Assessment of left ventricular myocardial work done by noninvasive pressure–strain loop technique in patients with essential hypertension

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Abstract

Objective: To investigate the value of the noninvasive pressure–strain loop (PSL) technique for assessing left ventricular myocardial work done in patients with essential hypertension.

Methods: Prospectively, 60 patients with hypertension visiting the hospital from August 2020 to July 2021 were collected and divided into the mild hypertension group (SBP 140–159 mmHg, 35 cases) and the moderate-to-severe hypertension group (SBP ≥160 mmHg, 25 cases). Another 40 cases of healthy adults were collected as the control group. The differences in the global long-axis strain (GLS) and peak strain dispersion (PSD) of the left ventricle, global work index (GWI), global constructive work (GCW), global wasted work (GWW), and global work efficiency (GWE) were compared among the three groups. The receiver operating characteristic curve was used to evaluate the PSD, GWI, GCW, and GWW. The myocardial work index (MWI) and MWI percentages in the apical, middle, and basal segments of the heart were also compared among the groups.

Results: (1) The PSD, GWI, GCW, and GWW were significantly different among the groups ($\chi^2 = 57.605, 79.203, 76.973, and 17.429$, respectively, $p < .05$), while the GLS and GWE were not ($\chi^2 = 1.559 and 5.849$, respectively, $p > .05$). (2) The GWI had the highest specificity (97.5%) and the GCW the highest sensitivity (95%) in predicting hypertension. The percentage of apical MWI gradually increased ($F = 11.230, p < .05$) and the percentage of basal MWI gradually decreased ($F = 10.665, p < .05$) from the control group to the mild hypertension group to the moderate-to-severe hypertension group; there was no significant difference in the percentage of mid-MWI ($F = 0.593, p > .05$).

Conclusions: The noninvasive PSL technique could be used to assess myocardial work done in patients with essential hypertension.

KEYWORDS
global constructive work, global wasted work, global work index, hypertension, myocardial work, noninvasive pressure–strain loop
INTRODUCTION

Essential hypertension is one of the most common chronic diseases in China and an important risk factor for death from cardiovascular disease. (Writing Group of 2018 Chinese Guidelines for the Management of Hypertension et al., 2019) In an Asia-Pacific cohort study including China, (Gil et al., 2003) the risk of stroke and fatal myocardial infarction in the Asian population increased by 53% and 31%, respectively, for every 10 mmHg increase in SBP; thus, early and accurate assessment of cardiac function in patients with essential hypertension is particularly important.

Currently, traditional echocardiography is used to evaluate left ventricular (LV) systolic function via parameters such as the LV ejection fraction (LVEF), LV short-axis shortening rate, Tei index, and LV wall motion integral index. However, these parameters are subject to image quality and observer subjectivity, so their accuracy is poor. Speckle-tracking echocardiography has high feasibility, repeatability, and accuracy (Ahmed et al., 2020; Saccheri et al., 2017; Zhu & Li, 2018) and can detect early subclinical changes in cardiac function before conventional echocardiography, but it also has some limitations; for instance, it cannot directly reflect myocardial work done. The recently developed pressure-strain loop (PSL) technique can accurately and timely determine LV systolic function abnormalities in patients with hypertension via parameters related to myocardial work (MW).

The aim of this study is to apply the noninvasive PSL technique to assess the systolic function of patients with early essential hypertension for the provision of clinical interventions, which can reduce the incidence of cardiovascular and cerebrovascular complications.

MATERIALS AND METHODS

Subjects

In total, 60 cases of patients with hypertension (aged 58.1 ± 9.1, 44 males and 56 females) who visited the Affiliated Hospital of Yangzhou University from August 2020 to July 2021 were collected for the study. The hypertensive patients were subdivided into the mild group (SBP 140–159 mmHg, 35 cases) and moderate-to-severe group (SBP ≥160 mmHg, 25 cases) according to the Guidelines for Prevention and Treatment of Hypertension in China (Writing Group of 2018 Chinese Guidelines for the Management of Hypertension et al., 2019) (2018 revised edition). Forty cases of healthy adults were collected as the control group.

Inclusion criteria (all criteria had to be met simultaneously): (1) patients suffering from cardiac arrhythmias, congenital heart disease, and severe heart valve disease; (2) patients with coronary artery stenosis ≥50% on DSA or CTA examination; (3) patients suffering from hypertrophic cardiomyopathy, dilated cardiomyopathy, myocardial amyloidosis, and other cardiomyopathies; (4) patients suffering from aortic constriction and subclavian artery steal; (5) patients with endocrine diseases such as hyperthyroidism, hypothyroidism, and diabetes mellitus; and (6) patients who could not cooperate with the examination and whose image quality was therefore poor.

