

Clinical Evaluation Versus Doppler Echocardiography in the Quantitative Assessment of Valvular Heart Disease

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We tested the hypotheses that Doppler echocardiography has a higher accuracy than clinical evaluation in the detection of significant aortic and mitral valvular heart disease and that Doppler echocardiography is highly accurate as compared with cardiac catheterization for the assessment of valvular disease severity. Thus, cardiac catheterization for the assessment of valve lesion severity may be unnecessary in selected patients. We prospectively evaluated 75 consecutive patients, ages 20–74 years (mean, 52 years), with clinically suspected valvular heart disease. Specific clinical and Doppler echocardiographic criteria were used to categorize each valve lesion as absent, insignificant, or significant. Criteria for a significant lesion at cardiac catheterization was an aortic or mitral valve area less than 1.1 or 1.5 cm², respectively, or equal to or greater than 3+ cm² aortic or mitral regurgitation at angiography. In all valve lesions, Doppler echocardiography had a higher overall accuracy than clinical evaluation. Increases in accuracies of 28%, 19%, 15%, and 7% occurred for mitral stenosis, aortic stenosis, aortic regurgitation, and mitral regurgitation, respectively, resulting in overall accuracies of 97%, 100%, 95%, and 96%. Clinical evaluation alone made 28 errors (37% of patients and 19% of valve lesions assessed), and 17 of these errors (23% of patients and 12% of valve lesions) would have resulted in inappropriate management. In only four (24%) of these 17 patients, the attending cardiologist would not have proceeded to assess the valve at cardiac catheterization. Doppler echocardiography corrected 25 (89%) of the 28 errors made by clinical evaluation and 16 (94%) of the 17 errors that would have resulted in inappropriate management. Doppler echocardiography committed five errors in 75 patients (7%) and 146 valve lesions (3%). Only one valve lesion would have been managed incorrectly. These results suggest that Doppler echocardiography is more accurate than clinical evaluation and that the need for the assessment of valve function at cardiac catheterization can be avoided in many patients. (*Circulation* 1988;78:267–275)

The need for cardiac catheterization before surgery in all patients with suspected valvular heart disease remains a controversial topic.^{1–9} Although the need for invasive studies depends on many factors, the central issue is whether clinical examination and currently available nonin-

vative methods are reliable enough to allow appropriate patient management without catheterization. Doppler echocardiography^{10–11} has provided widely available noninvasive methods to assess the severity of valvular heart disease. This technique has prompted reconsideration of the need to use invasive tests to evaluate patients with valvular heart disease. Although many studies have confirmed the accuracy of noninvasive Doppler echocardiography in the assessment of aortic^{12–16} and mitral^{17–20} val-

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vular heart disease, the clinical usefulness of this technique has not been widely tested. The overall accuracy of routine application of this method has been recently reviewed²¹; nevertheless, it is unclear

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how often the method provides information that is unavailable from clinical evaluation and standard echocardiography. Limited clinical studies^{22,23} suggest that Doppler echocardiography is more accurate than auscultation and simple M-mode echocardiography in the detection of aortic regurgitation. While the detection of valve disease is of some importance, the prime objective is assessment of severity. Three studies^{1,8,24} have shown that combined clinical evaluation and standard echocardiography can distinguish mild from severe aortic or mitral lesions in a high proportion of patients. Unfortunately, the criteria used in these previous studies to assess the severity of valve lesions, both clinically and by standard echocardiography, are not precisely defined. Thus, the application of their results to other centers is difficult. There are no prospective studies in consecutive, unselected patients that examine the relative accuracies of clinical evaluation and Doppler echocardiography in quantitating aortic and mitral valvular heart disease. Accordingly, we tested the hypotheses that Doppler echocardiography has a higher accuracy than clinical evaluation in the detection of significant aortic and mitral valvular heart disease and that Doppler echocardiography is highly accurate as compared with cardiac catheterization for the assessment of the severity of valvular disease. Thus, cardiac catheterization for the assessment of the severity of valve lesions can be avoided in many patients.

Materials and Methods

Patients

Over a 6-month period, we prospectively evaluated all consecutive patients with clinically suspected significant mitral or aortic valve disease for whom surgical intervention would be advised on confirmation of hemodynamic severity. In our institution, we offer surgery to patients who are considered to have significant disease by the following criteria: 1) symptomatic individuals [angina, syncope, dyspnea, New York Heart Association (NYHA) Class III or IV] with aortic or mitral valve areas of <1.1 or 1.5 cm², respectively; 2) all NYHA Class III or IV patients with angiographic grade 3+ (moderate) or 4+ (severe) aortic or mitral regurgitation; or 3) NYHA Class I or II patients with 3+ or 4+ aortic or mitral regurgitation and left ventricular end-systolic volumes of >70 and 60 ml/m², respectively.

