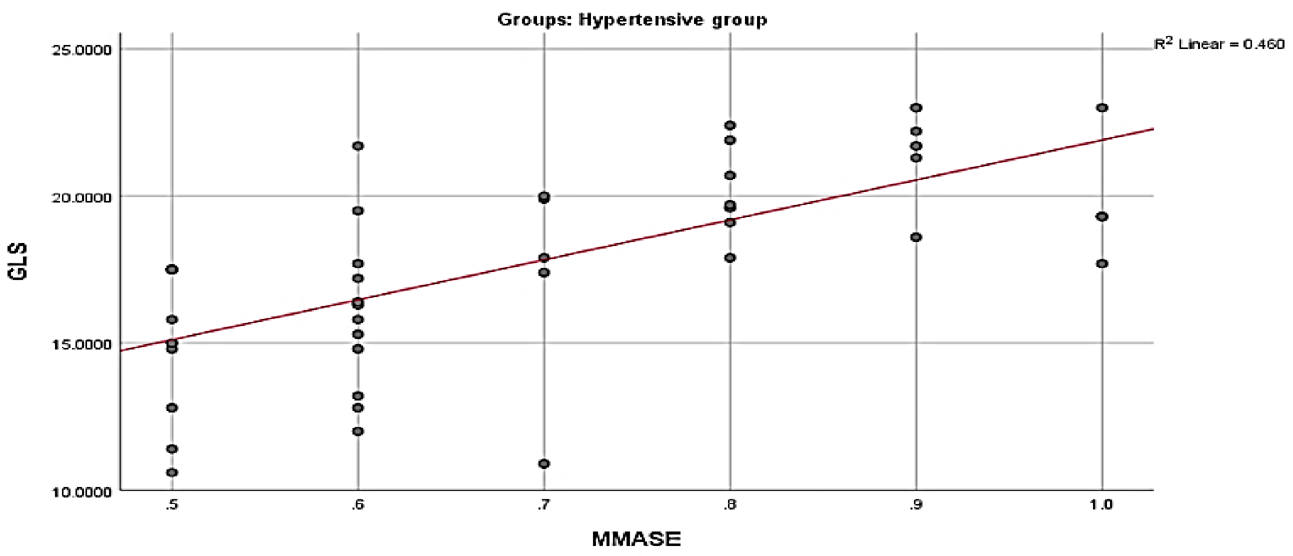


Figure (17): Scatter plot for positive correlation between MMASE and GLS in hypertensive patients.

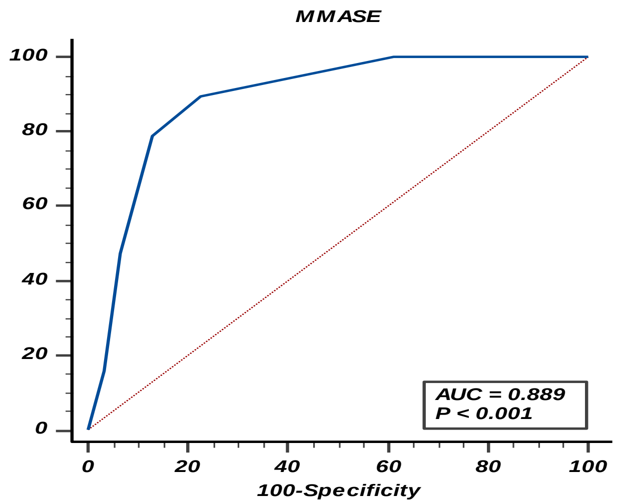
Table (8): M-Mode apical systolic excursion and subclinical left ventricular systolic dysfunction

Parameters	Cutoff value	AUC	Sensitivity	Specificity	PPV	NPV	P value
MMASE	<0.6	0.889	89.5%	77.4%	79.8%	88.1%	<0.001**

AUC= Area Under Curve, * : Significant, **: Highly significant,
PPV= Positive Predictive Value, NPV= Negatively Predictive Value.

