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Flow Dependence of Valve Area in Aortic Stenosis: Relation to Valve Morphology

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Objectives. **We sought to develop an index of flow dependence of valve area in aortic valve (AoV) stenosis and to determine whether this index is related to structural characteristics of the diseased valve.**

Background. **Many studies of AoV stenosis using Gorlin or continuity equation methods have demonstrated flow dependence (an increase in valve area with increased flow). Variation in flow dependence between patients despite similar flow rates remains unexplained.**

Methods. **Dobutamine Doppler echocardiography was used to calculate flow rate and valve area by the continuity equation in 27 patients with aortic stenosis. For each patient the slope of the regression line of valve area to flow rate was determined (slope of flow dependence). Transesophageal echocardiography was used to evaluate features of valve morphology potentially related to the etiology of AoV stenosis and the mechanism of flow dependence.**

Results. **Mean slope of flow dependence was 0.28 cm^2/100 ml per s (range −0.06 to 0.53); flow dependence was significantly >0 in 21 patients and was lower for bicuspid valves (slope 0.21 cm^2/100 ml per s) than for tricuspid valves with <10% commissural fusion (slope 0.35, $p < 0.01$). Off-center/ovoid orifices demonstrated the least flow dependence (slope 0.19), whereas star-shaped orifices showed the most (slope 0.36, $p < 0.01$). Greater flow dependence was related to a lower percentage of commissural fusion ($r = -0.46$, $p = 0.02$) as well as diffuse sclerosis, primarily involving the cusp bodies, rather than localized sclerosis, with involvement of cusp margins.**

Conclusions. **The slope of flow dependence of valve area in AoV stenosis differs markedly between patients. More flow dependence was associated with tricuspid valves and the morphologic features characteristic of calcific AoV stenosis, whereas less flow dependence was associated with bicuspid valves and the features of rheumatic disease.**

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Previous studies have shown (1–8) that exercise and dobutamine infusion cause an increase in cardiac output and transvalvular flow rate in patients with aortic valve (AoV) stenosis. In most patients these changes are accompanied by an increase in calculated valve area by both Gorlin and continuity equation methods. This apparent "flow dependence" of AoV area may be due to several factors. There may be systematic error in the terms of the equation being used to calculate valve area (9–11). In the continuity equation, for example, the orifice coefficient (calculated or "effective" area/anatomic area) might vary at different flow rates (12–14). Systematic measurement error at different flows may also occur. Finally, as first proposed 26 years ago, the anatomic AoV orifice may increase as a result of increased force of ventricular pressure acting to increase separation of the cusps (2,8,15).

Systematic error appears to cause flow dependence of AoV area in the case of underestimation of valve area by the Gorlin equation with low transvalvular flow rates (10,12). However, marked differences between patients in the degree of flow dependence have been observed at similar flow rates and seem unlikely to be systematic error (1–3,5–8). Furthermore, although valvular geometry may cause differences in the continuity orifice coefficient between patients, several studies have shown (11–14,16) valve areas calculated by the continuity equation to be independent of flow rate. Other laboratory models support the possibility of flow-related changes in anatomic orifice size (14).

Demonstration of a relation between flow dependence of AoV area and valve morphology would establish that flow dependence is not a form of error. Furthermore, knowledge of the specific morphologic features associated with flow dependence may provide insight into its mechanism. The purposes of the present study were to 1) develop an index for flow dependence of AoV area in aortic stenosis that is independent of specific flow conditions, and 2) determine whether the

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Abbreviations and Acronyms

AoV = aortic valve
LV = left ventricular
LVEF = left ventricular ejection fraction
LVOT = left ventricular outflow tract
TEE = transesophageal echocardiogram (echocardiographic)
TTE = transthoracic echocardiogram (echocardiographic)

degree of flow dependence is related to structural characteristics of the valve.

Methods

Patients. Twenty-seven patients with varying degrees of AoV stenosis were studied (Table 1). The study protocol was approved by the institutional Human Research Committee, and all patients provided written informed consent. Thirteen other patients were not included for technical reasons (two patients), lack of increase in transvalvular flow rate sufficient to quantitate flow dependence by the method described below (six patients) or prolongation of left ventricular outflow tract (LVOFT) acceleration time indicative of subvalvular obstruction (five patients). The six patients with an insufficient increase in flow rate, as well as the others not included, were not different from the 27 subjects with regard to left ventricular ejection fraction (LVEF), etiology of AoV disease, baseline flow rate or valve area.

