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Original Article

Evaluation on the changes of left ventricular structure and diastolic function in patients with essential hypertensions and left ventricular filling disorders by real-time three-dimensional echocardiography

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Abstract: Objective: To evaluate left ventricular mass (LVM) and diastolic function in hypertension patients by Real-Time Three-Dimensional Echocardiograph (RT-3DE). Methods: A total of 50 healthy subjects (as control group) and 50 subjects with essential hypertension and left ventricular filling disorders (as hypertension group) were enrolled in the study, and partial general echocardiographic parameters of their 17 regional left ventricular wall were measured by RT-3DE, including regional stroke volume (rSV), regional end-diastolic volume (rEDV), regional peak filling rate (rPFR), left ventricular peak filling rate (LVPFR), left interventricular septum, early and late diastolic peak velocity (Ea, Aa) of basal lateral (their ratio Ea/Aa was calculated), stroke volume (SV), left ventricular ejection fraction (LVEF), LVM and left ventricular end-diastolic volume (LVEDV). Results: One hundred cases acquired real-time three-dimensional images with clear endocardium boundary and 17 regional volume-time curves. Compared with the control group, LVPFR, Ea and Ea/Aa decreased, LVEDV, LVM and left ventricular myocardial mass index (LVMI) increased in hypertension group, the differences were statistically significant (all $P<0.001$). The increase of LVM in hypertension group was positively correlated with that of LVEDV ($r=0.913$). Conclusion: Compared with the normal population, decrease of left ventricular diastolic function and regional left ventricular wall diastolic dysfunction appeared in patients with essential hypertensions and left ventricular filling disorders.

Keywords: LVM, RT-3DE, essential hypertensions and left ventricular filling disorders, echocardiographic parameters

Introduction

Left ventricular diastolic function plays a vital role in patients with cardiovascular diseases (CVDs), especially in hypertensive heart disease, coronary heart disease and heart failure [1]. Ventricular remodeling is the result of changes in the size, shape and function of the ventricle due to long-term pressure, volume overload and injury, and it is a process of overall compensation, lesion repair, and secondary pathophysiological response in the ventricle. Echocardiography is one of the important methods for monitoring left ventricular function and ventricular remodeling [2].

Conventional echocardiographic assessment of regional left ventricular wall function lacks quantitative analysis methods. Recently, Real-Time Three-Dimensional Echocardiograph (RT-3DE) in evaluation of left ventricular function can obtain volume-time curves of various segments of ventricular wall rather than relying on geometrical assumptions, thereby making a more accurate measurement of the function of each segment [3, 4].

In this study, RT-3DE quantitation was used to evaluate the differences of left ventricular diastolic function and regional left ventricular wall diastolic function, and the feasibility and accuracy of ventricular remodeling between healthy people and hypertensive heart disease patients.

Materials and methods

Subjects

Patients with essential hypertensions and left ventricular filling disorders in our hospital were enrolled in this study. Inclusion criteria of hypertension group: (1) In accordance with diagnostic criteria of hypertension by echocardiography, other clinical examinations and by WHO in 1999; (2) Patient with abnormal left ventricular filling detected by routine three-dimensional echocardiography; (3) No liver, kidney, lung or other organ lesions; (4) Hypertension patient without special treatment or irregular medication (not taking antihypertensive drugs during the measurement); (5) Patient cooperating with the corresponding examinations.

Inclusion criteria of healthy control group: (1) No previous history of CVDs; (2) Two consecutive times of blood pressure measurement at quiet rest and both measured values <140/90 mmHg (1 mmHg=0.133 kPa); (3) Sinus rhythm as the results of routine electrocardiographic examination; (4) Routine three-dimensional echocardiography indicating no cardiac structure or abnormal blood flow; (5) No liver, kidney, lung or other organ lesions; (6) Patients cooperating with the corresponding examinations. The same instruments and methods were adopted to collect and analyze in the two groups.

This study was approved by the Medical Ethics Committee of our hospital and had signed informed consent for participation in the study.

Instruments

X3-I matrix three-dimensional probe was used for RT-3DE examination. The images were performed quantitative analysis by Philips IE33 Color Doppler Ultrasound Imager (1-3 MHz, built-in QLab 4.2 analysis software).

