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ORIGINAL ARTICLE

Assessment of Left Atrial Function by Full Volume Real-time Three-dimensional Echocardiography and Left Atrial Tracking in Essential Hypertension Patients with Different Patterns of Left Ventricular Geometric Models[△]

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Key words: essential hypertension; left atrial function; three-dimensional echocardiography; left atrial tracking

Objective To evaluate left atrial function in essential hypertension patients with different patterns of left ventricular geometric models by real-time three-dimensional echocardiography (RT-3DE) and left atrial tracking (LAT).

Methods One hundred and thirty-three patients with essential hypertension were divided into four groups according to criteria proposed by Ganau *et al*: 36 patients in normal pattern group (I), 34 patients in concentric remodelling pattern group (II), 33 patients in concentric hypertrophy pattern group (III), and 30 patients in eccentric hypertrophy pattern group (IV). Thirty-two healthy volunteers were enrolled in this study. RT-3DE and LAT were used to obtain the volume-time and emptying fraction curves, and then the maximal volume, minimal volume, stroke volume, presystolic volume, ejection fraction, systolic filling rate, early diastolic emptying rate and late diastolic emptying rate of the left atrium were measured. Conduit volume and passive emptying volume of the left atrium were calculated.

Results Left atrial indexes, conduit volume, passive emptying volume, and early diastolic emptying rate decreased, while the other indices increased in the group I compared with the control group (all $P < 0.05$). Compared with the control group, I and II groups, the left atrial volume parameters manifested change in the group III and group IV (all $P < 0.01$). Left atrial ejection fraction measured by RT-3DE or LAT, and late diastolic emptying rate were lower in the group IV compared with the group III (all $P < 0.05$). There was no

difference in left atrial conduit volume, passive emptying volume, and early diastolic left atrial emptying rate between the group II and group I (all $P>0.05$). There was a positive correlation between RT-3DE and LAT in evaluating left atrial function.

Conclusions Left atrial booster pump function decreases in the eccentric hypertrophy pattern. Left atrial conduit function is unchanged in the normal pattern and the concentric remodelling pattern groups. RT-3DE and LAT technology can be used for quantitative evaluation of left atrial volume and function.

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THE left atrium plays a critical role in satisfying left ventricular filling volume and supplement left ventricular output volume.¹ Essential hypertension is one of the main causes of left atrial enlargement and functional impairment. Developing a further understanding of left atrial function in essential hypertension patients with different patterns of left ventricular geometry will aid in the development of relevant standards for clinic treatment and prognosis.² Thus, we assessed left atrial function in essential hypertension patients with different patterns of left ventricular geometry using real-time three-dimensional echocardiography (RT-3DE) and left atrial tracking (LAT), with the goal of developing a fast and convenient method for clinic diagnosis and treatment.

PATIENTS AND METHODS

Patients

This study was approved by Human Research Ethics Committees at Second Affiliated Hospital of Dalian Medical University (Liaoning, China). All patients and volunteers gave their written informed consents. Selected essential hypertension inpatients in Second Affiliated Hospital of Dalian Medical University from November 2011 to March 2012, satisfied the criteria of hypertension diagnosis by WHO/ISH in 1999, excluding symptomatic hypertension, vitium cordis, and other diseases that may change cardiac patterns and function. Healthy volunteers satisfied the criteria of normal physical examination findings and echocardiography examination results. There were thirty-two healthy volunteers (18 male, 14 female; age 29-70 years, mean age 52.25 ± 10.87 years).

Grouping

The two-dimensional and M-mode parasternal long axis view of the left heart were performed using an S70 (2-6 MHz) transducer and a commercially available ultrasound system (Preirus; HIVISION, Japan). The following measures were obtained: interventricular septal end-diastolic thickness (IVST), left ventricular posterior wall end-diastolic thickness

(LPWT), and left ventricular end-diastolic dimension (LVDd). The following formula were used: body surface area (BSA) = $0.0061 \times \text{body height (cm)} + 0.128 \times \text{body weight (kg)} - 0.1529$ (m^2), left ventricular mass (LVM) = $0.8 \times 1.04 \times [(IVST + LPWT + LVDd)^3 - LVDd^3] + 0.6$ (g), left ventricular mass index (LVMI) = LVM/BSA (g/m^2), and relative wall thickness (RWT) = $(IVST + LPWT)/LVDd$.³