Dobutamine infusion. An incremental dobutamine infusion was used to increase transvalvular flow rate. Dobutamine was begun at 5 μg/kg body weight per ml and increased at ~8-min intervals through stages of 10, 20, 30 and 40 μg/kg per min or until hypotension (systolic blood pressure <80 mm Hg), chest discomfort or ST segment shift >2 mV on the electrocardiogram.

Table 1. Clinical Characteristics of 27 Patients

Age (yr)	69
Range	45–84
Male	25
LVEF (%)	53
Range	8–74
Pts with LVEF <25%	4
Coronary disease	11
LV wall thickness (cm)	1.08
Range	0.79–1.35
Pulmonary hypertension	7
Right atrial hypertension	4
Any symptom	14
Chest discomfort	10
LV failure	11
Syncope	1
Aortic regurgitation ≥2+	5
Rheumatic mitral valve	3

Data presented are mean value, range or number of patients. LV = left ventricular; LVEF = left ventricular ejection fraction; Pts = patients.

Doppler echocardiographic data. Both transthoracic (TTE) and multiplane transesophageal (TEE) Doppler echocardiographic data were obtained at baseline and after 5 min at each dobutamine dose (Hewlett-Packard 2500). LVOFT flow rate and AoV area were calculated by the continuity method (17,18).

LVOFT diameter was measured 1 to 1.5 cm below the aortic annulus from TTE and TEE two-dimensional images at baseline and at each stage of the infusion. The TTE "large" LVOT diameter described by Skjaerpe et al. (18) was used and was measured in the longitudinal view optimized by side to side manipulation of the probe. Valve areas were calculated from the mean value of the TEE LVOFT diameters over all flow conditions for the patient. Thus, changes in AoV area with dobutamine represent changes in the ratio of the mean velocities at the LVOFT and AoV.

The LVOFT velocity integral was planimetered from the TTE pulsed wave Doppler flow profile obtained from the LV apex with an 0.5- to 0.8-cm sample volume length positioned 1 to 1.5 cm below the aortic annulus. LVOFT ejection time was measured from the onset to end of LVOFT flow, with the point of flow onset determined by extrapolating the slope of velocity rise to the baseline in the presence of an LVOFT A wave. The AoV velocity integral was planimetered from the TTE continuous wave Doppler flow profile from the LV apex. Ejection time was determined from the onset of the leaflet opening click to the onset of the closure click. Mean LVOFT and AoV velocities were calculated as the respective velocity integrals divided by the ejection times. Stroke volume was calculated as (Mean LVOFT velocity) × (Ejection time)[(LVOFT diameter/2)]^2(3.1416) and cardiac output as (Stroke volume) × (Heart rate).

Before dobutamine infusion, end-diastolic and end-systolic volumes, LVEF and end-diastolic wall thickness were determined from apical two- and four-chamber views by Simpson's rule according to the American Society of Echocardiography standard (19). Right atrial and pulmonary artery pressures were estimated by previously described methods (20,21). All two-dimensional and Doppler measurements were the mean value of at least 3 beats.

Quantitation of flow dependence of valve area. Flow dependence of AoV area was quantitated for each patient as the slope of the least squares regression line for the relation of LVOFT flow rate to AoV area during dobutamine infusion. Only patients with Doppler echocardiographic data up to ≥10 μg/kg per min of dobutamine (three data points) and an increase in LVOFT flow rate of ≥25% above baseline were included.

AoV imaging. The short axis of the AoV was obtained by positioning the image plane to show the LVOFT as a circle ~1 cm below the annulus and the sinuses of Valsalva as equal in size (mean transducer rotation of 48°). Multiple views were recorded from below the annulus to above the cusp margins. For the long-axis view, the transducer was rotated 90° and adjusted to maximize the diameters of the LVOFT, aortic annulus and sinotubular junction. The AoV was scanned