Left ventricular wall segmentation

Left ventricular wall segmentation method: according to the method recommended by Cardiac Imaging Committee of American Heart Association (AHA) and the anatomical characteristics of coronary artery blood supply, through standardized myocardial segmentation for cardiac tomographic imaging, the cardiac muscle was divided into 17 segments as follows: (1) Apex (cardiac muscle of the farther bottom of ventricle cavity); (2) Apical segments (lower part of the papillary muscle to the bottom of the ventricular cavity): apical lateral, apical anterior, apical septal, apical inferior; (3) Mid-cavity segments (area of the entire papillary muscle): mid anterior, mid anteroseptal, mid inferoseptal, mid inferior, mid inferolateral, mid anterolateral; (4) Basal segments (area of mitral annulus to the top of the end-diastolic papillary muscle): basal anterior, basal anteroseptal, basal inferoseptal, basal inferior, basal inferolateral, basal anterolateral [5].

Collection and analysis of images

Collection of images

The subjects were asked to lie in the left-lateral position and keep a smooth breathing. Routine scanning of each prethoracic section was performed. Meanwhile, 2-lead electrocardiogram was recorded. The parameters were recorded as follows: left ventricular end-diastolic volume (LVEDV), left ventricular ejection fraction (LVEF), stroke volume (SV), early diastolic peak velocity (Ea) and late diastolic peak velocity (Aa). The ratio of Ea and Aa (Ea/Aa) was calculated, and then subjects were performed DTI examinations. Doppler velocity of PW-DTI was ranged of ±20 cm/s and the sampling volume was 9.4 mm. PW-DTI sampling volume was placed at the left ventricle lateral wall and interventricular septum in apical four chamber view and Ea, Aa and Ea/Aa of mitral annulus were measured. Placing the X3-I matrix three-dimensional probe at the apex, "full volume" mode in apical four chamber view was started until an appearance of biplane image. At the same time, the place of the probe was adjusted until a satisfying appearance of the contours of the epicardium and endocardium. Triggered by electrocardio signal, four consecutively collected cardiac cycles with 15°*60° narrow-angle "cake piece" stereo images shaped 60°*60° wide-angle "Pyramid"-shaped three-dimensional database, and then the images were stored in the built-in hard disk [6].

Analysis of images

QLab 4.2 3D QAdvance software was used for real-time measurement. "Pyramid"-shaped three-dimensional database was displayed

Table 1. Comparison of patients' general information in two groups

	Number of cases	Age (years old)	Height (cm)	Gender	
				Male	Female
Hypertension group	50	57.01±9.88	162±3.6	34	16
Control group	50	55.34±7.29	163±5.5	32	18
X^2/t		0.961	-1.076	0.182	
P value		0.339	0.285	0.673	

through the quarter image format. In the image, a, b and c were three mutually perpendicular sections (a: apical four chamber view, it could be manually adjusted by the green lines in b and c; b: apical two chamber view, it could be manually adjusted by the red lines in a and c; c: papillary muscle short axis view, it could be manually adjusted by the blue lines in a and b). By the adjustment, it insured to get a left ventricular three-dimensional image with the largest left ventricular long axis. Regarded image a and b as basic planes, the left ventricular end-diastolic and end-systolic phases were determined by electrocardiogram. Marking the position of mitral annulus and left ventricular apex respectively, the software would automatically outline the left ventricular endocardium, making it more fit to the actual endocardium boundary through manual adjustment. Adjusting it when papillary muscle and ventricular wall were connected, QLab 4.2 3D QAdvanee software would automatically generate a volume-time curve of left ventricle, thereby getting the results of end-diastolic volume (EDV), and SV. The volume data of each time point were recorded. And the result of $dv/dt = (Vt_2-Vt_1)/(t_2-t_1)$ was calculated manually, and left ventricular peak filling rate (LVPFR) = (diastolic maximum dv/dt)/EDV. The parameters were from 17 regional volume-time curve, including regional peak filling rate (rPFR), regional end-diastolic volume (rEDV) and regional stroke volume (rSV). All image analyses were performed by blind method independently [7].

