TOMOGRAPHY® RESEARCH ARTICLE

Feature Tracking Cardiac MRI Reveals Abnormalities in Ventricular Function in Patients With Bicuspid Aortic Valve and Preserved Ejection Fraction

Nicholas S. Burris[1], Ana Paula S. Lima[2], Michael D. Hope[2], and Karen G. Ordovas[2]

[1]Department of Radiology, University of Michigan, 1500 East Medical Center Drive,TC B1-132, SPC-5030 Ann Arbor, MI 48109-5030; and [2]Department of Radiology and Biomedical Imaging, University of California, San Francisco, San Francisco, CA

Corresponding Author:
Nicholas Burris, MD
Department of Radiology, University of Michigan, 1500 East Medical Center Drive, TC B1-132, SPC-5030 Ann Arbor, MI 48109-5030
E-mail: nburris@med.umich.edu

Key Words: Bicuspid aortic valve, diastolic dysfunction, cardiac MRI, feature-tracking, strain
Abbreviations: Bicuspid aortic valve (BAV), feature-tracking cardiovascular magnetic resonance (CMR-FT), ejection fraction (EF), electrocardiogram (ECG), magnetic resonance imaging (MRI), steady-state free precession (SSFP)

ABSTRACT

Subclinical systolic and diastolic left ventricular (LV) dysfunction has been reported in previous echocardiographic studies on congenital bicuspid aortic valve (BAV). Patients with BAV commonly undergo evaluation with magnetic resonance imaging, and feature-tracking cardiovascular magnetic resonance (CMR-FT) is an emerging technique that assesses myocardial strain using standard cine sequences. This study investigated differences in myocardial strain between patients with BAV with preserved ejection fraction (EF) and controls using CMR-FT. Patients with isolated BAV and preserved EF, who had previously undergone CMR (n = 42; mean age, 41.2 ± 13.9) were compared with controls (n = 19; 36.6 ± 9.8; $P = .2$). Investigational CMR-FT strain analysis software was used to measure circumferential systolic and diastolic strain values, as well as standard LV volumetric and functional parameters. The majority of patients with BAV had mild or no valve dysfunction, and LV myocardial mass end-diastolic volume indices were similar between groups. Peak diastolic circumferential strain rate was lower in patients with BAV than in controls (0.89 ± 0.27 vs 1.21 ± 0.21 s^{-1}, $P = .003$). After adjusting for covariates, only myocardial mass index was independently associated with peak circumferential systolic strain and diastolic strain rate. Feature-tracking CMR can identify abnormalities of LV strain in a clinical cohort of asymptomatic patients with BAV with preserved EF. Decreases in circumferential diastolic strain rate in patients with BAV suggest evidence of early diastolic dysfunction.

INTRODUCTION

Bicuspid aortic valve (BAV) is commonly identified in asymptomatic young adults with normal or mildly impaired valve function. Current clinical guidelines recommend these patients to undergo regular echocardiography for assessing valve and ventricular function, with surgery indicated only when the patient becomes symptomatic or has evidence of left dysfunction/dilation by imaging (1). The latency period from the time of diagnosis to the development of symptoms is often long and is characterized by progressive valvular obstruction and myocardial pressure overload (2). The typical ventricular adaptation to chronic pressure overload is myocardial hypertrophy, and although beneficial in maintaining left ventricular (LV) systolic function, hypertrophy is associated with deleterious chronic effects such as the development of myocardial fibrosis, decreased coronary blood flow reserve, impaired diastolic function, and increased risk of death from cardiovascular disease (2, 3). Specifically, the development of myocardial fibrosis has been proposed as a marker of chronic myocardial injury and can predict ventricular decompensation in patients with aortic stenosis (4, 5).

To improve the early detection of myocardial dysfunction, imaging-based techniques, including echocardiography-based techniques such as tissue Doppler imaging and speckle-tracking, and magnetic resonance imaging (MRI)-based techniques, including tagging for myocardial strain assessment and T1-mapping myocardial fibrosis assessment, have been developed for a detailed assessment of myocardial function. In brief, myocardial strain is a measurement of the myocardial deformation, related to shortening/lengthening and thickening of the myocardial fibers throughout the cardiac cycle, and it can be measured in three directions along the ventricular axis, namely, circumferential, longitudinal, and radial. By convention, higher degrees of shortening (ie, systolic contraction) and lengthening (ie, diastolic relaxation) are represented by more negative and positive

ISSN 2379-1381 http://dx.doi.org/10.18383/j.tom.2018.00005

values, respectively. Several recent studies of patients with BAV among whom speckle-tracking echocardiography was used have shown decreased systolic strain values despite preserved ejection fraction (EF) and lack of significant valve disease, suggesting that subclinical myocardial dysfunction exists in otherwise asymptomatic patients with BAV (6, 7). Furthermore, despite a well-established relationship between hypertrophy and diastolic dysfunction, and clearly demonstrated increased myocardial mass in asymptomatic patients with BAV, little has been reported about the role of hypertrophy in diastolic function in patients with BAV (8).