According to the LVMI and RWT standard proposed by Ganau *et al*,⁴ essential hypertension patients were classified into four groups: normal pattern group (I): male LVMI $\leq 116 \text{ g}/\text{m}^2$, female LVMI $\leq 109 \text{ g}/\text{m}^2$, RWT ≤ 0.42 , 36 patients (17 male, 19 female, age 42-80 years, mean age 58.8 ± 11.7 years); concentric remodelling pattern group (II): male LVMI $\leq 116 \text{ g}/\text{m}^2$, female LVMI $\leq 109 \text{ g}/\text{m}^2$, RWT > 0.42 , 34 patients (15 male, 19 female, age ~53-76 years, mean age 64.2 ± 7.2 years); concentric hypertrophy pattern group (III): male LVMI $> 116 \text{ g}/\text{m}^2$, female LVMI $> 109 \text{ g}/\text{m}^2$, RWT > 0.42 , 33 patients (18 male, 15 female, age ~40-76 years, mean age 56.4 ± 12.6 years); eccentric hypertrophy pattern group (IV): male LVMI $> 116 \text{ g}/\text{m}^2$, female LVMI $> 109 \text{ g}/\text{m}^2$, RWT ≤ 0.42 , 30 patients (13 male, 17 female, age ~48-74 years, mean age 61.4 ± 7.0 years).

RT-3DE image acquisition and data analysis

To perform the apical four-chamber view, the left atrial images on full-volume mode was collected using a 3V (2-4 MHz) transducer and a commercially available ultrasound system (Vivid7 Dimension; GE Medical Systems, USA) during breath-hold over 4 seconds. Images were saved to optical disks and transferred to a post-processing workstation running the EchoPAC system (Version 108.1.2, GE Medical Systems). Data were analysed off-line using four-dimensional volume tomtec software (GE Medical Systems). Each left atrial full volume image was analysed by manual tracking the left atrial endocardium, followed by software automation analysis of left atrial volume-time curve. The left atrial maximal volume (LAVmax_{3D}), left atrial minimal volume (LAVmin_{3D}), left atrial stroke volume (LASV_{3D}), and left atrial ejection fraction (LAEF_{3D}) were obtained, and left atrial conduit volume (LACV)⁵ = $LVS\dot{V} -$

(LAVmax–LAVmin) were calculated.

LAT image acquisition and data analysis

The apical four-chamber view over three cardiac cycles was collected with a clear display left atrial endocardium and image motion stability using a S70 (2-6 MHz) transducer and a commercially available ultrasound system (Preirus). Data analysis was performed using LAT software to manually track the left atrial endocardium, and then software automated tracking of left atrial endocardium motion, to obtain the volume-time (Fig. 1) and emptying fraction curves (Fig. 2). We measured LAVmax_{LAT}, LAVmin_{LAT}, left atrial presystolic volume (LAPre), systolic left atrial filling rate (dv/dtS), early diastolic left atrial emptying rate (dv/dtE) and late diastolic left atrial emptying rate (dv/dtA), and calculated left atrial parameters: ⁵ LASV_{LAT}=LAVmax–LAVmin, LAEF_{LAT}%=(LAVmax–LAVmin)/LAVmax × 100%,⁶ and left atrial passive emptying volume (LAVp)=LAVmax–LAVpre. All parameters were calculated over an average of three cardiac cycles.

All volume measurements of the left atrium were corrected to BSA. These parameters were left atrial maximal volume index (LAVmaxI), left atrial minimal volume index (LAVminI), left atrial stroke volume index (LASVI), left atrial conduit volume index (LACVI), left atrial passive emptying volume index (LAVpI), and left atrial ejection fraction index (LAEFI).