Calculation of body surface area

All subjects’ height and weight were measured, and the body surface area was calculated according to the following formula: body surface area (m²) = 0.0061 × height (cm) + 0.0124 × weight (kg) + 0.0099.

Conventional echocardiographic images and data acquisition

With the patient in a resting state in the left lateral recumbent position, a synchronized electrocardiogram was connected, and conventional echocardiographic parameters were measured, including the LVEF, LV end-diastolic diameter, LV post-diastolic wall thickness, diastolic septal thickness, early diastolic and late diastolic tissue motion velocity, aortic orifice and mitral orifice flow velocity, and peak mitral orifice flow...
velocity at early (E) and late (A) diastole. The frame rate was adjusted to 50–80 frames/second, and the kinetic images of five cardiac cycles of the apical four-chamber heart, apical two-chamber heart, and apical three-chamber heart were taken at the apex of the heart.

2.2.5 | Image analysis

The dynamic images were imported into the EchoPAC analysis software and entered into the automatic functional imaging mode. The software automatically identified the area of interest between the endocardium and epicardium in the apical four-chamber, two-chamber, and three-chamber views and derived the strain curves of the corresponding views and the 17-segment bull’s-eye map of the overall longitudinal strain of the left ventricle. Then, after clicking the “Myocardial work” button in the AP3 section to determine the aortic closure time, the subject’s blood pressure value was entered to obtain the values of the PSL, the bull’s-eye diagram of the 17-segment MW index, and each MW parameter.

The MW parameters included the following: (1) global work index (GWI), that is, the total work done by the left ventricle from mitral valve closure to mitral valve opening; (2) global constructive work (GCW), that is, the work done by myocardial lengthening during systole and myocardial elongation during isovolumic diastole (the work that contributes to ejection during systole); (3) global wasted work (GWW), that is, the work done by myocardial lengthening during systole and myocardial shortening during isovolumic diastole (the work not conducive to blood ejection during systole); and (4) global work efficiency (GWE), that is, the sum of the constructive work done divided by the constructive work and wasted work.

2.2.6 | Calculation of the local myocardial work index

The MW index (MWI) in the apical, middle, and basal regions was calculated according to the bull’s-eye diagram of the 17-segment MWI (Figure 1). The apical MWI was the sum of the MWIs of 5 apical segments (13–17 segments), the middle MWI was the sum of the MWIs of 6 middle segments (7–12 segments), and the basal MWI was the sum of the MWIs of 6 basal segments (1–6 segments). The formulas used to calculate the percentages of the MWIs were as follows: apical MWI/(apical MWI + mid-MWI + basal MWI); mid-MWI/(apical MWI + mid-MWI + basal MWI); and basal MWI/(apical MWI + mid-MWI + basal MWI).

2.3 | Statistical methods

All statistical analyses were performed using the SPSS 19.0 software. Quantitative data obeying the normal distribution were expressed as the mean ± standard deviation. One-way ANOVA was used for comparisons between groups, and Bonferroni-corrected significance levels were used for pairwise comparisons. Quantitative data that did not obey the normal distribution were expressed as M(P25, P75); comparisons between groups were performed using the nonparametric Mann–Whitney U test, and pairwise comparisons were still made using Bonferroni comparisons. The parameters were evaluated using the receiver operating characteristic (ROC) curve to determine the best cutoff value for each parameter. The intra- and interobserver reproducibility were assessed by the interclass correlation coefficient (ICC). A value of \( p < .05 \) was considered statistically significant.

3 | RESULTS

3.1 | Intra- and interobserver reproducibility assessment

Twenty cases were randomly selected, and their global long-axis strain (GLS), GWI, GCW, GWW, and GWE were evaluated for intra- and interobserver reproducibility. The intra-observer reproducibility was achieved by an experienced sonographer at different times, and the interobserver reproducibility was achieved by two experienced sonographers using the same method in a double-blind situation. For GLS, the intra-observer ICC was 0.957, and the interobserver ICC was 0.948; for GWI, the intra-observer ICC was 0.961, and the interobserver ICC was 0.958. For the GCW, the intra-observer ICC was 0.976, and the interobserver ICC was 0.949; for the GWW, the intra-observer ICC was 0.990, and the interobserver ICC was 0.936. For the GWE, the intra-observer ICC was 0.977, and the interobserver ICC was 0.955.