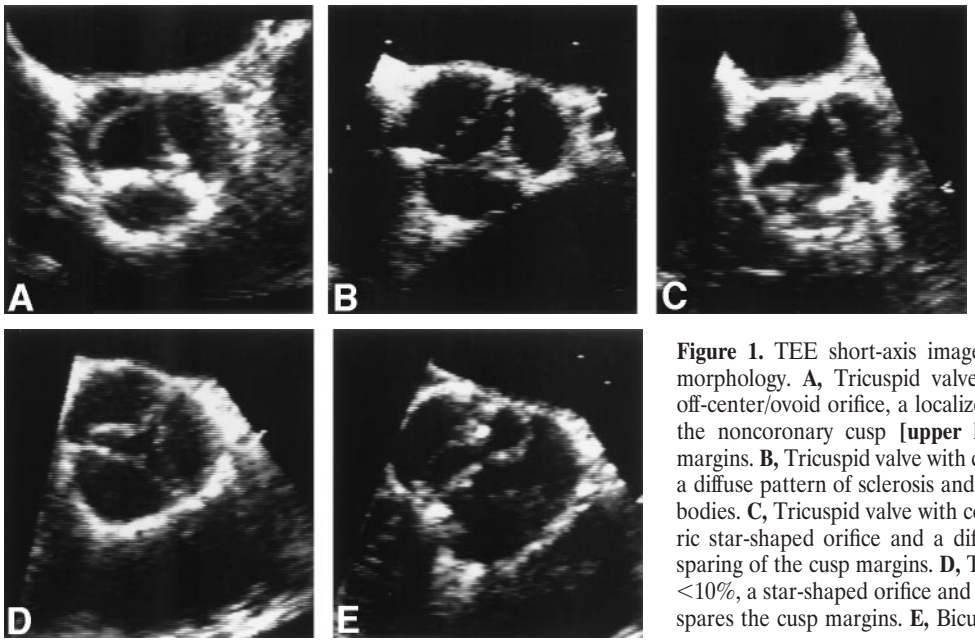


Figure 1. TEE short-axis images of different types of stenotic AoV morphology. **A,** Tricuspid valve with commissural fusion >33%, an off-center/ovoid orifice, a localized pattern of sclerosis (note sparing of the noncoronary cusp **[upper left]**) and extensive sclerosis of cusp margins. **B,** Tricuspid valve with commissural fusion >33%, a slit orifice, a diffuse pattern of sclerosis and involvement of both cusp margins and bodies. **C,** Tricuspid valve with commissural fusion <33%, an asymmetric star-shaped orifice and a diffuse pattern of sclerosis, with relative sparing of the cusp margins. **D,** Tricuspid valve with commissural fusion <10%, a star-shaped orifice and a pattern of sclerosis that is diffuse and spares the cusp margins. **E,** Bicuspid AoV.

medially for the noncoronary and right cusps and laterally for the left and right cusps.

Valve morphology. Classification and scoring of valve morphology were done by two experienced echocardiographers (G.A.C., B.K.S.) who had no knowledge of flow data or clinical information (Fig. 1). The AoV was classified as *rheumatic* if typical rheumatic mitral sclerosis was present and as *bicuspid* or *tricuspid* according to criteria described by Roberts (22) and Pomerance (23). Valves containing apparent raphes were classified as *bicuspid* only if the plane of the raphe was inferior to the plane of the commissure in systole and if the cusp lacking a raphe was clearly greater than one-third the total short-axis area of the valve.

Orifice shape was classified as a *star* if the three commissures formed by the cusps were approximately equal in length and width (the "triradiate" valve described by Roberts [22]). The orifice was classified as an *asymmetric star* if the commissures differed in length or width, without loss of the triradiate shape of the orifice. The orifice was classified as a *slit* if its shape was elongated, with margins tapering at each end, and as an *off-center/ovoid* if its shape was rounded or irregular, usually off-center in relation to the annulus.

For tricuspid valves, the percent fusion of each commissure was calculated as the length of that portion of the commissure demonstrating no separation during systole, divided by the total length of the commissure in the short-axis view. The percent fusion of the three cusps was summed and multiplied by 0.333 to give an overall percent commissural fusion. This method for calculation of percent fusion allowed combined analysis of commissural fusion for both tricuspid and bicuspid valves, because the length of the uniformed commissure of a bicuspid valve cannot be measured. For bicuspid valves, the single commissure was divided at its center point in diastole; each half was then treated as a commissure. The percent commissural fusion of each of these two commissures was then added to 100% (the assumed percent fusion of the congenitally absent third commissure) and multiplied by 0.333 to give an overall percent commissural fusion.

