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Study on Left Atrial Function in Patients with Early Left Ventricular Remodeling in Essential Hypertension Based on Two-Dimensional Speckle Tracking Technology

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Abstract: *Objective:* To use two-dimensional speckle tracking imaging (2D-STI) to analyze the functional changes of the left atrium before hypertrophic changes in the left ventricular configuration in the early stage of hypertension and to explore the clinical value of this technology in evaluating the changes of left atrial characteristics in patients with hypertension. *Methods:* 70 cases of patients with essential hypertension who met the requirements of this study after clinical diagnosis and routine ultrasound examination were recruited and divided into two groups according to the Ganan method: 38 cases in the left ventricular standard remodeling group, 32 cases in the left ventricular concentric remodeling group, and 40 healthy people with matched age and sex were randomly selected as the control group. The mean peak strains and strain rates of the left atrial systole, early diastole, and late diastole of each group were obtained using 2D-STI. The above parameters and indicators were used for comparative analysis. *Results:* Compared with the healthy control group, the values of peak strains and strain rates during early diastole were statistically different in both remodeling groups; compared with the standard remodeling group, the values of peak strains and strain rates in all periods were significantly different in the concentric remodeling group ($P < 0.05$). *Conclusion:* 2D-STI can be more sensitive and convenient to reflect the characteristic changes of left atrial myocardium in patients with early essential hypertension.

Keywords: Speckle tracking; 2D; Hypertension; Left atrium

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1. Background

Essential hypertension is a major modifiable risk factor for cardiovascular morbidity and mortality, which can cause changes in the structure and function of the left heart. Studies have proven that hypertension control can prevent changes in cardiac structure and function, as well as alleviate left heart disease [1]. Hypertensive heart disease mainly manifests in changes in left ventricular (LV) structure and function. Some studies have found that the left atrial function changes are earlier than the structural changes of the left atrium and left ventricle.

Even if the left ventricular structure of hypertensive patients is typical, the left atrium's mechanical function has been damaged [2,3]. Therefore, early detection of changes in left atrial function and early clinical intervention in patients with hypertension is of great significance in improving the prognosis of patients. Two-dimensional speckle tracking imaging (2D-STI) is a relatively popular new ultrasound technology in the cardiovascular field that can study left atrial function. Based on two-dimensional grayscale images, it regards myocardial tissue as countless echo speckles, which can accurately track each speckle mark and calculate its trajectory [4], obtain multi-angle, multi-directional left atrial strain and strain rate parameters, as well as quantitatively evaluate the functional changes of the left atrium. This study used 2D-STI to measure left atrial pressure and strain rate in patients with an early left ventricular remodeling in hypertension, aiming to explore the clinical value of early left atrial function changes.

2. Materials and methods

2.1. Research objects

70 hypertensive patients who visited Nanjing First Hospital from February 2020 to May 2022 were prospectively selected. The inclusion criteria included all patients who met the WHO or ISH diagnostic criteria for hypertension. Their heart function or left ventricular ejection fraction (LVEF) was within the normal range (LVEF > 55%), and the left ventricular mass index (LVMI) was within the normal range (LVMI ≤ 116 g/m^2 for male and ≤ 109 g/m^2 for female). Exclusion criteria included patients who had coronary heart disease, rheumatic heart disease, cor pulmonale, secondary hypertension, various cardiomyopathy, diabetes, and arrhythmia. According to the classification method of Ganau [5], they were divided into two groups according to the LVMI and relative wall thickness (RWT): (1) The left ventricular standard remodeling group, which both LVMI and RWT were within the normal range (RWT ≤ 0.42), with a total of 38 cases consisted of 20 males and 18 females, and the mean age was 57 ± 7 years old; (2) the left ventricular concentric remodeling group, which LVMI within the normal range and RWT >0.42, with a total of 32 cases consisted of 17 males and 15 females, and an average age of 58 ± 5 years old. In addition, 40 healthy volunteers who had a physical examination in the hospital during the same period, and did not have cardiovascular disease through echocardiography and various physical examination results, were randomly selected as the control group, which consisted of 21 males and 19 females, with an average age of 55 ± 9 years old.