Seventy-five patients fulfilled the criteria for entry. Patients with mechanical or porcine prosthetic valves were excluded. In each patient, the presence and severity of both aortic and mitral stenosis and regurgitation were assessed prospectively by clinical examination, Doppler echocardiography, and cardiac catheterization as the gold standard. Although 150 valves and 300 valve lesions were evaluated, we have chosen to exclude from the analysis valves with no stenosis or regurgitation by

all three methods of assessment (clinical, Doppler, and catheterization). Thus, our data relates to 146 valve lesions in 75 patients. The mean age was 52 years (range, 20–74 years). There were 39 men and 36 women. There was no aortic valve lesion in 28 (37%), isolated aortic regurgitation in 23 (31%), isolated aortic stenosis in 12 (16%), and a mixed lesion of the aortic valve in 12 (16%). There was no mitral valve lesion in 27 (36%), isolated mitral regurgitation in 19 (25%), isolated mitral stenosis in 12 (16%), and a mixed lesion of the mitral valve in 17 (23%). Isolated disease of a single valve was present in 39 (52%). Multivalvular disease (aortic and mitral lesions) occurred in 23 (31%). An error was defined as a significant lesion being classified as insignificant or conversely.

Clinical Evaluation

Five experienced cardiologists used specific clinical criteria to classify aortic stenosis, aortic regurgitation, mitral stenosis, and mitral regurgitation as absent, hemodynamically insignificant, or significant. For each of the four valve lesions assessed, if no cardiac murmur was audible, the lesion was classified as absent. The following clinical criteria were used to determine if a valve lesion was insignificant or significant.

Aortic stenosis. Aortic stenosis was insignificant if there was no leaflet calcification on fluoroscopy (patients over age 35). This was supported by normal splitting of the second heart sound and a normal pulse character (in younger patients). In elderly patients, the latter sign was not used. Conversely, a slow rising pulse in younger patients indicated significant stenosis. This was also suggested by a single or paradoxically split second heart sound or presence of left ventricular hypertrophy on the electrocardiograph.

Aortic regurgitation. The pulse character and pulse pressure were major criteria used to determine severity. Presence of a collapsing pulse (abrupt distention and poorly sustained) and a widened pulse pressure ($>50\%$ systolic blood pressure) indicated significant aortic regurgitation.

Mitral stenosis. Multiple clinical parameters were used to assess mitral stenosis. If present, a long diastolic murmur and early opening snap indicated significant stenosis. Many patients with heavily calcified valves and significant stenosis may not have an opening snap, and those with a low cardiac output may have short diastolic murmurs. The mid-diastolic murmur may also be influenced by the presence of mitral regurgitation. Thus, other criteria used to support the clinical diagnosis of significant stenosis were evidence of pulmonary hypertension (increased intensity of the pulmonary component of the second heart sound), electrocardiographic evidence of right ventricular hypertrophy, and interstitial edema on chest x-ray.

Mitral regurgitation. Mitral regurgitation was considered significant if the cardiac impulse was brisk

and hyperdynamic and there was a late systolic thrust in the parasternal region. On auscultation, there was a strong apical systolic murmur, and the third heart sound was audible. If present, cardiomegaly with left atrial enlargement and interstitial edema on chest x-ray were also used to grade the regurgitation as significant.

Confidence in the clinical evaluation was graded by the attending cardiologist as high or low. Cardiologists were asked to state whether, in standard practice, cardiac catheterization would have been required to assess the severity of the valve lesion. Because clinical confidence is a highly subjective parameter and is influenced strongly by the personality traits of the individual, no attempt was made to establish guidelines. Clinical evaluation and confidence levels were recorded before Doppler echocardiography and cardiac catheterization. History, clinical examination, chest x-ray, electrocardiography, and fluoroscopy were all used. Phonocardiography, carotid pulse tracings, and apexcardiography were not performed.

Doppler Echocardiography

Doppler echocardiography was performed within 48 hours of cardiac catheterization. A commercially available Doppler echocardiographic unit (model 77020, Hewlett-Packard) was used. This instrument incorporates both tomographic ultrasound imaging and Doppler velocimetry. Dynamically focused, phased-array, 2.5- or 3.5-MHz pulsed-Doppler transducers were used along with a 2.25-MHz nonimaging, continuous-wave Doppler transducer. On-line computer processing was used for data analysis. Two observers interpreted the echocardiograms. They were aware of what the clinically suspected dominant lesion was but had no knowledge of the catheterization results. Three cardiac cycles of Doppler echocardiography data were analyzed for patients in sinus rhythm, and 10 cycles were used if atrial fibrillation was present. The Doppler echocardiographic criteria used to define the severity of each of the four valve lesions are shown in Table 1.