Feature-tracking cardiac magnetic resonance (CMR-FT) is a relatively new technique that, similar to speckle-tracking echocardiography, assesses ventricular function in detail by measuring a variety of strain parameters. CMR-FT allows strain analysis, a significant benefit, that uses standard steady-state free precession (SSFP) cine images obtained during clinical cardiac MRI examinations; therefore, unlike in tagging techniques, CMR-FT images can be retrospectively analyzed. CMR-FT has been previously used to assess ventricular function in a variety of diseases including myocardial ischemia, congenital heart disease, and nonischemic cardiomyopathy; however, few studies have used CMR-FT to assess ventricular function in either acquired or congenital aortic valve disease (9-11).

The aim of this study was to investigate the utility of CMR-FT in assessing LV function in a cohort of asymptomatic patients with congenital BAV who were undergoing clinical CMR evaluation, and to determine associations between strain parameters and traditional imaging and clinical parameters. Furthermore, we aim to identify differences in systolic and diastolic LV function between this cohort of patients with BAV and a group of controls by the use of the CMR-FT technique. We hypothesized that among patients with BAV with preserved EF, there are abnormalities of systolic and diastolic function that are not apparent by standard clinical imaging evaluation.

MATERIALS AND METHODS

Patient Identification

Electronic charts of the diagnostic radiology reports were reviewed at our institution from January 2005 through to August 2014; 77 patients with at least 1 echocardiography study, confirming the presence of BAV, and at least 1 clinical cardiac MRI examination that contained short-axis SSFP images covering the entire LV, were identified. Exclusion criteria for the study included age $<$18 years, LV EF of $<$50% by echocardiogram, history of aortic valve replacement, and suboptimal short-axis SSFP images ($<$20 frames/cardiac cycle). After application of the inclusion/exclusion criteria, 49 patients with BAV who were undergoing CMR surveillance were selected for the study. A waiver of informed consent was obtained from our institutional review board for the retrospective data analysis performed for this study, which was compliant with the Health Insurance Portability and Accountability Act. Similarly, 19 controls were identified over the same interval by a review of the clinical charts and radiology reports consisting of 5 healthy volunteers and 14 patients with CMR studies for clinical evaluation. All patients had normal CMR studies, and there was no evidence of confirmed cardiovascular disease on review of medical records. The indications for clinical CMR in the controls included evaluation for occult shunt (n = 5), arrhythmogenic right ventricular dysplasia in the setting of palpitations/family history (n = 6), and coronary anomaly in the setting of syncope (n = 3). Clinical and demographic data were obtained by a review of the relevant charts. A review of the clinical echocardiogram report closest in time to the CMR imaging aided the grading of aortic stenosis/insufficiency and diastolic dysfunction by means of echocardiography.

MR Imaging Technique

Scans were acquired at 1.5 Tesla Achieva (Philips Medical Systems, Best, The Netherlands), using a 5-channel surface cardiac coil. All patients had (ECG)-gated SSFP cine images in the short-axis plane covering the entirety of the LV to quantify ventricular size and function. The following are the typical imaging parameters: repetition time/echo time, 3.7/1.9 milliseconds; section thickness, 8 mm; gap, 0 mm; field of view, 340 mm; matrix, 244 $\times$ 245; phases per cardiac cycle, 16; signals acquired, 1; sensitivity encoding factor, 2; sections per breath hold, 2; and acquisition time per breath hold for a heart rate of 80 beats per minute, 15 seconds.