By using ROC-curve analysis, MMASE had diagnostic cut off value for subclinical left ventricular systolic dysfunction less than 0.6 cm. The sensitivity, specificity, PPV and NPV were 89.5%, 77.4%, 79.8% and 88.1% respectively (p< 0.001) (Table 8 & f**igure 18).**

Figure (18): ROC curve of MMASE for prediction of subclinical left ventricular dysfunction.



DISCUSSION

Our present study revealed that LA had substantially larger diameter in hypertension sufferers than in controls (P value <0.001), which is in agreement with **Gerdts *et al.*** [13], and **Cipollini *et al.*** [14]. In essential hypertension, with regards to cardiac remodeling, **Su *et al.*** [15] suggested that LA was enlarged earlier than left ventricle (LV). Furthermore, compared to controls, hypertensive individuals' IVSD, PWD, and LV mass were all considerably higher (P values <0.001, <0.05 respectively), which are in agreement with **De Simone *et al.*** [16], and **De Marco *et al.*** [17]. **Diez and Frohlich** [18] suggested that in response to pressure overload from elevated blood pressure, consequences of neurohormones such as the renin-angiotensin process, endothelins, and some proliferative factors that result in cardiomyocyte enlargement, enhancing interstitial, perivascular collagens, and myocardial fibrosis, are contributing to the increase in septal wall thickness**.** Our patients suffering from hypertension showed normal EF, with a mean of 61.18 ± 8.21%. Similarly, **Narayanan *et al.*** [19] studied 52 hypertensive patients with preserved EF vs 52 healthy persons , and discovered that the EF was identical in both groups and that there was no clear differentiation between them.

Regarding deformation imaging in our study, in comparison with controls, hypertension patients' LV GLS was considerably lower (p<0.05). This is in agreement with **Sengupta *et al.*** [20], and **Imbalzano *et al.*** [21]. **Kraigher-Krainer *et al.*** [22] found that LV GLS decreased gradually when comparing controls with hypertensive patients with those with heart failure with preserved EF. **Navarini *et al.*** [23] also reported that teenagers with hypertension had considerably lower GLS in comparison with controls showed no differences in LVEF or LV volumes across the study groups. However, 2D-STE necessitates high technical expertise, which is expensive and not usually possible during routine practice [24, 25]**.**

We noticed that although all the hypertensive patients had preserved EF, most of them had significant decrease in MAPSE (septal and lateral, mean values were 1.4 ± 0.2**,** 1.7 ± 0.2 cm respectively) and MMASE (mean values were 0.69 ± 0.17 cm) giving an impression of subclinical systolic dysfunction that was confirmed by the significant reduction in LV GLS done by 2D-STE (mean values were -17.72 ± 3.31 %).

It was found that MAPSE, measuring the mitral annular excursion at systole, could be used to identify slight abnormal LV changes in a variety of cardiovascular diseases in which the longitudinal function is impacted before other functions (circumferential & radial), which might potentially be preserved or even improved to compensate .[25, 26]

In our study, there was a strong positive association between MMASE and septal MAPSE (r = 0.455, P=0.001) as well as LV GLS (r= 0.720, P<0.001). After using the ROC curve for in reference to the gold standard GLS, we established the cutoff value of 0.6 cm for MMASE for the identification of subclinical systolic dysfunction. **Xiao *et al.*** [27] hypothesized that in treated hypertensive patients with maintained EF and fractional shortness with or without hypertrophic hearts, total longitudinal systolic excursions in both the LV lateral and interventricular septum walls were dramatically decreased. This could be explained by microcirculatory abnormalities and interstitial fibrosis that result in repeated ischemic insults in the left ventricle's subendocardial layer, particularly in more hypertrophic hearts **[28].** This would lead to a decrease in MAPSE and our straightforward measure, MMASE, as well as drop in the longitudinal myocardial contraction force **[29].** Also, **Amado *et al.*[6]** hypothesized that in contrast to strain relying on complicated speckle analysis, subclinical systolic insufficiency can be evaluated utilising simpler, quicker, and basic procedures using MMASE.