Aortic stenosis. Left ventricular outflow tract Doppler spectral waveforms were recorded with the imaged-guided pulsed-Doppler transducer located at the cardiac apex.¹¹ For measurement of the maximal blood velocity in the left ventricular outflow tract (V_{ot} in centimeters per second), the pulsed-Doppler sample volume¹⁰ was placed just proximal to the insertion of the aortic valve leaflets. With the continuous-wave Doppler transducer on the suprasternal notch or right sternal border, the maximum velocity in the aortic valve (V_{av} in centimeters per second) also was measured.¹² We took great care to align the ultrasound beam with the stenotic jet and used multiple acoustic windows to determine the highest value for V_{av} . From the parasternal long-axis view, we used electrocardiographic gating to measure the internal lumen diameter of the outflow tract (D_{ot} in centimeters) in

mid-systole, just proximal to the insertion of the aortic valve leaflets. The outflow tract was assumed to be circular, and its cross-sectional area (A_{ot} in centimeters squared) calculated as:

$$A_{ot} = \frac{\pi \cdot (D_{ot})^2}{4}$$

Aortic valve area (AVA in centimeters squared) was calculated with the equation of continuity¹³:

$$AVA = \frac{A_{ot} \cdot V_{ot}}{V_{av}}$$

Aortic regurgitation. V_{ot} and D_{ot} were measured as described above. The left ventricular ejection time (T_{ot} in seconds) was also measured from the left ventricular outflow tract spectral waveforms. The patient was tilted 90° to lie on his left side, and the sample volume was positioned just distal to the pulmonary valve leaflets to measure the maximum velocity (V_{pa} in centimeters per second) and ejection time (T_{pa} in seconds) in the main pulmonary artery.¹⁵ Using electrocardiographic gating, the lumen diameter of the pulmonary artery (D_{pa} in centimeters) was measured at the level of the pulmonary valve leaflets in mid-systole. Assuming a circular cross-section, the pulmonary artery area (A_{pa} in centimeters squared) was calculated from D_{pa} . To simplify data processing, we assumed the Doppler spectral waveforms during ejection to be triangular.²⁵ Thus, stroke volumes across the left ventricular outflow tract (SV_{ot} in milliliters) and pulmonary artery (SV_{pa} in milliliters) were calculated as:

$$SV_{ot,pa} = 0.5 \cdot A_{ot,pa} \cdot V_{ot,pa} \cdot T_{ot,pa}$$

Aortic regurgitant fraction (ARF in percent) was calculated as:

$$ARF = \frac{SV_{ot} - SV_{pa}}{SV_{ot}} \times 100$$

We were unable to obtain technically adequate measurements of D_{pa} in 12 of 40 patients (30%) with aortic regurgitation. In these cases, we used a pulsed-Doppler flow-mapping technique¹⁶ to assess severity. Aortic regurgitation was considered significant if the diastolic flow disturbance was detected beyond the tip of the anterior mitral leaflet.

Mitral stenosis. Doppler spectral waveforms from the mitral valve were recorded with a Doppler continuous-wave transducer held at the cardiac apex. Care was taken to align the ultrasound beam with the stenotic jet to record the maximum velocity. By calculating the time ($T_{1/2}$ in milliseconds) required for the maximum velocity to fall to one half its maximum value in early diastole, the standard pressure half time method¹⁷ was used to calculate mitral valve area (MVA in centimeters squared):

$$MVA = \frac{220}{T_{1/2}}$$

Mitral regurgitation. The method for calculation of mitral regurgitant fraction (MRF in percent) was similar to that for ARF.^{18,19} SV_{pa} was calculated as described above. Mitral annulus diameter (D_{ma} in centimeters) was measured in diastole in the apical four-chamber view immediately after maximal mitral valve opening. With the assumption of circular cross-section, the area of the mitral annulus (A_{ma} in centimeters) was calculated from D_{ma} . Doppler spectral waveforms were recorded with pulsed-wave Doppler with the sample volume at the mitral annulus. The maximum velocities (V_{ma} in centimeters) and filling times (T_{ma} in seconds) were measured for the passive filling and atrial systolic portions of transmitral flow in patients in sinus rhythm. Again, the spectral waveforms were assumed to be triangles.²⁵