Observation indexes

Indexes of three-dimensional echocardiography including LVPFR, Ea, Aa, Ea/Aa, SV, LVEF, left ventricular mass (LVM), left ventricular myocardial mass index (LVMI) and LVEDV were observed and compared between patients with hypertension and left ventricular filling disorders and healthy people. Meanwhile, rSV and rPFR of 17 regional left ventricle were observed and compared between patients with hypertension and left ventricular filling disorders and healthy people. Besides, the linear correlations between LVM and LVEDV changes of patients with hypertension and left ventricular filling disorders were observed and analyzed.

Statistical processing

The measurement data were expressed as $\bar{x} \pm s$. SPSS 13.0 software was used for the correlation analysis. The comparison of the differences between the two groups' measurement data was performed by t test with two independent samples. Chi-square test was used for the analysis of gender and other count data. Linear correlation analysis was performed to analyze the correlation between LVM and LVEDV changes in patients with hypertension and left ventricular filling disorders. The differences were statistically significant when $P<0.05$.

Results

General information

In the hypertension group, 50 cases of patients with hypertension and left ventricular filling disorders were in accordance with the inclusive criterion, including 34 males and 16 females, aging 37-80 years old with an average age of 57.01±9.88. In the control group, a total of 50 healthy subjects were selected, including 32 males and 18 females, aging 35-75 years old with an average age of 55.34±7.29. Other related personal information is shown in **Table 1**, and the comparison of these information had no statistical significance ($P>0.05$).

Qualitative research

Seventeen regional left ventricular curves and clear left ventricular volume-time curves had been obtained from the 100 subjects underwent RT-3DE (**Figure 1**). From the volume-time curves, the curves of control group were in an ordered arrangement and with consistent ups and downs, the time points of minimal end systolic volume of all segments were able to approximately form a straight line. While the curves of the hypertension group were disor-