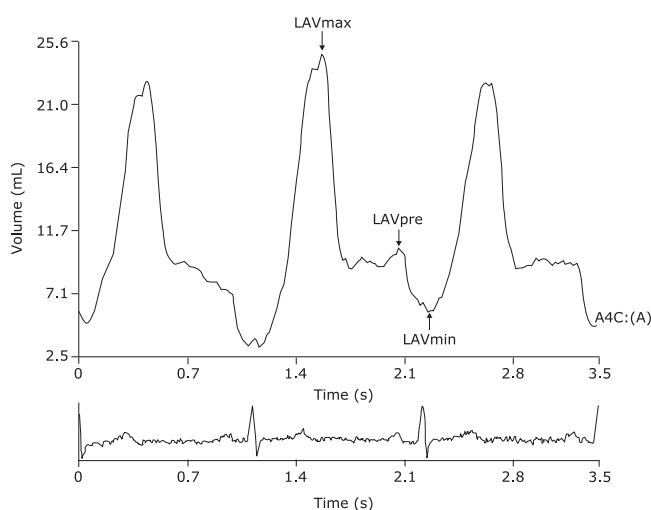


Figure 1. Volume-time curve of the left atrium obtained by left atrial tracking (LAT).

On echocardiography, left atrial maximal volume (LAVmax) was recorded at 2 seconds after the T wave, left atrial minimal volume (LAVmin) was recorded at the R wave, and left atrial presystolic volume (LAVpre) was recorded at the P wave.

Statistical analysis

Statistical analyses were performed with a commercially available SPSS (version 13.0) statistics programme. Values are expressed as mean±standard deviation (SD). Comparisons among groups were made using one-way factorial analysis of variance. Bland-Altman analysis and correlation analysis were used to evaluate the correlation between RT-3DE and LAT. A *P* value <0.05 was considered statistically significant.

RESULTS

Data analysis results of RT-3DE

The RT-3DE measurements are listed in Table 1. Compared with the control group, LAVmax_{3D}, LAVmin_{3D}, LASV_{3D}, LAVmaxI_{3D}, LAVminI_{3D}, LASVI_{3D}, LAEF_{3D}, and LAEFI_{3D} were significantly increased, while LACV_{3D} and LACVI_{3D} were significantly decreased, in the essential hypertension group (all *P*<0.05). All parameters of the left atrium were significantly different between the control group and the normal pattern group (I) (all *P*<0.05). LAVmax_{3D}, LAVmin_{3D}, LASV_{3D}, LAVmaxI_{3D}, LAVminI_{3D}, LASVI_{3D}, LAEF_{3D}, and LAEFI_{3D} were significantly increased, while LACV_{3D} and LACVI_{3D} were significantly reduced, in the concentric hypertrophy pattern group (III) and the eccentric hypertrophy pattern group (IV) compared with the other two essential hypertension groups and the control group (all *P*<0.01).

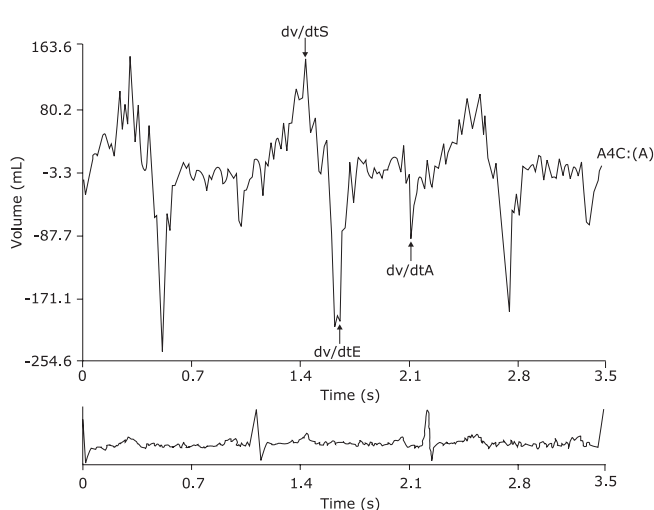


Figure 2. Volume emptying fraction curve of the left atrium obtained by LAT.

On echocardiography, systolic left atrial filling rate (dv/dtS) was recorded before the T wave, late diastolic left atrial emptying rate (dv/dtA) was recorded after the P wave, and early diastolic left atrial emptying rate (dv/dtE) was recorded after the T wave.

However, LAEF and LAEFI were lower in the eccentric hypertrophy pattern group (IV) compared with the concentric hypertrophy pattern group (III) (all $P < 0.05$). Furthermore, the decrease of LACV and LACVI was non-significant in concentric remodelling pattern group (II) compared with the normal pattern group (I).

