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Simplified estimation of aortic valve area[1]

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Simple linear measurements of the systolic pressure gradient across the stenosed aortic valve were sought to substitute for the mean systolic gradient in the calculation of aortic valve area, in order to eliminate the need for the time-consuming process of hand planimetry. Two measurements were found to be equally satisfactory, namely the peak systolic gradient and the maximum systolic gradient. Formulae for their use in this calculation have been evolved and are presented.

Computation of aortic valve area in patients with aortic stenosis, by relating the mean pressure gradient across the valve during systole to the mean rate of systolic aortic blood flow, provides a convenient assessment of the severity of stenosis (Gorlin and Gorlin, 1951). Mean aortic flow rate is calculated by dividing cardiac output, determined during cardiac catheterization, by the systolic ejection period which may be measured directly from the arterial pressure recording or from the superimposed left ventricular and aortic records. Measurement of the mean aortic valve systolic pressure gradient is somewhat more cumbersome, however, involving planimetric integration of the difference in systolic pressures recorded from the left ventricle and aorta.

To reduce the mathematical manipulation involved in this computation, Wong and Sanders (1965) prepared a nomogram for the determination of aortic valve area if these three component variables are known. Nevertheless, the time-consuming hand planimetry was still necessary. The present study was designed to determine whether a single linear measurement of the systolic pressure gradient across the aortic valve might be used instead of the mean aortic systolic pressure gradient to calculate aortic valve area, thus eliminating the process of planimetry which requires both time and special equipment. The linear pressure measurements considered were (1) the simple difference between peak left ventricular and peak aortic pressure during systole and (2) the maximum instantaneous pressure gradient developed across the aortic valve at any time during systole.

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Methods

Data were gathered from 32 consecutive patients with isolated aortic stenosis studied during routine diagnostic cardiac catheterization. Patients ranged in age from 16 to 64 years (mean = 47 years). All patients had clinical evidence of aortic valve stenosis which was confirmed by cardiac catheterization. Patients with mitral valve disease were excluded from the initial study. Sixteen patients had no evidence of aortic insufficiency by aortography while 16 had a trivial degree of it, shown as a barely discernible diastolic blush of contrast material in the left ventricular outflow tract which cleared with each ventricular contraction.

The ascending aorta was catheterized with a No. 5F thin-wall Teflon catheter introduced percutaneously through a brachial artery. The left ventricle was catheterized either by retrograde passage across the aortic valve of a similar Teflon catheter, or by use of the transseptal catheterization technique from the right femoral vein (Brockenbrough, Braunwald, and Ross, 1962). Pressures from the aorta and left ventricle were measured simultaneously using Statham P23Db electromanometers and recorded on an Electronics for Medicine DR-12 optical recorder at a paper speed of 100 mm/sec. Cardiac output was determined by the Fick method, the oxygen content of blood specimens withdrawn simultaneously from the main pulmonary artery and the ascending aorta being determined with the Van Slyke manometric apparatus. Finally, left ventriculography and aortography were performed in each patient.

Heart rate, aortic systolic and diastolic pressures, and peak left ventricular pressure were measured directly from the recordings. The duration of left ventricular ejection was measured as the width between the crossover points between aortic and left ventricular pressures. The mean systolic aortic valve gradient (MSG) was determined by planimetric integration of the area between the left ventricular and aortic pressure tracings during systole divided by the duration of left ventricular ejection. Individual measurements were performed on four consecutive heart beats. The peak-to-peak aortic valve systolic gradient (PPSG) was determined by subtracting aortic peak systolic pressure from left ventricular peak systolic pressure. The maximum aortic valve systolic gradient (MaxSG) was determined as the maximum instantaneous systolic pressure difference between the aortic and left ventricular pressures. This maximum pressure difference was easily measured using dividers held parallel to the 0·01 sec time lines on the recording. If time lines were recorded less frequently, this measurement was facilitated by placing a transparent overlay having a grid of 0·01 sec time lines over the original recording.

Aortic valve area (AVA) was calculated according to the formula of Gorlin and Gorlin (1951):

$$AVA = \frac{Q}{44{\cdot}5\sqrt{MSG}}$$

where Q = aortic blood flow (ml/sec) determined as cardiac output (ml/min)/systolic ejection period (sec/min). Statistical treatment of data and linear regression analysis were carried out using standard statistical methods (Snedecor and Cochran, 1967).

