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Evaluation of Global Left Ventricular Systolic Function in Newly Diagnosed Dipper and Non-dipper Hypertensive Patients by Strain Analysis Methods

Yeni Tanı Dipper ve Non-dipper Hipertansif Hastalarda Strain Analiz Metoduyla Sol Ventrikül Global Sistolik Fonksiyonlarının Değerlendirilmesi

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ABSTRACT Objective: Non-dipper hypertension has been associated with enhanced target organ damage and adverse cardiovascular outcomes. The effect of dipper and non-dipper status on cardiac target organ damage has not been comprehensively investigated by two-dimensional (2D) strain echocardiography. We aimed to investigate myocardial deformational strain parameters in dipper and non-dipper untreated hypertensive patients. **Material and Methods:** We included 42 newly diagnosed hypertensive patients without a previous history of cardiovascular disease and coexisting chronic disease. Study population consisted of two groups of patients, 23 dipper patients and 19 non-dipper patients. Global longitudinal strain (GLS), radial strain and circumferential strain analysis were measured by 2D speckle tracking method. **Results:** The study population included 42 patients (15 male) with a mean age of 54.5±9 years. The assessment of left ventricular (LV) systolic function by GLS showed decreased values in non-dippers compared with dippers (-18.13±2.07 vs. -13.7±1.95; p=0.001). But no significant intergroup differences were observed in circumferential and radial strain. The analysis showed that night-time mean arterial pressure (MAP), night-time systolic and diastolic blood pressures, 24-hr systolic blood pressure, dipping rate and nocturnal reduction rate of MAP were the parameters that correlated with GLS. Only dipping rate was independently associated with LV GLS. **Conclusion:** An isolated non-dipper BP was found to cause impaired LV systolic function detected by myocardial strain.

Keywords: Hypertension; non-dipper; dipper; strain; mean arterial pressure

ÖZET Amaç: Non-dipper hipertansiyon, artmış hedef organ hasarı ve olumsuz kardiyovasküler olaylarla ilişkilidir. Dipper ve non-dipper hipertansif hastalarda 2 boyutlu strain ekokardiyografi ile kardiyak hasar değerlendirilmesi, daha önce kapsamlı bir şekilde araştırılmamıştır. Biz daha önceden tedavi almamış, yeni tanı hipertansif hastalarda dipper ve non-dipper paternin miyokardiyal deformasyon strain parametreleri üzerine olan etkisini araştırdık. **Gereç ve Yöntemler:** Çalışmamıza daha önceden kardiyovasküler veya kronik hastalığı olmayan 42 yeni tanı hipertansif hastayı dâhil ettik. Hastalar 23 dipper ve 19 non-dipper olarak 2 gruba ayrıldı. "Global longitudinal strain (GLS)", radyal strain ve sirkümferansiyel strain analizleri 2 boyutlu "speckle tracking" metodu ile yapıldı. **Bulgular:** Çalışmaya dâhil edilen 42 hastanın (15 erkek), ortalama yaşı 54,5±9 idi. Sol ventrikül sistolik fonksiyonlarının analizinde dipper grupta GLS, non-dipper gruba göre anlamlı olarak daha yüksek bulundu (-18,13±2,07 vs. -13,7±1,95; p=0,001). Fakat radyal veya sirkümferansiyel strainde 2 grup arasında anlamlı fark yoktu. Gece ortalama arter basıncı, gece ve gündüz sistolik kan basıncı, 24 saat sistolik kan basıncı, dipping oranı, gece ortalama arter basınç düşme oranı, GLS ile korele bulundu. Fakat bu parametrelerden sadece dipping oranı, GLS ile bağımsız olarak ilişkili bulundu. **Sonuç:** İzole non-dipper kan basıncı paterni, miyokardiyal strain ile saptanan sol ventrikül fonksiyonlarında bozulmayla ilişkilidir.