Data analysis results of LAT

The measurements of LAT are listed in Table 2. Compared with the control group, LAVmax_{LAT}, LAVmin_{LAT}, LASV_{LAT}, LAEF_{LAT}, LAVmaxI_{LAT}, LAVminI_{LAT}, LASVI_{LAT}, LAEFI_{LAT}, dv/dtS, and dv/dtA were increased in the essential hypertension group, while LAVp, LAVpI and

Table 1. Comparisons of parameters of LAV in essential hypertension and control groups using RT-3DE[§]

Groups	n	LAVmax _{3D} (mL)	LAVmaxI _{3D} (mL/m ²)	LAVmin _{3D} (mL)	LAVminI _{3D} (mL/m ²)	LASV _{3D} (mL)
Control group	32	35.89±9.68	2.72±0.39	13.74±4.28	1.43±0.41	22.24±6.93
Group I	36	48.95±13.44*	3.91±0.75*	20.61±7.33*	2.48±1.12*	27.04±4.44*
Group II	34	55.32±20.32* [‡]	5.58±0.99* [‡]	27.53±10.75* [‡]	3.57±1.35* [‡]	34.65±6.31* [‡]
Group III	33	71.64±9.96 ^{†§#}	7.33±0.80 ^{†§#}	48.24±5.86 ^{†§#}	4.86±0.62 ^{†§#}	44.41±10.57 ^{†§#}
Group IV	30	79.41±33.37 ^{†§#}	10.87±2.95 ^{†§#}	54.83±17.36 ^{†§#}	7.54±1.47 ^{†§#}	49.58±18.59 ^{†§#}

Groups	LASVI _{3D} (mL/m ²)	LACV _{3D} (mL)	LACVI _{3D} (mL/m ²)	LAEF _{3D} (%)	LAEFI _{3D} (%/m ²)
Control group	2.31±0.38	20.44±16.10	2.31±0.38	33.35±13.86	3.69±0.76
Group I	3.35±0.90*	15.36±11.27*	1.67±0.36*	40.85±8.66*	4.63±1.14*
Group II	4.38±0.61* [‡]	14.84±13.94*	1.66±0.76*	48.57±9.47* [‡]	5.71±0.67* [‡]
Group III	5.74±0.86 ^{†§#}	8.20±10.18 ^{†§#}	0.85±0.56 ^{†§#}	61.16±8.90 ^{†§#}	7.46±0.57 ^{†§#}
Group IV	6.98±1.27 ^{†§#}	3.06±7.51 ^{†§#}	0.48±0.74 ^{†§#}	54.82±14.22 ^{†§#}	6.69±0.94 ^{†§#}

§ Plus-minus values are means±SD.

LAV: left atrial volume; RT-3DE: real-time three-dimensional echocardiography; LAVmax: left atrial maximal volume; LAVmaxI: left atrial maximal volume index; LAVmin: left atrial minimal volume; LAVminI: left atrial minimal volume index; LASV: left atrial stroke volume; LASVI: left atrial stroke volume index; LACV: left atrial conduit volume; LACVI: left atrial conduit volume index; LAEF: left atrial ejection fraction; LAEFI: left atrial ejection fraction index.

* $P < 0.05$, [†] $P < 0.01$ compared with the control group; [‡] $P < 0.05$, [§] $P < 0.01$ compared with the group I; [#] $P < 0.01$ compared with the group II; ^{||} $P < 0.05$ compared with the group III.

Table 2. Comparisons of parameters of LAV in essential hypertension and control groups using LAT[§]

