Association of Aortic Distensibility and Left Ventricular Function in Patients With Stenotic Bicuspid Aortic Valve and Preserved Ejection Fraction: A CMR study

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Abstract

To determine the relationship between aortic distensibility and left ventricular (LV) remodeling, myocardial strain and blood biomarkers in patients with stenotic bicuspid aortic valve (BAV) and preserved ejection fraction (EF) by cardiovascular magnetic resonance (CMR). 43 stenotic BAV patients were prospectively selected for 3.0T CMR. Patients were divided into LV remodeling group (LV mass/volume ≥ 1.15 , n=21) and non-remodeling group (LV mass/volume < 1.15 , n=22). Clinical characteristics, biochemical data including cardiac troponin T (cTNT), N-terminal pro-B type natriuretic peptide (NT-proBNP) and creatine kinase isoenzyme were noted. Distensibility of middle ascending aorta (mid-AA) and proximal descending aorta, LV structural and functional parameters, global and regional myocardial strain were measured. Compared to non-remodeling group, LV remodeling group had significantly decreased LV global strain (radial: 26.04 ± 8.70 % vs. 32.92 ± 7.81 %, $P=0.009$; circumferential: -17.20 ± 3.38 % vs. -19.65 ± 2.34 %, $P=0.008$; longitudinal: -9.13 ± 2.34 % vs. -11.63 ± 1.99 %, $P=0.001$), while radial and circumferential strain were significantly reduced at the base (radial: 28.52 ± 9.47 % vs. 39.65 ± 10.33 %, $P=0.001$; circumferential: -14.45 ± 2.97 % vs. -17.22 ± 2.38 %, $P=0.002$), longitudinal strain was significantly reduced at all regions (basal: -5.79 ± 3.43 % vs. -8.65 ± 2.42 %, $P=0.003$; mid: -8.62 ± 2.21 % vs. -11.33 ± 2.58 %, $P=0.001$; apical: -12.79 ± 2.49 % vs. -15.04 ± 2.20 %, $P=0.003$). In addition, mid-AA distensibility was independently associated with LV remodeling ($\beta=-0.282$, $P=0.003$), and it was also significantly correlated with LV global strain (radial: $r=0.392$, $P=0.009$; circumferential: $r=-0.348$, $P=0.022$; longitudinal: $r=-0.333$, $P=0.029$), cTNT ($r=-0.333$, $P=0.029$) and NT-proBNP ($r=-0.440$, $P=0.003$). In this cohort with stenotic BAV and preserved EF, mid-AA distensibility is found significantly associated with LV dysfunction, which may be an important factor for predicting adverse cardiovascular events and a potential therapeutic target to prevent heart failure.

Introduction

Bicuspid aortic valve (BAV) is the most common congenital cardiovascular malformation in adult, affecting 0.5-2% of the population. Almost 50% of BAV subjects with severe aortic stenosis (AS) require surgery in their lifespan[1, 2]. BAV is characterized by a narrowed valve orifice and severe valve calcification, concomitant AS aggravates the degree of left ventricular (LV) outflow tract obstruction, resulting in increased LV afterload. Studies have indicated that stenotic BAV patients exhibited increased LV mass, depressed LV contractility and impaired diastolic function with marked hemodynamic alterations[3, 4]. And notably, the impaired LV diastolic function is related to reduced aortic elasticity [5–7], supporting the hypothesis that BAV disease is not confined to valve but also affects aorta and left ventricle.

Aorta is recognized as a conduit for buffering blood pressure, and its abnormal elastic property is a major contributor to increased LV afterload. LV remodeling, the result of myocardial injury or overload, is manifested by alterations in geometry and structure, systolic and diastolic dysfunction and myocardial fibrosis[8]. LV remodeling has emerged as a key predictor of adverse cardiovascular events in BAV, especially for patients with significant valvular dysfunction[9, 10]. However, there has been few reports so

far documenting the relationship between aortic distensibility and LV remodeling and myocardial strain in patients with stenotic BAV and preserved ejection fraction (EF).