CONCLUSION

We confirmed the role of MMASE for detection of early LV longitudinal impairment and subclinical LV systolic dysfunction before LV EF reduction in most of hypertensive patients.

LIMITATIONS

- The offline analysis required for 2D-STE needs specialized technical expertise and unquestionably prolongs examination time.
- Insufficient careful follow-up.
- Exclusion of people who have windows with bad acoustics.
- A limited sample size, from a single hospital.

RECOMMENDATIONS

- Be aware about 2D-STE can be used as an additional diagnostic technique in everyday practice.
- The association between LV geometrical changes and hypertension (treated vs untreated) in a large sample should be kept in mind**.**

Conflict of Interest: The authors declared no conflict of interest. This work was fully funded by the authors.

REFERENCES

1. **Williams B, Mancia G, Spiering W *et al.* (2018):** ESC Scientific Document Group. 2018 ESC/ESH Guidelines for the management of arterial hypertension. Eur Heart J., 39: 3021-104.
2. **Lewington S, Clarke R, Qizilbash N *et al.* (2002):** Prospective Studies Collaboration. Age-specific relevance of usual blood pressure to vascular mortality: a meta-analysis of individual data for one million adults in 61 prospective studies. Lancet, 360 (9349): 1903-13.
3. **Chemaly E, Chaanine A, Sakata S *et al.* (2012):** Stroke volume-to-wall stress ratio as a load-adjusted and stiffness-adjusted indicator of ventricular systolic performance in chronic loading. Journal of Applied Physiology, 113 (8): 1267-84.
4. **Naeije R, Vanderpool R, Dhakal B *et al.* (2013):** Exercise-induced pulmonary hypertension: physiological basis and methodological concerns. American journal of respiratory and critical care medicine, 187 (6): 576-83.
5. **Wenzelburger F, Tan Y, Choudhary F *et al.* (2011):** Mitral annular plane systolic excursion on exercise: a simple diagnostic tool for heart failure with preserved ejection fraction. European journal of heart failure, 13 (9): 953-60.
6. **Amado J, Islas F, de Isla I *et al.* (2015):** M-mode apical systolic excursion: A new and simple method to evaluate global left ventricular longitudinal strain. Revista Portuguesa de Cardiologia (English Edition), 34 (9): 551-4.
7. **Mitchell C, Rahko P, Blauwet L *et al.* (2019):** Guidelines for performing a comprehensive transthoracic echocardiographic examination in adults: recommendations from the American Society of Echocardiography. Journal of the American Society of Echocardiography, 32 (1): 1-64.
8. **Nagueh S, Smiseth O, Appleton C *et al.* (2016):** 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 SocEchocardiogr., 29: 277-314.
9. **Mogelvang R, Biering-Sørensen T, Jensen J *et al* (2015):** Tissue Doppler echocardiography predicts acute myocardial infarction, heart failure, and cardiovascular death in the general population. European Heart Journal, 16 (12): 1331–1337.
10. **Terada T, Mori K, Inoue M *et al.* (2016):** Mitral annular plane systolic excursion/left ventricular length (MAPSE/L) as a simple index for assessing left ventricular longitudinal function in children. Echocardiography, 33 (11): 1703- 170922.
11. **Matos J, Kronzon I, Panagopoulos G *et al.* (2012):** Mitral annular plane systolic excursion as a surrogate for left ventricular ejection fraction. J Am Soc Echocardiogr., 25: 969-974.
12. **Castel A, Menet A, Ennezat P *et al.* (2016):** Global longitudinal strain software upgrade: Implicationsfor intervendor consistency and longitudinal imaging studies. Archives of Cardiovascular Disease, 109: 22— 30.
13. **Gerdts E, Oikarinen L, Palmieri V *et al.* (2002):** Correlates of left atrial size in hypertensive patients with left ventricular hypertrophy: the Losartan Intervention For Endpoint Reduction in Hypertension (LIFE) Study. Hypertension, 39 (3): 739-43.
14. **Cipollini F, Arcangeli E, Seghieri G *et al.* (2016):** Left atrial dimension is related to blood pressure variability in newly diagnosed untreated hypertensive patients. Hypertension Research, 39 (8): 583-7.
15. **Su G, Cao H, Xu S *et al.* (2014):** Left atrial enlargement in the early stage of hypertensive heart disease: a common but ignored condition. The Journal of Clinical Hypertension,16 (3): 192-7.
16. **De Simone G, Devereux R, Chinali M *et al.* (2008):** Left ventricular mass and incident hypertension in individuals with initial optimal blood pressure: the Strong Heart Study. J Hypertens., 26 (9): 1868–1874.