LV Analysis

Standard LV volumetric and functional analyses were performed by using commercially available cardiac MRI analysis software (cvi^{42}®, Circle Cardiovascular Imaging Calgary, Canada) after LV endocardial and epicardial contours were segmented from base to apex on short-axis SSFP images at end diastole and end systole by use of the standard segmentation technique (12). Papillary muscles were excluded when measuring the myocardial mass and were included when measuring LV volumes. An observer (NSB) with 6 years of experience with CMR, who was blinded to the patient's clinical and demographic information, performed the segmentation; however, blinding of BAV status during LV functional and volumetric assessment was not possible, as the aortic valve is visible on cine images being segmented for CMR-FT analysis. After ventricular segmentation, 2-dimensional tissue tracking analysis was performed on the short-axis SSFP images by use of an investigational software plugin (Tissue Tracking module, Circle Cardiovascular). In brief, the feature-tracking strain analysis involves using small windows to generate a pixel-intensity map/pattern for a small region of the myocardium on SSFP cine images, and then using algorithms to identify the most similar patterns of pixel-intensity on images from all subsequent images in the cardiac cycle, thus creating the ability to "track" a specific point in the myocardium over time. Detailed descriptions of the algorithms used by this and other software vendors remain proprietary. A more comprehensive review of the CMR-FT strain analysis technique is described in detail elsewhere (13), and a screenshot of the CMR-FT analysis software with superimposed displacement fields and strain curve analysis is shown in Figure 1. Myocardial tracking was visually assessed for adequacy, any apparent deviations of the tracking contours from the myocardial borders were corrected, and the tracking analysis was repeated. Multiple global circumferential LV strain parameters including, peak systolic strain, systolic strain rate (SR), diastolic SR, and systolic time to peak (TTP) strain were measured. Of note, systolic strain values are negative by convention, meaning that less negative peak systolic strain values indicate decreased ventricular con-

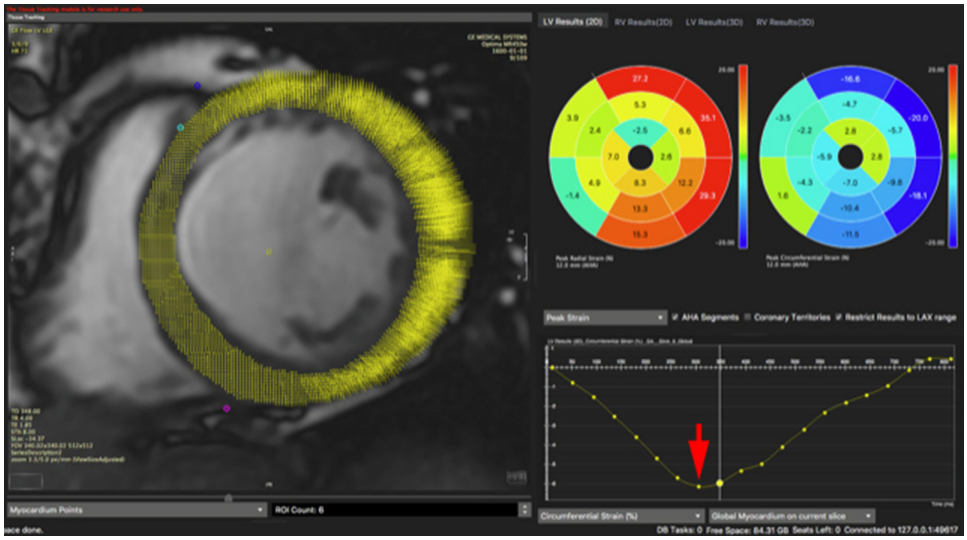

Figure 1. Screenshot of the feature-tracking cardiovascular magnetic resonance (CMR-FT) analysis software (cmr^{42}, tissue-tracking plug-in), showing typical appearance during strain analysis. The displacement field (yellow lines) is superimposed over short-axis steady-state free precession (SSFP) cine images and represents the displacement of tracked points from their resting diastolic location. Strain curves can be generated from these data (lower right), with global circumferential strain depicted in this example. Stain strain assessment can be analyzed on the basis of anatomic myocardial segments (upper right), although segmental measurements were not analyzed in this study (only global ventricular values).

traction. For simplicity of measurement and interpretation, and given the global nature of aortic valve-related myocardial abnormalities, segmental strain data were not analyzed. Longitudinal strain parameters were not analyzed given that the horizontal long-axis SSFP images required for longitudinal strain assessment were available in only a minority of cases owing to the fact that our institutional aortic valve clinical CMR protocol did not include standard long-axis SSFP for a majority of the study period. Radial strain values were not analyzed owing to known issues of measurement inaccuracy with feature-tracking techniques (13).

Data Analysis and Statistics

Baseline characteristics were reported as mean ± SD for continuous variables and frequencies for categorical variables. Pearson correlations were used to assess associations between imaging variables and other clinical/demographic variables. Group means were compared using 2-tailed unpaired Welch unequal variances' *t*-tests. Chi-square analysis and Fisher exact tests were used to evaluate difference in frequency of categorical variables. The threshold for statistical significance was prospectively set at $P < .05$. Pairwise correlation matrices were used to identify multicollinearity among predictor variables. Subsequently, parsimonious multiple linear regression models were used to identify independent predictors of peak systolic circumferential strain and peak diastolic strain rate among a group of potential predictor variables including age, history of hypertension, EF, myocardial mass index, and LV end-diastolic volume index and severity of aortic stenosis/insufficiency. Given the low frequency of significant aortic valve stenosis or insufficiency, valve dysfunction was analyzed as a binary variable with moderate-to-severe dysfunction considered as "significant" and none-to-mild dysfunction considered as "not significant." All statistical analyses were performed using Stata 14.0 (StataCorp LP, College Station, TX).

