

Evaluation of left ventricular function by treadmill exercise stress echocardiography combined with layer-specific strain technique in essential hypertension patients

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Abstract

The purpose of this study was to evaluate the diagnostic utility of treadmill exercise stress echocardiography (TESE) combined with left ventricular (LV) layer-specific strain (LSS) in subclinical myocardial and reserve function of hypertensive patients. A total of 55 hypertensive patients and 51 controls were evaluated during rest and exercise. Two-dimensional speckle tracking (2DST) and LSS technique was used to measure longitudinal and circumferential strains at rest and peak exercise, strain difference characteristics were then evaluated. Compared to the control subjects, both longitudinal and circumferential LSS showed different degrees of reduction in hypertensive group, which was more pronounced at peak exercise. The global longitudinal endocardium strain (GLS_{endo}) at rest was $24.4\% \pm 1.5\%$ in the control group versus $20.4\% \pm 2.3\%$ in the hypertensive group, while the difference was more obvious at peak state (control vs. hypertensive group, $30.8\% \pm 2.8\%$ and $22.8\% \pm 2.9\%$, respectively). In particular, endocardial strain under exercise can be used as a sensitive indicator where the LV contractile reserve (CR) function of the three layers are all impaired. TESE combined with LSS might increase diagnostic accuracy of myocardial performance in hypertension patients.

KEYWORDS

hypertension, layer-specific strain, myocardial function, treadmill exercise stress echocardiography

1 | INTRODUCTION

Hypertension is one of the major risk factors affecting the morbidity and mortality of cardiovascular diseases. Long-term hypertension has been established to directly induce and aggravate the irreversible deterioration of left ventricular (LV) function.^{1,2} At present, the application of treadmill exercise stress echocardiography (TESE) in subclinical car-

diac function and related reserve evaluation of essential hypertension still need to be improved, most reports just focus on global myocardium rather than different layers.^{3,4} A number of studies have shown that when the LV ejection fraction (EF) is within the normal range, speckle-tracking strain analysis can be used for the early detection of subclinical myocardial function injury, and represents superior predictor of adverse outcome.⁵⁻⁷ As an emerging indicator, the layer-specific strain

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(LSS) has attracted much attention in clinical application and has been achieved to quantify.⁸ Rowin and colleagues showed that TESE had higher sensitivity and specificity in the diagnosis of suspected myocardial functional damage proposing this approach as an important new technique for noninvasive evaluation.⁹ Therefore, TESE was applied to evaluate the left ventricular LSS in subclinical myocardial function and peak reserve characteristics of patients with essential hypertension.

2 | METHODS

2.1 | Study population and inclusion criteria

A total of 55 patients (average age 54 ± 7.2 years) with high blood pressure constituted the hypertensive patient group, the inclusion criteria: According to the European Guidelines for the Management of Hypertension¹⁰ with blood pressure $\geq 140/90$ mmHg or who explicitly took antihypertensive drugs. Patients were excluded: there was definitive evidence of coronary artery disease (stenosis $\geq 50\%$), stent implantation, diabetes, congenital heart disease, cardiomyopathy of any kind, cardiac valvular disease, arrhythmia, or poor imaging quality. A second sex and age-matched group (51 ± 9.4 years) consisting of 51 healthy person with normal range blood pressure ($<140/90$ mmHg) were used as controls. Patients who participated in TESE were discontinued from β -blockers for 48 h and caffeine or theophylline intake for 12 h. The study was approved by ethics review committee of the hospital [Lun Shen (Research) No. 23, 2019], and all patients signed informed consent before examination.

2.2 | TESE and image acquisition

A General Electrics (GE) Medical System E95 ultrasound system was employed to acquire the study data using the adult heart M5s probe (frequency 1.5–5 MHz). All participants received a complete transthoracic echocardiography examination at rest and peak status. Five standards (4-, 2-, and 3-chamber, papillary muscle level of short axis, parasternal long axis) views were obtained. TESE was performed using the standard Bruce protocol and the metabolic equivalent (MET)¹¹ was used to derive the metabolic tolerance index. A 12-lead ECG was used to monitor subjects throughout the process with blood pressure recorded every 2 min. The target exercise heart rate was 85% of 220-age, peak blood pressure rises of more than 210 mmHg, obvious electrocardiogram changes (ST-segment horizontal or oblique depression more than .1 mV), and intolerable chest pain or fatigue were indications to terminate the test. Immediately after exercise, subjects were instructed to lie in the lateral decubitus position and peak images collect for about 2–3 min. Image collection and data analysis were completed by the same physician.