Anahtar Kelimeler: Hipertansiyon; non-dipper; dipper; strain; ortalama arter basıncı

Numerious studies showed that a non-dipping blood pressure (BP) defined as insufficient night-time fall (<10%) determined by ambulatory blood pressure measurement (ABPM), has been associated with increased cardiovascular risk and has strong prognostic value of morbidity and mortality.[1]

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In non-dipper patients, left ventricular (LV) and left atrial sizes increased and thus have been linked to impaired LV diastolic function as well as systolic function compared to dippers.[2,3] Measurements of myocardial function by strain echocardiography have advantages over other conventional echocardiographic measurements, and subclinical organ damage can be detected earlier than convential LV ejection fraction (EF) measurements.[4,5]

To date, there are a few investigations that define the role of LV mechanics in detecting subclinical cardiovascular abnormalities in newly diagnosed dipper-non-dipper hypertensives with normal LV function.[6,7] Consequently, we aimed to evaluate myocardial deformational strain parameters in dipper/non-dipper status.

MATERIAL AND METHODS

We included 42 newly diagnosed hypertensive patients (15 male, and mean age: 54.5±9 years) with no previous underlying cardiovascular disease, heart failure, valvular heart disease, cerebrovascular disease, coronary stents, metallic prosthetic valves, peripheral artery disease, malignancy, atrial fibrillation, active autoimmune disorders, and chronic kidney disease. Office BP measurements used in the study were taken with a mercury sphygmomanometer. For each subject, 24-hour blood pressure was measured with Tonoport V (GE Medical system IT Inc., Milwaukee WI, USA) using the software CardioSoft V6.0 Software (GE Medical System IT Inc.). Hypertension was defined as 24-hour ABP readings ≥130/80 mmHg in subjects who had not been prescribed any antihypertensive drugs. A systolic blood pressure (SBP) decrease of less than 10% during sleep was regarded as non-dipper hypertension.

ETHICAL ASPECTS OF THE STUDY

This study was conducted in accordance with the principles of the Helsinki Declaration. It was approved by the clinical research ethics committee of Istanbul Medipol University dated 24 December 2020 and numbered 998. Patient (or legally authorized representative) has given voluntary, informed consent before enrolling the study.

CLINICAL EXAMINATION AND BLOOD SAMPLES

Blood samples were taken in the morning following a 12 hour fast. Baseline clinical and demographic data were collected. A thorough medical history and a detailed physical examination were recorded. Fasting blood glucose, HbA1c, lipid parameters, creatinine and hemoglobin values were measured. Body mass index was calculated as the ratio of weight (kg) divied by height (m^2).

CONVENTIONAL AND SPECKLE TRACKING ECHOCARDIOGRAPHY

Measurements by two-dimensional echocardiography, conventional pulsed Doppler were recorded using a commercially available echocardiography machine (VIVID S-5 General Electric Medical System Vingmed Ultrasound AS; General Electric Medical System, Horten, Norway). Offline analysis was performed using EchoPAC V.112.0 (General Electric-Vingmed, Horten, Norway). M-Mod measurements of interventricular septum and posterior wall thickness and LV dimensions were measured at end-diastole by a cardiologist who was blind to 24-h ABPM measurements.[8] The endocardial border was traced at end-systolic and end-diastolic frames in both the apical four-chamber and two-chamber views and LV volumes and EF were calculted using the bi-plane Simpson's formula. From the transmitral flow signal, peak early diastolic velocity (E), peak late diastolic velocity (A) and the E/A ratio were assessed. From the tissue doppler imaging (TDI) recordings, peak systolic (s′) and 'e'' were measured from the 4 acquisition sites with a 2-5 mm sample volume. We calculated the E/e' ratio by dividing E wave by e' velocity.

Two-dimensional (2D) speckle tracking strain analysis has been proposed as a more sensitive way to assess early decline in myocardial systolic function. LV global longitudinal strain (GLS), global circumferential strain and global radial strain were respectively obtained from three standard apical (4-chamber, long-axis, and 2-chamber) and parasternal short-axis views (basal, mid, and apical levels). GLS is determined by the average value of three views assesed in the 18 LV segments (Figure 1).