3.2 | Comparison of general clinical data

The differences in age, systolic blood pressure, and diastolic blood pressure were statistically significant among the three groups.
**TABLE 1** Comparison among three groups in terms of general clinical data

| Group                                | Number of cases | Age (y) ± | Heart rate (beats/min) ± | Body surface area (m²) ± | BMI (kg/m²) ± | Systolic blood pressure (mmHg) ± | Diastolic blood pressure (mmHg) |
|--------------------------------------|-----------------|-----------|--------------------------|--------------------------|---------------|---------------------------------|-------------------------------|
| Control group                        | 40              | 49.3 ± 14.2 | 67.1 ± 7.6               | 1.48 ± 0.22              | 22.7 ± 2.2    | 119.3 ± 10.4                    | 77.6 ± 6.6                    |
| Mild hypertension group              | 35              | 57.0 ± 9.7 ± | 66.4 ± 10.5              | 1.50 ± 0.22              | 23.1 ± 2.4    | 148.6 ± 5.9 ±                   | 90.4 ± 6.3 ±                  |
| Moderate to severe hypertension group| 25              | 59.7 ± 8.3 ± | 68.1 ± 13.8              | 1.50 ± 0.24              | 23.3 ± 2.4    | 175.7 ± 11.3 ± ab               | 98.7 ± 7.8 ± ab               |

F: 7.519, p < .001, 818, p = .202, 940, p = .062, 640, p = .448, 290.2, p = .787

p: 0.000, 0.000, 0.000, 0.000, 0.000, 0.000

a, b p < .05 versus control group.

**TABLE 2** Comparison among three groups in terms of conventional echocardiographic parameters

| Group                                | LVDd (mm) ± | IVS (mm) ± | LVPW (mm) ± | LVMl (mm) ± | Mitral orifice flow velocity (cm/s) ± | Aortic orifice flow velocity (cm/s) ± | LVEDV (ml) ± | LVESV (ml) ± | LVEF (%) ± | E/e′ ± | E/A ± |
|--------------------------------------|-------------|------------|-------------|-------------|---------------------------------------|---------------------------------------|-------------|-------------|-------------|--------|------|
| Control group                        | 45.3 ± 2.2  | 9.0 ± 0.8  | 8.8 ± 0.7   | 91.1 ± 4.5  | 100.3 ± 8.9                           | 101.7 ± 11.5                          | 106.0 ± 18.9 | 35.0 ± 7.4  | 66.8 ± 3.2 | 8.2 ± 1.6 | 1.2 ± 0.2 |
| Mild hypertension group              | 45.2 ± 2.0  | 9.1 ± 0.8  | 9.0 ± 0.8   | 92.2 ± 4.3  | 102.8 ± 13.7                          | 106.0 ± 13.7                          | 103.3 ± 16.8 | 34.2 ± 6.4 | 66.5 ± 3.2 | 8.7 ± 1.5 | 1.1 ± 0.2 |
| Moderate to severe hypertension group| 44.2 ± 2.2  | 9.4 ± 1.1  | 9.3 ± 0.9   | 93.3 ± 5.2  | 102.2 ± 12.6                          | 104.1 ± 15.4                          | 101.1 ± 27.3 | 34.8 ± 11.6 | 65.9 ± 3.6 | 8.8 ± 1.2 | 0.9 ± 0.2 |

F: 2.242, p = .155, 1.900, p = .185, 1.003, p = .371, 0.473, p = .625, 0.449, p = .640, 0.111, p = .895, 0.601, p = .303, 1.208, p = .000

p: .112, .202, .155, .185, .371, .625, .640, .895, .055, .303, .000

a, b p < .05 versus control group.

**Abbreviations:** E/A, peak mitral inflow velocity at early diastole (E)/peak mitral inflow velocity at late diastole (A); E/e’, peak mitral inflow velocity at early diastole (E)/peak early diastolic mitral annular velocity (e’); EDV, end-diastolic volume; ESV, end-systolic volume; IVSd, interventricular septal thickness at diastole; LVDd, left ventricle end-diastolic diameter; LVEF, left ventricular ejection fraction; LVMl, Left ventricular mass index; LVPWd, left ventricular posterior wall depth.
(p < .05), but the differences in the remaining indexes were not (p > .05). Age was statistically significant between the mild hypertension group and the control group as well as between the moderate-to-severe hypertension group and the control group (p < .05 for both), but there was no statistically significant difference between the mild and moderate-to-severe hypertension groups (p > .05). See Table 1.