Overall degree of sclerosis of the valve was scored as 0 for a normal valve, 1+ for slight increase in reflectance of the cusp bodies or margins and 2+ for mild increase in overall reflectance and cusp thickness. The valve was scored as 3+ when hyperreflectance was generalized and apparent overall cusp thickness was 2 to 4 mm; 4+ was assigned when cusps were essentially replaced by markedly hyperreflectant masses with an apparent cusp thickness >4 mm.

Sclerosis distribution was categorized as either *diffuse*, when all cusps appeared hyperreflectant and thickened, or *localized*, when there was a clear difference of at least two grades in the degree of sclerosis in different cusps or portions of cusps. *Sclerosis location* was classified as either primarily involving the cusp bodies and sparing the margins or affecting the margins as well as the bodies.

Statistical analysis. Changes from baseline to maximal dobutamine dose of clinical, flow-related and valve area-related variables were tested for significance with the Student *t* test for paired data. The slopes of flow dependence were tested for equality to zero by the Wilcoxon rank sum test. The relations of slope of flow dependence to other Doppler echocardiographic data and features of valve morphology were assessed by Spearman correlations (percent commissural fusion) and Kruskal-Wallis and Wilcoxon tests, respectively, for categoric and dichotomous morphologic variables.

Interobserver measurement variability was assessed by Pearson correlation, mean difference and range of differences between independent observers (B.K.S., G.A.C., R.K.C.) for selected key variables. Beats to be measured for variability calculations were not prespecified. Data for 32 sets of selected

Table 2. Flow- and Valve Area-Related Variables: Response to Dobutamine

	Baseline	Max Dose	Change
LVOFT			
Diameter (cm)	2.29 ± 0.29	2.29 ± 0.32	0 ± 0.10
Mean velocity (cm/s)	53 ± 14	81 ± 19*	28 ± 9
Ejection time (s)	0.308 ± 0.037	0.214 ± 0.019*	−0.094 ± 0.039
Flow rate (ml/s)	214 ± 51	328 ± 78*	114 ± 43
Stroke vol (ml/s)	67 ± 21	70 ± 19†	3.7 ± 14
CO (ml/min)	4.6 ± 1.2	8.1 ± 2.2*	3.5 ± 1.6
AoV			
Mean velocity (cm/s)	207 ± 67	242 ± 70*	35 ± 20
Ejection time (s)	0.304 ± 0.035	0.198 ± 0.022*	−0.106 ± 0.036
Area (cm^2)	1.12 ± 0.37	1.44 ± 0.47*	0.33 ± 0.19

*$p < 0.001$, †$p = 0.06$ versus baseline. Data presented are mean value ± SD. AoV = aortic valve; CO = cardiac output; Max = maximal; vol = volume; LVOFT = left ventricular outflow tract.

Doppler echocardiographic variables were as follows: LVOFT diameter (TEE), r = 0.92, 0.1 and 0 to 0.3 cm; mean LVOFT velocity, r = 0.98, 2 and 0 to 5 cm/s; LVOFT ejection time, r = 0.90, 19 and 0 to 97 ms; mean AoV velocity, r = 0.98, 11 and 2 to 30 cm/s; AoV ejection time, r = 0.97, 10 and 0 to 36 ms; interobserver variability in 14 patients for percent commissural fusion, r = 0.92, mean difference 5.8 and range 1 to 13. For classification of orifice shape, sclerosis distribution and sclerosis location, there were 2 of 14, 1 of 14 and 3 of 14 disagreements, respectively, between the two observers. For scoring of sclerosis severity (0 to 4+ scale), disagreement was 5 of 14 by one grade and 0 by two grades.

Results

Clinical response to dobutamine. The maximal dobutamine dose achieved was 40 μg/kg per min in 17 patients, 30 μg/kg per min in 4, 20 μg/kg per min in 3 and 10 μg/kg per min in 3. Mean rise in heart rate was 45 beats/min (68% above baseline, $p < 0.001$); systolic and diastolic blood pressures did not change significantly. Six patients developed chest discomfort; two of these had new ST segment depression. Seven patients had a fall of systolic pressure to <80 mm Hg. Symptoms resolved during the recovery period (20 min) in all patients, and no sequelae were observed.