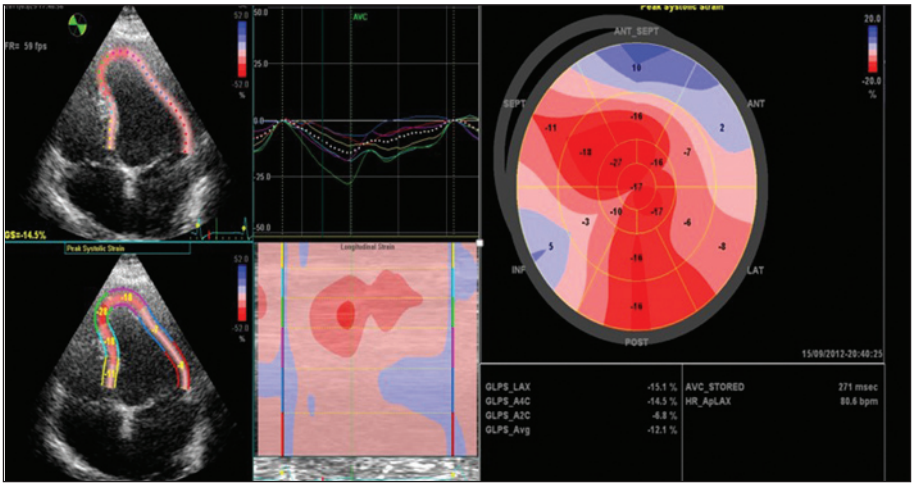

FIGURE 1: Assessment of global 4 chamber, 2 chamber and avarage longitudinal strain of a patient with non-dipper hypertension by two-dimensional speckle tracking echocardiography.

STATISTICAL ANALYSIS

Data are expressed as mean±standard deviation for continuous variables. Frequencies and percentages were used for categorical variables. Normal distribution of variables was assessed by Kolmogorov-Smirnov test. Student's t-test and Mann-Whitney U test were used for comparing continuous variables whereas chi-square was used for categorical variables. Data were analyzed by using IBM SPSS Statistics for Windows, Version 21 (IBM Corp., Armonk, N.Y., USA). Pearson's correlation coefficient was used for determining correlation between different BP readings and LV strains. A multivariable linear regression analysis was employed to assess the independent predictors of 2D GLS. Variables with a p value <0.10 were included in regression analysis. A significance was defined as p value <0.05.

RESULTS

CLINICAL CHARACTERISTICS

The clinical characteristics and BP readings of the study population are summarized in Table 1. The study population included 42 patients (15 male) with a mean age of 54.5±9 years. Nineteen patients (45.2%) had a non-dipper BP pattern. No significant difference between the laboratory measurements of the two groups was observed, except for higher LDL cholesterol (p=0.028) and fasting glucose levels (p=0.037) in non-dipper group (Table 2).

Conventional echocardiographic and 2D-speckle-tracking echocardiography (STE) parameters of the patients are also presented in Table 2. LV end-diastolic and end-systolic diamaters and volumes, and LV EF were similar for both groups. Septal thickness and posterior wall thickness values were higher in non-dippers (p=0.002, p=0.045, respectively). Non-dippers showed a higher left atrium enlargement (37.7±4 vs. 40.25±3; p=0.048) with similar left atrium volume index values (median: 22, IQR: 20-31 vs. median 22 IQR: 18-23). Moreover, non-dipper group had a tendency of higher median (IQR) ratio of E/e′ 14.5 (11.3-16) vs. 11 (10-15.3) (p=0.07) suggesting raised LV filling pressures. Importantly, we found reduced GLS values in non-dippers compared with dippers (-18.13±2.07 vs. -13.7±1.95; p=0.001) whereas, no significant inter-group differences were observed in circumferential and radial strain as shown in Table 2.

CORRELATION AND REGRESSION ANALYSES

Table 3 illustrates correlations between different BP readings, and LV strain parameters. The analysis showed that night-time mean arterial pressure (MAP), night-time SBP and diastolic blood pressure, 24-hr SBP, dipping rate and nocturnal reduction rate of MAP were the parameters that correlated with GLS. Only dipping rate was independently associated with LV GLS (Table 4).

TABLE 1: Clinical data for dipper and non-dipper hypertensive patients.