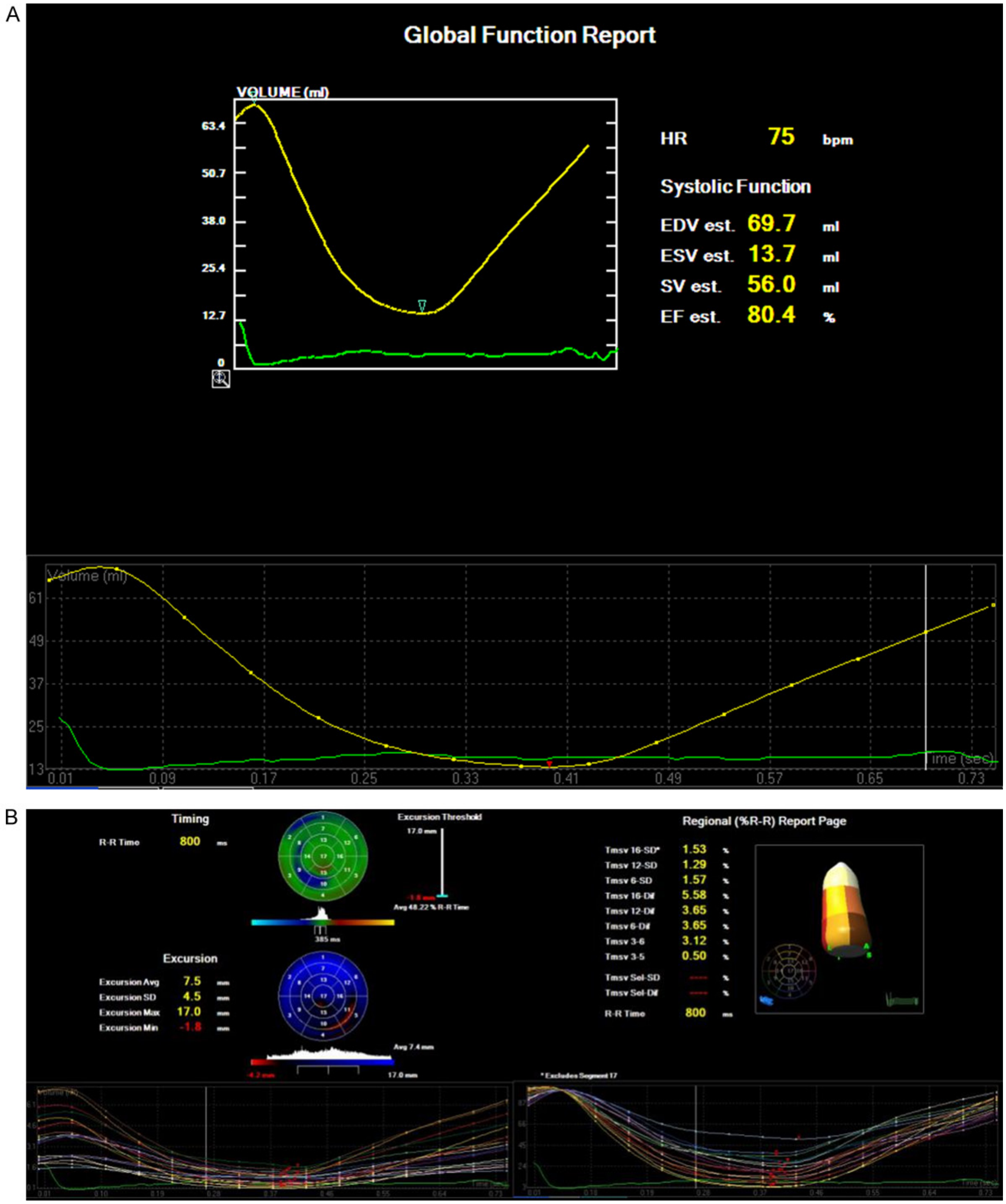

Figure 1. Qualitative research. A: Normal left ventricular volume-time curve; B: Normal regional left ventricular curve.

dered and the time points of minimal end diastolic volume had large differences.

Quantitative research

Through RT-3DE examination, it found that compared with the control group, LVPFR, Ea and Ea/Aa of hypertension group decreased, while Aa, LVEDV, LVM and LVMI of that increased, with statistically significant differences (P<0.001) (**Table 2**). In the two groups, the rSV of apical inferior and mid anterior in 17 regional left ventricle had statistical differences (P=0.034). **Table 3** shows that rSV of hypertension group was higher than that of control group. The rEDV of mid anterolateral (P=0.022),

Table 2. Comparison of the indexes of RT-3DE between hypertension group and control group

Item	Hypertension group	Control group	t	P
LVPFR (ml/s)	148.43±8.23	217.34±12.31	-32.906	<0.001
Ea (m/s)	0.61±0.06	0.78±0.09	-11.113	<0.001
Aa (m/s)	0.78±0.07	0.66±0.08	7.982	<0.001
Ea/Aa	0.74±0.03	1.20±0.03	-76.667	<0.001
SV	45.13±3.93	46.26±4.12	-1.403	0.164
LVEF (%)	60.05±4.63	61.82±4.83	-1.871	0.064
LVM (g)	133.34±34.69	109.78±26.71	3.805	<0.001
LVMI (g/m^2)	105.23±10.64	81.42±7.86	12.727	<0.001
LVEDV (ml)	130.66±54.88	83.94±27.85	5.368	<0.001

basal anterolateral (P=0.015), apical lateral (P=0.043), apical inferior (P=0.029) in 17 regional left ventricle were of statistical differences between control group and hypertension group, and their EDV of hypertension group was higher than that of control group. The rPFR of basal anterolateral (P=0.004), mid anterior (P=0.012), basal inferolateral (P=0.017), mid an-teroseptal (P=0.001), mid inferoseptal (P=0.032), mid inferior (P=0.009), apical anterior (P=0.027), mid anterolateral (P=0.018), apical inferior (P=0.035) and apical lateral (P=0.026) in 17 regional left ventricle of hypertension group were apparently lower than those of control group (**Table 3**).

Correlation analysis

The results indicated that compared with the control group, LVM and LVEDV of hypertension group increased. And the correlation analysis found that the changes of LVM in hypertension group were positive related to those of LVEDV (r=0.913). See **Figure 2**.

