A NEW METHOD OF DETERMINING THE DEGREE OR ABSENCE OF MITRAL OBSTRUCTION :

AN ANALYSIS OF THE DIASTOLIC PART OF INDIRECT LEFT ATRIAL PRESSURE TRACINGS

BY

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For some years we have been interested in the y descent of the venous pulse. Until quite recently conspicuous diastolic collapse of distended cervical veins was believed to be pathognomonic of chronic constrictive pericarditis. The sign was first described by Friedreich (1864) and attributed by him to the sudden negative intrathoracic pressure created by outward rebound of the chest wall when released from the inward pull of ventricular systole in cases of adherent pericardium. A jugular phlebogram showing the phenomenon was published by Mackenzie in 1902; he called the diastolic trough Z, and accepted Friedreich's explanation. Years later, cardiac catheterization revealed that a marked early diastolic pressure dip in the right ventricle accompanied the steep y descent of the venous pulse (Bloomfield *et al.*, 1946); it was at first attributed to the same cause (Eliasch *et al.*, 1950). Hansen *et al.* (1951), however, proved that the dip was independent of the movements of the chest wall, and suggested that it was due to an unusually high pressure gradient between atrium and ventricle at the end of the isometric relaxation phase; early diastolic filling was therefore very rapid and the maximum capacity of the ventricle was reached quickly.

It was soon apparent, however, that Friedreich's diastolic collapse was not confined to Pick's disease, but occurred in severe right ventricular failure from any cause: we have recorded it in hypertensive heart failure, ischæmic heart failure, isolated myocarditis, and heart failure from severe pulmonary hypertension (Wood, 1954); in some of these cases there was convincing evidence of tricuspid incompetence, but by no means in all. The steep y descent following v was associated with a dip and plateau in the right ventricular diastolic tracing. Indirect left atrial pressure tracings, using the wedged catheter technique, showed the same steep y descent in cases of left heart failure with high pulmonary venous pressures.

The next step was the discovery that a steep y descent did not occur in tricuspid stenosis despite a high filling pressure; instead of Friedreich's abrupt trough, the venous pressure fell relatively slowly after the summit of v, and failed to rise again before the next atrial or ventricular contraction. Similarly, a relatively slow and steady rise of pressure replaced the dip and plateau pattern in the right ventricular tracing (Wood and Gibson, 1954). It followed that Friedreich's sign was no more than evidence of a potentially high right atrio-ventricular pressure gradient at the end of the isometric relaxation phase, a state of affairs highly characteristic of Pick's disease but also occurring, though usually in less florid form, in any condition with an unusually high venous filling pressure, *provided there was no obstruction at the atrio-ventricular (tricuspid) orifice.*

At about this time, towards the end of 1953, we were searching for a better method of deciding whether mitral stenosis or incompetence was dominant when there was clinical evidence of both. Up till then the interpretation of indirect left atrial pressure tracings had not served to distinguish them; but attention had always been directed to the systolic part of the curve. In the light of the

observations described above, we wondered whether the diastolic part of the tracing would not be more informative. In fact, this proved to be so, and it is the purpose of this paper to present data indicating that the behaviour of the y descent in indirect left atrial pressure tracings provides good evidence of the presence or absence of obstruction at the mitral orifice.

Terminology. " Indirect left atrial " is used synonymously with " wedged pulmonary arterial " and " pulmonary capillary venous " in referring to pressure, acceptance of their unity in both phase and magnitude being thereby implied (Hellems *et al.*, 1949; Dow and Gorlin, 1950; Epps and Adler, 1953). " a " and " v " are the two main positive deflections of the left atrial pulse associated respectively with atrial contraction and with passive atrial filling against a closed mitral valve; the subsequent decline of atrial relaxation and atrio-ventricular diastolic flow are termed " x " and " y " (Mackenzie, 1902).

METHODS

Indirect left atrial tracings were obtained by wedging a cardiac catheter during inspiration in a distal branch of the pulmonary artery and recording the pressures by means of a Sanborn electromanometer employing hydraulic damping (Hansen, 1949) and a Polyviso direct-writing recorder. In some instances, inclusion of a filter device in the electronic circuit permitted variable high-frequency attenuation. Manometer sensitivity was adjusted so that a deflection of 40 mm. above the base-line represented a pressure of 40 mm. Hg in the system; but when the pressure was very high the sensitivity had to be reduced so that a deflection of 40 mm. represented a pressure of 100 mm. Hg. Calibration was recorded at the end of each section of tracing together with the zero level (sternal angle) and an electronically determined mean pressure. The speed of the paper, on which an electrocardiogram was simultaneously recorded, was 25 mm. per second.