3.3 | Comparison of conventional echocardiographic parameters

The difference in E/A among the three groups was statistically significant (p < .05), but the difference in the remaining indexes was not (p > .05). The E/A was statistically significant between the mild hypertension group and the control group, between the moderate-to-severe hypertension group and the control group, and between the moderate-to-severe hypertension group and the mild hypertension group (p > .05). See Table 2.

3.4 | Comparison of global long-axis strain, peak strain dispersion, and overall myocardial work parameters

The differences in the peak strain dispersion (PSD), GWI, GCW, and GWW were statistically significant among the three groups (p < .05), but the differences in the GWE and GLS were not (p > .05). The PSD, GWI, GCW, and GWW showed an increasing trend among the three groups in the order of control group, mild hypertension group, and moderate-to-severe hypertension group, and the differences in the PSD, GWI, and GCW were statistically significant between every two groups (p < .05 for all). The differences in the GWW between mild hypertension and control groups as well as between moderate-to-severe hypertension and control groups were statistically significant (all p < .05), but the differences between mild hypertension and moderate-to-severe hypertension groups were not (p > .05). See Table 3 and Figure 2.

3.5 | Analysis of the ROC curves for each parameter

The ROC curves of the PSD and MW-related parameters (GWI, GCW, and GWW) for predicting hypertension are shown in Figure 3. The area under the ROC curves of the GWI, GCW, GWW, and PSD was 0.978, 0.980, 0.735, and 0.937, respectively, and the optimal cutoff values were 2092 mmHg%, 2383.5 mmHg%, 101.5 mmHg%, and 38.5 msec, respectively, corresponding to sensitivities of 90.0%, 95.0%, 63.3%, and 94.0% and specificities of 97.5%, 92.5%, 82.5%, and 82.5%, respectively.

3.6 | Comparison of local myocardial work indexes

The apical MWI, mid-MWI, and basal MWI showed a gradual increase in the order of the control group, mild hypertension group, and moderate-to-severe hypertension group, and the differences among the groups were statistically significant (F = 107.361, 80.368, and 52.964, respectively, p < .05). The apical MWI percentage showed an increasing trend in the order of the control group, mild hypertension group, and moderate-to-severe hypertension group, and the difference among the groups was statistically significant (F = 11.230, p < .05). The basal MWI percentage was not statistically significant among the three groups (F = 0.593, p > .05). The basal MWI percentage showed a decreasing trend in the order of the control group, mild hypertension group, and moderate-to-severe hypertension group, and the difference was statistically significant among the groups (F = 10.665, p < .05). See Table 4.

4 | DISCUSSION

4.1 | Development of noninvasive pressure–strain loop techniques

Patients with essential hypertension may suffer from cardiomyocyte hypertrophy, fibroblast proliferation, and a series of changes in the

| Table 3 | Comparison among three groups in terms of GLS, PSD, and myocardial work parameters |
|---------|--------------------------------|----------------|----------------|----------------|----------------|----------------|
| Group | GLS (%) | PSD (msec) | GWI (mmHg%) | GCW (mmHg%) | GWW (mmHg%) | GWE (%) |
| Control group | 19 (19,21) | 36 (32,38) | 1714 (1586,1879) | 2100 (1974,2219) | 73 (56,99) | 96 (95.97) |
| Mild hypertension group | 19 (18,20) | 47 (42,54)* | 2283 (2151,2383)* | 2617 (2490,2729)* | 105 (68,147)* | 95 (94.96) |
| Moderate to severe hypertension group | 19 (17,19) | 56 (46,64)* | 2601 (2509,2738)* | 3011 (2835,3101)* | 144 (87,153)* | 95 (93.96) |
| F | 1.559 | 57.605 | 79.203 | 76.973 | 17.429 | 5.849 |
| p | .459 | .000 | .000 | .000 | .000 | .054 |

*p < .05 versus control group.

*b < .05 versus mild hypertension group.