2.2. Instruments and methods

The Philips EPIQ 7C color Doppler ultrasound imager with an S5-1 two-dimensional heart probe (frequency 2.0–3.5 MHz) set at 1.0–3.0 MHz was used and equipped with a QLAB 6.0 quantitative analysis workstation. The subject was placed in the left decubitus position, and the electrocardiogram was displayed synchronously. The subject was instructed to breathe steadily, and if necessary, hold his/her breath to ensure the quality of the collected images for image acquisition. The left atrial diameter (LAD), left ventricular end-diastolic diameter (LVEDd), left ventricular end-systolic diameter (LVED) and interventricular septal end-diastolic thickness (IVST), left ventricular posterior wall thickness (LVPWT), the passive blood flow from the left atrium to the left ventricle (E wave) and the blood flow generated by active atrial contraction (A wave), as well as the early diastolic mitral annular velocity (e' velocity) and the late diastolic mitral annular velocity (a' velocity) were measured using the S5-1 two-dimensional cardiac probe, followed by an automatic calculation of the left ventricular mass (LVM), the left ventricular mass index [LVMI = LVM / body surface area (BSA)], and relative wall thickness [RWT = (IVST + LVPWT)/LVEDd] by the system, and measurement of left ventricular ejection fraction (LVEF) using Simpson method. The dynamic images of the apical three-chamber, four-chamber, and two-chamber views were recorded, and the dynamic images of four cardiac cycles were continuously recorded for each view and stored in the hard disk.

The two-dimensional images were imported into the Philips QLAB workstation, the range and width of the myocardium in the region of interest of the atrium were manually adjusted so that the spots cover entirely the content of the myocardium, and the atrial muscle was divided into three segments (base segment, middle segment, upper segment) and five walls (the anterior wall and inferior wall of the apical two-chamber view, the atrial septum and side wall of the apical four-chamber view, and the posterior wall of the apical three-chamber view). The software was used to track the atrial wall, followed by obtaining the strain and strain rate of each segment after successful tracking. The mean peak strain (mεs, mεe, mεa) and strain rate (mSRs, mSRe, mSRa) of the left atrial myocardium during systole, early diastole, and late diastole were recorded (**Figures 1** and **2**).