Groups	n	LAVmax _{LAT} (mL)	LAVmaxI _{LAT} (mL/m ²)	LAVmin _{LAT} (mL)	LAVminI _{LAT} (mL/m ²)	LAVp _{LAT} (mL)	LAVpI _{LAT} (mL/m ²)
Control group	32	36.84±13.82	3.71±0.76	14.80±12.94	1.26±0.58	25.84±9.56	2.80±0.59
Group I	36	48.44±13.82*	4.78±0.94*	19.01±8.20*	2.20±0.50*	18.30±6.01*	2.04±0.34*
Group II	34	54.55±11.57* [‡]	6.02±0.51* [‡]	25.54±5.62* [‡]	3.25±0.37* [‡]	17.22±6.77*	1.77±0.34*
Group III	33	69.25±11.74 ^{†§#}	7.66±0.54 ^{†§#}	47.13±10.82 ^{†§#}	4.65±0.95 ^{†§#}	10.63±6.83 ^{†§#}	1.00±0.49 ^{†§#}
Group IV	30	75.16±35.75 ^{†§#}	8.41±1.00 ^{†§#}	52.37±19.44 ^{†§#}	6.16±1.76 ^{†§#}	4.97±5.76 ^{†§#}	0.58±0.30 ^{†§#}

Groups	LASV _{LAT} (mL)	LASVI _{LAT} (mL/m ²)	LAEF _{LAT} (%)	LAEFI _{LAT} (%/m ²)	dv/dtS (mL/s)	dv/dtE (mL/s)	dv/dtA (mL/s)
Control group	22.60±8.41	2.29±0.41	30.58±6.02	3.14±0.61	178.67±25.91	-258.73±31.30	-144.52±30.70
Group I	28.14±7.04*	2.84±0.59*	38.70±8.60*	3.82±0.58*	183.21±39.58*	-237.72±29.56*	-189.69±39.22*
Group II	34.89±7.33* [‡]	3.95±0.67* [‡]	45.98±10.16* [‡]	4.57±0.53* [‡]	191.07±29.19* [‡]	-234.01±32.90*	-224.69±34.22* [‡]
Group III	43.71±13.49 ^{†§#}	4.86±0.70 ^{†§#}	60.73±9.39 ^{†§#}	6.40±0.70 ^{†§#}	222.44±32.84 ^{†§#}	-203.69±30.54 ^{†§#}	-241.33±38.00 ^{†§#}
Group IV	47.80±15.87 ^{†§#}	5.60±1.07 ^{†§#}	54.96±6.59 ^{†§#}	5.76±0.98 ^{†§#}	251.86±39.04 ^{†§#}	-178.11±34.00 ^{†§#}	-231.26±34.09 ^{†§#}

§ Plus-minus values are means±SD.

LAVp: left atrial passive emptying volume; LAVpI: left atrial passive emptying volume index; dv/dtS: systolic left atrial filling rate; dv/dtE: early diastolic left atrial emptying rate; dv/dtA: late diastolic left atrial emptying rate.

* $P < 0.05$, [†] $P < 0.01$ compared with the control group; [‡] $P < 0.05$, [§] $P < 0.01$ compared with the group I; [#] $P < 0.01$ compared with the group II; ^{||} $P < 0.05$ compared with the group III.

dv/dtE were decreased in the essential hypertension group (all $P < 0.05$). There was statistically significant difference between the control group and normal pattern group (I) (all $P < 0.05$), which indicates that left atrial function was changed in early essential hypertension. LAVmax_{LAT}, LAVmin_{LAT}, LASV_{LAT}, LAEF_{LAT}, LAVmaxI_{LAT}, LAVminI_{LAT}, LASVI_{LAT}, LAEFI_{LAT}, dv/dtS, and dv/dtA were significantly increased, and LAVp, LAVpI and dv/dtE were significantly reduced, in the concentric hypertrophy pattern group (III) compared with the other groups (all $P < 0.01$). However, LAEF_{LAT}, LAEFI_{LAT}, and dv/dtA were lower in the eccentric hypertrophy pattern group (IV) than those in the concentric hypertrophy pattern group (III) (all $P < 0.05$). Furthermore, LAVp, LAVpI, and dv/dtE in the concentric remodelling

pattern group (II) were similar to the normal pattern group (I).

Correlation between RT-3DE and LAT

There was a positive correlation between LAVmaxI_{3D} and LAVmaxI_{LAT} ($r = 0.826$, $P < 0.01$), between LAVminI_{3D} and LAVminI_{LAT} ($r = 0.857$, $P < 0.01$), between LASVI_{3D} and LASVI_{LAT} ($r = 0.827$, $P < 0.01$), between LAEFI_{3D} and LAEFI_{LAT} ($r = 0.838$, $P < 0.01$), respectively. According to the Bland-Altman principle, RT-3DE and LAT analyses results showed well agreement with LAVmaxI (mean = -0.7, agreement = 1.7, -3.0), LAVminI (mean = 0.21, agreement = 1.68, -1.27), LASVI (mean = 0.39, agreement = 2.01, -1.22), LAEFI (mean = 0.77, agreement = 2.06, -0.52, Fig. 3).