Pulmonary and peripheral arterial blood samples were analysed for oxygen unsaturation in a Haldane blood-gas analysis apparatus; cardiac output calculations were based on the arterio-venous oxygen difference so determined and a Benedict-Roth estimation of the oxygen uptake at the time of catheterization.

It was usually possible to record acceptable tracings in the wedged position, although several attempts might be required to do so and careful inspection of the pulse contour at the time of recording was indispensable. Factors that sometimes militated against success were considerable enlargement of the right heart (so that the catheter was too short); too soft or too large a catheter (greater than size U.S. No. 7); and extreme pulmonary hypertension (causing loss of normal tapering of the pulmonary arterial tree).

For analysis, the tracings were required to be venous in pattern and of undistorted wave form (Wood, 1952). High-frequency sound deflections were superimposed on all but grossly overdamped records; although these did not as a rule obscure the venous pulse, some distorted tracings had to be discarded on this account. Doubt did not often exist as to whether the manometer was reflecting left atrial or pulmonary arterial pressures, but an appreciable increase in the slope of the y descent accompanying the expiratory rise in left atrial pressure confirmed its venous origin. In general, the clearest and most accurately measurable pulse waves were recorded during held expiration, with the atrial pressure at its maximum.

For purposes of measurement, vertical intervals were interpolated with the eye to 0·5 mm. and time intervals to 0·25 mm. (0·01 sec.). The average rate of the y descent (Ry, in mm. Hg per sec.) was calculated as

$$\frac{(p_1 - p_2) \text{ mm.} \times \text{calibration factor}}{(t_2 - t_1) \text{ sec.}}$$

where p_1 is the first point on the v wave free from sound artefact at which a pressure fall is perceptible and p_2 is either the point at which the descent first reaches its subsequent isotonic level, or, if it continues throughout diastole until interrupted by atrial contraction or mitral valve closure, the last point on the slope to be unobscured by these events; and t_1 and t_2 are the corresponding points on the time scale. In the former case, the brief terminal dip below the isotonic sometimes displayed by the y descent was ignored in calculating Ry, p_2 being taken immediately before its occurrence (Fig. 1). These points were adopted arbitrarily for purposes of standardization. As indicated below, it became desirable to relate the rate of the y descent to the absolute pressure represented by the v wave. The ratio between the two (Ry/v) was then derived by inserting the height of v in millimetres above the zero reference point (i.e. p_1) into the denominator and removing the calibration factor from the numerator:

$$Ry/v = \frac{(p_1 - p_2) \text{ mm.}}{p_1 \text{ mm.} \times (t_2 - t_1) \text{ sec.}}$$
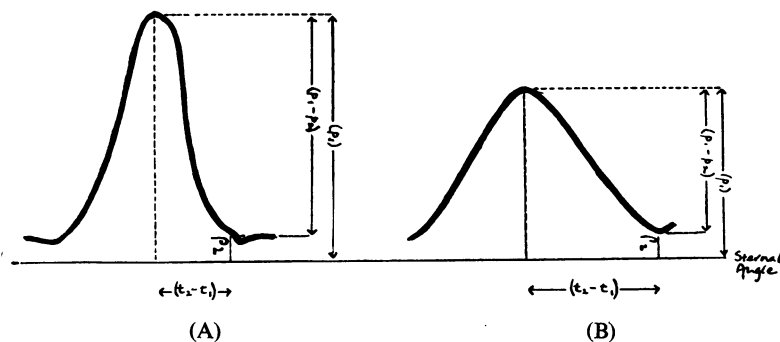
(A)   (B)

FIG. 1.—Diagram of typical v waves in indirect left atrial pressure tracings in mitral incompetence (A), and mitral stenosis (B), illustrating how the rate of y descent is measured (see text).

Material. The study is based on an analysis of 54 wedged pulmonary arterial pressure records obtained during right heart catheterization. All patients were suffering from mitral valve disease and were undergoing this investigation in order that the appropriateness of surgical treatment might be assessed. They form part of a series of such cases, the clinical and other features of which have already been reported in detail (Wood, 1954). According to the nature of the mitral lesion, they fall into five groups, as follows.

