

Usefulness of the Doppler Mean Gradient in Evaluation of Children with Aortic Valve Stenosis and Comparison to Gradient at Catheterization

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To assess the usefulness of the Doppler mean gradient as a noninvasive indicator of the need for intervention, 33 children (ages 3 months to 20 years) with valvular aortic stenosis (AS) underwent a 2-dimensional and Doppler echocardiographic examination a median of 1 day before cardiac catheterization. The clinical decision for intervention was based on finding a catheterization peak-to-peak pressure gradient of >75 mm Hg or from 50 to 75 mm Hg in the presence of symptoms or an abnormal exercise treadmill test result. Of the 33 patients, 23 required intervention. The decision for intervention was compared to the Doppler mean gradient, and the Doppler peak and mean gradients were compared to the catheterization peak-to-peak gradient. All 12 patients with a Doppler mean gradient >27 mm Hg had intervention and had a catheterization peak-to-peak gradient of ≥ 75 mm Hg. All 3 patients with a Doppler mean gradient <17 mm Hg had no intervention and had a peak-to-peak gradient <50 mm Hg. The remaining 18 patients with Doppler mean gradients between 17 and 27 mm Hg comprised an intermediate group in whom the Doppler mean gradient alone did not predict the need for intervention.

From a chi-square table, a Doppler mean gradient >27 mm Hg predicted the need for intervention with 100% specificity (no false positives) and 52% sensitivity (11 false negatives). If a Doppler mean gradient >24 mm Hg was used to predict intervention, the sensitivity increased to 91% (2 false negatives) but specificity decreased to 70% (3 false positives). To improve the ability to predict the need for intervention in patients with a Doppler mean gradient between 17 and 27 mm Hg, the presence of symptoms or an abnormal exercise treadmill test result was combined with the Doppler mean gradient as criteria for intervention. When the criteria for intervention were a Doppler mean gradient >27 mm Hg or a Doppler mean gradient from 17 to 27 mm Hg in the presence of symptoms or an abnormal exercise test, sensitivity was 96% (1 false negative) and specificity was 80% (2 false positives). Catheterization peak-to-peak gradients correlated well with Doppler mean and peak gradients ($r = 0.74$ and 0.73 , respectively).

Thus, the Doppler mean gradient is a useful indicator of the need for intervention in children with AS. A Doppler mean gradient >27 mm Hg indicates the need for intervention with 100% specificity while a Doppler mean gradient <17 mm Hg predicts mild AS. For patients with Doppler mean gradient between 17 and 27 mm Hg, additional noninvasive data are necessary to determine the need for intervention.

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In children with valvular aortic stenosis (AS), the peak-to-peak pressure gradient measured at cardiac catheterization is often used to determine the severity of AS and the need for intervention. Currently, the most widely used noninvasive technique for estimating the severity of AS is measurement of the peak instantaneous pressure gradient with Doppler echocardiography.¹⁻⁴ The Doppler-derived peak instantaneous pressure gradient does not always correlate well with the catheterization-measured peak-to-peak pressure gradient.⁴⁻⁶ Therefore, additional noninvasive estimates of the severity of AS would be helpful in making patient management decisions. The Doppler mean gradient is another noninvasive measurement that has proven useful in the evaluation of adult patients with AS.⁵⁻¹² In pediatric patients, little information is available correlating the Doppler mean gradient with the hemodynamic severity of the AS. This study assesses the usefulness of the Doppler mean gradient in predicting the need for intervention in children with AS.

METHODS

Patient population: All children with AS who underwent 2-dimensional and Doppler echocardiographic examination and cardiac catheterization at this institution between September 1984 and August 1988 were included in the study. The study population consisted of 33