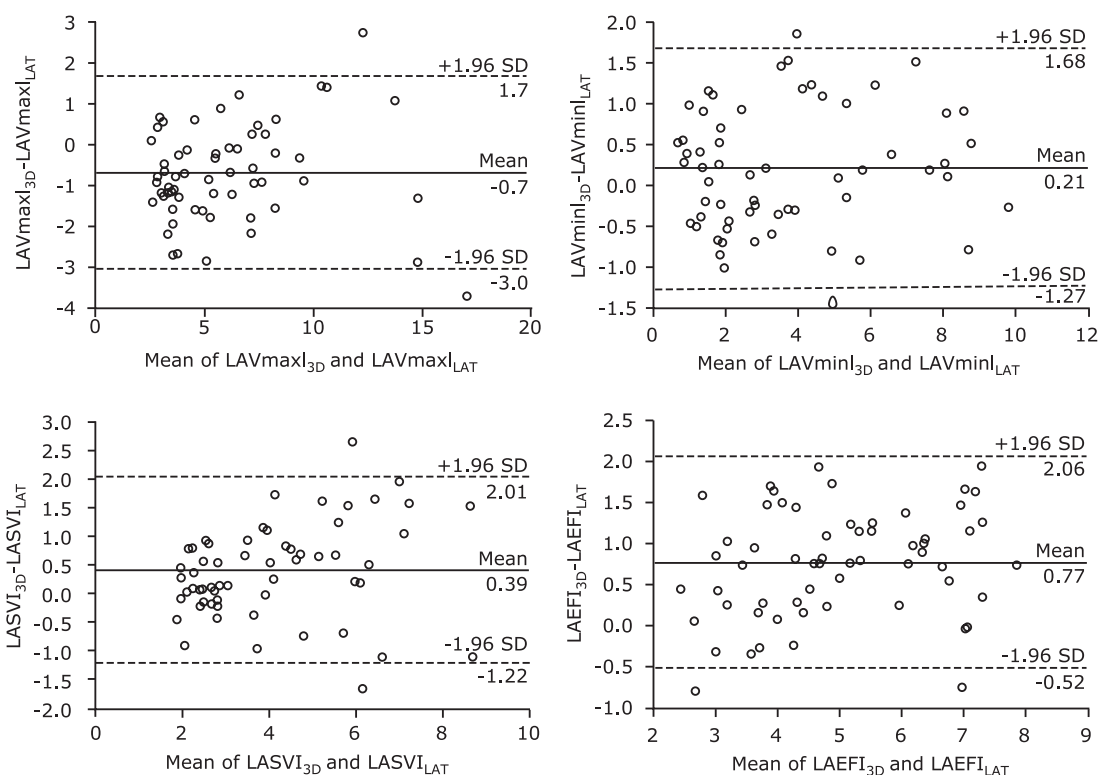


Figure 3. Bland-Altman agreement for measuring left atrial volume parameters by RT-3DE and LAT.

---- represents ± 1.96 standard deviation (SD, 95% limits of agreement); — indicates mean difference between left atrial volume by RT-3DE and LAT.

DISCUSSION

Left atrial function

Left atrium has different functions at different periods of the cardiac cycle, for example reservoir function during ventricular systole (reservoir for the blood flow coming from the pulmonary veins), conduit function during early diastole (blood flow from the pulmonary veins to the left ventricle through the left atrium), and booster pump function during late diastole (surplus blood is ejected into the left ventricle by active contraction).⁷ Essential hypertension is an important cause of left ventricular diastolic dysfunction, and compliance appears to be reduced due to increased peripheral resistance and left ventricular afterload.⁸ Furthermore, essential hypertension can result in increased filling pressure during ventricular diastole, and increased thickness and stiffness of the ventricular wall. Hence, hypertension can lead to left atrial enlargement and functional