2.3 | Speckle tracking image analysis

Analyses were carried out according to the methods recommended by the American Society of Echocardiography (ASE) guidelines. The

images were analyzed offline after transferring to the GE-Echo PAC workstation. Calculated parameters included the LV end-diastolic volume index (LVEDVI); LV end diastolic diameter (LVDD); interventricular septum diastolic diameter (IVSd), LV posterior wall diastolic diameter (LVPWd); LV ejection fraction (LVEF); s,E/A,e/a and E/e values from transmitral flow spectrum and mitral annular motion curve were measured at rest and peak state for the two groups and LV mass index (LVMI) was calculated according to the Devereux formula.¹²

GE-Q-analysis technology was used to manually track and correct the endocardial margin. The area of interest in each segment covered the entire thickness of the myocardial wall and avoided inclusion of the pericardium. The software automatically generated the outline curve to obtain layer strain data of speckle-tracking in resting and peak stress, respectively. The longitudinal layer-specific strain (LLSS) and circumferential layer-specific strain (CLSS) were divided into three layers: endocardium (Endo), mid-myocardium (Mid), and epicardium (Epi). The characteristics of LLSS and CLSS in three apical (4-, 2-, and 3-chamber) views and parasternal short-axis view at the papillary muscle level were compared between two groups in resting and peak status, respectively. The parameters of GLS and CS myocardial deformation were evaluated at three layer-specific levels. The reserve function of strain change from rest to peak was evaluated with absolute contractile reserve (CR) calculated as the difference in multi-layer strain between the peak and their corresponding resting values.

2.4 | Statistical analysis

Conventional ultrasonic parameters with continuous variables including left ventricular LSS and absolute CR values were shown as the mean \pm SD. The data of two groups were compared using independent sample *t*-test. The Chi-square test was used for comparisons of case numbers and gender. ANOVA with Bonferroni correction was used to compare the values of strain between each layer of myocardium. Pearson correlation coefficient was used to analyze relationships between two parameters. The intraclass correlation coefficient (ICC) of 10 patients were randomly selected for consistency evaluation in the same observer and different observers. An ICC greater than .75 indicated good consistency. The Endo, Mid, and Epi layer strain differences between the same and different observers were 10.9%, 11.4%, 12.9%, and 10.7%, 13.5%, 14.6%, respectively. SPSS25.0 software was used for all analyses and $p < .05$ was considered to indicate statistically significant differences.

3 | RESULTS

3.1 | Study population and general echocardiographic data

Comparisons of the demographic and basic clinical characteristics of the hypertensive and control subject groups established there were no significant differences in gender, mean age, body surface area (BSA)

TABLE 1 Demographic and clinical characteristics of the study population

	Control group (N = 51)	Hypertension group (N = 55)	t/ χ^2 value	p-Value
Age (years)	51.2 ± 9.4	54.0 ± 7.2	-4.451	.761
Male (%)	58.8	52.7	.398	.528
BSA (m ²)	1.6 ± .25	1.7 ± .28	-1.537	.136
BMI	21.2 ± 4.5	23 ± 3.9	-3.454	.234
Duration of hypertension (≥5 years) (%)	-	26 (47.3)	-	-
Medications (%)	-	-	-	-
Aspirin		17 (30.9)		
β -blockers		16 (29.1)		
Calcium channel blockers		19 (34.5)		
ACEI		6 (10.9)		
ARB		9 (16.3)		
Statin		18 (32.7)		
Hypercholesterolemia (%)	3 (5.9)	9 (16.4)	2.896	.089
SBP-rest (mmHg)	113.3 ± 17.2	136.7 ± 12.6	-4.641	<.001
SBP-peak (mmHg)	135.8 ± 14.6	157.9 ± 16.7	-7.774	<.001
METs	8.5 ± 2.1	7.0 ± 1.6	2.142	.022

Abbreviations: ACEI, angiotensin-converting enzyme inhibitor; ARB, angiotensin receptor blocker; BMI, body mass index; BSA, body surface area; MET, metabolic equivalent; SBP, systolic blood pressure.