Patient characteristics	Total (n=42)	Dippers (n=23, 54.8%)	Non-dippers (n=19, 45.2%)	p value
Demographic data				
Sex male	15 (35.7%)	6 (40%)	9 (60%)	0.2
Age (years)	54.5±9	52±10	57±8	0.1
BSA* kg/m² (IQR)	1.9 (1.8-2)	1.9 (1.8-2)	1.9 (1.9-2)	0.23
BMI, kg/m²	30.8±4	30.7±5	30.8±4	0.9
Clinical data				
Office SBP mmHg	149.7±11	145.5±11	154.3±10	0.01*
Office DBP mmHg	93.9±10	92.1±7	95.8±11	0.2
Heart rate	76±12	79.9±13	72±11	0.07
Mean arterial pressure, mmHg	114.89±10	112.4±9	117.5±11	0.1
Mean arterial pressure (daytime), mmHg	112.7±11	110.98±11	114.7±11	0.6
Mean arterial pressure (nighttime), mmHg	99.18±11	91.21±8.4	107.9±8.1	0.85
Dipping rate,%	10.32±7.4	15.7±4.7	3.7±3.9	0.001
Nocturnal reduction rate of MAP (%)	12.22±7.0	18.14±4.3	5.06±4.7	0.001
Pulse pressure , mmHg	52.59±10	52.9±8	52±12	0.7
24th average SBP, mmHg	144.9±13	139.9±12	150.3±13	0.013*
24th average DBP, mmHg	89.8±8	87.2±7	92.6±8	0.03*
24th average day-time SBP, mmHg	149±15	145.7±14	152.7±15	0.1
24th average day-time DBP, mmHg, (IQR)	92 (86-98.8)	91 (86-97)	92 (87-101)	0.73
24th average night-time SBP, mmHg	133.6±16	122.5±12	145.8±11	0.001
24th average night-time DBP, mmHg	81.9±10	75.5±7	89±7	0.001
QTc, mm	404.8±11	403±25	406±16	0.6

BSA: Body surface area; BMI: Body mass index; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; MAP: Mean arterial pressure; *IQR: Inter-quartile range.

DISCUSSION

The present study has shown that non-dippers with no history of prior cardiovascular event had higher prevalence LVH, relatively increased LV diastolic dysfunction and decreased LV global longitudinal systolic functions compared to a dipper pattern. 2D-STE revealed significantly impaired GLS in non-dippers before LVEF appeared abnormal.

Studies have demonstrated that every 10 mmHg reduction in SBP lowers the risk of heart failure by 12%.[9] Non-dippers have higher rates of LV hypertrophy and impaired LV diastolic function compared to dippers. Normally, LVEF has been promoted as the main prognostic indicator of cardiac dysfunction. However, this method has severe shortcomings depending on simple conventional measures which are only a representative of LV geometric change other than the function change.[10] It is becoming increasingly apparent that LV EF is inaccesible particularly in those patients with subtle degrees of LV systolic impairment. Maciver et al. reported that LVEF may be normal due to the compensation of increased radial wall thickness in LV hypertrophy even so longitudinal systolic strain had been reduced earlier.[11] Similarly, Seo et al. showed that non-dipper BP patients with preserved LV EF had reduced strain and strain rates and suffered adverse cardiac remodeling.[4] Our results were compatible with these studies which verified the usefulness of the strain in reflecting early and subtle myocardial impairment in non-dipper BP patients despite having early normal LV EF measurements.

Gokdeniz et al. found that non-dippers with Type 2 diabetes mellitus (DM) had impaired LV rotational mechanics compared with hypertensive dippers with Type 2 DM.[12] Taking into account their

TABLE 2: Parameters of blood tests and echocardiography in dipper and non-dipper hypertensive patients.