Mitral annulus stroke volumes (SV_{ma} in milliliters) were determined for each portion of the inflow and were added and calculated as:

$$SV_{ma} = 0.5 \cdot A_{ma} \cdot V_{ma} \cdot T_{ma}$$

Patients in atrial fibrillation had a single triangular waveform that was used to calculate SV_{ma} directly. Thus, MRF was calculated as:

$$MRF = \frac{SV_{ma} - SV_{pa}}{SV_{ma}}$$

We were unable to measure MRF in 30 of 45 patients (67%) with mitral regurgitation. In 16 patients, the image quality was too poor to accurately measure D_{pa} . In 14 patients, adequate measurements of V_{ma} could not be recorded because of coexisting mitral stenosis. In these 30 patients, we used a pulsed-Doppler flow-mapping technique²⁰ to assess severity. Mitral regurgitation was considered significant if systolic flow disturbance was detected beyond the midpoint of a dilated left atrium.

Cardiac catheterization. All patients were premedicated with 10 mg diazepam and 0.6 mg atropine 1 hour before cardiac catheterization. Fluid-filled catheters connected to strain gauge pressure transducers were used for pressure measurements. Three consecutive cycles were analyzed for patients in sinus rhythm; 10 cycles were analyzed if atrial

fibrillation was present. Cardiac output was measured by the standard Fick technique. The cardiac catheterization criteria used to define the severity of each of the four valve lesions are shown in Table 1.

Aortic stenosis. Simultaneous left ventricular and ascending aortic pressures were recorded in 24 of 32 patients (75%) with aortic stenosis. Simultaneous left ventricular and femoral artery traces were obtained in four patients, and withdrawal traces were obtained in four patients. Simultaneous left ventricular and femoral artery traces were used only if both the femoral artery pressures via the end-hole of the catheter and the wide arm of the sheath were identical. We used the modified Gorlin formula to calculate aortic valve area.²⁶ In seven of 32 patients (22%) with aortic stenosis, we were unable to use the Gorlin formula because of coexisting significant aortic regurgitation. We used the mean pressure gradient to assess the severity of the aortic stenosis in these patients. The criteria used to define the severity of aortic stenosis by cardiac catheterization are shown in Table 1.

Aortic regurgitation. An 8F Gensini catheter was placed with its tip 1 cm above the upper margin of the aortic sinuses for injection of 40 ml contrast medium containing 370–400 mg iodine/ml at a flow rate of 22 ml/sec. Cineangiograms were recorded in the right anterior oblique 40° projection. Aortic regurgitation was assessed by the following semi-quantitative method²⁷:

1+ = No outlining of left ventricular cavity with contrast confined to the outflow tract.

2+ = Left ventricle outlined faintly, transiently, or slowly.

3+ = Rapid outlining of left ventricle with aortic-ventricular densities equal after three diastoles and contrast eliminated by 10 seconds.

4+ = Rapid outlining of left ventricle with aortic-ventricular densities equal within three diastoles and contrast persisting beyond 10 seconds.

Mitral stenosis. Satisfactory simultaneous pulmonary arterial wedge and left ventricular pressure recordings were obtained in 29 of 31 patients (94%) with mitral stenosis. We used the modified Gorlin formula to calculate mitral valve area.²⁶ Nine of 29

TABLE 1. Criteria Used to Grade the Severity of Valve Lesions by Doppler Echocardiography and Cardiac Catheterization

	Aortic stenosis		Aortic regurgitation		Mitral stenosis		Mitral regurgitation	
	DE	CC	DE	CC	DE	CC	DE	CC
Absent	AVA >2.2	AVA >2.2 (MPG <20)	ARF <10	≤1+	MVA >2.2	MVA >2.2 (MPG <6)	MRF <10	≤1+
Insignificant	AVA 1.1–2.2	AVA 1.1–2.2 (MPG 20–39)	ARF 10–29	2+	MVA 1.5–2.2	MVA 1.5–2.2 (MPG 6–11)	MRF 10–29	2+
Significant	AVA <1.1	AVA <1.1 (MPG ≥40)	ARF ≥30	≥3+	MVA <1.5	MVA <1.5 (MPG ≥12)	MRF ≥30	≥3+

DE, Doppler echocardiography; CC, cardiac catheterization; AVA, aortic valve area (cm²); ARF, aortic regurgitant fraction (%); MVA, mitral valve area (cm²); MRF, mitral regurgitant fraction (%); MPG, mean pressure gradient (mm Hg) (used in seven patients with aortic stenosis and moderate or severe aortic regurgitation and nine patients with mitral stenosis and moderate or severe mitral regurgitation).