TABLE 2 Echocardiographic characteristics of the study population

	Control group (N = 51)	Hypertension group (N = 55)	t-Value	p-Value
LVMI (g/m ²)	98.5 ± 9.9	129.4 ± 11.3	-9.083	<.001
LVDd (mm)	44.7 ± 2.8	47.9 ± 3.7	-2.219	.027
IVSd (mm)	9.8 ± .5	12.1 ± .8	-4.823	.013
PWd (mm)	9.4 ± .6	11.5 ± 1.0	-6.547	<.001
LVEDVI-rest	43.1 ± 6.9	47.5 ± 8.5	2.411	.022
(m ³ /m ²)-peak	39.7 ± 8.4	41.3 ± 8.9	3.537	.079
E/e-rest	6.5 ± .67	8.5 ± .36	-4.352	<.001
E/e-peak	5.8 ± .78	12.1 ± .38	-5.891	<.001
EF-rest	.65 ± .08	.63 ± .04	1.896	.527
EF-peak	.82 ± .07	.80 ± .05	.511	.382
HR(bpm)-rest	69.2 ± 16.3	65.3 ± 19.2	1.889	.069
HR(bpm)-peak	125.4 ± 16.5	120.5 ± 21.6	5.347	.021
s (cm/s)-rest	.14 ± .03	.12 ± .04	1.024	.214
s (cm/s)-peak	.20 ± .04	.16 ± .03	4.621	.045

Abbreviations: HR, heart rate; IVSd, interventricular septum diameter; LVDd, left ventricular end diastolic diameter; LVEDVI, Left ventricle end-diastolic volume index; LVEF, left ventricular ejection fraction; LVMI, left ventricular mass index; PWd, posterior wall diameter; E, early diastolic mitral flow (pulsed Doppler); e, average of the peak early diastolic relaxation velocity of the septal and lateral mitral annulus (tissue Doppler); s, average of the peak systolic velocity of the septal and lateral mitral annulus (tissue Doppler). Data are presented as mean ± SD.

and body mass index (BMI). As anticipated, systolic BP for rest and peak measurements were higher in the hypertensive group along with lower exercise METs. The detailed use of antihypertensive medications, prevalence of hypercholesterolaemia, and duration of hypertension were showed (Table 1).

We next compared the general ultrasound parameters for resting and peak states are summarized in Table 2. There were significant differences observed in LVDd, IVSd, PWd and LVMI, as well as LVEDVI-rest between the two groups. Both s-peak and HR-peak values were significantly lower in the hypertensive group, while no differences

occurred in LVEF. For the hypertensive group, E/e ratios were significantly higher versus control subjects, which suggests that the diastolic reserve function was reduced, particularly evident by the increased E/e ratios at peak exercise.

3.2 | LSS difference characteristics between hypertensive and normal group

Tables 3 and 4 depicts the difference in the three LSS values at four/two/three and the papillary muscle level chamber views. Both LLSS and CLSS values showed a gradually decreasing trend from the endocardial to epicardial layers, and revealed different degrees of reduction in hypertensive group, especially the endocardial strain which was significantly decreased both at rest and peak states. At rest, comparisons for 4LSendo, 4LSmid, 3LSendo, 3LSmid, 2LSendo were significantly lower in hypertensive group ($p < .01$), whereas each LLSS values were lower ($p < .01$) except 3LSepi at peak exercise. Example for the resting GLSendo was (control group $24.4\% \pm 1.5\%$ vs. hypertensive group $20.4\% \pm 2.3\%$), while the difference was more obvious at peak exercise (control vs. hypertensive group, $30.8\% \pm 2.8\%$ and $22.8\% \pm 2.9\%$, respectively).