ction during late diastole (surplus blood is ejected into the left ventricle by active contraction).⁷ Essential hypertension is an important cause of left ventricular diastolic dysfunction, and compliance appears to be reduced due to increased peripheral resistance and left ventricular afterload.⁸ Furthermore, essential hypertension can result in increased filling pressure during ventricular diastole, and increased thickness and stiffness of the ventricular wall. Hence, hypertension can lead to left atrial enlargement and functional

changes.⁹

Determination of cardiac parameters

Left atrial volume was the best index for assessment of left atrial function by volume variance. On echocardiography, LAVmax was recorded at 2 seconds after the T wave, LAVmin was recorded at the R wave, and left atrial Vpre was recorded at the P wave.¹⁰ dv/dtS was recorded before the T wave, dv/dtA was recorded after the P wave, and dv/dtE was recorded the after the T wave. LAVmax, LAVmin, and dv/dtS reflect the left atrial reservoir function, LAEF, LASV, and dv/dtA reflect the left atrial booster pump function, while LACV, LAVp, and dv/dtE reflect the left atrial conduit function.¹¹

Left atrial reservoir function

Left atrial reservoir function was reported to be increased in essential hypertension patients,¹² which likely resulted from hypertensive left ventricular early diastolic dysfunction and decreased filling during diastole, and a concomitant progression of left ventricular dysfunction and impaired left ventricular diastolic filling. In the present study, we found that reservoir function began to increase in the normal pattern group, and was obviously higher in the concentric hypertrophy pattern group and the eccentric hypertrophy pattern group.

Left atrial conduit function

Left atrial conduit function was reported to be decreased in essential hypertension patients,¹² which likely resulted from the increased pressure during ventricular diastole from the left atrium to the left ventricle due to the increased left ventricular stiffness and wall thickness.¹³ In the present study, we found no differences between the normal pattern group and the concentric remodelling pattern group, which may be because only left ventricular compliance appears reduced, while left ventricular contractile function was not changed.

Left atrial booster pump function

Left atrial booster pump function was reported to be increased in essential hypertension patients.¹² In the presence of left ventricular dysfunction and decreased diastolic filling, sufficient cardiac output may be maintained by increasing atrial booster pump function.¹⁴ In the present study, we found a decrease in left atrial booster pump function in the eccentric hypertrophy pattern group compared with the concentric hypertrophy pattern group, which may result from a long term higher capacitance load and afterload.

RT-3DE

RT-3DE was reported to be useful for evaluating left atrial volume and function.¹⁵ The result of the study showed that RT-3DE and Magnetic Resonance Imaging were consistently elevated, and RT-3DE was more efficient than two-dimensional echocardiography, in evaluating left atrial function.¹⁶ We confirmed that RT-3DE may provide a more accurate determination of left atrial volume and function, as this method does not require any geometric assumptions and remodelling of multiple cutting planes.^{16, 17}

LAT

The new technique of left atrial tracking is based on two-dimensional speckle tracking imaging. In the present study, left atrial volume-time and the emptying fraction curves were acquired by semiautomated contour tracing of the endocardium region of interest, followed by data analysis,¹⁰ allowing non-invasive, rapid and accurate quantitative analysis of left atrial volume and function. Previous studies have shown that RT-3DE and LAT were consistently elevated in evaluating left atrial function.¹⁸

Limitations

RT-3DE imaging requires a regular rate of cardiac rhythm during subject breath-holding. Thus, patients with anisorhythmia, dyspnoeic respiration, obesitas, multi-lung-QI, a diminutive ultrasound acoustic window, or the people (children, gerontism etc.) who cannot cooperate with the examination may have increased errors in their data records. Myocardium motion is three-dimensional, while LAT imaging is two-dimensional, producing a two dimensional record of endocardium motion. Thus, it is possible that some motion information may be lost. RT-3DE provides three-dimensional motion data, and the LAT image is not affected by anisorhythmia and breathing. Thus, RT-3DE and LAT are complimentary techniques that can be used in combination for improved evaluation of left atrial function. Bland-Altman analysis results show a well agreement between RT-3DE and LAT. So RT-3DE combined with LAT can better evaluate left atrial function.

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