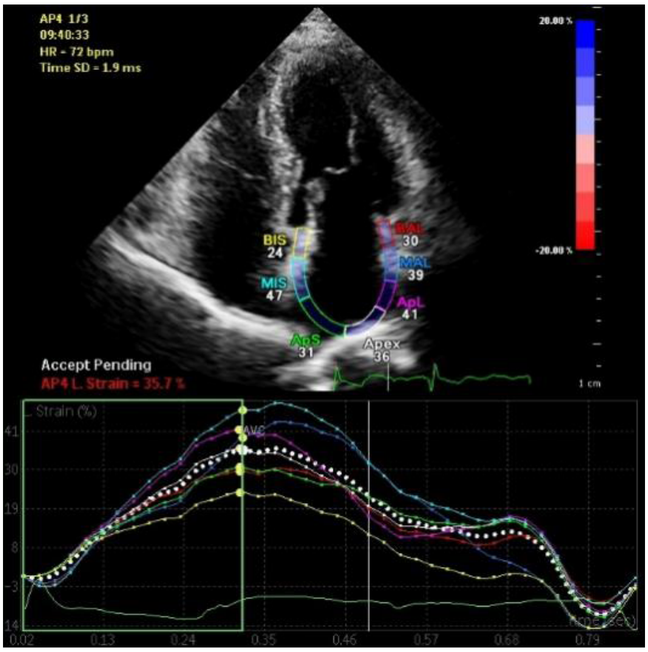

Figure 1. Left atrial strain curve in hypertensive patients

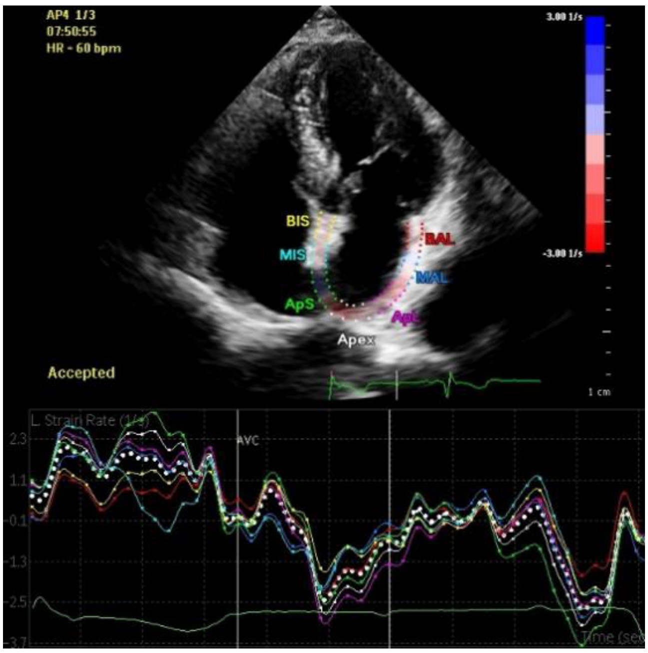

Figure 2. Left atrial strain rate curve in hypertensive patients

2.3. Statistical analysis

SPSS 23.0 statistical software was used for statistical analysis, measurement data were expressed as mean ± standard deviation (SD), comparison among multiple groups was performed by one-way analysis of variance (ANOVA), and pairwise comparison between groups was performed by LSD-*t* test. $P < 0.05$ means the difference is statistically significant.

3. Results

3.1. Comparison results of general information and conventional ultrasound parameters in each group

There was no significant difference in age, gender, BSA, heart rate, and LVEF among the three groups ($P > 0.05$). Compared with the healthy control group, the systolic and diastolic blood pressure, LAD, and E/e in both remodeling groups were all increased ($P < 0.05$), but there was no significant difference between the two subgroups of hypertension ($P > 0.05$).

Table 1. General information, conventional echocardiography, and tissue Doppler measurement parameters comparison

Index	Healthy control group	Standard remodeling group	Concentric remodeling group
Age (years)	54.8 ± 9.4	56.7 ± 6.6	57.5 ± 4.7
Gender (Male/Female)	21/19	20/18	17/15
Systolic blood pressure (mmHg)	107.7 ± 9.4	135.4 ± 10.6*	136.4 ± 11.8*
Diastolic blood pressure (mmHg)	75.4 ± 6.8	96.3 ± 9.6*	98.8 ± 10.6*
LAD (mm)	32.2 ± 2.6	35.5 ± 4.8	37.5 ± 3.8*
IVST (mm)	8.8 ± 0.1	9.8 ± 0.3	10.6 ± 0.4
LVEDd (mm)	45.9 ± 0.3	46.6 ± 0.4	47.6 ± 0.3
LVPWT (mm)	8.90 ± 0.07	9.10 ± 0.06	10.50 ± 0.07
LVMI (g/m^2)	90.4 ± 13.1	91.7 ± 8.2	92.2 ± 9.1
SV	65.1 ± 3.5	66.5 ± 3.7	66.6 ± 4.6
LVEF (%)	66.7 ± 4.3	66.8 ± 4.7	65.6 ± 5.3
E (dm/s)	6.6 ± 0.7	7.6 ± 0.9*	7.9 ± 0.8*
E/A	1.14 ± 0.09	0.94 ± 0.01*	0.95 ± 0.15*
e’ (dm/s)	0.80 ± 0.32	0.70 ± 0.25	0.60 ± 0.39
E/e’	8.1 ± 1.0	9.3 ± 1.6*	9.9 ± 1.6*

Abbreviations: LAD, left atrial diameter; IVST, interventricular septal end-diastolic thickness; LVEDd, left ventricular end-diastolic diameter; LVPWT, left ventricular posterior wall thickness; LVMI, left ventricular mass index; SV, stroke volume; LVEF, left ventricular ejection fraction; E, the passive blood flow velocity from the left atrium to the left ventricle; E/A, the ratio between early and late transmitral velocity; e’, the early diastolic mitral annular velocity; E/e’, E wave divided by e’ velocities to evaluate the LV filling pressure. *$P < 0.05$ when compared with the healthy control group.