Cardiovascular magnetic resonance (CMR) is considered the gold standard for evaluating the structure and function of aorta and left ventricle owing to its superior temporal and spatial resolution and less operator dependence. Compared to simple measurements of LVEF, feature-tracking allows comprehensive and quantitative measurements of global and regional myocardial strain, which reflects early and subtle changes in subclinical LV dysfunction[11].

Therefore, the purpose of this study is to determine the relationship between aortic distensibility and LV remodeling, myocardial strain and blood biomarkers in stenotic BAV patients with preserved EF by using CMR.

Methods

Study population

BAV patients with moderated to severe AS and persevered EF were diagnosed by transthoracic echocardiography at our institution and prospectively recruited for CMR from September 2020 to November 2021. BAV patients were categorized into two groups according to LV remodeling index as follows: LV remodeling group (LV mass /volume ≥ 1.15 , n=21) and non-remodeling group (LV mass/volume < 1.15 , n=22).

Moderated to severe AS was defined as peak velocity ≥ 3.0 m/s and (or) mean transaortic pressure gradient ≥ 20 mmHg. Exclusion criteria were as follows: LVEF $\leq$ 50%, other valvular dysfunction (including more than mild aortic insufficiency), aortic dissection, coronary artery disease and myocardial infarction, previous cardiac surgery. The present study conformed to the Declaration of Helsinki and was approved by the Ethics Committee of the Zhongshan Hospital Fudan University, Shanghai, China. Informed consent was obtained from all participants.

Echocardiography

All BAV patients underwent transthoracic echocardiography with a commercially available system (iE33, Philips Medical Systems, Bothell WA, USA). Standard 2D and Doppler echocardiographic examinations were performed at rest in the left lateral decubitus position according to ASE recommendations[12]. The diagnosis of BAV and aortic valve morphology was evaluated in the parasternal short-axis views with only two valve cusps clearly identified. Valve morphology was classified by leaflet fusion type, left and right cusp fusion type (LR), right and non-coronary cusp fusion type (RN) and left and non-coronary cusp fusion type (LN)[13]. Continuous-wave Doppler was used to measure the aortic valve peak velocity. Mean transaortic pressure gradient was calculated using the simplified Bernoulli equation.

Aortic and CMR Imaging

All examinations were performed on 3.0T scanner (Ingenia CX; Philips Healthcare, Best, The Netherlands) with 32-channel body phased-array surface coil. Aortic and LV images were acquired using ECG-gated steady state free precession acquisition with breath hold. The scanning parameters are as follows: TR 2.6-3.1 msec, TE 1.3-1.5 msec, flip angle 45°, slice thickness 8 mm, 2 mm section gap (for short-axis images), FOV 304 mm×304 mm×8 mm, matrix 152×225×1. The number of images was 25-30 per cardiac cycle. In cine short-axis view, 8-10 continuous images were obtained from mitral valve to LV apex. Cine images of two 2-chamber, 3-chamber and 4-chamber views were also acquired. Based on the transverse, coronal and sagittal positions, cine images of the middle ascending aorta (mid-AA) and proximal descending aorta (PDA) were obtained at the level of the pulmonary artery (Fig.1).

LV Analysis

LV structure and function analysis were performed with commercial postprocessing software (cvi42 v5.11, Circle Cardiovascular Imaging, Alberta, Canada). The short axis stack was analyzed automatically contouring the epicardial and endocardial borders from base to apex at end-diastole and end-systole with manually correction when necessary (Fig.2). LVEF, LV end-systolic volume (LVESV), LV end-diastolic volume (LVEDV), LV stroke volume (LVSV), LV mass (LVM) were quantified and indexed to the body surface area (LVESVi, LVEDVi, LVSVi and LVMi, respectively) using the Mosteller formula. The trabeculae and papillary muscles were included. LV remodeling index was defined as LVM/LVEDV.

MR cine images (short-axis, 2-chamber, 3-chamber and 4-chamber views) were input to the Tissue Tracking module for myocardial strain analysis according to the 16 AHA segmentation model. The borders of LV endocardium and epicardium were automatically delineated with manually correction when necessary. Global and regional (basal, mid, apical) strain values in radial, circumferential and longitudinal directions were obtained.