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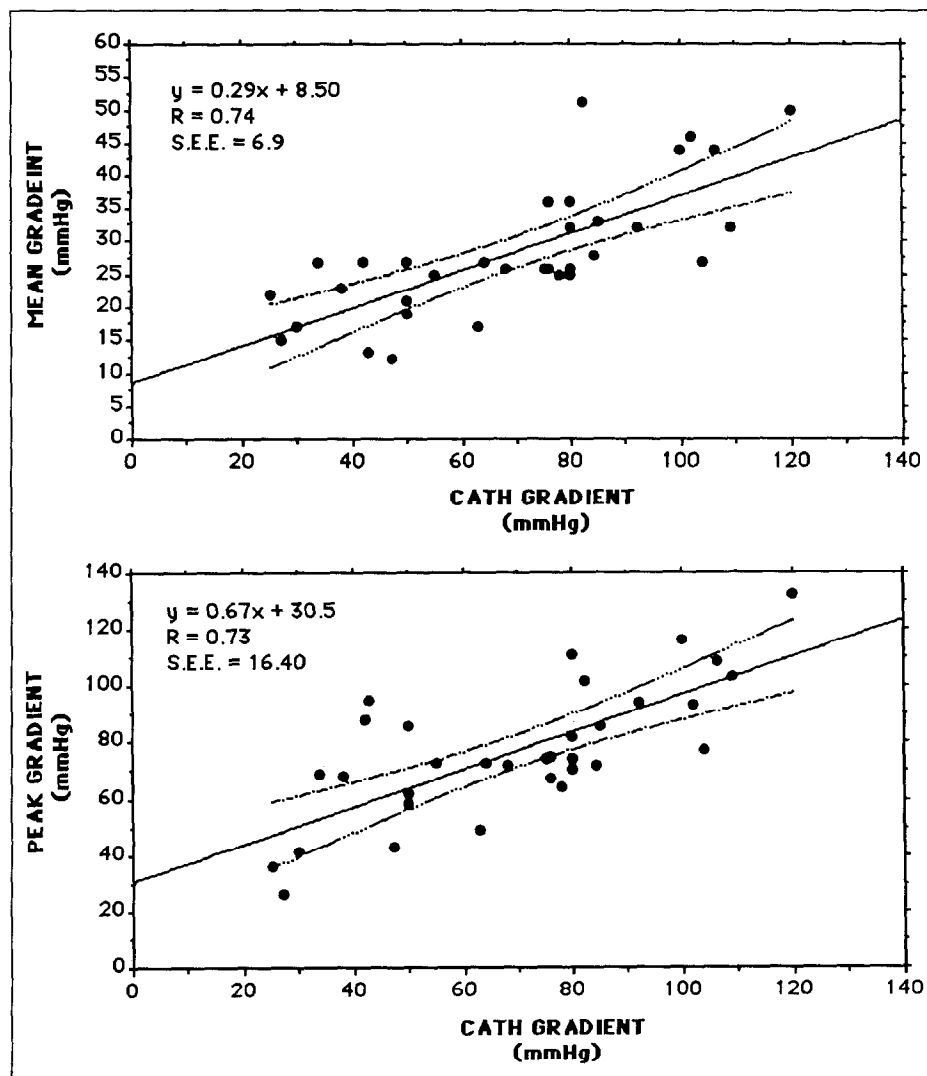
patients whose ages ranged from 3 months to 20 years (10 ± 6 years, mean \pm standard deviation) and whose weights ranged from 5 to 109 kg (41 ± 29). Four infants <3 months old with critical AS were excluded from the study because critical AS in the neonatal period has different hemodynamic features and criteria for intervention. In addition, all children with subvalvular or supra-valvular levels of left ventricular outflow obstruction were excluded.

The patients in the study group had several additional lesions. Aortic regurgitation was detected at cardiac catheterization in 17 patients. Regurgitation was graded at angiography as 1+ in 12 patients, 2+ in 4 and 3+ in 1. Two children had previous repair of aortic coarctation with no residual descending aorta gradient at catheterization. Two patients had a small ventricular septal defect and 2 patients had mitral valve abnormalities including mitral valve prolapse in 1 and mild mitral stenosis in the other.