There were also significant differences in CSendo and CSmid between the two groups at rest, while more pronounced differences occurred during peak exercise in the three circumferential layers. Subsequently, the parameters of GLS and CS myocardial deformation were evaluated at three layer-specific levels (Tables 3 and 4), revealed lower GLS endocardial-to-epicardial gradient both at rest and peak in hypertensive group ($p < .05$). Furthermore, comparisons of LSS contractile reserve values between the two groups showed significant differences ($p < .01$). Absolute CR value was calculated as the difference in multi-layer strain between the peak and their corresponding resting values. The absolute increased multi-layer strain value in hypertensive group was lower, suggesting that CR function of the three layers were all impaired (Table 5).

3.3 | LSS difference characteristics between rest and peak exercise

We evaluated the detailed strain characteristics between resting and peak state conditions. While there were significant increases in each LLSS and CLSS in normal group at peak states ($p < .05$), among the hypertensive group, only 4LSmid, 4LSepi, 2LSepi, 3LSmid, 3LSepi, and CSepi showed significant increase ($p < .05$) between resting and peak states (Figures 1 and 2). Variation characteristics of LSS from rest to peak also indicating the CR function of hypertensive group was reduced.

3.4 | Univariate correlation analysis during peak exercise

Univariate relationships between general and global LLSS parameters were assessed during peak exercise. GLSendo showed significant neg-

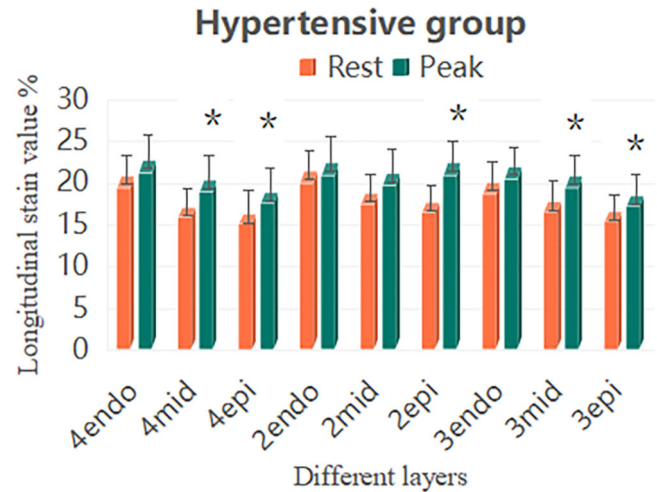


FIGURE 1 Variation characteristics of longitudinal layer-specific strain (LLSS) at rest and peak state in hypertensive group. *Indicating LLSS value of different layers were significantly increased ($p < .05$) at peak state

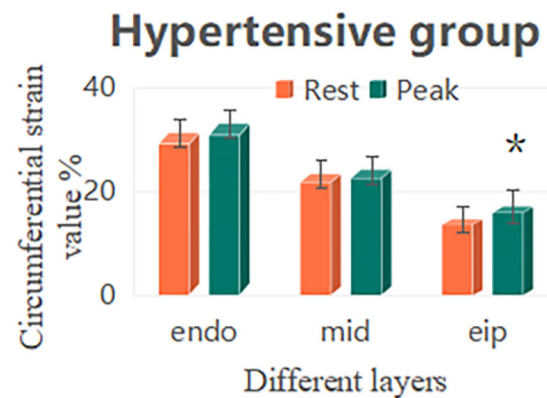


FIGURE 2 Variation characteristics of circumferential layer-specific strain (CLSS) at rest and peak state in hypertensive group. *Indicating CLSS value of epicardial layer was significantly increased ($p < .05$) at peak state

ative correlations with LVMI ($r = -.44, p < .05$), SBP ($r = -.41, p < .05$), and E/e ($r = -.36, p < .05$). We further found no significant association between E/e and GLS-CR, along with GLSepi demonstrated no significant relationship with SBP, LVMI. Moreover, GLSmid were weakly associated with LVMI with the correlation coefficients of $-.24$ ($p < .05$). LVMI was significantly correlated with E/e ($r = .39, p < .05$), and associated with SBP ($r = .48, p < .05$) at peak.

