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Left Ventricular Strain in Patients with Hypertensive Heart Disease and Normal Ejection Fraction Assessed by Speckle Tracking Echocardiography

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ABSTRACT

Background: Hypertension is a major risk factor for cardiovascular diseases and is associated with increased all-cause and cardiovascular mortality. Cardiac changes such as impaired left ventricular (LV) function, left ventricular hypertrophy (LVH), and heart failure are consequences of chronic exposure to elevated blood pressure. Speckle tracking echocardiography (STE) is a sensitive method for detecting early regional and global myocardial dysfunction missed in asymptomatic patients with cardiovascular disease by conventional modalities.

Objectives: This study aimed to assess the ability of 2D-STE in assessing regional and global LV strain to diagnose subclinical LV dysfunction in patients with systemic hypertension and preserved ejection fraction.

Methods: This prospective observational study included 80 hypertensive patients and 30 healthy controls. In the hypertensive group, at least six months had passed from diagnosis of hypertension according to AHA guidelines. 2D echocardiographic LV images were acquired in apical 4, 2, and 3-chamber and parasternal short axis views. Left ventricular global longitudinal strain (LVGLS) and circumferential strain (LVGCS) were quantified in all segments using a Philips Affiniti 70 device. Differences between hypertensive patients and controls were analyzed using the independent t-test. A P-value less than 0.05 was considered statistically significant.

Results: In comparison, LVGLS and LVGCS were significantly ($P < 0.001$) lower among the hypertensive group (GLS: -17.43 ± 1.71, GCS: -23.76 ± 3.35) than the control group (GLS: -20.18 ± 1.11, GCS: -27.46 ± 4.33). LVGLS was significantly ($P < 0.001$) lower in uncontrolled hypertension (-16.91 ± 1.70) vs. controlled hypertension (-17.96 ± 1.57). Similarly, LVGLS was significantly ($P < 0.001$) lower among the cases with LVH on 2D echocardiography (16.23 ± 1.69) compared to those without LVH (17.96 ± 1.6). In the hypertensive group, LVGLS was significantly lower in males (-16.84 ± 1.42) than in females (-18.02 ± 1.78; $P < 0.05$).

Conclusion: This study demonstrates the potential benefits of using STE as a non-invasive imaging technique in assessing cardiac remodeling and providing a further risk assessment of hypertensive patients.

1. Background

Hypertension is a highly prevalent disease that affects over 1.2 billion individuals worldwide, representing a serious public health concern (1). Impaired left ventricular (LV) function, left ventricular hypertrophy (LVH), and myocardial fibrosis are recognized markers of target organ damage in patients with long-standing hypertension (2).

High blood pressure increases LV afterload and peripheral vascular resistance. Prolonged exposure leads to pressure and volume-mediated LV structural remodeling, ultimately

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leading to heart failure (3, 4). Chronic hypertension ultimately causes maladaptive left LVH, which sets the stage for irreversible deterioration of LV function and eventually results in progression to congestive heart failure, further increasing mortality and morbidity (5, 6). Therefore, it is of utmost importance to detect the early stage of LV impairment in patients with hypertension, identifying those at high risk for developing heart failure and commencing appropriate medical interventions.

Assessment of LV systolic function is a central part of the evaluation of cardiac disease. Accurate assessment of LV function is important for guiding patient management and prognosis, and it is essential in evaluating patients with known or suspected cardiac disease. The modified Simpson biplane method is the currently recommended method of quantifying LV volume and systolic function. This method calculates the LV volume by manually tracking the LV endocardial border in two planes: the apical four-chamber and two-chamber views. The LV is then approximated to a series of elliptical discs that are summated to determine the LV volume. Assessment of the change in ventricular volumes between systole and diastole allows estimation of the left ventricular ejection fraction (LVEF) (7).

Myocardial strain refers to the percentage of myocardium deformation during the cardiac cycle. It represents the extent of regional myocardial deformation in a specified period in three orthogonal directions (longitudinal, radial, and circumferential). Initially, two techniques were introduced to assess myocardial strain: cardiac magnetic resonance (CMR) in the late 1980s (8) and tissue Doppler imaging (TDI) in the 1990s (9). Speckle tracking echocardiography (STE) signaled a new era in echocardiographic strain imaging, introduced in the early 2000s (10). This technique is based on tracking the movement of the speckles generated by the interaction of ultrasound waves with the myocardium. Semiautomated tracking of the clusters of speckles allows the assessment of myocardial deformation and offers an angle-independent measure of strain (11, 12). In addition, compared with tissue Doppler strain, this technique offers the clear advantages of easier and faster strain assessment, and 2-D STE is superior because of improved correlation with MRI, improved feasibility, and reduced interobserver and intraobserver variability (12).