Echocardiographic examinations: In each patient, the 2-dimensional and Doppler echocardiographic examination was reviewed by 2 observers who had no

knowledge of the results of catheterization or the patient's subsequent management. All echocardiographic examinations were performed from 1 to 90 days (median 1 day) before catheterization using either an Advanced Technology Laboratories Mark 600 or Ultramark 8 system or an Acuson 128 computed sonography system. Using high pulse repetition frequency or continuous wave Doppler techniques, the AS jet was recorded on videotape at 50 or 100 mm/s sweep speed. The AS jet was recorded from apical, right parasternal and suprasternal transducer positions. The Doppler recording that provided the highest value for the peak velocity was used for subsequent measurements of the peak and mean gradients. The simplified Bernoulli equation (pressure gradient = $4 \times$ maximum velocity²) was used to calculate instantaneous pressure gradients. The peak instantaneous pressure gradient was defined as the largest of all the instantaneous gradients throughout systole and the mean gradient was calculated as the average of all the instantaneous gradients throughout systole. Using an off-line analysis system (Microsonics CAD 888), the gradients were calculated from a digital tracing of

FIGURE 1. Comparisons of Doppler mean (*top*) and peak (*bottom*) gradients with the catheterization peak-to-peak gradient in 33 children with aortic stenosis. The dotted lines represent the 5 and 95% confidence intervals.



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the outermost border of the Doppler spectral recording through systole. All data presented represent the average of 3 or more cardiac cycles.

Record review: The medical records of each patient were reviewed for the following information: (1) the medical history, with particular attention paid to the presence of symptoms including chest pain, syncope, dyspnea and easy fatigability; (2) results of exercise treadmill tests; and (3) results of cardiac catheterization, with peak-to-peak pressure gradient across the aortic valve, left ventricular end-diastolic pressure, thermodilution cardiac index and diagnosis of additional lesions obtained from the catheterization report.

Criteria for intervention: In our institution, the decision for intervention was based on finding a catheterization peak-to-peak gradient of ≥ 75 mm Hg or from 50 to 75 mm Hg in the presence of symptoms or an abnormal exercise treadmill test result. Using these criteria, 23 of the 33 patients required intervention. Twenty-two had balloon valvuloplasty and 1 had aortic valve replacement.

Statistical analysis: The sensitivity and specificity of different Doppler mean gradients for predicting the need for intervention were calculated from a chi-square table. Doppler mean and peak instantaneous pressure gradients were compared to catheterization-measured,

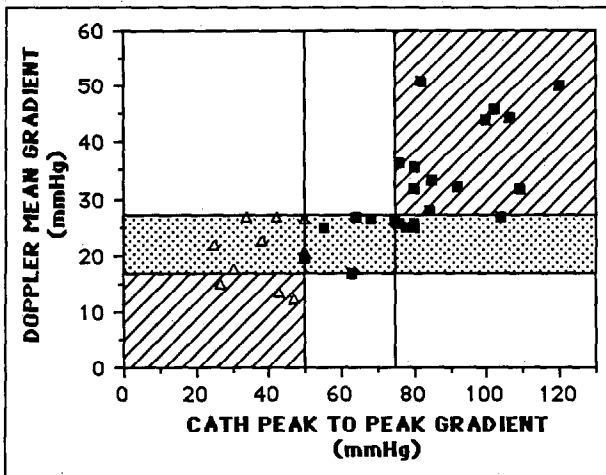


FIGURE 2. Comparison of the Doppler mean gradient, the catheterization peak-to-peak gradient and the need for intervention in 33 children with aortic stenosis. Children who required intervention are represented by solid squares. The children who did not need intervention are depicted as open triangles. The cross-hatched box on the upper right depicts the data from 12 children who required intervention and who had a Doppler mean gradient >27 mm Hg and a catheterization peak-to-peak gradient ≥ 75 mm Hg. The cross-hatched box on the lower left represents the data from 3 patients who did not require intervention and who had a Doppler mean gradient <17 mm Hg and catheterization peak-to-peak gradient <50 mm Hg. The intermediate group in the dotted area represents 18 children, 11 of whom required intervention and 7 who did not. In this intermediate group, the mean gradient was between 17 and 27 mm Hg, and the catheterization peak-to-peak gradient was between 50 and 75 mm Hg. In these children, the Doppler mean gradient alone did not predict the need for intervention. Several data points on this figure are superimposed.

peak-to-peak pressure gradients using linear regression analysis ($p < 0.05$ indicated a significant correlation).

RESULTS

The data obtained from the review of the Doppler examination, the cardiac catheterization report and the medical records are listed in Table I. Using linear regression analysis, the Doppler mean and peak instantaneous pressure gradients were compared to the catheterization peak-to-peak gradients (Figure 1). Significant correlations were found for both relations and the correlation coefficients were similar ($r = 0.74$ for mean gradient and 0.73 for peak instantaneous gradient).