Aortic Distensibility Analysis

Maximum and minimum aortic cross-sectional areas and diameter over the cardiac cycle were determined on the postprocessing software (IntelliSpacePortal version 9.0.4; Philips Healthcare, Best, The Netherlands). Aortic distensibility was calculated by the following equation[14]: $(A_{\text{max}} - A_{\text{min}}) / A_{\text{min}} \times (\text{systolic-diastolic blood pressure})$. A_{max} and A_{min} are the maximum systolic aortic area and the minimum diastolic area, respectively. The brachial artery systolic and diastolic blood pressure were measured before CMR examination.

Laboratory testing

Venous blood samples were obtained before CMR examinations for all BAV patients. Cardiac troponin T(cTNT), N-terminal pro-B type natriuretic peptide (NT-proBNP), creatine kinase isoenzyme (CK-MB) levels were measured using the Elecsys Electro-chemo luminescent assay (Cobase 411 analyzer, Roche Diagnostics, Mannheim, Germany) in our laboratory department.

Statistical analysis

Analysis was performed with SPSS 20.0 software (Chicago IL, USA). Normality of data distribution was determined using the histogram and Shapiro-Wilk test. Data were reported as mean $\pm$ SD or medians (interquartile ranges) for continuous variables and as frequencies (percentages) for categorical variables. Differences between two groups were assessed by the Student's T test (Gaussian distribution) or Mann-Whitney U-test (non-Gaussian distribution). Differences in percentages were evaluated using the chi-square tests or Fisher's exact tests. Relationship between aortic distensibility and LV global strain, blood biomarkers were assessed by Pearson's correlation coefficient. Data on cTNT and NT-proBNP were skewed and thus logarithmically transformed. Statistical significance was defined as 2-sided $p < 0.05$. Multivariate linear regression analysis was performed to determine the independent predictor of LV remodeling. Variables were entered in the model if $p < 0.10$ in univariate analyses. To avoid collinearity between peak velocity and mean transaortic pressure gradient, only peak velocity was entered in the multivariate models. Intra- and interobserver reliabilities were evaluated by the intraclass correlation (ICC).

Results

Baseline characteristics

The demographics and biochemical data of all subjects were summarized in Table 1. There were no differences in age, gender, body mass index, systolic blood pressure, diastolic blood pressure, pulse pressure, heart rate, comorbid condition, medication status and valve phenotype in BAV patients. Compared to non-remodeling group, LV remodeling group had greater mean transvalvular pressure gradient (60.24 ± 19.69 mm Hg vs. 45.36 ± 12.01 mm Hg, $P = 0.005$), higher peak velocity (4.86 ± 0.64 m/s vs. 4.37 ± 0.52 m/s, $P = 0.009$) and elevated NT-proBNP level (593.80 (238.85-792.25) pg/ml vs. 110.20 (78.15-204.33) pg/ml, $P < 0.001$). There was no significant difference in cTNT and CK-MB between two groups.

Table 1
Baseline Characteristics and biochemical data in BAV patients

Variables	LV mass/volume <1.15 (n=22)	LV mass/volume ≥1.15 (n=21)	P value
Age (years)	60.82±7.40	58.05±8.27	0.253
Male, n (%)	12 (54.55%)	16 (76.19%)	0.137
Body mass index (kg/m ²)	23.63±3.32	25.12±3.22	0.141
Systolic blood pressure (mm Hg)	127.45±13.47	132.38±13.77	0.243
Diastolic blood pressure (mm Hg)	77.41±8.29	78.57±11.19	0.700
Pulse pressure (mm Hg)	50.05±11.47	53.81±10.40	0.267
Heart rate (bpm)	69.14±9.95	68.76±7.53	0.890
Comorbid conditions			
Hypertension, n (%)	11 (50.00%)	9 (42.86%)	0.639
Diabetes, n (%)	1 (4.55%)	3 (14.29%)	0.345
Bate-blocker therapy, n (%)	2 (9.09%)	1(4.76%)	1.000
ACEI/ARB therapy, n (%)	8 (36.36%)	7 (33.33%)	1.000
BAV phenotypes			
LR, n (%)	11 (50.00%)	9 (42.86%)	0.763
RN, n (%)	11 (50.00%)	12 (57.14%)	0.763
Mean pressure gradient (mm Hg)	45.36±12.01	60.24±19.69	0.005
Peak velocity (m/s)	4.37±0.52	4.86±0.64	0.009
cTNT (ng/ml)	0.010 (0.008-0.015)	0.015 (0.010-0.022)	0.061
NT-proBNP (pg/ml)	110.20 (78.15-204.33)	593.80 (238.85-792.25)	<0.001
CK-MB (U/L)	13.73±3.27	15.10±2.90	0.155
All continuous data are presented as mean ± standard deviation or median (25–75% interquartile range).			
LV left ventricle, LR left and right cusp fusion type, RN right and non-coronary cusp fusion type, cTNT cardiac troponin T, NT-proBNP N-terminal pro-B type natriuretic peptide, CK-MB creatine kinase isoenzyme.			