Left ventricular systolic function results from a combination of longitudinal and circumferential myofiber shortening. Global longitudinal strain (GLS) assesses the function of longitudinally orientated myofibers, most vulnerable to myocardial disease because of their subendocardial location; global circumferential strain (GCS) assesses the circumferential myofibers, predominantly located in the mid myocardial wall and typically affected by a more clinically significant myocardial disease (13). GLS can be assessed from the apical window using standard apical four-chamber, two-chamber, and long-axis images. GCS and global radial strain (GRS) can be assessed using parasternal short-axis imaging performed at the basal, mid, and apical levels. During systole, the shortening of the longitudinal and circumferential myocardial fiber length (assessed by GLS and GCS, respectively) is denoted by negative values (11, 13).

For patients with impaired LVEF, GLS and LVEF have a linear relationship, with a GLS of -11% or -12% corresponding to an LVEF of 35%. In contrast, GLS and LVEF have a curvilinear relationship in patients with normal LVEF. Therefore, the ability of GLS to detect subclinical myocardial dysfunction is likely greatest for patients with normal LVEF, and the advantage of GLS over LVEF might be its sensitivity in detecting early subclinical cardiomyopathy before LVEF (14).

The most widely used clinical application of STE is measuring the GLS. It has been recommended by the American Society of Echocardiography (ASE) for the evaluation of global LV systolic function, with the 2D-GLS validated as a powerful predictor of cardiac mortality and morbidity in various cardiac conditions, providing additional prognostic information over LVEF assessment alone (15-17). Assessing the GLS is beneficial in populations with various ejection fractions (17). Two-dimensional GLS remains the predominant tool for clinical application because of its ease of use, reproducibility, time efficiency, and simplicity (15, 17).

2. Objectives

This study aimed to assess the ability of 2D-STE in assessing regional and global LV strain to diagnose subclinical LV dysfunction in patients with systemic hypertension and preserved ejection fraction.

3. Patients and Methods

3.1. Study Subjects and Study Design

This prospective observational study was conducted at Rajaie Cardiovascular Medical and Research Center on 80 hypertensive patients and 30 age- and sex-matched healthy controls. In the hypertensive group, at least six months had passed from diagnosis of hypertension according to AHA guidelines (office/home mean blood pressure ≥ 130/80 mmHg and 24-hr mean blood pressure ≥ 125/75 mmHg). The control subjects had no identifiable cardiovascular risk factors and were not receiving any medications; they were healthy volunteers from the hospital staff and local community members. The inclusion criteria included any adult patient with essential chronic hypertension, the ability to monitor daily blood pressure at home (at least once in the morning and once in the evening), a normal sinus rhythm, and a normal ejection fraction (EF).

We excluded patients with EF < 55% (estimated with Simpson's method); those with signs and symptoms of heart failure; diabetes mellitus patients; those with any known coronary artery disease, regional wall motion abnormalities on echocardiography, significant valvular disease and diastolic dysfunction, or hypertrophic cardiomyopathy; and patients with pulmonary arterial hypertension or cardiac arrhythmias (e.g., atrial fibrillation).

At the beginning of the study, patients with the diagnosis of systemic hypertension were examined after taking a clinical history and evaluating their past medical history and average systolic and diastolic blood pressures over the preceding 12 weeks. If a normal sinus rhythm was present, conventional echocardiography and 2D speckle tracking imaging were performed using Philips Affiniti 70 machines.

All images were obtained in hypertensive patients and controls during end-expiration in the left lateral position, with single-lead ECG monitoring.

3.2. Echocardiographic Measurements

A single echocardiography fellow obtained all standard measurements in the parasternal short-axis views, apical four-chamber, apical three-chamber, and apical two-chamber views. For parasternal short-axis imaging, the transducer was placed in the left parasternal third or fourth intercostal space. The apical views were obtained with the transducer placed in the fifth intercostal space in the anterior axillary line close to the maximal impulse. Images were recorded at a frame rate of more than 55 frames per second.