For each patient, the Doppler mean gradient, the catheterization peak-to-peak gradient and the need for intervention are compared in Figure 2. All patients with a Doppler mean gradient >27 mm Hg required intervention. This group included 12 children, all of whom had a catheterization peak-to-peak gradient of ≥ 75 mm Hg. All patients with Doppler mean gradients <17 mm Hg did not require intervention. This group included 3 patients, all with peak-to-peak gradients <50 mm Hg. The remaining 18 patients with Doppler mean gradients between 17 and 27 mm Hg comprised an intermediate group in whom the Doppler mean gradient alone did not predict the need for intervention. In this group, catheterization peak-to-peak pressure gradients were between 50 and 75 mm Hg.

The sensitivity and specificity of a given Doppler mean gradient for predicting intervention were calculated from a chi-square table (Figure 3). As Figure 3 shows, a Doppler mean gradient >27 mm Hg predicts the need for intervention with 100% specificity (no false positives); however, the sensitivity is low at 52% (11 false negatives). In other words, there were 11 patients

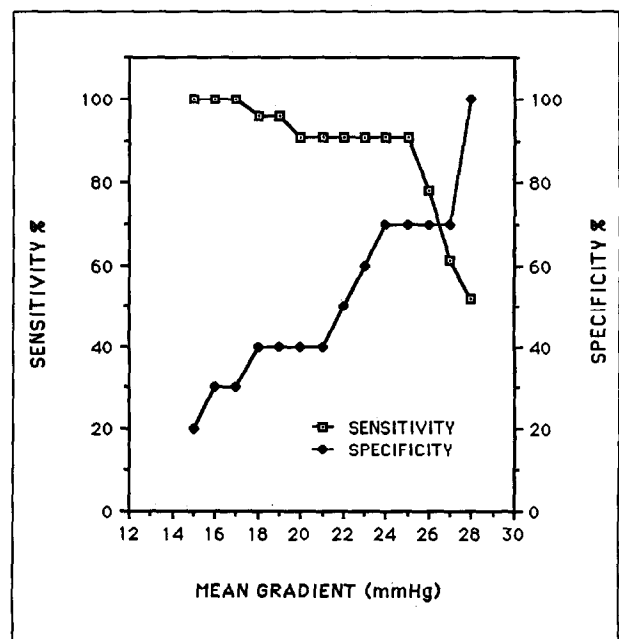


FIGURE 3. The sensitivity and specificity for predicting the need for intervention in children with aortic stenosis.

TABLE I Data for the 33 Children with Aortic Stenosis

Pt	Age (yrs)	Doppler Gradients		Catheterization Data					
		Mean (mm Hg)	Peak (mm Hg)	PPG (mm Hg)	CI (Liters/min/m ²)	LV S/D (mm Hg)	S	ETT	I
1	0.25	27	88	42	4.4	132/18	0	—	0
2	0.25	32	94	92	—	168/16	0	—	+
3	0.33	46	93	102	3.1	162/12	+	—	+
4	0.75	44	109	106	2.5	178/15	+	—	+
5	1.5	27	77	104	5.5	176/18	0	—	+
6	1.9	23	68	38	4.2	148/12	0	—	0
7	2	32	103	109	2.3	191/15	0	—	+
8	4.5	36	111	80	3.9	184/12	0	—	+
9	4.7	26	72	68	4	176/20	+	—	+
10	4.8	51	102	82	3.9	178/12	0	—	+
11	5	25	73	55	3.9	160/17	+	+	+
12	6	15	26	27	4	122/20	0	—	0
13	6.5	26	75	76	4.5	198/15	+	—	+
14	7	13	95	43	3.5	131/10	+	0	0
15	8.5	27	86	50	4	170/14	0	0	0
16	11	26	74	80	3.7	210/22	+	+	+
17	11	50	132	120	4.3	220/10	0	+	+
18	12	28	72	84	3.9	194/17	+	+	+
19	12	19	62	50	4.9	170/10	+	+	+
20	14	26	74	75	2.9	175/13	0	+	+
21	14	36	67	76	4.9	188/13	0	+	+
22	14	12	43	47	4	160/10	0	+	0
23	14	25	70	80	4.5	200/12	0	+	+
24	15	17	49	63	3.4	173/14	+	+	+
25	15	27	73	64	4.9	200/22	0	+	+
26	16	33	86	85	2.9	200/16	0	—	+
27	16	17	41	30	3.2	120/12	0	0	0
28	16	32	82	80	3.7	190/15	+	—	+
29	16	44	116	100	4	220/18	0	+	+
30	17	27	69	34	3.6	180/20	0	+	0
31	18	22	36	25	3	143/12	+	0	0
32	18	21	58	50	3.2	145/8	0	0	0
33	20	25	64	78	2.8	192/9	0	+	+