TABLE 2. Characteristics of Valve Lesions and Errors Committed by Clinical Evaluation and Doppler Echocardiography

Lesion	Age range (mean)	N	Errors	Clinical evaluation		Doppler echocardiography			
				Important errors	Important errors with high confidence in CE	CE errors corrected by DE	DE errors	Total DE errors	Important errors
Aortic stenosis	20-74 (54)	32	6	4	1	6/6	0	0	0
Aortic regurgitation	24-74 (50)	40	8	5	2	6/8	0	2	1
Mitral stenosis	26-71 (47)	29	9	4	0	8/9	0	1	0
Mitral regurgitation	20-74 (52)	45	5	4	1	5/5	2	2	0
Total (% except for mean age)	20-74 (52)	146	28 (19)	17 (12)	4 (5)	25/28 (89)	2 (1)	5 (3)	1 (1)

CE, clinical evaluation; DE, Doppler echocardiography.

patients (31%) with mitral stenosis had more than 3+ mitral regurgitation, and mitral valve area was not calculated because the Fick cardiac output will underestimate transmitral blood flow and the valve area. Because 1+ and 2+ mitral regurgitation would increase diastolic transmitral flow by less than 30%, the maximum error in using a Fick cardiac output to calculate a valve area in 2+ mitral regurgitation would be 30%. Because of the high incidence of atrial fibrillation and coexisting aortic regurgitation, it was not possible to calculate angiographic stroke volume. In these patients, we used the mean pressure gradient to assess the severity of mitral stenosis (Table 1).

Mitral regurgitation. Left ventricular cineangiograms were recorded at 50 frames/sec on a 9-in. image intensifier field in the right anterior oblique 40° projection. Mitral regurgitation as assessed by the following semiquantitative criteria:

- 1+ = Insufficient contrast to outline the left atrium.
- 2+ = Contrast faintly outlines the left atrium, but there is no equalization of contrast density between the left atrium and left ventricle.
- 3+ = Contrast rapidly outlines the left atrium, and there is equalization of contrast density between the left atrium and left ventricle. Equalization does not occur until after the end of the third systole.
- 4+ = Contrast rapidly outlines the left atrium with equalization of contrast densities between the left atrium and left ventricle by the end of the third systole.

Statistics. Sensitivity, specificity, and accuracy (in the diagnosis of aortic and mitral valve areas of <1.1 and 1.5 cm², respectively, and ≥3+ cm² aortic or mitral regurgitation) of the clinical and Doppler echocardiographic examinations compared with cardiac catheterization were determined by standard methods.²⁸ Significant differences ($p < 0.05$) between the sensitivities, specificities, and accuracies of the clinical and Doppler echocardiographic examinations were determined by McNemar's test.²⁹ AVA and MVA by Doppler echocardiographic examination and cardiac catheterization were compared by standard linear regressions.

Because the prevalence of significant valvular heart disease in our patient population was unknown, we did not determine the positive or negative predictive values of the clinical or Doppler echocardiographic examination.²⁸

Results

The mean heart rates were 75 ± 13 beats/min at Doppler echocardiography and 81 ± 16 beats/min at cardiac catheterization. Systolic blood pressures were 125 ± 20.3 and 134 ± 24.1 mm Hg, respectively. Neither difference was significant. Table 2 gives the number and age data for each valve lesion.

Aortic Stenosis

Thirty-four of 75 patients (45%) had aortic stenosis by clinical, Doppler, or catheter examination. Two were excluded. In one patient, the left ventricle could not be centered at cardiac catheterization.

TABLE 3. Sensitivity, Specificity, and Accuracy of Clinical Evaluation and Doppler Echocardiography in the Diagnosis of Significant Valve Lesions

	Aortic stenosis			Aortic regurgitation			Mitral stenosis			Mitral regurgitation		
	SN	SP	AC	SN	SP	AC	SN	SP	AC	SN	SP	AC
Clinical evaluation (%)	83	79	81	75	85	80	68	70	69	95	85	89
Doppler echocardiography (%)	100*	100*	100*	100*	90	95*	100*	90*	97*	100	93	96

SN, sensitivity; SP, specificity; AC, accuracy.

* $p < 0.05$ versus clinical evaluation.