3.2. Comparison results of left atrial strain rate parameters detected by 2D-STI

The strain (ε) and strain rates (SR) of the left ventricular standard remodeling group and the concentric remodeling group were compared with those of the healthy control group. The values of strain and strain rates during early diastole in the standard remodeling group were significantly different as compared to the healthy control group, whereas the strain and strain rates during all periods in the concentric remodeling group were significantly different as compared to the healthy control group ($P < 0.05$). The strain and strain rates of the concentric remodeling group during systole and early diastole were significantly different as compared to the standard remodeling group ($P < 0.05$).

Table 2. Comparison of average strain rates among the three groups

	Healthy control group	Standard remodeling group	Concentric remodeling group
mεs	43.17 ± 6.50	42.16 ± 4.60	36.64 ± 4.0*#
mεe	12.59 ± 0.76	10.51 ± 0.44*	8.47 ± 0.33*#
mεa	-7.43 ± 0.32	-8.48 ± 0.64	-9.94 ± 0.54*
mSRs	2.77 ± 0.45	2.65 ± 0.44	2.36 ± 0.66*#
mSRe	-2.78 ± 0.57	-2.52 ± 0.45*	-2.23 ± 0.69*#
mSRa	-2.97 ± 0.32	-3.02 ± 0.67	-3.23 ± 0.33*

Abbreviations: mεs, mean left atrial strain during left ventricular systole; mεe, mean left atrial strain during left ventricular early diastole; mεs, mean left atrial strain during left ventricular late diastole; mSRs, mean left atrial strain rate in left ventricular systole; mSRe, mean left atrial strain rate in left ventricular early diastole; mSRa, mean left atrial strain rate in left ventricular late diastole. *$P < 0.05$ when compared with the healthy control group; #$P < 0.05$ when compared with the normal configuration group.

4. Discussion

In recent years, with the development of new ultrasound technology, the research on the functional structure of the left atrium in patients with hypertension has gradually attracted the attention of clinicians. In regulating left ventricular filling in the cardiac cycle, the left atrium can be divided into 3 phases, a reservoir during systole, a conduit during early diastole, and a booster pump during late diastole according to their functional characteristics. The three time-image functions of the left atrium play an essential role in maintaining left ventricular filling and left cardiac output [6]. The hemodynamic changes caused by long-term hypertension not only affect the changes in left ventricular morphology but also cause the adaptation and adjustment of the three-phase functions of the left atrium. Currently, echocardiography clinically evaluates patients' left atrial structure changes by measuring parameters such as left atrial volume and diameter. The American Society of Echocardiography guidelines only use the left atrial volume index, which represents left atrial structural parameters, as prognostic reference indicators [7], but these parameters cannot be used to evaluate the functional changes of left atrial myocardium in an early and intuitive way [8]. The two-dimensional speckle tracking technology conducts quantitative research on myocardial structural changes in the region of interest by automatically tracking the myocardial movement speckle echo. Subclinical local myocardial dysfunction can be detected in real time [9].

Relevant studies have shown that with the help of two-dimensional speckle tracking technology, the strain and strain rate parameters of the left atrium systole, early diastole, and late diastole can be obtained, respectively [10-12]. Among them, mεs and mSRs reflect the reservoir function of the left atrium during left ventricular systole, mεe and mSRe reflect the conduit function of the left atrium in early diastole, whereas mεa and mSRa reflect the booster pump function of the left atrium in late diastole. The reservoir function of the left atrium is mainly affected by the relaxation and stiffness of the left atrium myocardium and the contractility of the left ventricle. The function is influenced primarily by the contractility of the left atrial myocardium.