LV parameters

There were no differences in LVEF, LVEDVi, LVESVi and LVSVi in BAV patients. The LV remodeling group demonstrated significantly higher LVMI (97.50 ± 23.45 g/m² vs. 66.61 ± 20.08 g/m², $P < 0.001$) and LV mass/volume (1.29 ± 0.21 g/ml vs. 0.91 ± 0.12 g/ml, $P < 0.001$) than non-remodeling group (Table 2).

BAV patients with LV remodeling had significantly lower global radial (GRS) ($26.04 \pm 8.70\%$ vs. $32.92 \pm 7.81\%$, $P = 0.009$), global circumferential (GCS) ($-17.20 \pm 3.38\%$ vs. $-19.65 \pm 2.34\%$, $P = 0.008$) and global longitudinal strain (GLS) ($-9.13 \pm 2.34\%$ vs. $-11.63 \pm 1.99\%$, $P < 0.001$) than those without LV remodeling. Moreover, the distribution of regional myocardial impairment is heterogeneously from base to apex, marked in radial and circumferential at base (radial: $28.52 \pm 9.47\%$ vs. $39.65 \pm 10.33\%$, $P = 0.001$; circumferential: $-14.45 \pm 2.97\%$ vs. $-17.22 \pm 2.38\%$, $P = 0.002$), slightly at middle (radial: $25.33 \pm 10.26\%$ vs. $31.29 \pm 7.53\%$, $P = 0.035$; circumferential: $-18.03 \pm 4.07\%$ vs. $-20.22 \pm 2.79\%$, $P = 0.045$), and no significant difference at apex (Table 2). For longitudinal strain, significant differences were seen from base to apex (base: $-5.79 \pm 3.43\%$ vs. $-8.65 \pm 2.42\%$, $P = 0.003$; middle: $-8.62 \pm 2.21\%$ vs. $-11.33 \pm 2.58\%$, $P = 0.001$; apex: $-12.79 \pm 2.49\%$ vs. $-15.04 \pm 2.20\%$, $P = 0.003$).

Table 2
Left Ventricular Parameters in BAV patients

Variables	LV mass/volume <1.15 (n=22)	LV mass/volume ≥1.15 (n=21)	P value
LV volumes, mass and function			
LVEF (%)	68.73±5.80	67.88±6.27	0.647
LVEDVi (ml/m ²)	75.33±13.45	76.18±14.23	0.840
LVESVi (ml/m ²)	23.79±6.45	24.15±5.51	0.842
LVSVi (ml/m ²)	52.19±9.91	51.65±11.86	0.871
LVMi (g/m ²)	66.61±20.08	97.50±23.45	<0.001
LV mass/volume (g/ml)	0.91±0.12	1.29±0.21	<0.001
LV strain			
Radial strain (%)			
- basal	39.65±10.33	28.52±9.47	0.001
- mid	31.29±7.53	25.33±10.26	0.035
- apical	31.41±10.41	28.07±11.05	0.314
- global	32.92±7.81	26.04±8.70	0.009
Circumferential strain (%)			
- basal	-17.22±2.38	-14.45±2.97	0.002
- mid	-20.22±2.79	-18.03±4.07	0.045
- apical	-21.86±3.74	-19.39±4.50	0.056
- global	-19.65±2.34	-17.20±3.38	0.008
Longitudinal strain (%)			
- basal	-8.65±2.42	-5.79±3.43	0.003
- mid	-11.33±2.58	-8.62±2.21	0.001

All continuous data are presented as mean ± standard deviation.