Parameters	Total (n=42)	Dippers (n=23, 54.8%)	Non-dippers (n=19, 45.2%)	p value
Blood tests				
Fasting glucose (mg/dL)	104.92±13	100.6±15	109.1±9	0.037*
HbA1C (%)	5.39±0.96	5.2±0.99	5.54±0.92	0.9
Hemoglobin (mg/dL)	13.59±0.94	13.42±1.09	13.79±0.7	0.1
LDL (mg/dL)	133.4±26	122.6±26	144.2±20	0.028*
HDL (mg/dL)	45.8±11	49.2±10	42.4±11	0.7
Triglyceride (mg/dL)	121.8±45	116.1±43	127.5±48	0.89
Creatinine (mg/dL), (IQR)	0.7 (0.7-1)	0.95 (0.7-0.85)	0.7 (0.69-0.85)	0.19
Echocardiograpic parameters				
LV EF %	59.12±5.2	59.7±5	58.4±5	0.4
LV end-diastolic dimension (mm)	47.6±3.8	27±3	29±6	0.9
LV end-systolic dimension (mm)	28.5±5.2	40±12	45±19	0.1
LV mass, g	236±49	228±41	245±56	0.2
LV mass index, (g/m^2) (IQR)	119.5 (101.5-144)	121 (102-144)	111 (100-144)	0.71
LV end-diastolic volume (mL/m^2)	89.6±19	84.9±12	94.95±23	0.09
LV end-systolic volume (mL/m^2), (IQR)	40 (30-50)	39 (30-42)	40 (33-51)	0.27
LA, mm	38.9±4	37.7±4	40.25±3	0.048*
LAVI, (IQR)	22 (20-24.3)	22 (18-23)	22 (20-31)	0.26
Septal wall thickness,mm	12.4±1	11.8±0.9	12.8±0.9	0.002
Posterior wall thickness,mm	11.5±1.2	11.1±1.3	11.8±0.9	0.045
E wave (m/s) (IQR)	0.6 (0.5-0.7)	0.6 (0.5-0.7)	0.6 (0.5-0.7)	0.77
A wave (m/s) (IQR)	0.8 (0.7-0.9)	0.8 (0.7-0.83)	0.75 (0.7-0.9)	0.87
E/e' ratio (IQR)	13.5 (10-16)	11 (10-15.3)	14.5 (11.3-16)	0.07
Global longitudinal strain	-16.12±2.9	-18.13±2.07	-13.70±1.95	0.001*
Global radial strain	52.57±9.2	53.30±10.44	51.68±7.6	0.5
Global circumferancial strain	-15.93±2.0	-15.50±2.4	16.41±1.4	0.13

LDL: Low density cholesterol; HDL: High density cholesterol; EF: Ejection fraction; LV: Left ventricle; LA: Left atrium; LAVI: Left atrium volume index; IQR: Inter-quartile range.

TABLE 3: Correlation between left ventricle systolic strain and blood pressure parameters.

	Longitudinal strain		Radial strain		Circumferancial strain	
Variable	**r value**	**p value**	**r value**	**p value**	**r value**	**p value**
Office SBP mmHg	-0.154	0.32	-0.236	0.132	-0.070	0.66
Office DBP mmHg	0.036	0.8	-0.168	0.28	-0.098	0.5
Heart rate	0.269	0.08	-0.132	0.406	- 0.130	0.41
Mean arterial pressure, mmHg	-0.080	0.6	-0.241	0.124	-0.013	0.9
Mean arterial pressure (daytime), mmHg	-0.087	0.58	-0.234	0.136	-0.147	0.352
Mean arterial pressure (nighttime), mmHg	-0.616**	0.001	-0.279	0.074	-0.052	0.7
Dipping rate,%	0.760**	0.001	0.067	0.6	0.118	0.45
Nocturnal reduction rate of MAP (%)	0.707**	0.001	0.112	0.4	0.231	0.14
Pulse pressure, mmHg	-0.052	0.7	-0.117	0.461	-0.040	0.8
24th average SBP, mmHg	-0.331*	0.032	-0.317*	0.041	-0.081	0.610
24th average DBP, mmHg	-0.288	0.065	-0.179	0.257	-0.004	0.98
Day-time SBP, mmHg	-0.156	0.325	-0.290	0.06	-0.133	0.4
Day-time DBP, mmHg	-0.039	0.80	0.130	0.414	-0.100	0.52
Night-time SBP, mmHg	-0.639**	0.001	-0.275	0.078	-0.021	0.89
Night-time DBP, mmHg	-0.548**	0.001	-0.259	0.097	-0.107	0.499

SBP: Systolic blood pressure; DBP: Diastolic blood pressure; MAP: Mean arterial pressure; *p<0.05; **p<0.01.

TABLE 4: Predictors of global longitudinal strain.