Abbreviations: GCW, global constructive work; GLS, global long-axis strain; GWE, global work efficiency; GWI, global work index; GWW, global wasted work; PSD, peak strain dispersion.
coronary arteries and even the conduction system due to the long-term afterload elevation, which can gradually develop into serious life-threatening cardiac diseases such as ventricular hypertrophy, coronary heart disease, and arrhythmia. Therefore, early detection of LV systolic function alterations in patients with essential hypertension can better assist clinical interventions. As a new method for studying myocardial mechanics that has emerged in recent years, the noninvasive PSL technique combines the pressure curve of the left ventricle with the strain measured by speckle tracking imaging (STI) to derive the MW done by both the left ventricle as a whole and each segment; thus, it assesses the systolic function of the myocardium. Compared with conventional LVEF, PSL is more sensitive and can diagnose subtle abnormalities in early cardiac systolic function. Compared with STI, it provides information on the MW while incorporating strain and load into the analysis. (Lei et al., 2020) Initially, Suga (Suga & Wakatake, 1974) and others assessed MW by invasive means, so PSL was not widely used clinically. However, with the advent of noninvasive PSL techniques, the method’s application has gradually expanded, but there have been few studies in patients with early essential hypertension. Therefore, the aim of this study was to apply the noninvasive PSL technique to assess LV MW in patients with essential hypertension.

4.2 Assessment of overall systolic function

This study found that although there was no significant difference in the GLS between the mild and moderate-to-severe hypertension groups and the normal control group, the GWI and GCW of the former increased significantly compared with the latter, and these values increased further with a statistically significant difference with the blood pressure elevation, consistent with the findings of Chan et al (Chan et al., 2019) Manganaro et al. (Manganaro et al., 2019) found that the GWI and GCW have a strong correlation with blood pressure; when the systolic blood pressure increases, the level of MW done in the left ventricle is higher. In this study, it was also found that the GWW was increased in the hypertension group compared with the normal control group as well, which might be due to the increased myocardial stiffness of the LV wall in patients with hypertension with prolonged high levels of afterload. In addition, there was no significant difference in the GWE among the three groups, probably because the GCW and GWW increase almost equally when there is no ventricular remodeling, as confirmed by El Mahdiui et al. (El Mahdiui et al., 2019) Thus, the GWI, GCW, and GWW could be used as indexes to assess myocardial systolic function abnormalities.
in patients with early essential hypertension with preserved GLS and GWE in the absence of structural changes in the heart.

Additionally, in this study, the diagnostic efficacy of the GWI, GCW, and GWW for hypertension was further analyzed by the area under the ROC curve. The results showed the area under the ROC curve for the diagnosis of hypertension by the GWI, GCW, and GWW was 0.978, 0.980, and 0.735, respectively, and the optimal cut-off values were 2092, 2383.5, and 101.5 mmHg%, respectively, corresponding to sensitivities of 90.0%, 95.0%, and 63.3% and specificities of 97.5%, 92.5%, and 82.5%, respectively. These results indicated that these MW parameters obtained by applying the non-invasive PSL technique have high sensitivity and specificity in predicting the occurrence of hypertension, further indicating that they could detect abnormalities in the overall myocardial systolic function and metabolic level at an early stage in patients with essential hypertension who have no significant changes in the GLS.

### 4.3 Assessment of local systolic function

From the bull’s-eye diagram of the 17-segment MWI, the segments with normal MW appeared green, and the segments with high MW appeared red. It ranged from uniform green in the control group to the mild hypertension group and the moderate-to-severe hypertension group, with a gradual increase in the red area, which was the greatest in the moderate-to-severe hypertension group (the apical region). Comparing the apical MWI, mid-MWI, and basal MWI among the three groups, all indexes showed a gradual increase in the order of the control group, mild hypertension group, and moderate-to-severe hypertension group, and the differences among the groups were statistically significant, indicating that the overall MW done by the hypertensive population to ensure a normal EF was increased. Thus, the apical MWI, mid-MWI, and basal MWI ratios were further compared, and it was found that the difference in the mid-MWI ratio was not statistically significant among the three groups. The apical MWI percentage showed an increasing trend in the order of the control group, mild hypertension group, and moderate-to-severe hypertension group, and the difference among the groups was statistically significant. The MWI percentage tended to decrease in the order of the control group, the mild hypertension group, and the moderate-to-severe hypertension group, and the difference was also statistically significant, indicating that the MWI in patients with hypertension exhibits a more significant trend of increased MW at the apical level, as confirmed by Loncaric’s study. (Loncaric et al., 2021) In the current study, in the patients with hypertension, the percentage of apical MWI increased, while the percentage of basal MWI decreased; the percentage of MWI in the middle segment did not change significantly, implying that the increased apical work done in such patients may be due to potential myocardial remodeling. The basal segment had a larger bending radius; (Bogaert & Rademakers, 2001) the region with a larger bending radius was exposed to higher wall stress, and the pressure increased disproportionately with the increasing blood pressure. The imbalance between the elevated wall stress and local pressure might have