LVEF left ventricular ejection fraction, *LVEDVi* left ventricular end-diastolic volume index, *LVESVi* left ventricular end-systolic volume index, *LVSVi* left ventricular stroke volume index, *LVMi* left ventricular mass index.

Variables	LV mass/volume <1.15 (n=22)	LV mass/volume ≥1.15 (n=21)	P value
- apical	-15.04±2.20	-12.79±2.49	0.003
- global	-11.63±1.99	-9.13±2.34	<0.001
All continuous data are presented as mean ± standard deviation.			
<i>LVEF</i> left ventricular ejection fraction, <i>LVEDVi</i> left ventricular end-diastolic volume index, <i>LVESVi</i> left ventricular end-systolic volume index, <i>LVSVi</i> left ventricular stroke volume index, <i>LVMi</i> left ventricular mass index.			

Aortic Distensibility

Though mid-AA diameter was similar between two groups, distensibility of mid-AA was lower in LV remodeling group than non-remodeling group ($1.22 \pm 0.24 \times 10^{-3} \text{ mm Hg}^{-1}$ vs $1.60 \pm 0.41 \times 10^{-3} \text{ mm Hg}^{-1}$, $P=0.001$). There were no differences in diameter and distensibility of PDA among two groups (Table 3).

Table 3
Aortic Diameter and Distensibility in BAV patients

Variables	LV mass/volume <1.15 (n=22)	LV mass/volume ≥1.15 (n=21)	P value
Mid-AA diameter (cm)	4.22±0.43	4.09±0.52	0.382
Mid-AA distensibility ($10^{-3} \text{ mm Hg}^{-1}$)	1.60±0.41	1.22±0.24	0.001
PDA diameter (cm)	2.38±0.25	2.45±0.17	0.302
PDA distensibility ($10^{-3} \text{ mm Hg}^{-1}$)	2.42±0.76	2.22±0.66	0.339
All continuous data are presented as mean ± standard deviation.			
<i>Mid-AA</i> middle ascending aorta, <i>PDA</i> proximal descending aorta.			

Univariable and Multivariable Predictors of LV Remodeling

Univariate and multivariate analysis results are shown in Table 4, gender, body mass index, pulse pressure, mean transvalvular pressure gradient, peak velocity and mid-AA distensibility were correlated with LV remodeling, presented as LV mass/volume. On multivariable regression, only body mass index ($\beta = 0.021$, $P=0.020$), peak velocity ($\beta = 0.112$, $P=0.024$) and mid-AA distensibility ($\beta=-0.282$, $P=0.003$) were independently associated with LV remodeling ($R^2=0.769$).

Table 4 Univariate and multivariate predictors of LV remodeling in BAV Patients

Variables	Unadjusted Correlates of		Multivariate Correlates of		
	LV remodeling		LV remodeling		
	ρ	P value	β	95% (CI)	P value
Man	-0.185	0.023	-0.134	-0.272, 0.004	0.057
Age	-0.005	0.375			
Body mass index	0.026	0.031	0.021	0.004, 0.039	0.020
Systolic blood pressure	0.003	0.282			
Diastolic blood pressure	-0.003	0.437			
Pulse pressure	0.007	0.039	0.002	-0.004, 0.008	0.516
Heart rate	0.003	0.493			
Mean pressure gradient	0.007	0.002			
Peak velocity	0.192	0.002	0.112	0.016, 0.209	0.024
Mid-AA distensibility	-0.409	<0.001	-0.282	-0.459, -0.106	0.003
PDA distensibility	-0.078	0.165			