17. **De Marco M, De Simone G, Roman M *et al.* (2009):** Cardiovascular and metabolic predictors of progression of prehypertension into hypertension: the Strong Heart Study. Hypertension, 54 (5): 974-80.
18. **Díez J, Frohlich E (2010):** A translational approach to hypertensive heart disease. Hypertension, 55: 1-8.
19. **Narayanan A, Aurigemma GP, Chinali M *et al.* (2009):** Cardiac mechanics in mild hypertensive heart disease: a speckle-strain imaging study. Circ Cardiovasc Imaging, 2 (5): 382– 90.
20. **Sengupta S, Caracciolo G, Thompson C *et al.* (2013):** Early impairment of left ventricular function in patients with systemic hypertension: new insights with 2-dimensional speckle tracking echocardiography. Indian heart journal, 65 (1): 48-52.
21. **Imbalzano E, Zito C, Carerj S *et al.* (2011):** Left ventricular function in hypertension: new insight by speckle tracking echocardiography. Echocardiography, 28 (6): 649-57.
22. **Kraigher-Krainer E, Shah A, Gupta D *et al.* (2014):** PARAMOUNT Investigators. Impaired systolic function by strain imaging in heart failure with preserved ejection fraction. J Am Coll Cardiol., 63: 447–456.
23. **Navarini S, Bellsham H, Chubb H *et al.* (2017):** Myocardial deformation measured by 3-dimensional speckle tracking in children and adolescents with systemic arterial hypertension. Hypertension, 70: 1142–1147.
24. **Collier P, Phelan D, Klein A (2017):** A test in context: myocardial strain measured by speckle-tracking echocardiography. Journal of the American College of Cardiology, 69 (8): 1043–1056.
25. **Zito C, Longobardo L, Citro R *et al.* (2018):** Ten years of 2D longitudinal strain for early myocardial dysfunction detection: a clinical overview. https://pubmed.ncbi.nlm.nih.gov/30627581
26. **Cikes M, Sutherland G, Anderson L *et al.* (2010):** The role of echocardiographic deformation imaging in hypertrophic myopathies. Nature Reviews Cardiology, 7 (7): 384-96.
27. **Xiao H, Kaleem S, McCarthy C *et al.* (2006):** Abnormal regional left ventricular mechanics in treated hypertensive patients with 'normal left ventricular function, Int J Cardiol., 112: 316-21.
28. **Todaro M, Khandheria B, Longobardo L *et al.* (2015):** New diagnostic perspectives on heart failure with preserved ejection fraction: systolic function beyond ejection fraction. Journal of Cardiovascular Medicine, 16 (8): 527-37.
29. **Baltabaeva A, Marciniak M, Bijnens B *et al.* (2008):** Regional left ventricular deformation and geometry analysis provides insights in myocardial remodeling in mild to moderate hypertension. European Journal of Echocardiography, 9 (4): 501-8.