Since regression analyses performed on data from the initial 32 patients were designed to minimize the error about the regression line, the resultant confidence limits might be expected to be better for that population of data than for similar data independently gathered from a different group of patients. To test the precision of these regression equations, data were gathered from additional patients with valvular aortic stenosis studied under identical conditions. Data from these 20 patients were then substituted into the previously derived regression equations and confidence limits for estimation of MSG from PPSG and MaxSG were measured. None of these 20 patients had more than a trace of aortic insufficiency but 11 had additional rheumatic involvement of the mitral or tricuspid valves.

Results

At the time of study heart rates ranged from 60 to 107 beats per minute (mean = 77 SD ± 11). Mean cardiac output was 5·3 ± 1·5 l./min (range = 3·0 to 7·7 l./min). Mean systolic ejection period was 22·8 ± 2·5 sec/min (range = 17·7 to 26·8 sec/min). The mean rate of aortic blood flow was 239 ± 65 ml/sec (range = 112 to 361 ml/sec).

Peak left ventricular pressure averaged 199 ± 38 mmHg (range = 145 to 305 mmHg) and peak aortic systolic pressure was 123 ± 19 mmHg (range = 90 to 170 mmHg). The average difference between peak left ventricular and peak aortic pressures (PPSG) was 76 ± 32 mmHg (range = 9 to 176 mmHg). Peak left ventricular and peak aortic pressures did not occur simultaneously, peak left ventricular pressure occurring 155 ± 30 msec after the onset of left ventricular ejection while peak aortic pressure occurred 235 ± 45 msec after the onset of left ventricular ejection. Total duration of ejection was 290 ± 30 msec/beat. The maximum systolic gradient (MaxSG) developed across the aortic valve was 93 ± 35 mmHg (range = 23 to 206 mmHg) and occurred before peak left ventricular systolic pressure at 125 ± 35 msec after the onset of left ventricular ejection. The mean systolic gradient developed across the aortic valve, as

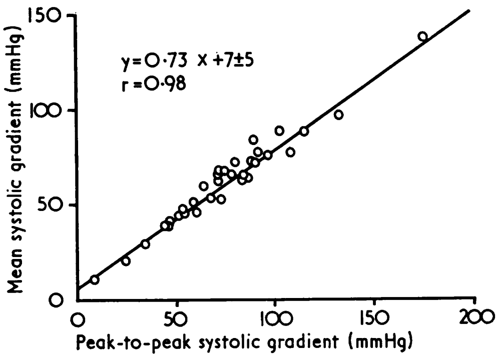
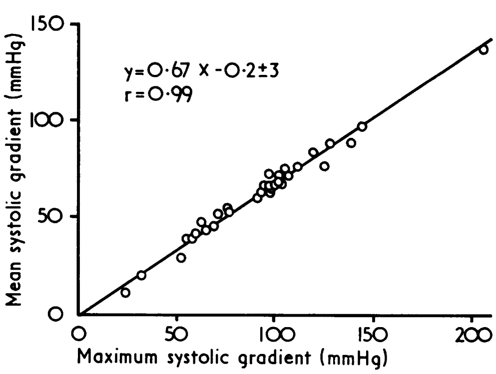


FIG. 1 *Relation between mean aortic valve systolic pressure gradient and the difference between peak left ventricular and peak aortic systolic pressures in 32 patients with isolated aortic stenosis.*

FIG. 2 *Relation between mean aortic valve systolic pressure gradient and the maximum instantaneous pressure gradient developed across the aortic valve during systole in 32 patients with isolated aortic stenosis.*



determined by planimetric integration, was 62 ± 24 mmHg (range = 12 to 137 mmHg).