$R^2=0.769$

Correlation of Aortic Distensibility with Other Variables

GRS was positively and significantly correlated with mid-AA distensibility ($r= 0.392$, $P=0.009$, Fig. 4A), while GCS ($r= -0.348$, $P=0.022$, Fig. 4B) and GLS ($r= -0.333$, $P=0.029$, Fig. 4C) were negatively correlated with mid-AA distensibility. Log cTNT ($r= -0.333$, $P=0.029$, Fig. 4D) and Log NT-proBNP ($r= -0.440$, $P=0.003$, Fig. 4E) were negatively correlated with mid-AA distensibility. CK-MB was not significantly correlated with mid-AA distensibility. There was no significant correlation between PDA distensibility and Log cTNT, Log NT-proBNP, CK-MB, GRS, GCS, GLS.

Reproducibility

Intra- and interobserver variabilities of MRI parameters (aortic distensibility, LVEDVi, LVMi, GRS, GCS, GLS) were obtained with 26 random cases by two observers. The intra- and inter-observer variability results were shown in Table 5. All the MRI parameters demonstrated good agreements.

Table 5
Inter- and Intraobserver Analyses for MRI parameters

	Intraobserver		Interobserver	
	ICC	95%CI	ICC	95%CI
Mid-AA distensibility	0.921	0.834, 0.964	0.959	0.910, 0.982
PDA distensibility	0.925	0.842, 0.966	0.961	0.914, 0.983
LVEDVi	0.968	0.747, 0.990	0.984	0.855, 0.995
LVMi	0.977	0.947, 0.990	0.988	0.973, 0.990
GRS	0.926	0.763, 0.971	0.961	0.865, 0.986
GCS	0.935	0.783, 0.975	0.966	0.878, 0.987
GLS	0.901	0.757, 0.958	0.948	0.862, 0.978
GRS: global radial strain; GCS: global circumferential strain; GLS: global longitudinal strain.				

Discussion

Current ESC/EACTS guideline has formulated strong recommendations for early intervention in patients with symptomatic severe AS or those who are asymptomatic but with impaired LV function (LVEF<50%) [15]. Management of asymptomatic patients with moderate to severe AS and preserved EF is otherwise controversial[16, 17]. BAV with moderate to severe AS is more prevalent in young individuals and is associated with ascending aorta dilatation, aneurysm formation and dissection. Moreover, BAV tends to have a higher degree of LV outflow tract obstruction than the tricuspid aortic valve (TAV) with AS, making it difficult to determine the appropriate interventions and their timing. The present study focused exclusively on stenotic BAV patients with preserved EF and for the first time, identified the significant association between mid-AA distensibility and LV dysfunction by means of CMR, providing an additional method for assessing early and subtle ventricular dysfunction.

In this study, we utilized CMR strain-based technique to characterize the global and regional strain. We found a reduction of global myocardial strain in BAV patients with LV remodeling, which is consistent with prior echocardiography studies[4, 9]. We further demonstrated that the difference in strain was prominent in the base of the heart, which has large amount of myocardial fibers of the LV. This pattern of systolic dysfunction is similar to that seen in dilated cardiomyopathy[18] and isolated AS[19]. The asymmetric distribution of myocardial fibrosis may contribute to the heterogeneous contractile injury in patients with LV outflow tract obstruction. It should be noted that, LV remodeling group exhibited significantly decreased strain from base to apex longitudinally when compared to non-remodeling group. GLS has emerged as a more sensitive and objective marker to quantify subendocardial contraction. William et al. [9] reported that impaired GLS was independently associated with adverse cardiovascular events during a median follow-up period of 36 months in BAV patients. In 294 patients with severe AS, Ng et al.[20]

revealed that impaired GLS was an independent predictor of all-cause mortality. Thus, tissue tracking technique may facilitate early detection of abnormal LV strain in sentinel regions and identify stenotic BAV patients who might benefit from earlier surgical interventions.