Strain imaging was analyzed using Philips QLAB commercial software 13 after 2D strain imaging with the speckle tracking method. After manual tracing of the endocardial border of 2D tomographic LV images in the longitudinal and short-axis planes at the mid-cavity level at the end-diastolic frame, the software automatically determined six segments in each view. Each segmental strain curve was generated by tracking acoustic markers in the myocardial tissue. Peak systolic longitudinal strain was measured in 18 segments (basal anterolateral, mid-anterolateral, apical anterolateral, basal inferoseptal, mid inferoseptal, apical inferoseptal, basal inferior, mid-inferior, apical inferior, basal anterior, mid anterior, apical anterior, basal inferolateral, mid inferolateral, apical inferolateral, basal anteroseptal, mid anteroseptal, and apical anteroseptal) (figure 1). Peak circumferential strain was measured in 6 segments from the mid-LV short-axis view (mid anterior, mid anteroseptal, mid inferior, mid inferoseptal, mid anterolateral, and mid inferolateral).

3.3. Statistical Analysis

Data analysis was done using the Statistical Package for Social Sciences (SPSS Inc., Chicago, IL, USA), version 26. Descriptive statistics, including mean and standard deviation, were considered. The t-test was used to assess the significant difference in left ventricular strain between hypertensive patients and controls. A P-value less than 0.05 was considered statistically significant.

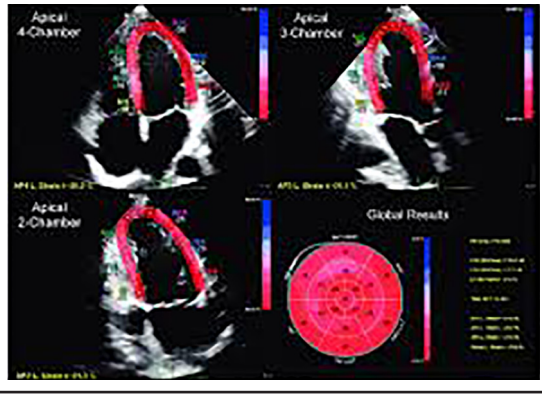

Figure 1. Example of Left Ventricular Global Longitudinal Strain (LVGLS) Measurement

4. Results

Regarding the risk factor of the study population, there were no significant differences between the hypertensive subjects and the normal group. In both groups, 50% of the subjects were female, and 50% of them were male. The mean age of patients with hypertension was 51.00 ± 10.00 years, and that of healthy controls was 45 ± 9.80 years.

In the hypertensive group, 50% (n = 40) had uncontrolled hypertension (average systolic blood pressure ≥ 140 mmHg or diastolic blood pressure ≥80 mmHg in the preceding 12 weeks ago based on home mean blood pressure monitoring) with an average duration of hypertension of 6.91 ± 6.00 years, and 50% had controlled hypertension (average systolic blood pressure < 140 mmHg and diastolic blood pressure < 80 mmHg in preceding 12 weeks based on home mean blood pressure monitoring). The average duration of hypertension was about 4.16 ± 5.47 years. The mean age of uncontrolled hypertensive patients was approximately 51.01 ± 9.85 years, and that of the controlled hypertensive patients was 52 ± 10.90 years. In the hypertensive patients, 17.5% (n = 14) had mild LVH on 2D echocardiography (wall thickness > 1 cm in males and > 0.9cm in females).

An independent t-test was conducted to compare the LV strain in the normal and hypertensive groups. LVGLS was significantly (P < 0.001) lower in the hypertensive group (-17.43 ± 1.71) compared with the control group (-20.18 ± 1.11) (Table 1); the regional longitudinal strain was also significantly lower in the hypertensive patients in all LV segments except the apico-anterolateral, apico-anterior, and apico-inferoseptal segments (Table 2).

Similarly, LVGCS was significantly (P < 0.001) lower among hypertensive cases (23.76 ± 3.35) compared with the controls (27.46 ± 4.33) (Table 1). The left ventricular circumferential strain (LVCS) parameters in different LV segments were significantly (P < 0.05) lower among hypertensive patients compared with the controls (Table 3).

In hypertensive patients, LVGLS was significantly (P < 0.05) lower in hypertensive men (16.84 ± 1.42) in comparison to women (18.02 ± 1.78), but LVGCS was insignificantly (P < 0.25) lower in hypertensive men (-23.33 ± 3.89) compared with women (-24.20 ± 2.69)

Notably, LVGLS was significantly (P < 0.001) lower among cases with uncontrolled hypertension (-16.91 ± 1.70) compared to cases with controlled hypertension (-17.96 ± 1.57) (Table 4). Similarly, LVGLS was found to be significantly (P < 0.001) lower among cases with LVH on 2D echo (16.23 ± 1.69) in comparison to cases without LVH (17.96 ± 1.6).