RESULTS

Patient Characteristics

The average age of the patients with the BAV group was 41.2 ± 13.9 years and that for the controls was 36.6 ± 9.8 years ($P = .15$); male patients were marginally more in the BAV group (55% vs 39%, $P = .26$). There was a trend toward higher BSA (body surface area) among patients with BAV, which did not reach statistical significance (1.86 m^2 vs 1.74 m^2, $P = .06$). The majority of patients with BAV had either none/mild aortic stenosis (78%) and none/mild insufficiency (74%) by echocardiography. The majority of patients had no evidence of diastolic dysfunction by clinical echocardiography (81%). Patient characteristics are detailed in Table 1.

LV Parameters

There was a trend toward higher mean EF among the controls compared with patients with BAV (60.1% ± 6.0% vs 57.5% ± 4.3%, $P = .10$), although the mean EF in both groups was within the normal range. Heart rate was similar between patients with BAV and controls (63.6 ± 10.2 vs. 68.5 ± 8.1, $P = .16$). LV end-diastolic volume index, stroke volume index, and myocardial mass index were comparable between the 2 groups. Peak systolic circumferential strain was comparable between the patients with BAV and control groups (−20.0 ± 2.0% vs 19.6 ± 2.3%, $P = .41$); however, the mean peak diastolic strain rate was significantly lower in patients with BAV (0.89 ± 0.27 vs 1.21 ± 0.21 s^{-1}, $P = .0003$) (Figure 2). No significant differences were

Table 1. Demographic and Clinical Parameters

Characteristics	Controls (n = 19)	Patients With BAV (n = 42)	*P*-Value
Age (y)	36.6 ± 9.8	41.2 ± 13.9	.15
Male, n (%)	7 (39%)	23 (55%)	.26
BSA (m^2)	1.74 ± 0.21	1.86 ± 0.23	.06
Hypertension, n (%)	—	6 (14%)	—
Anti-hypertensive use, n (%)	—	15 (36%)	—
History of coarctation, n (%)	—	11 (26%)	—
History of CHD, n (%)	—	5 (12%)	—
Aortic stenosis, n (%)	—	—	—
None		25 (64%)	
Mild		6 (14%)	
Moderate		7 (17%)	
Severe		2 (5%)	
Aortic insufficiency, n (%)	—	—	—
None		20 (48%)	
Mild		11 (26%)	
Moderate		9 (21%)	
Severe		2 (5%)	
Diastolic dysfunction by echocardiography, n (%)		—	
None		34 (81%)	
Present		6 (14%)	
Unable to assess		2 (5%)	

*CHD other than coarctation.

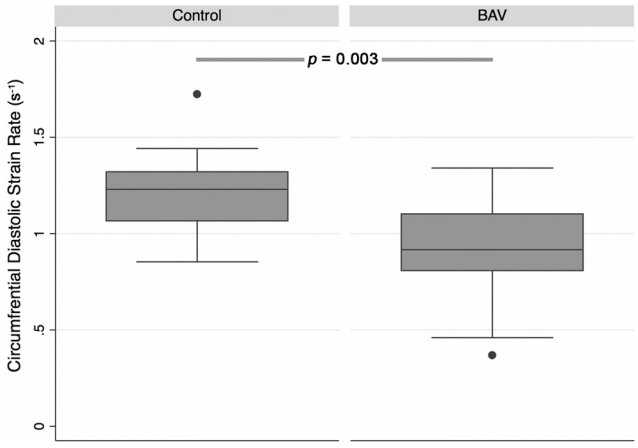

Figure 2. Differences in diastolic strain rate between patients with a bicuspid aortic valve (BAV) and controls. Patients with BAV with preserved ejection fraction (EF) showed a significantly lower mean circumferential diastolic strain rate compared with controls (0.89 ± 0.27 vs 1.21 ± 0.21 s^{-1}, $P = .003$).

observed between groups for circumferential systolic strain rate or time to peak strain. The statistical significance of these results did not change when patients with diastolic dysfunction by echocardiography were excluded from the analysis. LV parameters for each group are detailed in Table 2.