In the other patient, the peak velocity across the aortic valve could not be obtained with Doppler echocardiography. In the 32 remaining patients, 17 (53%) had significant aortic stenosis at catheterization. In 15 (47%), the confidence in the clinical evaluation was high and cardiac catheterization was considered unnecessary. Seven patients (22%) had associated significant aortic regurgitation at aortography. Clinical evaluation committed six errors (Table 3). In two patients, the clinical error would not have led to mismanagement because both patients had clinically suspected, significant aortic regurgitation confirmed at cardiac catheterization. Both patients required valve replacement. In four patients, the error was important, but in only one patient was the confidence in clinical evaluation high. Compared with cardiac catheterization, Doppler echocardiography committed no errors and corrected all mistakes made by clinical evaluation. Results were unchanged when aortic valve area was normalized to body surface area. There was a significant correlation between aortic valve area measured by Doppler echocardiography and cardiac catheterization ($r=0.95$; Doppler AVA = $0.73 \cdot \text{catheter AVA} + 0.24$; $p<0.05$).

Aortic Regurgitation

Forty-six of 75 patients had aortic regurgitation by clinical, Doppler, or catheter examinations. Six were excluded because of inadequate catheterization data (five had severe aortic stenosis and one had significant mitral stenosis). All were judged too ill to have an aortography performed at the conclusion of the procedure. Of the 40 remaining patients, 20 (50%) had significant aortic regurgitation at aortography. In 23 (58%) of the 40 patients, the confidence in the clinical evaluation was high and catheterization was considered unnecessary. Eight of the 40 patients (20%) had associated significant aortic stenosis. None of the 20 patients with significant aortic regurgitation had significant aortic stenosis. Clinical evaluation committed eight errors (Table 3). In three of these eight patients, the error was not important because it would not have resulted in inappropriate management. Two false-negatives had coexisting aortic stenosis (requiring surgery), and one false-positive had severe impairment of left ventricular function. Cardiac surgery was not indicated in this case. In five patients, the error would have resulted in incorrect management by clinical evaluation alone. In two of these, the confidence in the clinical evaluation was high, and the attending cardiologist did not consider angiography necessary to assess the aortic regurgitation.

Doppler echocardiography made no additional errors but failed to correct two of the mistakes made by clinical evaluation. Both were false-positives (regurgitant fractions of 34% and 38% by Doppler and angiographic grade at 2+, respectively). In only one patient would the error have resulted in incorrect management.

Mitral Stenosis

Thirty-one of 75 patients had mitral stenosis by clinical, Doppler, or catheter examination. Two were excluded because a satisfactory wedge tracing could not be obtained. In the 29 remaining patients, 18 (62%) had significant mitral stenosis at cardiac catheterization. In 15 (52%), the confidence in clinical evaluation was high and cardiac catheterization was judged unnecessary. Nine patients had associated significant mitral regurgitation. Clinical evaluation committed nine errors (Table 3). Five of the errors were unimportant because the patients had significant mitral regurgitation suspected clinically and confirmed by cardiac catheterization. All required mitral valve replacement. In three patients, clinical evaluation underestimated the severity of mitral stenosis; in one patient, it overestimated the severity. These four patients had no additional valve lesions and the error was clinically important. In no case was the confidence in clinical evaluation high; thus, the attending cardiologist would have proceeded to cardiac catheterization in all cases.

Doppler echocardiography corrected all mistakes made by clinical evaluation, except in one patient, where it overestimated the severity of mitral stenosis. This would not have resulted in mismanagement because significant mitral regurgitation was diagnosed by Doppler (confirmed at cardiac catheterization) and the patient required surgery. Use of the mean gradient at cardiac catheterization (8 mm Hg) may have underestimated the severity of the mitral stenosis because the cardiac output was low (1.6 l/min/m^2). When mitral valve area was normalized to body surface area, overall results were unchanged. There was a significant correlation between mitral valve area measured by Doppler echocardiography and cardiac catheterization ($r=0.89$; Doppler MVA = $0.93 \cdot \text{catheter MVA} + 0.14$; $p<0.05$).

Mitral Regurgitation

Fifty-two of 75 patients had mitral regurgitation by clinical, Doppler, or catheter examinations. Seven were excluded. In four patients, the left ventricular angiogram was technically unsatisfactory, and three patients were too ill for angiography to be performed. Of the remaining 45 patients, 19 (42%) had significant mitral regurgitation at ventriculography. In 29 (64%) of the 45 patients, the confidence in clinical evaluation was high and catheterization was considered unnecessary. Fourteen of the 45 patients (31%) had associated significant mitral stenosis. Only two of the 19 patients (11%) with significant mitral regurgitation also had significant mitral stenosis. Four other patients (21%) also had significant aortic regurgitation. Consequently, 13 patients (68%) had isolated significant mitral regurgitation. Clinical evaluation committed five errors (Table 3). In one patient, the error was unimportant as the patient had significant mitral stenosis suspected clinically and confirmed at cardiac catheterization. Mitral

valve replacement was performed. In four patients, important errors were made, one with high confidence. In three of these patients, clinical evaluation overestimated the severity of mitral regurgitation, while in one patient, clinical evaluation underestimated the severity. In only one patient (false-positive) was the confidence at clinical evaluation high. The attending cardiologist considered cardiac catheterization unnecessary, and the patient would have had unnecessary surgery.