Flow and valve area response to dobutamine. For all patients and flow conditions there was no difference between TEE and TTE LVOFT diameters or a directional change in these measures with dobutamine. Mean cardiac output increased from 4.6 to 8.1 liters/min as a result of increased heart rate, and mean flow rate increased from 214 to 328 ml/s. AoV area increased 33%, from 1.12 to 1.44 cm^2, $p < 0.001$ (Table 2).

Slope of flow dependence. Regression lines demonstrating slopes of flow dependence for each of the 27 patients are shown in Figure 2 (mean slope 0.28 cm^2/100 ml per s, range of −0.06 to 0.53). The mean slope was significantly >0 ($p < 0.001$), and 21 of the 27 individual slopes were significantly >0 to at least the $p < 0.05$ level. There was no significant relation between slope and baseline valve area, change in flow rate, percent change in flow rate or LVEF.

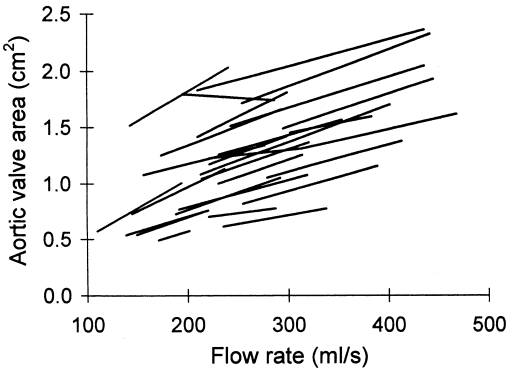
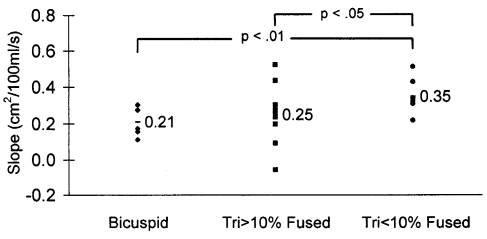


Figure 2. Regression lines of individual slopes of flow dependence of AoV area for each of the 27 study patients. **Lines** begin and end at the baseline and maximal flow rates, respectively.

Relation of flow dependence to valve morphology. The slope of flow dependence was significantly associated with valve type when a distinction was made between tricuspid AoVs with <10% versus >10% fusion commissural fusion. Bicuspid valves had significantly less flow dependence (slope 0.21) than tricuspid valves with <10% fusion (slope 0.35, $p < 0.01$), and tricuspid valves with >10% fusion (slope 0.25) had significantly less flow dependence than valves with <10% fusion ($p < 0.05$) (Fig. 3). Flow dependence was related to commissural fusion ($r = -0.46$, $p = 0.02$); if bicuspid valves are excluded, the significance level for this relation is $p = 0.06$. The 10 patients with a slope >0.32 (marked flow dependence) all had <22% commissural fusion.

Flow dependence demonstrated a significant relation to orifice shape, as shown in Figure 4, with off-center/ovoid orifices demonstrating the least degree of flow dependence (slope 0.19) and star-shaped orifices showing the greatest flow dependence (slope 0.36). A diffuse rather than localized sclerosis pattern was associated with greater flow dependence (slope 0.30 with interquartile range 0.10 for diffuse; slope 0.21 with range 0.06 for localized). Sclerosis involving primarily the cusp bodies and sparing the margins in contrast to sclerosis

Figure 3. Slope of flow dependence versus morphologic type of aortic stenosis. Slope of flow dependence is significantly different for bicuspid versus tricuspid valve (Tri) with commissural fusion <10% and for tricuspid valve with >10% versus <10% commissural fusion (Kruskal-Wallis and Wilcoxon tests).



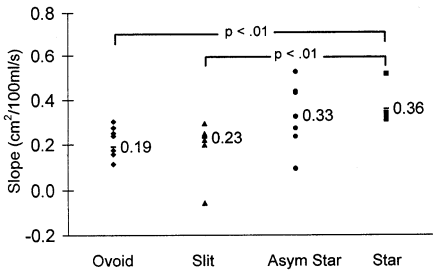


Figure 4. Relation of slope of flow dependence to orifice shape. Slope of flow dependence is significantly different between ovoid versus star-shaped ($p < 0.01$) and slit-like versus star-shaped ($p < 0.01$) and close to significant for ovoid versus asymmetric star-shaped (Asym Star) ($p = 0.09$, Kruskal-Wallis and Wilcoxon tests).

involving the cusp margins as well as bodies was also associated with a higher slope of flow dependence (0.33, range 0.06, vs 0.23, range 0.15, respectively). The three valves classified as rheumatic shared the features of tricuspid >10% fused, ovoid orifice, localized sclerosis and body plus margin sclerosis. There was no relation between flow dependence and overall degree of valve sclerosis. Figure 5 shows individual data points for the three patients whose valves are illustrated in Figure 1 and who are representative of the major morphologic types.