Strain Parameter Correlations

Peak systolic circumferential strain showed a weak negative association with history of hypertension ($r = -0.33$, $P = .04$) and a moderate negative correlation with EF ($r = -0.49$, $P = .01$). In addition, there was a moderate positive correlation with myocardial mass index ($r = 0.51$) and a weak positive association with aortic stenosis severity ($r = 0.29$), although these associations did not reach predefined levels of statistical significance (both, $P = .06$). As a reminder, systolic strain values are negative by convention, meaning a positive correlation coefficient indicates a decrease in myocardial strain (eg, less negative values) with an increase in the clinical variable.

Peak diastolic circumferential strain rate showed moderate negative correlations with myocardial mass index ($r = -0.66$, $P = .003$) and LV end-diastolic volume index ($r = -0.5$, $P = .04$), as well as a weak-to-moderate positive correlation with heart rate ($r = 0.46$, $P = .05$). Additional weak correlations with peak diastolic circumferential strain rate were noted with a history of congenital heart disease ($r = 0.4$), and aortic insufficiency severity ($r = -0.4$) showed a weak correlation with peak diastolic strain rate,

Table 2. Measured Left Ventricular Parameters

Characteristics	Controls (n = 19)	Patients With BAV (n = 42)	*P*-Value
Ejection fraction (%)	60.1 ± 6.0	57.5 ± 4.3	.10
Heart rate (beats/min)	68.5 ± 8.1	63.6 ± 10.2	.16
Stroke volume index, n (%)	44.5 ± 13.3	39.8 ± 11.2	.19
LV EDVDI (m^2)	74.7 ± 18.4	71.4 ± 18.9	.52
Myocardial mass index, g/m^2	57.1 ± 17.0	56.7 ± 13.9	.94
Peak circumferential systolic strain, (%)	−19.6 ± 2.3	−20.1 ± 2.0	.41
Peak circumferential diastolic strain rate (s^{-1})	1.21 ± 0.21	0.89 ± 0.27	.0003

although these correlations did not reach statistical significance. Complete correlation data are presented in Table 3.

Regression Analysis

Multiple linear regression analyses of peak systolic circumferential strain and diastolic strain rate were conducted including independent variables of age, heart rate, EF, aortic stenosis, aortic insufficiency, myocardial mass index, and LV end-diastolic volume index and history of hypertension. After adjusting for covariates, variables that were independently associated with peak systolic circumferential strain were myocardial mass index ($\beta = 0.064$; SE = 0.025; 95% CI = 0.014, 0.114; $P = .01$) and EF ($\beta = -0.16$; SE = 0.058; 95% CI = −0.279, −0.044; $P = .01$) Table 4. Similarly, after adjusting for covariates, the only variable that was independently associated with peak circumferential diastolic strain rate was myocardial mass index ($\beta = -0.019$; SE = 0.008; 95% CI = 0.037, 0.000; $P = .05$) Table 5.

DISCUSSION

The results of the present study show lower mean diastolic strain rate in a cohort of asymptomatic patients with BAV compared with controls, suggesting impaired diastolic relaxation, despite preserved EF. However, we did not find any significant abnormalities of systolic strain between patients with BAV and controls. Myocardial mass index had a moderate correlation with both peak circumferential systolic strain and diastolic strain rate, and after controlling for covariates, only myocardial mass index was independently associated with these strain parameters. Our findings suggest that CMR-FT strain analysis can detect myocardial dysfunction in asymptomatic patients with BAV in whom there is no evidence of ventricular dysfunction by routine clinical cardiac MRI techniques.

The bicuspid aortic valve is a complex spectrum of disease with genetic underpinnings, resulting in dysmorphic valve development and structural wall abnormalities of the ascending aorta that predispose to aneurysm development (14). LV dysfunction becomes clinically apparent in significant aortic valve disease. However, echocardiography studies have shown abnormal systolic and diastolic strain parameters in patients with mild or no valve dysfunction, suggesting that subclinical myocardial abnormalities exist in asymptomatic patients with BAV (7, 15, 16). Our results support these observations and lend further

Table 3. Pearson Correlation Coefficients Between Strain Parameters and Clinical Variables in Patients With BAV

Characteristics	Peak Circumferential Systolic Strain		Peak Circumferential Diastolic Strain Rate	
	Pearson *r*	*P*-Value	Pearson *r*	*P*-Value
Age	−0.06	0.71	0.14	0.59
Hypertension	−0.33	0.04	0.33	0.19
Coarctation	−0.09	0.58	−0.14	0.59
Congenital heart disease*	−0.07	0.68	0.40	0.11
Significant aortic stenosis	0.29	0.06	0.23	0.37
Significant aortic insufficiency	0.0	0.95	−0.25	0.34
Ejection fraction	−0.49	0.01	0.24	0.33
Heart rate	−0.06	0.73	0.46	0.05
Myocardial mass index	0.51	0.06	−0.66	0.003
LV end-diastolic volume index	0.29	0.07	−0.50	0.04

*Other than coarctation.