Doppler echocardiography corrected all errors made by clinical evaluation but made two additional mistakes. In both patients, a regurgitant fraction could not be calculated and mapping techniques overestimated the severity of mitral regurgitation. However, the errors were clinically unimportant because both patients had significant mitral stenosis diagnosed by Doppler echocardiography (confirmed at cardiac catheterization) and required surgery.

Overall Results

Clinical evaluation made 28 errors (37% of patients and 19% of valve lesions assessed). Seventeen would have resulted in inappropriate management if clinical evaluation alone was used. In only four (24%) of these 17 patients would the attending cardiologist *not* have proceeded to assess the valve at cardiac catheterization. In 82 of 146 valve lesions assessed, the confidence in clinical evaluation was high, and the attending cardiologist would not have proceeded to catheterization. In this subgroup (56% of all valve lesions), appropriate management by clinical evaluation alone would have occurred in 78 (95%) lesions.

Doppler echocardiography committed five errors in 75 patients (7%) and 146 valve lesions (3%). In only one valve lesion would inappropriate management have occurred by Doppler echocardiography alone. Doppler echocardiography corrected 25 (89%) of the 28 errors made by clinical evaluation and 16 (94%) of the 17 errors that would have resulted in incorrect management of the patient.

The sensitivity, specificity, and overall accuracy of clinical evaluation and Doppler echocardiography for each of the four valve lesions are shown in Table 3.

Discussion

The principal findings of this study are that 1) in the detection of significant valvular disease, Doppler echocardiography is more accurate than clinical evaluation alone; and 2) when compared with cardiac catheterization, Doppler echocardiography is highly accurate. Our study population included many patients with mixed or multivalvular lesions (a reflection of the high incidence of rheumatic heart disease in our region) as well as a number of elderly patients with isolated lesions. We took consecutive patients, and exclusions due to either inadequate Doppler echocardiographic or catheterization data were few. The sensitivity, specificity, and overall accuracy of clinical evaluation and Doppler echo-

cardiography are strongly influenced by the nature of the population studied. Although we assessed each of four valves in all 75 patients, we chose to exclude from the final analysis any valve of a patient with absent disease as determined by all three methods (clinical evaluation, Doppler echocardiography, and cardiac catheterization). Had these patients been included in the final analysis, the overall accuracy of both clinical evaluation and Doppler echocardiography would have been higher.

Clinical evaluation was performed by five experienced cardiologists who have exposure to many patients with valvular heart disease. It is difficult to define clinical criteria of hemodynamic significance because these often vary depending on the characteristics of the individual patient. Furthermore, the parameters used are subjective. Although we did not determine the interobserver variability of clinical examination, the clinical accuracies of the five cardiologists were similar. This suggests they applied the criteria equally well.

Doppler echocardiographers were aware of which valves were suspected of being diseased but not of the detailed clinical evaluation made by the attending cardiologist. This is the normal practice. Thus, a more precise description of the present study would be clinical evaluation versus clinical evaluation plus Doppler echocardiography. Despite Doppler echocardiography and cardiac catheterization not being performed simultaneously, there was no statistically significant difference in either heart rate or systolic blood pressure. Although valve area should be relatively independent of loading conditions, the degree of valvular regurgitation may have changed between the times of echocardiography and cardiac catheterization. We believe this is only a minor limitation of our study.

With the exception of the assessment of mitral stenosis, standard cross-sectional echocardiography cannot be compared with Doppler echocardiography. Cross-sectional echocardiography cannot quantitate the severity of valvular regurgitation. Additionally, although measurement of cusp separation distinguishes normal from stenotic aortic valves, it does not reliably separate critical from noncritical disease. Our data for mitral stenosis show that overall accuracy increased from 69% with clinical evaluation to 85% with cross-sectional echocardiography and to 97% with Doppler echocardiography. Doppler not only added 12% to overall accuracy, but it allowed evaluation in *all* patients with mitral stenosis, including the three in whom inadequate images were obtained with cross-sectional echocardiography.