	Correlation regression r value	Multivariate β
Dipping rate, %	0.760**	0.613*
Nocturnal reduction rate of MAP (%)	0.707**	-0.002
MAP (nighttime), mmHg	-0.616**	-0.244

MAP; Mean arterial pressure; *p<0.05; **p<0.01.

small sample size and technique limitations such as angle dependency of tissue Doppler imaging, and high inter-observer variance for the rotation of LV, their general applicabiliy is limited. So, non-doppler 2D-strain imaging derived from speckle tracking used in the present study seems to be more accurate and sensitive tool for the evaluation of subclinical myocardial dysfunction. Different from the previous studies, we found that only GLS rather than radial or circumferential strain was related with non-dipper BP patterns.[7,13] Previously, reproducibility of GLS has shown good accuracy than circumferential and radial assessment.[14] The reason that reduced GLS may be that non-dipper hypertension extending to the nocturnal period causes microscopic changes such as increased accumulation of collagen, myocardial fibrosis thus leading to higher wall stress, hypertrophy and early intrinsic depression of subendocardial longitudinal fiber contractility as shown by other studies.[7,13] For this reason, longitudinal myocardial performance is initially impaired, whereas in the early stages of hypertension, transverse-oriented circumferential fibers promotes normal EF values. In line with the findings of our study, Kosmala et al showed that longitudinal strain firstly reduced in hypertensives and become lower prior to the cardiac function deteriorated whereas radial strain as well as circumferential strain is preserved, even might be slightly higher in the early stage of hypertension in compensation for the decrease in longitudinal strain.[15] In the later stages of hypertension, a further LV modelling will occur, with resultant impairment of other components of LV strain.[16]

Impairment in myocardial function in non-dipper pattern is related to more prominent cardiovascular risk for these patients. The evaluation of non-dipper BP using ABPM may help to clarify those with subtle myocardial injury and this might prevent future cardiac adverse outcomes.

LIMITATIONS

A major limitation of the current study is its cross-sectional design, preventing essential data for calculating cardiovascular risk estimates, together with relatively small sample size to generalize our findings. Diagnosis of dipper and non-dipper hypertension was based on a single 24 hours ABPM which may lead to an inaccurate judgment however definition of dipper/non-dipper BP pattern should be based on two ABPM recordings to correctly diagnose patients at risk for target organ damage. Patients with comorbidities were excluded in our study and this might have impeded the potential generalization of our results and concealed actual real-life data. However, we aimed mainly to determine the relationship of non-dipper BP and LV deformation irrespective of other risk factors. Another important limitations of our study are the lack of a control group of healthy individuals and being a single center trial with strict selection of few patients. Finally, even magnetic resonance imaging (MRI) seems to be the gold standard for myocardial strain imaging, 2D-STE correlates well with MRI.[17]

CONCLUSION

An isolated non-dipper BP was found to cause impaired LV systolic functions detected by myocardial strain. More close follow-up and aggressive BP treatment especially in those with reduced LV GLS in non-dipper patients could improve risk stratification and prevent premature adverse events in this high-risk population.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Source of Finance

During this study, no financial or spiritual support was received neither from any pharmaceutical company that has a direct connection with the research subject, nor from a company that provides or produces medical instruments and materials which may negatively affect the evaluation process of this study.

Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

Idea/Concept: *Sinem Çakal;* ***Design:*** *Beytullah Çakal;* ***Control/Supervision:*** *Beytullah Çakal;* ***Data Collection and/or Processing:*** *Sinem Çakal;* ***Analysis and/or Interpretation:*** *Sinem Çakal;* ***Literature Review:*** *Beytullah Çakal;* ***Writing the Article:*** *Beytullah Çakal;* ***Critical Review:*** *Sinem Çakal;* ***References and Fundings:*** *Sinem Çakal;* ***Materials:*** *Sinem Çakal.*