Table 4. Multilinear Regression Predictors of Peak Circumferential Systolic Strain

Variable	β Coefficient	SE	95% CI	*P*-Value
Myocardial mass index	0.064	0.025	0.014, 0.114	.01
Significant aortic stenosis	0.758	0.626	−0.519, 2.035	.24
Significant aortic insufficiency	−0.674	0.700	−2.093, 0.745	.34
LV end-diastolic volume index	−0.008	0.021	−0.051, 0.036	.72
Hypertension	−0.727	0.694	−2.141, 0.688	.30
Age	−0.001	0.017	−0.034, 0.035	.98
Ejection fraction	−0.162	0.058	−0.279, −0.044	.01

Overall model adjusted $R^2 = 0.44$.

support for these echocardiographic observations using an MRI-based strain assessment technique.

Reduced EF—the traditional marker of a failing LV—is a relatively late finding along the path leading to myocardial decompensation. However, impaired diastolic function related to myocardial hypertrophy and fibrosis precedes systolic abnormalities and predicts surgical outcomes in patients with aortic stenosis (17, 18). Myocardial hypertrophy is known to be strongly associated with myocardial dysfunction and cardiovascular mortality. The cellular processes that lead to hypertrophy begin before clinical definitions of myocardial hypertrophy are reached, and are promoted by the increased afterload that results from fused valve leaflets, even if the valve function is classified as normal on echocardiography (19). Similar to our findings, others have observed increased LV myocardial mass among young patients with BAV with normal valve function, as well as increased myocardial interstitial fibrosis in patients with stenotic BAV, further highlighting the early deleterious effects on myocardial function that can occur with BAV (5, 8, 20).

While the mechanism of subclinical myocardial dysfunction remains an area of active research, our results further stress the potential prognostic importance of myocardial mass measurement, as it was the only variable that was associated with diastolic strain rate in our adjusted analysis. Patients with BAV have a variable clinical course, with some developing significant valve and ventricular dysfunction, while some remaining minimally symptomatic or asymptomatic throughout their life. Given this clinical variability, improved methods to detect subclinical disease and improve patient risk stratification are needed to achieve optimal treatment of patients with BAV before symptoms or overt signs of ventricular dysfunction develop. Diastolic function plays a significant role in the development of heart failure in patients with AS (21). Early detection of diastolic dysfunction could prompt changes in pharmacological treatment, such as initiation of angiotensin-converting enzyme inhibitors, or earlier surgical or transcatheter aortic valve replacement in the hopes of minimizing irreversible myocardial fibrosis (22). A recent study showed that preoperative assessment of diastolic strain rate with echocardiography predicated long-term postoperative mortality after surgical aortic valve replacement (23).

Although patients with BAV are most commonly evaluated with echocardiography, they are frequently referred for cardiac MRI/MRA, particularly when young (owing to concerns of radiation exposure) or if there are associated congenital heart abnormalities. An MRI-based method of assessing early LV dysfunction by using only standard SSFP cine images is attractive, particularly in the evaluation of diastolic function, where, unlike with echocardiography, there is currently no well-validated MRI assessment technique. Several studies have shown good agreement between echocardiographic speckle-tracking and CMR-FT techniques, although additional studies assessing the agreement between these two strain measurement techniques are required (11, 24).

Table 5. Multilinear Regression Predictors of Peak Diastolic Strain Rate With Regression

Variable	β Coefficient	SE	95% CI	*P*-Value
Myocardial mass index	−0.019	0.008	−0.037, −0.000	.05
Significant aortic stenosis	0.273	0.142	0.049, 0.594	.09
Significant aortic insufficiency	−0.075	0.162	−0.442, 0.292	.67
LV end-diastolic volume index	0.005	0.005	−0.006, 0.015	.33
Hypertension	0.304	0.242	−0.243, 0.851	.24
Age	0.003	0.006	−0.010, 0.015	.63
Heart rate	0.010	0.007	−0.006, 0.025	.21

Overall model adjusted $R^2 = 0.42$.