Elastic fiber degeneration and extracellular matrix disorder are the major pathogenic mechanism for the impairment of aortic elasticity in stenotic BAV patients [21, 22]. In the results of our study, ascending aorta was involved earlier and more obviously, largely due to its high elastin to collagen ratio[23]. It was particularly noticeable that mid-AA distensibility was a significant predictor of LV remodeling in patients with stenotic BAV and preserved EF. This association was independent of blood pressure and is similar to the findings reported by Rider et al. in hypertension patients[24]. It is possible that with the decreased aortic elasticity, accelerated reflected pressure wave arrives in late systole, leading to increased LV afterload, subendocardial ischemia, increased oxygen demand and further interstitial fibrosis[25–27]. The present study supports the hypothesis that aortic stiffening increases the risk of poorer cardiovascular events in stenotic BAV patients through adverse LV remodeling. BAV with AS should be diagnosed at an early stage when LV and aortic remodeling are more likely to be reversible. Optimal medical therapy, especially angiotensin-converting enzyme inhibitor and angiotensin receptor blocker, may have favorable effects before the onset of LV dysfunction by modifying aortic stiffness.

This study also demonstrated that increased aortic stiffening was associated with reduced global myocardial strain in stenotic BAV patients with preserved EF, which is similar to the echocardiography findings in patients with chronic kidney disease[28] and type 2 diabetes[29]. Additionally, the upregulation of cTNT and NT-proBNP after myocardial dysfunction is closely linked to activation of inflammatory cytokines, oxidative stress and myocardial wall stretch[30, 31]. The present study showed a significant relationship between mid-AA distensibility and cTNT, NT-proBNP, whose prognostic value has been proven in AS patients[32, 33], indicating that stenotic BAV patients with reduced aortic elasticity were probably at a more advanced disease stage.

Study Limitations

This was a cross-sectional study with a small sample size, and the cause-effect relationship between aortic and LV remodeling cannot be identified. Therefore, further longitudinal researches with larger sample sizes may be needed. In addition, we did not recruit stenotic TAV as controls, since these patients are older and complicated with more cardiovascular risk factors^[34], which may cause bias into the study.

Conclusions

The detection of abnormal strain in longitudinal or radial and circumferential at base may aid in identifying sub-clinical LV dysfunction. In line with the concept of ventricular vascular coupling, this CMR study further confirms that mid-AA distensibility is independently associated with LV remodeling. Mid-AA distensibility may therefore represent a valuable indicator for optimized risk stratification, appropriate timing of intervention for stenotic BAV patients with preserved EF.

Declarations

Authors' contributions Yijun Pan-data collection, analysis, manuscript draft; Jiang Lin -study conception and design, manuscript review; Yongshi Wang, Jun Li -data collection, analysis; Pengju Xu, Mengsu Zeng -manuscript review; Yan Shan-study conception and design, data collection, manuscript review. All authors read and approved the final manuscript.

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Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

Ethical approval This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the local ethics committee of our institution (NO: B2020-232).

Informed consent Informed consent was obtained from all individual participants included in the study.

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Figures

Figure 1

Examples of measuring distensibility of mid-AA and PDA. An BAV patient with moderate to severe AS and RN fusion (Plane A). Coronal (Plane B) and sagittal planes (Plane C) of the aorta are used to select the level of right pulmonary artery (dashed line) and measure diameter and cross-sectional area of mid-AA and PDA; Images of mid-AA and PDA acquired during systole (Plane D) and diastole (Plane E). RN: right and non-coronary cusp fusion type; Mid-AA: middle ascending aorta; PDA: proximal descending aorta.

A

B

Figure 2

Examples of LV structure and function analysis on the short-axis cine images. The trace of LV endocardial and epicardial contours from base to apex at end-diastole (Plane A) and end-systole (Plane B).

Figure 3

Examples of measuring LV myocardial strain by Tissue Tracking software. Standard cardiac images of short-axis (Plane A), two-chamber (Plane B), four-chamber (Plane C) and three-chamber views (Plane D); AHA segmentation of radial (Plane E), circumferential (Plane F) and longitudinal (Plane G) strain.

Figure 4

Relationship between Mid-AA distensibility and global radial (Plane A), circumferential (Plane B) and longitudinal (Plane C) strain, cTNT (Plane D), NT-proBNP (Plane E) in BAV patients. Mid-AA middle ascending aorta, cTNT cardiac troponin T, NT-proBNP N-terminal pro-B type natriuretic peptide.