REFERENCES

1. O'Brien E, Parati G, Stergiou G, Asmar R, Beilin L, Bilo G, et al; European Society of Hypertension Working Group on Blood Pressure Monitoring. European Society of Hypertension position paper on ambulatory blood pressure monitoring. J Hypertens. 2013;31(9):1731-68. Erratum in: J Hypertens. 2013;31(12):2467. [Crossref] [Pubmed]
2. Aydin M, Ozeren A, Bilge M, Dursun A, Cam F, Elbey MA. Effects of dipper and non-dipper status of essential hypertension on left atrial mechanical functions. International Journal of Cardiology. 2004;96(3):419-24. [Crossref]
3. Laukkanen JA, Kurl S, Eränen J, Huttunen M, Salonen JT. Left atrium size and the risk of cardiovascular death in middle-aged men. Arch Intern Med. 2005;165(15):1788-93. [Crossref] [Pubmed]
4. Seo HS, Kang TS, Park S, Choi EY, Ko YG, Choi D, et al. Non-dippers are associated with adverse cardiac remodeling and dysfunction (R1). Int J Cardiol. 2006;112(2):171-7. [Crossref] [Pubmed]
5. Soylu A, Duzenli MA, Yazici M, Ozdemir K, Tokac M, Gok H. The effect of nondipping blood pressure patterns on cardiac structural changes and left ventricular diastolic functions in normotensives. Echocardiography. 2009;26(4):378-87. [Crossref]
6. Tadic M, Cuspidi C, Majstorovic A, Sljivic A, Pencic B, Ivanovic B, et al. Does a nondipping pattern influence left ventricular and left atrial mechanics in hypertensive patients? J Hypertens. 2013;31(12):2438-46. [Crossref] [Pubmed]
7. Chen Y, Liu JH, Zhen Z, Zuo Y, Lin Q, Liu M, et al. Assessment of left ventricular function and peripheral vascular arterial stiffness in patients with dipper and non-dipper hypertension. J Investig Med. 2018;66(2):319-24. [Crossref] [Pubmed] [PMC]
8. Lang RM, Bierig M, Devereux RB, Flachskampf FA, Foster E, Pellikka PA, et al; Chamber Quantification Writing Group; American Society of Echocardiography's Guidelines and Standards Committee; European Association of Echocardiography. Recommendations for chamber quantification: a report from the American Society of Echocardiography's Guidelines and Standards Committee and the Chamber Quantification Writing Group, developed in conjunction with the European Association of Echocardiography, a branch of the European Society of Cardiology. J Am Soc Echocardiogr. 2005;18(12):1440-63. [Crossref] [Pubmed]
9. UK Prospective Diabetes Study Group. Tight blood pressure control and risk of macrovascular and microvascular complications in type 2 diabetes: UKPDS 38. UK Prospective Diabetes Study Group. BMJ. 1998;317(7160):703-13. Erratum in: BMJ 1999;318(7175):29. [Crossref] [Pubmed] [PMC]
10. Hurlburt HM, Aurigemma GP, Hill JC, Narayanan A, Gaasch WH, Vinch CS, et al. Direct ultrasound measurement of longitudinal, circumferential, and radial strain using 2-dimensional strain imaging in normal adults. Echocardiography. 2007;24(7):723-31. [Crossref]
11. Maciver DH, Townsend M. A novel mechanism of heart failure with normal ejection fraction. Heart. 2008;94(4):446-9. [Crossref] [Pubmed]
12. Gökdeniz T, Kalaycıoğlu E, Aykan AÇ, Gül İ, Boyacı F, Gürsoy MO. Effects of non-dipper blood pressure pattern on left ventricular rotational mechanics in hypertensive patients with type 2 diabetes mellitus: a speckle tracking study. Int J Cardiovasc Imaging. 2014;30(1):57-65. [Crossref] [Pubmed]
13. Liu H, Wang J, Pan Y, Ge Y, Guo Z, Zhao S. Early and quantitative assessment of myocardial deformation in essential hypertension patients by using cardiovascular magnetic resonance feature tracking. Sci Rep. 2020;10(1):3582. [Crossref] [Pubmed] [PMC]
14. Mirea O, Pagourelias ED, Duchenne J, Bogaert J, Thomas JD, Badano LP, et al; EACVI-ASE-Industry Standardization Task Force. Intervendor differences in the accuracy of detecting regional functional abnormalities: a report from the EACVI-ASE strain standardization task force. JACC Cardiovasc Imaging. 2018;11(1):25-34. [Pubmed]
15. Kosmala W, Plaksej R, Strotmann JM, Weigel C, Herrmann S, Niemann M, et al. Progression of left ventricular functional abnormalities in hypertensive patients with heart failure: an ultrasonic two-dimensional speckle tracking study. J Am Soc Echocardiogr. 2008;21(12):1309-17. [Crossref] [Pubmed]
16. Fung MJ, Thomas L, Leung DY. Left ventricular function and contractile reserve in patients with hypertension. Eur Heart J Cardiovasc Imaging. 2018;19(11):1253-9. [Crossref] [Pubmed]
17. Cho GY, Chan J, Leano R, Strudwick M, Marwick TH. Comparison of two-dimensional speckle and tissue velocity based strain and validation with harmonic phase magnetic resonance imaging. Am J Cardiol. 2006;97(11):1661-6. [Crossref] [Pubmed]