4 | DISCUSSION

Previous studies have proposed that the longitudinal, circumferential, and radial strains of hypertensive patients were lower than normal subjects.¹³ However, these reports have focused on global myocardial strain rather than considering the non-homogeneous nature of

TABLE 3 Comparison of longitudinal LSS in different views

Longitudinal strain (%)	Normal group	Hypertensive group	t-Value	p-Value
4Endo				
rest	24.0 ± 2.7	20.9 ± 3.2	6.543	<.001
peak	30.3 ± 3.3	22.8 ± 3.0	9.427	<.001
4Mid				
rest	20.6 ± 1.4	17.1 ± 1.8	6.833	<.001
peak	26.1 ± 3.2	20.4 ± 3.0	10.165	<.001
4Epi				
rest	18.6 ± 1.4	16.3 ± 2.9	1.923	.116
peak	22.7 ± 3.0	18.9 ± 2.9	7.117	<.001
2Endo				
rest	24.3 ± 1.5	21.0 ± 2.5	4.779	<.001
peak	32.2 ± 2.6	23.5 ± 3.4	13.671	<.001
2Mid				
rest	21.1 ± 1.4	18.8 ± 2.2	1.290	.605
peak	28.1 ± 2.3	21.2 ± 3.0	11.725	<.001
2Epi				
rest	18.4 ± 1.5	17.7 ± 2.0	1.138	.982
peak	25.6 ± 2.3	20.5 ± 2.5	7.792	<.001
3Endo				
rest	24.2 ± 1.5	20.1 ± 2.6	7.454	<.001
peak	30.1 ± 2.5	22.0 ± 2.4	6.973	<.001
3Mid				
rest	20.8 ± 1.1	17.8 ± 2.6	4.388	<.001
peak	25 ± 2.2	20.9 ± 2.5	6.549	<.001
3Epi				
rest	18.5 ± 1.0	16.6 ± 2.7	.178	.077
peak	21.4 ± 2.2	18.5 ± 2.2	2.328	.054
GLS-Endo				
rest	24.4 ± 1.5	20.4 ± 2.3	7.346	<.001
peak	30.8 ± 2.8	23.3 ± 2.9	10.177	<.001
GLS-Mid				
rest	20.9 ± 1.3	17.8 ± 2.1	6.125	<.001
peak	26.7 ± 2.5	19.8 ± 2.8	8.162	<.001
GLS-Epi				
rest	18.4 ± 1.6	16.8 ± 2.4	1.750	.349
peak	23.2 ± 2.5	18.3 ± 2.7	3.866	<.001
p-Value				
-rest	<.001	.007		
-peak	<.001	.042		
(GLS between layers)				

Abbreviations: The endo/mid/epi layer strain value at the four chamber view (4endo, 4mid, 4epi); the endo/mid/epi layer strain value at the two chamber view (2endo, 2mid, 2epi); the endo/mid/epi layer strain value at the three chamber view (3endo, 3mid, 3epi). GLS, global longitudinal strain; GLS-endo, the average value of GLS in the endocardium layer at the four, two, and three chamber views. GLS-mid, the average value of GLS in the midcardium layer at the three different views; GLS-epi, the average value of GLS in the epicardium layer at the three different views; LSS, layer-specific strain. Data are presented as mean ± SD.

TABLE 4 Comparison of circumferential LSS

Circumferential strain (%)	Normal group	Hypertensive group	t-Value	p-Value
CSEndo				
rest	36.3 ± 3.3	31.3 ± 2.6	15.445	<.001
peak	39.2 ± 2.5	33.1 ± 2.7	12.478	<.001
CSMid				
rest	27.3 ± 2.6	23.4 ± 2.7	8.545	<.001
peak	31.3 ± 2.6	24.2 ± 2.6	9.087	<.001
CSEpi				
rest	16.2 ± 2.4	14.7 ± 2.4	2.066	.272
peak	20.2 ± 2.7	17.1 ± 3.1	6.648	<.001
p-Value				
-rest	<.001	<.001		
-peak	<.001	<.001		
(CS between layers)				

Abbreviations: CSEndo/CSmid/CSEpi, the endo/mid/epi circumferential strain value at the papillary muscle level; LSS, layer-specific strain. Data are presented as mean ± SD.