This study has several limitations. First, the BAV population was relatively small and heterogeneous; however, we made a concerted effort to control for variability in patient characteristics through adjusted analyses and exclusion of patients with clinically apparent myocardial dysfunction, and we feel that our cohort is representative of a typical population of patients with BAV referred for cardiac MRI at an academic medical center. Second, patients were not excluded on the basis of the presence of moderate/severe valve dysfunction, and while the majority of patients with BAV in our study did not have significant valve dysfunction, few did. The inclusion of such patients could contribute to the lower diastolic strain rate we observed in patients with BAV. However, interestingly, the degree of valve dysfunction did not show a significant association with diastolic strain rate on unadjusted or adjusted analyses, and our results suggest that increased myocardial mass—a downstream consequence of valve dysfunction—is more closely related to the deleterious pathomechanisms that result in diastolic dysfunction. Third, our strain analyses were limited to assessment circumferential strain, given that the long-axis SSFP images required to measure longitudinal strain are not routinely acquired as part of our aortic valve CMR protocol. Finally, given the retrospective nature of our study, the strain measurements were based on CMR-FT, an emerging technique, with myocardial tagging techniques still considered the gold-standard for assessing myocardial strain. However, it is encouraging that our findings agree with those of other studies using echocardiographic techniques.

CONCLUSION

We found evidence of impaired diastolic function, in particular decreased diastolic strain rate, among a cohort of asymptomatic patients with BAV with preserved EF using CMR-FT imaging. Only myocardial mass was independently associated with circumferential diastolic strain rate on multivariate analysis, further supporting the role of myocardial hypertrophy in the development of ventricular dysfunction among patients with BAV. Considering the increasing availability of CMR, the lack of accepted CMR methods for assessing diastolic function and the fact that only standard cine images are required for analysis, CMR-FT may be a useful and practical tool for assessing ventricular function among patients with BAV. CMR-FT analysis shows promise as a method to improve risk stratification though the early detection of LV diastolic dysfunction for minimally symptomatic or asymptomatic patients with BAV prone to future ventricular dysfunction.