This study demonstrates the use of an index of flow dependence of AoV area—the slope of the regression line of transvalvular flow rate in response to dobutamine infusion to valve area. The slope of flow dependence was found to be unrelated to change in flow rate. Using this index, flow dependence is common but not universal in patients with AoV stenosis: In 78% of subjects the slopes of flow dependence were significantly >0. The degree of flow dependence of valve area was highly variable between patients and was related to several features of valve morphology. The valves with more flow dependence (higher slopes) were tricuspid valves with lesser degrees of commissural fusion, a star-shaped orifice and a pattern of sclerosis diffusely involving the bodies of the three cusps. Valves with less flow dependence (lower slopes) were either bicuspid valves or tricuspid valves with extensive commissural fusion, an ovoid or slit-like orifice and sclerosis localized to one or two of the cusps and involving the cusp margins as well as bodies.

Theoretic implications. Descriptions of calcific tricuspid AoV stenosis (absence of commissural fusion, diffuse sclerosis of cusp bodies and a star-shaped orifice) closely match the morphology of valves with more flow dependence found in this study, whereas valves with less flow dependence possess the features of rheumatic disease (commissural fusion, involvement of cusp margins and an off-center/ovoid orifice) (15,22,23). Thus, the etiology of AoV stenosis may determine the functional characteristics of the valve under different flow conditions. Furthermore, the association of more flow dependence with less commissural fusion favors increased cusp separation as a mechanism of flow dependence.

Previous studies of flow dependence. Flow dependence of the AoV area has been observed in almost all previous studies

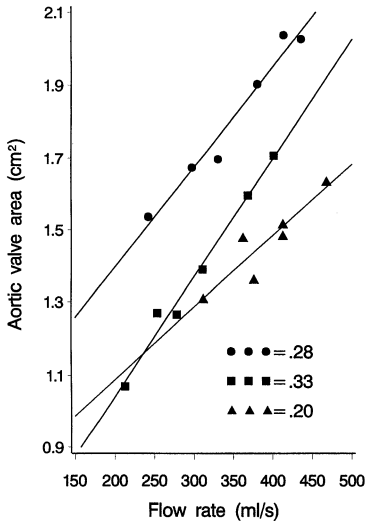


Figure 5. Data points for three patients whose valves are illustrated in Figure 1. **Regression line** and **slope of line** (slope of flow dependence) are shown. The patient with slope 0.33 has typical calcific stenosis (Fig. 1D), whereas the patient with slope 0.20 has rheumatic aortic stenosis (Fig. 1A). The patient with slope 0.28 has an acquired bicuspid valve (Fig. 1B).

of patients and in animal models (1–14). Catheterization studies of the effects of exercise in AoV stenosis (mean valve area ≤0.8 cm^2 in each report) showed marked individual differences in the response of valve area to increases in flow, and a rise in Gorlin-calculated valve area was observed in 43 of 60 patients (1–3). In these studies the baseline flow rates and the increases in valve area per unit increase in flow rate were similar to those in the present study. Few patients in those studies had a low cardiac output, and a review of the data shows that there was no association between a low baseline flow rate and an increase in valve area or any correlation between the magnitude of the increases in flow rate and increases in valve area (1–3).

In 28 patients with AoV stenosis (mean valve area 1.17 cm^2), Otto et al. (5) reported that flow rate increased on average from 300 to 366 ml/s (22%) during exercise, with a mean increase in continuity valve area of 0.11 cm^2 (9.4%). Review of individual patient data in their study shows wide differences between patients in the relation of valve area to flow. Subsequent data from the same investigators showed an increase in valve area with exercise of 14.5%, with a flow rate increase of 25% (6). Casale et al. (4) did not find a significant increase in valve area in six patients during dobutamine infusion; however, the increase in flow rate was low (21%).