This study used two-dimensional speckle tracking technology to record the strain and strain rate indicators of the left atrial wall myocardium to quantitatively analyze the changes in left atrial function during different early stages of hypertension. The results showed that compared with the healthy control group, mεs, mSRs, mεe, and mSRe were significantly different in the hypertension group, and the change in the left ventricular concentric remodeling group was also statistically significant compared with the left ventricular standard remodeling group; the mεa and mSRa were also different in the left ventricular concentric remodeling group, with statistical significance. Changes in these indicators indicate that the reservoir function and conduit function of the left atrium in patients with hypertension are significantly reduced, and there is a trend of further reduction with the development of hypertension; the blood booster pump function of the left atrium in patients with hypertension has been enhanced. The reason for the analysis of the results of this study is that due to the increase in cardiac afterload in patients with hypertension, the left atrium has to resist the increased afterload while maintaining the ejection volume of the left ventricle, causing its pressure to increase, and due to its pressure gradient with the left ventricular became smaller, the blood intake into the left ventricle becomes lesser, and the residual blood volume in the left atrium increases, hence increasing preload. The increase in long-term pressure and volume load will cause the left atrium and ventricular myocardial interstitium, as well as the collagen fiber synthesis and myocardial stiffness to increase, while deformation ability, compliance, and the reservoir function of the left atrium decrease. While the left ventricular afterload and stiffness increase, the abstract effect on the left atrium decreases in early diastole, resulting in the further decline of the blood entering the left ventricle and the conduit function of the left atrium; the residual blood volume in the left atrium increases in late diastole. According to the Frank-Starling Law, the left atrium increases its contraction to maintain the filling of the left ventricle and ensure that the left ventricle is filled with blood so the booster pump function of the left atrium is enhanced. Dai used two-dimensional speckle tracking imaging and real-time three-dimensional echocardiography to observe early changes in left atrial structure and function in patients with hypertension and found that the left atrial conduit function decreased and the auxiliary pump kinetic energy increased [13]. Chang *et al.* applied two-dimensional speckle tracking technology to evaluate the relationship between atrial septal thickness and left atrial function in patients with essential hypertension and found that the left atrial compliance gradually decreased, the conduit function and reservoir function weakened, while the booster pump function enhanced [14]. Chen *et al.* used magnetic resonance to detect left atrial enlargement in the early hypertension stage quantitatively [15]. They found that the ejection fraction and strain of the left atrial reservoir period and conduit period were significantly reduced compared with the control group, whereas the booster pump function was preserved. The results of this study are consistent with the aforementioned related research results. In summary, two-dimensional speckle tracking technology can accurately and sensitively detect functional changes in the left atrial myocardium of patients with hypertension at an early stage.

Two-dimensional speckle tracking technology has the advantages of non-invasiveness, no angle dependence, little influence from adjacent tissue traction, and high repeatability. Compared with traditional echocardiography to evaluate the left atrial function, two-dimensional speckle tracking technology can provide more accurate quantitative analysis and detect the movement of the local myocardium in real-time [16,17]. However, this study also has some limitations: Firstly, the two-dimensional speckle tracking technology has relatively high requirements for the quality of the two-dimensional image, which directly affects the quality of tracking detection; Secondly, the left atrial wall is relatively thin and has extremes such as the opening of the pulmonary vein and the interatrial septal fossa ovale. It is easy to cause echo loss, which will also affect tracking and detection; Lastly, tracking based on a two-dimensional plane cannot reflect the three-dimensional motion of the left atrium, concerning the accuracy of the results [18]. In addition, the sample size included in this study is relatively small, and further large-scale randomized controlled studies can be conducted in the future to support this study.

There are still many shortcomings in the research on left atrial detection using two-dimensional speckle tracking technology. With the further development of technology and in-depth research, automatic analysis algorithms based on machine learning artificial intelligence and other imaging technologies can be combined to study left atrial function in the future. Multimodal assessment can provide a more accurate basis for early clinical diagnosis, treatment, and evaluation of the prognosis of hypertension.

Disclosure statement

The authors declare no conflicts of interest.

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