Discussion

Hypertension patients are often associated with ventricular remodeling and left ventricular diastolic function changes [8]. Ventricular remodeling refers to the changes in myocardial function and organ's characteristic, which results from the changes of ventricular structure. Diastolic dysfunction of hypertension patients can occur before the obvious abnormalities in myocardial structure, which is caused by cardiomyocyte dysfunction and isovolumic diastolic abnormality, and will have significantly effects on myocardial diastolic function [9]. The main pathological changes caused by essential hypertension in the left ventricle are cardiomyocyte hypertrophy, ribosome increase, golgibody enlargement, etc., thereby making the changes of cardiac configuration, especially the changes of left ventricular configuration [10, 11]. It has recently found that, among the hypertension patients without significant left ventricular hypertrophy, left ventricular filling damage is affected by high energy phosphate metabolic disorder. Some examination methods can detect changes of filling velocity caused by diastolic dysfunction [12]. Diastolic function of regional left ventricular wall plays an important role in the whole diastolic function of the left ventricle [13]. Although left ventricular diastolic dysfunction can be sensitively measured by these parameters, its routine application in clinical practice is limited due to itsinvasion [14].

Non-invasion RT-3DE is not only easy to operate but also fast in imaging, and it can immediately show the three-dimensional structure of the heart. With its accurate evaluation of cardiac function and good repeatability, it better meets the clinical application requirements. Left ventricular volume-time curve technique can accurately measure the local systolic and diastolic function of left ventricular myocardium, which provides a certain basis for clinical diagnosis and treatment. RT-3DE, as a new ultrasound technology, can obtain rPFR and rEDV values in each segment through the regional volume-time curve, so as to quantify the segment diastolic function [15, 16]. In addition, the early decrease in left ventricular diastolic function can also be assessed by RT-3DE volume-time curve parameter (LVPFR) [17].

This study, through the comparison of three-dimensional echocardiography between hypertension patients and healthy people, found that there were significant differences in diastolic function in the two groups. RT-3DE detection found that there were of significant differences in LVMI and LVM between hypertension patients and healthy people, which indicated the changes of left ventricular structure; and there also existed differences between hypertension patients and healthy people by calculating LVPFR with three-dimensional volume. The results we-

Table 3. Comparison of rSV, rEDV and rPFRin 17 left ventricular segmentation of healthy people and hypertension patients with left ventricular filling disorders

Segment	rSV (ml)		rEDV (ml)		rPFR (ml/s)	
	Control group	Hypertension group	Control group	The experimental group	Control group	Hypertension group
Basal anterior	4.94±0.92	5.01±2.35	8.58±2.64	8.62±3.05	21.64±2.95	19.94±5.31
Basal anteroseptal	2.85±1.67	3.06±2.27	5.84±1.05	5.91±2.74	7.45±4.86	6.32±1.05
Basal inferoseptal	2.42±1.05	2.03±1.35	5.04±1.04	4.73±1.91	5.56±2.31	5.32±3.76
Basal inferior	2.43±0.83	2.06±1.32	4.77±1.23	4.68±1.74	5.82±1.53	5.45±2.97
Basal inferolateral	2.63±1.53	3.17±1.63	3.01±3.01	6.28±3.32	9.53±5.14	6.32±3.10*
Basal anterolateral	4.62±1.83	5.36±2.95	7.37±3.06	10.25±4.06*	24.98±14.84	10.06±4.27*
Mid anterior	2.26±1.27	3.69±2.26*	4.88±2.94	6.05±3.26	8.78±4.56	5.17±3.06*
Mid anteroseptal	2.95±1.74	3.06±2.88	4.52±1.47	4.68±3.32	6.83±4.36	5.38±2.17*
Mid inferoseptal	2.74±0.84	2.48±1.26	4.75±1.63	4.17±1.74	11.05±2.37	5.62±2.48*
Mid inferior	1.97±0.64	2.31±1.05	3.75±0.73	4.12±1.72	5.83±2.06	4.36±0.92*
Mid inferolateral	2.58±1.42	2.49±1.85	4.55±2.16	5.38±2.53	6.53±6.73	5.92±3.06
Mid anterolateral	3.04±1.74	3.58±2.17	4.76±2.96	7.58±3.17*	10.05±7.32	7.02±3.99*
Apical anterior	1.39±0.84	1.62±1.69	1.96±0.86	2.53±1.92	3.92±2.31	2.81±1.38*
Apical septal	1.51±0.58	1.68±1.04	2.39±0.79	2.19±1.26	3.94±2.01	3.74±1.03
Apical inferior	1.28±0.31	1.92±1.03*	2.01±0.29	2.82±1.21*	4.85±2.28	2.93±0.73*
Apical lateral	1.56±0.89	1.95±1.53	2.01±1.05	3.48±1.49*	5.32±4.83	3.16±2.17*
Apex	1.84±0.58	1.92±0.62	3.26±0.76	3.57±0.94	5.49±2.36	4.65±1.87