Variation in flow rate of the orifice coefficient could account for flow dependence of valve areas calculated by the continuity equation (12–14). However, in vitro studies (12) have shown that although this coefficient varies markedly for valves with different orifice geometry, it shows little variation caused by flow within the physiologic range. Kitabatake et al. (24) demonstrated no significant changes in stenosis area calculated by the continuity equation despite marked changes

in pressure gradient. In a flow tank study (11), nondiseased bioprosthetic valves under varying flow rates similar to those of the present study (a 34% increase from a baseline of 225 ml/s) showed only a 4% increase in area by the continuity equation. In another in vitro study, Chambers et al. (14) demonstrated an increase in anatomic area of explanted stenotic native AoVs with increasing flow rates in a range (140 to 340 ml/s) similar to our data.

Recently, Bermejo et al. (8) examined changes in valve area and resistance with low dose dobutamine in 35 patients with severe AoV stenosis (mean valve area 0.5 cm^2) and low baseline flow rates (164 ml/s). These investigators used absolute change in valve area at a specific dobutamine dose as a measure of flow dependence. They found significant differences in change in valve area between patients, but change in valve area was primarily related to flow conditions (baseline flow rate and change in flow rate) and ventricular function. Although Bermejo et al. (8) did not primarily address valve morphology, in their multivariate analysis calcific etiology of stenosis appeared as an independent predictor of greater flow dependence, consistent with the results of the present study.

Two similar TEE studies from Tardif et al. (25,26) did not show an increase in planimetered valve area with variations in flow, such as following premature beats or dobutamine. However, the technical difficulty of planimetry of AoVs with complex orifice geometry and dense sclerosis for the detection of small changes in area limit the interpretation of these data. Whatever the mechanism of flow dependence, the results of the present study show that flow dependence has a morphologic basis.

Limitations. The present study used TEE to determine the morphology of the stenotic AoV. Although this method is well suited to the assessment of the number of cusps and valve orifice geometry, it may be less accurate for characterizing the severity or location of sclerosis. The use of visualized commissural separation to determine the presence or absence of commissural fusion remains to be validated at intraoperative or pathologic examination. The motion of doming cusps with fused margins into the image plane might be confused with commissural separation. This possibility was minimized by scanning the valve carefully with serial short-axis views.

Unidentified sources of systematic error may be present in the methods used in the present study to determine flow dependence. The spatial mean velocity in the LVOFT was estimated by pulsed Doppler sampling of velocity in the center of the LVOFT. An increase in the ratio of central velocity to mean velocity could result in an overestimation of stroke volume and an apparent increase in valve area. However, with increased flow velocity, the central velocity should more closely approximate the mean value (27).

Patients with severe AoV stenosis or LV dysfunction, or both, may have been excluded from this study because of the >25% increase in flow rate on dobutamine required for quantitation of flow dependence. Of note, 49% of the subjects of Bermejo et al. (8) also had a <25% increase in flow rate. The basis of these observations is not known.

The present study included only three patients with definite rheumatic AoVs; thus, our data address the relation of flow dependence to features of valve morphology rather than etiology. Further studies that include patients with more severe stenosis and left ventricular disease are needed for a more complete analysis of the basis of flow dependence.

Clinical implications. Flow dependence varies markedly between patients, with some demonstrating no flow-related increase in valve area and others an increase in valve area ≤50% with dobutamine (Fig. 2). Similarly, symptoms, such as syncope and LV hypertrophy, and natural history differ greatly between patients with the same severity of AoV stenosis at rest. Flow dependence may contribute to these differences by modulating the expected rise in intraventricular systolic pressure during periods of increased flow (28). Patients with flow dependence may thus experience a prolonged asymptomatic interval during the course of their disease.

Doppler TTE testing with dobutamine has been recommended to assist in identifying those patients with reduced LV function in whom the severity of AoV stenosis may be overestimated because rest transvalvular flow is low (7). Our data suggest that the Doppler echocardiographic continuity valve area obtained at rest may overestimate the functional severity of AoV stenosis, not only in patients with low transvalvular flow rates, but also in many with normal rest flow rates. Furthermore, our data identify patients most likely to demonstrate marked flow dependence as those with calcific degenerative aortic stenosis and <10% commissural fusion (Fig. 5). Thus, dobutamine testing with calculation of the slope of flow dependence may be useful for assessing the functional significance of AoV stenosis in individual patients.

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