Table 1. Comparison between Hypertensive and Normal Subjects regarding Left Ventricular Global Longitudinal (LVGLS) and Circumferential Strain (LVGCS)

Parameter	Case (n = 80)	Control (n = 30)	P-value
LVGLS (mean ± SD)	-17.43 ± 1.71	-20.18 ± 1.11	< 0.001
LVGCS (mean ± SD)	-23.76 ± 3.35	27.46 ± 4.33	< 0.001

Table 2. Comparison of Left Ventricular Longitudinal Strain (LVLS) in all Segments between Hypertensive and Normal Subjects

LVLS Parameter	Hypertensive (n = 80)	Controls (n = 30)	P-value
BI	-16.08 ± 4.29	-18.70 ± 3.08	0.001
MI	-17.58 ± 3.00	-21.23 ± 2.59	0.000
AI	-21.29 ± 3.95	-23.29 ± 3.62	0.015
BA	-16.40 ± 4.32	-19.51 ± 4.34	0.002
MA	-16.40 ± 3.83	-18.66 ± 3.65	0.006
AA	-18.76 ± 4.23	-19.80 ± 5.41	0.384
BIS	-14.87 ± 3.73	-17.03 ± 2.28	0.000
MIS	-18.18 ± 3.23	-20.11 ± 2.47	0.001
AIS	-23.00 ± 3.74	-24.37 ± 3.10	0.056
BAL	-16.65 ± 4.75	-20.01 ± 3.21	0.000
MAL	-16.00 ± 3.63	-19.45 ± 2.40	0.000
AAL	-19.73 ± 3.66	-20.41 ± 3.47	0.374
BIL	-13.97 ± 4.47	-17.91 ± 4.05	0.000
MIL	-15.48 ± 2.924	-19.54 ± 2.95	0.000
AIL	-20.54 ± 4.59	-22.49 ± 3.75	0.026
BAS	-15.58 ± 3.60	-18.01 ± 3.02	0.001
MAS	-18.67 ± 3.20	-21.73 ± 2.88	0.000
AAS	-20.15 ± 3.57	-23.47 ± 3.24	0.000

Abbreviations: AA, apical anterior; AAL, apical anterolateral; AAS, apical anteroseptal; AI, apical inferior; AIS, apical inferoseptal; AIL, apical inferolateral; BA, basal anterior; BAL, basal anterolateral; BAS, basal anteroseptal; BI, basal inferior; BIS, basal inferoseptal; BIL, basal inferolateral; MA, mid-anterior; MAL, mid-anterolateral; MAS, mid-anteroseptal; MI, mid-inferior; MIS, mid-inferoseptal; MIL, mid-inferolateral

Table 3. Comparison of Left Ventricular Circumferential Strain (LVCS) in all Segments between Hypertensive and Normal Subjects

LVCS Parameter	Hypertensive (n=80)	Controls (n = 30)	P-value
MA	-22.45 ± 4.28	-25.25 ± 5.45	0.015
MI	-23.70 ± 4.29	-26.63 ± 5.48	0.012
MIS	-25.06 ± 4.67	-29.93 ± 4.41	0.000
MAS	-24.13 ± 4.46	-27.30 ± 5.11	0.004
MAL	-23.63 ± 4.99	-28.43 ± 5.36	0.000
MIL	-23.88 ± 3.99	-26.26 ± 5.45	0.035

Abbreviations: MA, mid anterior; MAL, mid-anterolateral; MAS, mid-anteroseptal; MI, mid-inferior; MIS, mid-inferoseptal; MIL, mid-inferolateral

Table 4. Comparison between Uncontrolled and Controlled Hypertensive Patients regarding Left Ventricular Global Longitudinal (LVGLS) and Circumferential Strain (LVGCS)

Parameter	Uncontrolled Hypertension (n = 40)	Controlled Hypertension (n = 40)	P-value
LVGLS (mean ± SD)	-16.91 ± 1.70	-17.96 ± 1.57	< 0.001
LVGCS (mean ± SD)	-23.69 ± 3.70	-23.85 ± 3.01	0.856

As shown in Table 4, LVGCS was statistically similar between the cases with LVH on 2D echo (23.76 ± 3.50) and cases without LVH (23.78 ± 2.68). A similar finding was seen when comparing patients with uncontrolled -23.69 ± 3.70) and controlled hypertension (-23.85 ± 3.01) (Table 4).