REFERENCES

1. Nishimura RA, Otto CM, Bonow RO, Carabello BA, Erwin JP 3rd, Guyton RA, O'Gara PT, Ruiz CE, Skubas NJ, Sorajja P, Sundt TM 3rd, Thomas JD, Anderson JL, Halperin JL, Albert NM, Bozkurt B, Brindis RG, Creager MA, Curtis LH, DeMets D, Guyton RA, Hochman JS, Kovacs RJ, Ohman EM, Pressler SJ, Sellke FW, Shen WK, Stevenson WG, Yancy CW; American College of Cardiology; American College of Cardiology/American Heart Association; American Heart Association. 2014 AHA/ACC guideline for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. Circulation. 2014;129:e521–e643.
2. Carabello BA, Paulus WJ. Aortic stenosis. Lancet. 2009;373:956–966.
3. Marcus ML, Doty DB, Hiratzka LF, Wright CB, Eastham CL. Decreased coronary reserve: a mechanism for angina pectoris in patients with aortic stenosis and normal coronary arteries. N Engl J Med. 1982;307:1362–1366.
4. Chin CW, Everett RJ, Kwiecinski J, Vesey AT, Yeung E, Esson G, Jenkins W, Koo M, Mirsadraee S, White AC, Japp AG, Prasad SK, Semple S, Newby DE, Dweck MR. Myocardial fibrosis and cardiac decompensation in aortic stenosis. JACC Cardiovasc Imaging. 2017;10:1320–1333.
5. Hein S, Arnon E, Kostin S, Schönburg M, Elsässer A, Polyakova V, Bauer EP, Klövekorn WP, Schaper J. Progression from compensated hypertrophy to failure in the pressure-overloaded human heart: structural deterioration and compensatory mechanisms. Circulation. 2003;107:984–991.
6. Kurt M, Tanboga IH, Bilen E, Isik T, Kaya A, Karakas, MF, Büyükkaya E. Abnormal left ventricular mechanics in isolated bicuspid aortic valve disease may be independent of aortic distensibility: 2D strain imaging study. J Heart Valve Dis. 2012;21:608–614.
7. Santarpia G, Scognamiglio G, Di Salvo G, D'Alto M, Sarubbi B, Romeo E, Indolfi C, Cotrufo M, Calabrò R. Aortic and left ventricular remodeling in patients with bicuspid aortic valve without significant valvular dysfunction: a prospective study. Int J Cardiol. 2012;158:347–352.
8. Grotenhuis HB, Ottenkamp J, Westenberg JJ, Bax JJ, Kroft LJ, de Roos A. Reduced aortic elasticity and dilatation are associated with aortic regurgitation and left ventricular hypertrophy in nonstenotic bicuspid aortic valve patients. J Am Coll Cardiol. 2007;49:1660–1665.
9. Schuster A, Paul M, Bettencourt N, Morton G, Chiribiri A, Ishida M, Hussain S, Jogiya R, Kutty S, Bigalke B, Perera D, Nagel E. Cardiovascular magnetic resonance myocardial feature tracking for quantitative viability assessment in ischemic cardiomyopathy. Int J Cardiol. 2013;166:413–420.
10. Bhatti S, Vallurupalli S, Ambach S, Magier A, Watts E, Truong V, Hakeem A, Mazur W. Myocardial strain pattern in patients with cardiac amyloidosis secondary to multiple myeloma: a cardiac MRI feature tracking study. Int J Cardiovasc Imaging. 2018;34:27–33.
11. Kempny A, Fernandez-Jimenez R, Orwat S, Schuler P, Bunck AC, Maintz D, Baumgartner H, Diller GP. Quantification of biventricular myocardial function using cardiac magnetic resonance feature tracking, endocardial border delineation and echocardiographic speckle tracking in patients with repaired tetralogy of fallot and healthy controls. J Cardiovasc Magn Reson. 2012;14:32.
12. Schulz-Menger J, Bluemke DA, Bremerich J, Flamm SD, Fogel MA, Friedrich MG, Kim RJ, von Knobelsdorff-Brenkenhoff F, Kramer CM, Pennell DJ, Plein S, Nagel E. Standardized image interpretation and post processing in cardiovascular magnetic resonance: Society for Cardiovascular Magnetic Resonance (SCMR) board of trustees task force on standardized post processing. J Cardiovasc Magn Reson. 2013;15:35.
13. Pedrizzetti G, Claus P, Kilner PJ, Nagel E. Principles of cardiovascular magnetic resonance feature tracking and echocardiographic speckle tracking for informed clinical use. J Cardiovasc Magn Reson. 2016;18:51.
14. Siu SC, Silversides CK. Bicuspid aortic valve disease. J Am Coll Cardiol. 2010; 55:2789–2800.
15. Demir M. Left ventricular systolic and diastolic functions in subjects with a bicuspid aortic valve without significant valvular dysfunction. Eur J Heart Fail. 2013; 12:S212–S213.
16. Bilen E, Akcay M, Bayram NA, Koçak U, Kurt M, Tanboğa IH, Bozkurt E. Aortic elastic properties and left ventricular diastolic function in patients with isolated bicuspid aortic valve. J Heart Valve Dis. 2012;21:189–194.
17. Lund O, Flo C, Jensen FT, Emmertsen K, Nielsen TT, Rasmussen BS, Hansen OK, Pilegaard HK, Kristensen LH. Left ventricular systolic and diastolic function in aortic stenosis. Prognostic value after valve replacement and underlying mechanisms. Eur Heart J. 1997;18:1977–1987.
18. Zaid RR, Barker CM, Little SH, Nagueh SF. Pre- and post-operative diastolic dysfunction in patients with valvular heart disease: diagnosis and therapeutic implications. J Am Coll Cardiol. 2013;62:1922–1930.
19. Swamy RS, Lang RM. Echocardiographic quantification of left ventricular mass: prognostic implications. Curr Cardiol Rep. 2010;12:277–282.
20. Pacileo G, Calabro P, Limongelli G, Russo MG, Pisacane C, Sarubbi B, Calabrò R. Left ventricular remodeling, mechanics, and tissue characterization in congenital aortic stenosis. J Am Soc Echocardiogr. 2003;16:214–220.
21. Hess OM, Villari B, Krayenbuehl HP. Diastolic dysfunction in aortic stenosis. Circulation. 1993;87:IV73–IV76.
22. Ha JW, OH JK. Therapeutic strategies for diastolic dysfunction: a clinical perspective. J Cardiovasc Ultrasound. 2009;17:86–95.
23. Dahl JS, Barros-Gomes S, Videbaek L, Poulsen MK, Issa IF, Carter-Storch R, Christensen NL, Kumme A, Pellikka PA, Møller JE. Early diastolic strain rate in relation to systolic and diastolic function and prognosis in aortic stenosis. JACC Cardiovasc Imaging. 2016;9:519–528.
24. Amaki M, Savino J, Ain DL, Sanz J, Pedrizzetti G, Kulkarni H, Narula J, Sengupta PP. Diagnostic concordance of echocardiography and cardiac magnetic resonance-based tissue tracking for differentiating constrictive pericarditis from restrictive cardiomyopathy. Circ Cardiovasc Imaging. 2014;7: 819–827.