Note: Compared with control group, the *P* value of rSV, rEDV and rPFR of all segments was as $^{*}P<0.05$.

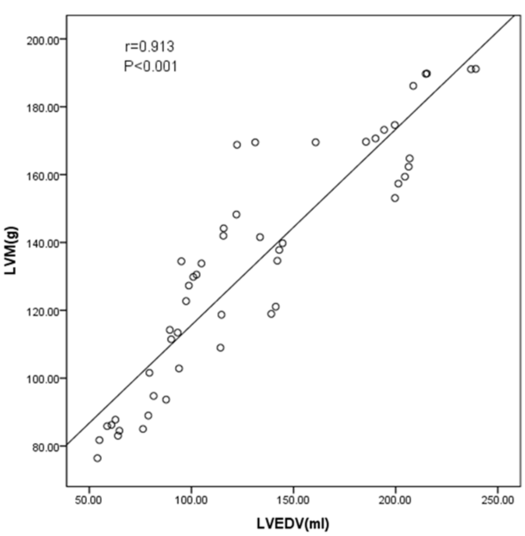

Figure 2. Linear correlation between LVM and LVEDV in hypertension group.

re consistent with traditional two-dimensional echocardiographic detection findings [18]. Studies have found that the SV of patients with hypertension was lower than that of healthy people [19]. However, the study results suggested that the trend that the SV of hypertension patients was lower than that of normal people measured by RT-3DE, but the difference was not statistically significant. It may because RT-3DE was mainly three-dimensional volume imaging and there may be some errors in its measurement for SV, thus it needs to increase the sample size and improve the measurement method to carry out further clinical research. Through the comparison of rSV, rPFR and rEDV in 17 regional left ventricle between healthy people and patients with hypertensive heart disease, it was found that most of rEDV and rSV in their left ventricles were not statistically different. There were differences in rSV of left ventricular mid anterior and apical inferior between hypertension patients and healthy people; there were differences in rEDV of left ventricular basal anterolateral, apical inferior, mid anterolateral and apical lateral. A large part of segmental rPFR in left ventricle of hypertension patients showed a weakening trend, with a weakening trend of middle segment as the most obvious condition.Peripheral resistance, arterial pressure and other after loads of hypertension patients increased in contrast to healthy people. Its myocardial movement has always been in a high power state, leading to a decrease in diastolic function of the heart [20, 21]. The research results indicated that left ventricular wall and ventricular septal diastolic amplitude reduction and varying degrees of concentric hypertrophy in patients with hypertension, and their rSVs were significantly lower than those in control group. There appeared the decrease phenomenon in most of the segments in the diastolic function of hypertension patients. Studies have shown that LVM was determined by left ventricular wall thickness and cavity size [22].

The results of this study showed that LVEDV, LVM, and LVMI in hypertension patients were significantly higher than those in control group, indicating that LVM and cardiac function injury of hypertension patients could be shown by RT-3DE. In this study, the correlation between LVEDV and LVM was investigated and it found that LVEDV increased significantly with the increase of LVM with a positive relation. Therefore, this study believed that, the increased weight of ventricle during left ventricular remodeling can lead to the expansion of the left ventricular cavity.

Disclosure of conflict of interest

None.

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