| Group                        | Apical MWI (mmHg%) | Mid MWI (mmHg%) | Basal MWI (mmHg%) |
|------------------------------|-------------------|----------------|------------------|
| Control group                | 941.8 ± 1614.6    | 12241.6 ± 1344.6 | 13081.3 ± 1513.0 |
| Mild hypertension group      | 12877.7 ± 1445.9  | 13546.8 ± 1762.3   | 138.5 ± 153.6   |
| Moderate to severe hypertension group | 15546.8 ± 1874.8  | 14670.7 ± 1488.2   | 11.230 ± 0.395   |

|   | Percentage of apical MWI (%) | Percentage of mid MWI (%) | Percentage of basal MWI (%) |
|---|-----------------------------|---------------------------|-----------------------------|
| Control group                | 90.0 ± 0.01               | 97.5 ± 0.01               | 82.5 ± 0.01               |
| Mild hypertension group      | 95.0 ± 0.01               | 92.5 ± 0.01               | 82.5 ± 0.01               |
| Moderate to severe hypertension group | 63.3 ± 0.01             | 92.5 ± 0.01               | 82.5 ± 0.01               |

|       | p            | F            | p            | F            | p            |
|-------|--------------|--------------|--------------|--------------|--------------|
| Control group                | 0.000        | 0.000        | 0.000        | 0.000        | 0.000        |
| Mild hypertension group      | 0.000        | 0.000        | 0.000        | 0.000        | 0.000        |
| Moderate to severe hypertension group | 0.000       | 0.000        | 0.000        | 0.000        | 0.000        |

Abbreviation: MWI: index of myocardial work.
triggered hypertrophy of the basal local myocardium. In the patients with hypertension without altered LV configuration, although the basal MWI increased numerically, its share of work done by the entire LV myocardium was decreased when the LV systolic function could be maintained by increasing the share of apical MWI. This might be a compensatory mechanism in patients with EF-normal essential hypertension, as confirmed in Gaudron et al.’s study. (Gaudron et al., 2016)

4.4 Study on systolic synchronization

The PSD is the standard deviation of the time taken from the onset of myocardial shortening to the peak of longitudinal strain and is often used to assess the synchronization of myocardial contraction, with smaller values indicating better synchronization and larger values indicating worse synchronization. (Oleynikov et al., 2018) In the present study, the PSD gradually increased in the order of the control group, the mild hypertension group, and the moderate-to-severe hypertension group, which was consistent with the findings of Wang et al. (Wang et al., 2019) This might have been because the morphology of the LV myocardium was altered with increased afterload; the electrophysiological properties of the myocardium, including increased autoregulation, action potential instability, conduction block, and foldback, could have caused a decrease in myocardial contraction synchronization. (Kim et al., 2016) The asynchronous myocardial motion in turn could have decreased the cardiac ejection efficiency, leading to an increase in the GWW. Thus, the gradual increase in the GWW in the order of the control group, mild hypertension group, and moderate-to-severe hypertension group in this study might have been related to the decreased synchronization of LV systolic function in the patients with essential hypertension.

4.5 Limitations

Two of the study’s shortcomings were as follows: (1) This was a single-center study with a small sample size, so it is recommended to be validated by a large multicenter study in the future. (2) The noninvasive PSL technique cannot be used in patients with inconsistent LV and arterial pressure in the body circulation.

5 CONCLUSION

In summary, the noninvasive PSL technique has unique advantages in assessing LV systolic function in patients with early essential hypertension, and its derived MWI can provide a reliable basis for clinical interventions in such patients.

AUTHOR CONTRIBUTIONS

Jun Ding conducted the study and wrote the article. Hong-Guang Sun designed and supervised the study. Juan Liu and Dan Wu helped collect data.

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CONFLICT OF INTEREST

The authors declare that they have no competing interests.

DATA AVAILABILITY STATEMENT

All data generated or analysed during this study are included in this article. Further enquiries can be directed to the corresponding author.

ETHICAL APPROVAL

The study was conducted in accordance with the Declaration of Helsinki (as was revised in 2013). The study was approved by Ethics Committee of the Affiliated Hospital of Yangzhou University (2021-YKL4-28-002). Written informed consent was obtained from all participants.

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