TABLE 5 Comparison of LS and CS contractile reserve value

Contractile reserve value	Normal group	Hypertensive group	t-Value	p-Value
LSendo-CR	6.4 ± .21	2.9 ± .27	7.645	<.001
LSmid-CR	5.8 ± .22	2 ± .20	8.468	<.001
LSepi-CR	4.8 ± .19	1.5 ± .19	9.039	<.001
GLS-CR	5.3 ± .21	2.1 ± .27	6.742	<.001
CSEndo-CR	2.9 ± .29	1.8 ± .23	5.947	<.001
CSmid-CR	4.0 ± .27	.8 ± .18	7.491	<.001
CSEpi-CR	4.2 ± .32	2.4 ± .22	2.783	<.001

Abbreviations: CR, contractile reserve; CR was calculated as the difference in multi-layer strain between the peak and their corresponding resting values. LSendo/LSmid/LSepi, the average longitudinal strain value of the endocardium/midcardium/epicardium layer. GLS, global longitudinal strain. CSEndo/CSmid/CSEpi, the average circumferential strain value of the endocardium/midcardium/epicardium layer at the papillary muscle level. Data are presented as mean ± SD.

the structures involved. Indeed, the LV myocardium is a complex multi-layer structure with an innermost layer, mid-myocardium layer and outer epicardium layer.¹⁴ As a new method to evaluate the strain of different myocardial layers, the LSS technique has the characteristics of higher accuracy and repeatability compared with global myocardial strain analysis technique.^{15,16} There have been several studies of pharmacological stress test on LV strain analysis,^{17,18} but it cannot replicate the complex hemodynamic and neurohormonal responses similar to those in the TESE. Therefore, we innovatively applied TESE combined with LSS technique to study the impairment of myocardial function and the variation characteristics in patients with hypertension.

Firstly, we found MET was mainly affected by the fluctuation of patients' exercise tolerance and blood pressure, and there were no statistically significant differences in gender, BMI, and average age between the two groups. Variations in conventional ultrasound param-

eters and increased LVMI suggested LV remodeling occurred but LVEF was normal in the hypertensive patients. A previous study¹⁹ found a significant correlation between E/e ratio and global longitudinal strain (GLS) suggesting both systolic and diastolic impairments exist in patients with hypertension. More rewardingly we found the E/e ratio in hypertensive patients increased during exercise, which predicates compromised diastolic reserve function. Consistently, Burgess and colleagues²⁰ demonstrated that the E/e ratio correlated with invasively measured LV diastolic pressure during exercise.

Longitudinal strain impairment is frequently seen in hypertensive subjects with preserved EF in LV hypertrophy and remodeling and is considered a marker for heart failure progression. The cardiac changes likely reflect the effects of longstanding arterial hypertension, resulting from complex interactions of several hemodynamic and non-hemodynamic variables. Consistent with our findings, a prior TESE study²¹ of hypertensive patients with normal EF found that the GLS

at rest and peak were lower than normal subjects. A study by Sun and colleagues²² also reported LS and CS in uremia with hypertension patients gradually decreased from the endocardium to epicardium. However, their study only examined these parameters at rest and their findings were possibly influenced by factors associated with renal failure. Our study demonstrated that LLSS and CLSS values showed a gradual decrease from endocardium to epicardium, and revealed lower GLS endocardial-to-epicardial gradient both at rest and peak in hypertensive group. Our data extensively indicates that all three myocardial layers at (4-, 2-, and 3-chamber) and parasternal short-axis views were affected by hypertension. The LLSS and CLSS values at rest were decreased to varying degrees between hypertensive and normal subjects, while differences were more obvious during peak stress. We believe that subtle changes in myocardial strain may not be obvious at rest and need to be detected by stress speckle tracking technique, however, this regularity was not noticed in LSS values before. Feihl and colleagues reported²³ that the high pulse wave velocity of hypertension, which might cause pressure waves reflection in the cardiac microcirculation, and could provoke changes in all three layers of the myocardium, especially at peak exercise.