CI = cardiac index; ETT = exercise treadmill test; I = intervention; LV S/D = left ventricular systolic/diastolic pressures; PPG = peak-to-peak gradient; S = symptoms; + = present; 0 = absent; — = not done.

who required intervention and who were not detected by this criterion alone. If a Doppler mean gradient of >24 mm Hg is used as the criterion for intervention, then the sensitivity increases dramatically to 91% (2 false negatives), but the specificity decreases to 70% (3 false positives). At lower Doppler mean gradients, sensitivity does not increase appreciably while specificity drops off considerably.

To improve our ability to predict the need for intervention in patients with a Doppler mean gradient between 17 and 27 mm Hg, we combined symptoms and an abnormal exercise treadmill test result with the Doppler mean gradient as criteria for intervention (Figure 4). Thus, if the criterion for intervention is a Doppler mean gradient >27 mm Hg or a Doppler mean gradient between 17 and 27 mm Hg in the presence of symptoms or an abnormal exercise treadmill test result, then the sensitivity and specificity improve considerably (Figure 4). A Doppler mean gradient \geq 17 mm Hg in the presence of symptoms or an abnormal exercise treadmill test result predicts the need for intervention with 96% sensitivity (1 false negative) and 80% specificity (2 false positives).

These combined criteria did not predict the need for intervention correctly in 3 of the 33 study patients (Table II). One patient who required intervention was not detected. This patient had a borderline Doppler mean gradient of 27 mm Hg with no symptoms and a catheterization peak-to-peak gradient of 104 mm Hg. Two patients were predicted as requiring intervention but did not receive it. One patient had a Doppler mean gradient of 27 mm Hg, a catheterization peak-to-peak gradient of 50 mm Hg and an abnormal blood pressure response to exercise. Although the patient had criteria for intervention, the decision was made not to intervene. The second patient had syncope with a Doppler mean gradient of 22 mm Hg and a catheterization peak-to-peak gradient of 25 mm Hg. It is likely that symptoms in this patient were unrelated to AS.

DISCUSSION

In children with AS, the peak-to-peak pressure gradient measured at cardiac catheterization is usually a reliable indicator of the severity of the obstruction and the need for intervention. This pressure gradient is affected not only by the severity of the AS but also by the

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TABLE II Patients Not Correctly Identified by Doppler Mean Gradient >27 mm Hg or Between 17 and 27 mm Hg with Symptoms or Abnormal Exercise Treadmill Test

Pt	Outcome	Doppler Mean Gradient (mm Hg)	Catheterization Gradient (mm Hg)	ETT	Symptoms
1	False —	27	104	—	0
2	False +	27	50	Abn	0
3	False +	22	25	NI	Syncope

Abn = abnormal; ETT = exercise treadmill test; NI = normal; — = not done.

amount of transvalvular flow. Children with AS, unlike adults, do not usually have diminished or increased left ventricular stroke volume; therefore, this and other pressure gradients can be used to predict accurately the degree of AS.