5. Discussion

In patients with hypertension, LV systolic function is commonly considered normal if the global EF is preserved. Early subclinical LV systolic dysfunction usually remains undetected by conventional measures of LV systolic function. 2D STE appears more sensitive than conventional echocardiography in identifying the reduction of myocardial contractility.

Chronic hypertension causes structural and functional changes in the heart, ultimately leading to heart failure (18). This study showed an impairment of longitudinal and circumferential LV systolic function detected by a significant reduction of LVGLS and LVGCS in hypertensive patients, even without structural changes such as LVH. Although a significant reduction in longitudinal strain values was found in hypertensive patients with LVH compared with those without LVH, the LVGCS did not show a significant difference. The lack of proper blood pressure control significantly reduced the longitudinal LV strain in asymptomatic patients with preserved EF, but LVGCS did not reveal a significant difference. The present study showed that hypertension was associated with a significant decrease in longitudinal strain in men compared with women, though this finding was not repeated for circumferential strain. These findings emphasize the importance of 2D STE in the diagnosis of impairment of LV systolic function in hypertensive patients.

The present study results are in line with the findings from previous studies. Tadic et al. showed that LVGLS was significantly impaired in the hypertensive group compared to healthy controls (19). Additionally, Imbalzano et al. showed significant impairment of LV longitudinal strain in all hypertensive patients with and without LVH (4). Saghir et al. also demonstrated that hypertensive

individuals with LVH had a significantly decreased systolic longitudinal strain compared with control subjects without LVH (20). Change et al. revealed that intensive treatment in patients with uncontrolled hypertension improved LVGLS, enhancing LV function independent of blood pressure readings (21). Tadic et al. showed that LV longitudinal and circumferential strain were significantly reduced in hypertensive patients. However, the changes were more pronounced in hypertensive men than women (22).

The present study also compared the peak left ventricular longitudinal strain (LVLS) in different LV segments. The LVLS was significantly lower in hypertensive cases compared to the controls in all segments except the apical anterior, apical inferoseptal, and apical anterolateral segments, where the difference did not reach statistical significance. However, the peak left ventricular circumferential strain (LVCS) in all LV segments was significantly lower in hypertensive cases compared to the controls. These results are fairly compatible with the study of Jamwal et al. on hypertensive patients with preserved EF, which revealed that the regional LV longitudinal strain was significantly reduced in the apical posterolateral, apical posteroseptal, and mid-inferoseptal segments of the LV in the hypertensive population compared to the normotensive group, and peak LVCS in different LV segments was significantly lower among the patients compared with the controls (23).

In our study, the reduction of LV longitudinal and circumferential strain was common in isolated hypertension with preserved LVEF, and impairment of LV function happened earlier than structural change (LVH), with cases of controlled hypertension having significantly better results. The assessment of LV longitudinal and circumferential strain represents a novel means of systolic LV function assessment that can identify high-risk asymptomatic hypertension patients who may benefit from an intensive antihypertensive treatment program, preventing irreversible symptomatic heart failure (24, 25).

The limitations of the present study include its single-center, non-randomized design. There was no blinding of the operator regarding hypertensive patients, and the controls had a small sample size, so the trends of reduced regional strain observed in the longitudinal and circumferential axes may not be generalizable to the entire population. We did not check the reproducibility of obtaining estimates of regional strain by different operators; thus, there could have been measurement bias.

5.1. Conclusions

Hypertension is associated with a reduction in LV systolic strain in asymptomatic patients with normal EF with and without LVH, suggesting that LV mechanical abnormalities precede the development of heart failure. STE imaging is a novel, non-invasive, affordable cardiovascular imaging modality that may be used in clinical practice to detect subclinical LV systolic dysfunction and identify high-risk hypertensive patients. A greater extent of impairment was linked with the male gender, LVH, and poorly controlled blood pressure. This study also provides insights into the pattern of early LV dysfunction.

5.2. Ethical Approval

The study design and protocols were approved by the Ethics Committee of the Research Deputyship of Rajaie Cardiovascular, Medical, and Research Center (ID: IR.RHC.REC.1401.022).

5.3. Informed Consent

Written informed consent about the data registration and follow-up policy was obtained from all patients after explaining the purpose of the study. We ensured that the research and the participation of patients did not influence diagnosis and management.

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Authors' Contribution

HK conceived the idea for the manuscript in cooperation with SB. HB was involved in the study design. RK collected the data. AA and HB drafted the manuscript. HB revised the manuscript. MG supervised the article preparation. All authors read and approved the final manuscript.

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Financial Disclosure

All authors declare no conflicts of interest.

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