As shown in Fig. 1, a close linear relation existed between MSG and PPSG. Regression of PPSG on MSG resulted in the equation MSG = 0·73 (PPSG) + 7 with 95 per cent confidence limits of ± 10 mmHg ($r = 0{\cdot}98$). Substituting this expression in the Gorlin and Gorlin (1951) formula resulted in the following equation for direct calculation of aortic valve area:

$$\text{Aortic valve area} = \frac{Q}{37{\cdot}8\sqrt{\text{PPSG} + 10.}}$$

The maximum aortic systolic gradient was also found to bear a direct linear relation to MSG (Fig. 2). Linear regression analysis resulted in the equation MSG = 0·67 (MaxSG) − 0·2 with 95 per cent confidence limits of ± 6 mmHg ($r = 0{\cdot}99$). Since aortic valve gradients were measured to the nearest whole mmHg, the y-intercept of 0·2 mmHg was ignored. The resultant equation for direct computation of aortic valve area was:

$$\text{AVA} = \frac{Q}{36{\cdot}4\sqrt{\text{MaxSG}}}$$

Though use of MaxSG resulted in slightly better estimates of MSG and AVA than did PPSG, this difference was not statistically significant ($P > 0{\cdot}10$).

Data from 20 additional patients with aortic stenosis were used to test the validity of the previously derived formulae for estimation of MSG from PPSG or MaxSG (Table). For these 20 patients average planimetrically determined MSG was 64·7 mmHg. Using the previously derived linear regression equation, PPSG estimated the average MSG as 64·5 mmHg; the mean difference between measured and estimated MSG was $-0{\cdot}2 \pm$ SD 4·9 mmHg. Similarly, using the previously derived formula, MaxSG estimated average MSG as 65·4 mmHg; the mean difference be-

TABLE *Difference between peak left ventricular and peak aortic systolic pressures, maximum systolic instantaneous aortic valve pressure gradient, mean aortic valve systolic pressure gradient determined planimetrically and estimated from peak-to-peak systolic gradient and maximum systolic gradient, and differences between mean systolic gradient determined planimetrically and those estimated from peak-to-peak systolic gradient and maximum systolic gradient for 20 patients with valvular aortic stenosis*

Patient No.	*Additional valvular lesions*	*Peak-to-peak systolic gradient (mmHg)*	*Maximum systolic gradient (mmHg)*	*Mean systolic gradient measured (mmHg)*	*Mean systolic gradient estimated from:*		*Error in estimation of mean systolic gradient from:*	
					Peak-to peak systolic gradient (mmHg)	*Maximum systolic gradient (mmHg)*	*Peak-to-peak systolic gradient (mmHg)*	*Maximum systolic gradient (mmHg)*
1	Mitr. sten. and insuf.	25	41	27	25	27	−2	0
2	Mitr. sten. and insuf.	24	44	28	24	29	−4	1
3		30	50	33	28	33	−5	0
4		47	55	36	41	36	5	0
5	Mitr. and tri. insuf.	54	64	44	46	43	2	−1
6	Mitr. sten.	58	74	51	49	49	−2	−2
7	Mitr. sten. and insuf.; tric. insuf.	62	80	55	52	53	−3	−2
8	Mitr. sten. and insuf.	67	101	58	55	67	−3	9
9		82	96	63	66	64	3	1
10	Mitr. sten. and insuf.	79	88	64	64	59	0	−5
11	Mitr. insuf.	78	104	69	63	70	−6	1
12		81	103	69	65	69	−4	0
13		90	103	69	72	69	3	0
14		100	113	75	79	76	4	1
15	Mitr. sten. and insuf.	89	114	77	71	76	−6	−1
16		114	122	88	89	82	1	−6
17		119	154	92	92	103	0	11
18		123	137	93	95	92	2	−1
19	Mitr. insuf.	122	153	98	95	103	−3	5
20	Mitr. insuf.	156	160	104	119	107	15	3
	Mean	80·0	97·8	64·7	64·5	65·4	−0·2	0·7
	SD						4·9	4·0

tween measured and estimated MSG was 0·7 ± SD 4·0 mmHg. Thus, using either linear measurement, individual values for MSG were estimated within 2 standard deviations of less than ± 10 mmHg of the value determined by hand planimetry. Similarly, AVA was estimated using either of these linear measurements of aortic valve gradient within 2 standard deviations of less than ± 10 per cent of the values obtained using planimetrically determined MSG. The reliability of these estimates was not influenced by the presence of coexisting disease of the mitral valve, even when severe.

Discussion

This degree of predictive accuracy using either of the simple linear measurements described above for calculation of aortic valve area appears acceptable, since it is well within the reported reproducibility for cardiac output estimates during cardiac catheterization using either the direct Fick or an indicator dilution technique (Hamilton *et al.*, 1948; Sleeper *et al.*, 1962; Thomasson, 1957).

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