Furthermore, we found that endocardial strain was a more sensitive measure, possibly because the myocardial metabolic rate was higher and cardiac fibers located below the endocardial are more susceptible to ischemia, hypoxia, and increased shear wall forces.²⁴ Our data of layer-specific changes in myocardial mechanics emphasize the requirement to conduct LSS analyses during stress testing.

The peak LSS were all significantly increased in normal subjects, while for hypertensive subjects one of the notable differences we observed the lack of change in partial LLSS and CLSS during peak exercise. This could be interpreted as impaired contractility reserve function and this notion was supported by Fung and colleagues²⁵ who published that hypertensive patients have impaired LV GLS both at rest and after low dose dobutamine. Badran and colleagues²⁶ also found that the longitudinal strain were reduced in hypertensive and hypertrophic cardiomyopathy (HCM) patients, noting their systolic reserve function was reduced, especially in HCM patients. Consistently, we found that systolic cardiac reserve function was reduced when evaluating the left ventricular LSS in hypertensive patients, and the uneven functional changes observed during exercise could explain the layer-specific differences in systolic strain. The multilayer strain enables detection of LV mechanics in all three myocardial layers and provides insight into LV deformation from an anatomical point of view.

Lastly, it was important to consider the relationships between the different measured parameters. Notably, we found significant correlations between E/e ratio and GLS_{endo}, and between LVMI and SBP. We further found no significant correlations between GLS-CR and E/e ratio. To our knowledge, our study was the first to evaluate the relationship between E/e ratio and LV contractile performance during treadmill exercise. Strain deformation is a load-dependent parameter, with previous study²⁷ demonstrating an inverse correlation between LV pressure load and longitudinal strain, we further found GLS_{endo} was also associated with SBP at peak, our results are therefore more likely to reflect the real impact of hypertension during peak exercise.

4.1 | Limitations

Although speckle tracking strain imaging shows excellent application prospects, there are still some challenges that limit its clinical application. The instrumentation has high-end technical requirements, and the image acquisition and analysis methods are both time-consuming and complex. The definition of endocardial boundaries are subjective and there are different judgments of abnormal ventricular wall motion between individuals, especially during peak exercise. Our study concentrated on the assessment of longitudinal strain rather than circumferential strain, whereas circumferential strain data were analyzed at the papillary muscle level where peak imaging quality is more reliable. Although our study measured variations due to intra-observer and inter-observer differences, these differences will have a certain influence on the results. Thus, there is a strong need for optimized parameters and methodologies to be developed by expert consensus. Future investigations may also benefit from increasing the sample size of the cohorts used. Regardless of any upcoming developments in cardiac physiopathology technologies, our study highlights the benefit of assessing hypertension-related cardiovascular dysfunction under exercise stress.

5 | CONCLUSIONS

The application of speckle tracking LSS technique combined with TESE has improved the diagnostic level of cardiac function changes in patients with hypertension at the subclinical stage. Patients with hypertension have reduced systolic function reserve and more dynamic dyssynchrony with exercise compared with normal subjects. Two-dimensional strain imaging during stress may provide a new and reliable method to identify patients at higher cardiovascular risk. The next logical step to be undertaken would be a correlation study between stress LSS and clinical prognosis evaluation in hypertensive patients.

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CONFLICT OF INTEREST

None.

AUTHORS CONTRIBUTION

Zhang Qingfeng is the first author, contributed to incubate the experiment, collect and analysis research data, draft this article. Wang yi/Li Wenhua contributed to design the experiment, technical assistance and part of funding support. Zhang Hongmei, Ding Geqi helped for collect research data, participate in the experiment. Liu Xuebin, Li Chunmei, Deng yan helped for statistical analysis, and provide guidance. Yin Lixue is the corresponding author, reviewed this article and funding support.

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