With Doppler echocardiography, satisfactory data were obtained in all patients with stenotic lesions except in one patient with aortic stenosis. However, we were unable to apply quantitative methods for calculation of regurgitant fraction in approximately one third of patients, either because the pulmonary artery diameter could not be accurately

measured or because mitral stenosis precluded measurement of mitral annulus stroke volume. Due to the high incidence of multivalvular disease, no attempt was made to quantitate net forward flow from another flow region. With the mapping method, overestimation of the severity of mitral regurgitation occurred in two patients. Both patients had mildly enlarged left atria. Although the jet was not widely dispersed, it reached nearly to the back of the chamber. Because both patients had significant mitral stenosis identified by Doppler and confirmed at operation, the error was not clinically important. In aortic regurgitation, the mapping technique separated significant from nonsignificant disease in all cases, while in mitral regurgitation, it overestimated the severity in two cases. With regurgitant fraction, two errors (discussed below) occurred in aortic regurgitation and none occurred in mitral regurgitation.

Cardiac catheterization was used as the gold standard. These are many inaccuracies in both the Gorlin method for the calculation of valve area³⁰ and the semiquantitative grading system for regurgitant lesions.³¹ We did not calculate angiographic regurgitant fractions because of the high prevalence of combined aortic and mitral regurgitation in our population. Several of the "errors" in Doppler echocardiography may reflect inaccuracies in the catheterization data. Two patients with angiographic grade 2+ aortic regurgitation had regurgitant fractions of 34% and 38%. It is possible that the angiographic grading is incorrect or, conversely, that the arbitrary figure of 30%, taken to indicate significant aortic regurgitation, is too low. In one patient who had Doppler-determined significant mitral stenosis, use of mean gradient at cardiac catheterization resulted in categorizing the mitral stenosis as significant. The patient had significant mitral regurgitation precluding calculation of mitral valve area. Although the results of cardiac catheterization and angiography are widely accepted, a true gold standard for assessment of valvular regurgitation has yet to be established.

In all four valve lesions, Doppler echocardiography had a higher overall accuracy than clinical evaluation. Significant ($p < 0.05$) increases in accuracy occurred in mitral stenosis (28%), aortic stenosis (19%), and aortic regurgitation (15%). The increase in mitral regurgitation was modest (7%), largely because of the surprisingly high accuracy of clinical evaluation. Although clinical evaluation made the correct diagnosis in 63% of patients, if cardiac catheterization were unavailable and clinical evaluation alone was relied on, correct management would have occurred in only 77% of patients. Almost one fourth of the patients would have been either denied valve surgery or operated on unnecessarily. This is clearly unsatisfactory. We were able to identify a subgroup in which the attending cardiologist was confident with the clinical evaluation and believed that cardiac catheterization (to assess the abnormal valve) was not required. As clinical con-

fidence is a highly subjective parameter and was almost certainly influenced by the knowledge that all patients in the present series would have catheterization performed as part of the protocol, it is possible that these results would not be reproduced outside the setting of a clinical trial. However, in this group where confidence was high, comprising just over one half of lesions assessed, correct management would have occurred 95% of the time. If Doppler echocardiography was added, the figure for all lesions and all patients increased to 99%. These results were obtained without the use of real time, two-dimensional, Doppler echocardiographic color flow mapping techniques,³² which may facilitate the quantitative Doppler methods, particularly in the assessment of regurgitant lesions. It is important to note that we did not investigate patients with acute mitral or aortic regurgitation or prosthetic (mechanical or porcine) valves.

Decisions concerning the appropriate time for cardiac surgery in patients with valvular heart disease involve many factors in addition to the severity of the lesion and were not specifically tested in this study. Severity of symptoms, ventricular performance, pulmonary vascular resistance, and the presence or absence of coexistent coronary artery disease are important factors in the management of the patient. Doppler echocardiography often can be used to estimate pulmonary artery pressure and resistance.³³ Left ventricular performance can be assessed with standard M-mode and two-dimensional echocardiography.

Our results suggest that by combined clinical evaluation and Doppler echocardiography, the need for assessment of valve function by cardiac catheterization can be avoided in a majority of patients. Nevertheless, to rule out significant coronary artery disease, many of the older patients would require coronary arteriography. The yield and necessity of coronary angiography in patients with valvular heart disease but without ischemic symptoms are yet to be determined. Avoidance of detailed hemodynamic and angiographic evaluation of valvular heart disease will save considerable time and expense and may reduce the risks of cardiac catheterization.

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