Transvalvular pressure gradients can be measured reliably by Doppler echocardiography as well. The peak instantaneous pressure gradient across the aortic valve can be calculated from the Doppler recording of the peak transaortic flow velocity using the simplified Bernoulli equation.¹⁻⁴ When simultaneous Doppler and cardiac catheterization studies are performed, the Doppler-predicted peak instantaneous pressure gradient correlates closely with that measured at cardiac catheterization.^{6,13} However, the peak instantaneous pressure gradient is not routinely measured at cardiac catheterization as an indicator of the need for intervention; therefore, the clinician has no suitable reference standard to which the Doppler peak instantaneous pressure gradient can be compared. The Doppler-predicted mean pressure gradient is directly comparable to mean pres-

sure gradient measured at cardiac catheterization.⁷⁻¹² Little information, however, is available in pediatric patients relating the mean pressure gradient to the severity of stenosis and the need for intervention. In this study, we found that all children with a Doppler mean gradient >27 mm Hg had a catheterization peak-to-peak pressure gradient ≥ 75 mm Hg and, therefore, required intervention. All children with a Doppler mean gradient <17 mm Hg had a catheterization peak-to-peak pressure gradient <50 mm Hg and did not require intervention. Children with Doppler mean gradients between 17 and 27 mm Hg comprised an intermediate group with peak-to-peak pressure gradients between 50 and 75 mm Hg. In this group, the Doppler mean gradient alone was not sufficient to predict the need for intervention; however, the presence of symptoms or an abnormal exercise test provided the additional necessary information for an accurate noninvasive assessment of the severity of the AS.

In this study, a Doppler mean gradient >27 mm Hg or between 17 and 27 mm Hg in the presence of symptoms or an abnormal exercise treadmill test predicted the need for intervention with 96% sensitivity (1 false negative) and 80% specificity (2 false positives). One of the false-positive patients had clinical criteria for intervention and did not receive it. Management decisions in any individual patient cannot always adhere to a rigid set of guidelines. This patient represents a deviation from the guidelines rather than an erroneous test result. In the other false-positive patient, intervention was predicted on the basis of a Doppler mean gradient in the intermediate range in the presence of symptoms (syncope). However, symptoms in this patient were unrelated to the AS and no intervention was necessary. The remaining false-negative patient had a borderline Doppler mean gradient of 27 mm Hg, no symptoms and a catheterization peak-to-peak gradient of 104 mm Hg. The large discrepancy between the Doppler mean gradient and the catheterization peak-to-peak gradient in this patient probably stems from failure during the Doppler examination to record the jet velocities at an acceptable intercept angle.

The Doppler-predicted mean and peak instantaneous pressure gradients correlated significantly with the peak-to-peak pressure gradient measured at cardiac catheterization ($r = 0.74$ for mean gradient and 0.73 for peak instantaneous gradient). In several previously reported studies,^{2,3,5} correlation coefficients have been higher. We believe that the correlation coefficients in our study were lower for the following reasons: (1) the Doppler and catheterization measurements were not made simultaneously¹³; (2) no patient was excluded because of the quality of the Doppler tracing; and (3) the study was performed retrospectively rather than prospectively, which influences who does the examination and how hard the examiner works to obtain the perfect Doppler tracing.

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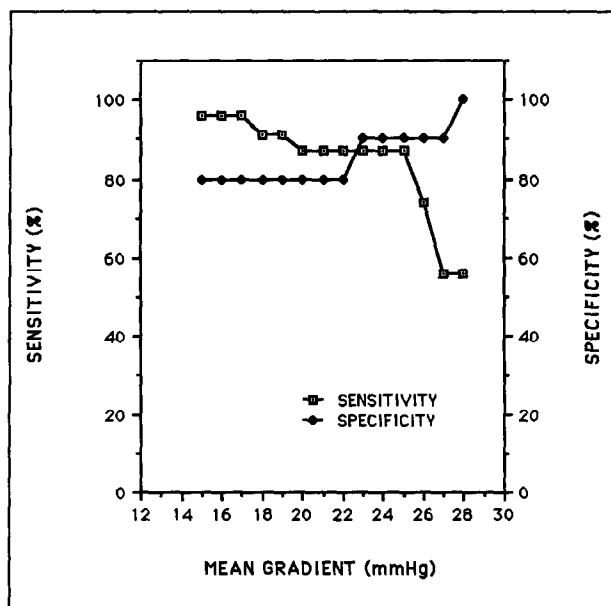


FIGURE 4. The sensitivity and specificity for predicting the need for intervention in children with aortic stenosis when the criterion for intervention is a Doppler mean gradient >27 mm Hg or a Doppler mean gradient between 17 and 27 mm Hg in the presence of symptoms or an abnormal exercise treadmill test result.

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