(1) Pure mitral stenosis severe enough to warrant valvotomy, where that diagnosis was confirmed, and the absence of incompetence established at cardiotomy (23 cases).

(2) Mitral stenosis of comparable severity in which a trivial degree of incompetence was detected at operation (5 cases).

(3) Mitral stenosis combined with moderate incompetence, so classified on the operative findings in 2 and on clinical grounds in 6 cases (8 cases).

(4) Mitral stenosis with considerable incompetence, the latter being considered the dominant lesion. In 2 this assessment was surgical, in 8 clinical (10 cases).

(5) Pure or almost pure mitral incompetence, the diagnosis being clinical in 4 and surgically confirmed in 4 (8 cases).

The criteria for the clinical diagnosis of mitral incompetence have been discussed elsewhere (Wood, 1954).

THE LEFT ATRIAL PULSE IN MITRAL VALVE DISEASE

Preliminary Observations. That the amplitude of v by itself does not usefully distinguish between dominant mitral stenosis and dominant incompetence was confirmed by the results of a pilot study in which tracings from known examples of the two conditions were compared (Table I). The samples used were small (6 cases of incompetence, 8 of stenosis) and influenced by selection in several ways, but it was considered unlikely that a characteristic of practical value would fail to show a clear-cut difference between the groups. In fact, as Table I indicates, although the expected differences occurred—the rate of pressure rise and the amplitude and height of v all being

TABLE I

MEASUREMENTS OF THE " V " ASCENT AND " Y " DESCENT IN MITRAL STENOSIS AND INCOMPETENCE

Mean values	" V " Ascent			" V "	" Y " Descent		
	Rise mm. Hg	Time sec.	Rate mm./sec.	Peak mm. Hg	Fall mm. Hg	Time sec.	Rate mm./sec.
Stenosis ..	10·4	0·38	31·5	23·6	10·8	0·41	27·6
Incompetence ..	17·0	0·32	59·7	26·5	16·5	0·25	68·3
Difference ..	+ 6·6	−0·06	+28·3	+ 2·9	+ 5·7	−0·16	+40·7
$t =$ ..	1·47	0·83	1·59	0·45	1·42	3·98	2·61
p	>0·1	>0·1	>0·1	>0·1	>0·01	>0·01	>0·05

greater among the incompetence cases—these were small and showed considerable variability among individuals; and on application of the " t " test only the differences in time of inscription of the y descent and its calculated rate of fall proved significant at the 95 per cent level of probability.

Fig. 2 and 3 are idealized curves drawn through the mean values of these observations and represent the average form of the v wave and y descent in stenosis and incompetence respectively. The pattern is similar in sinus rhythm and atrial fibrillation. In incompetence the y descent is rapid and the rate of fall tends to decrease in its lower part as it approaches a flat isotonic level; unless diastole is much abbreviated, such a level constantly precedes the next cycle. In contrast, the curve in stenosis is flatter, and although the average height of the v wave above the sternal angle is little less, the diastolic fall-off in pressure proceeds more gradually; a decrease in the rate of fall is not usually apparent in the lower part of the y descent and there is no isotonic interval before the onset of the next a wave or first sound artefact.
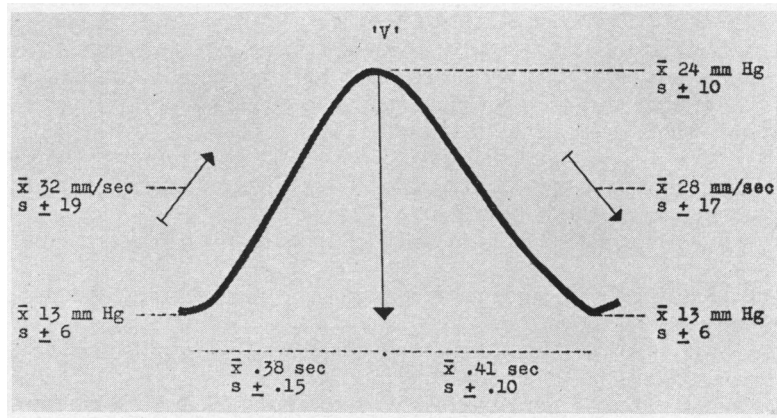

FIG. 2.—Drawing of typical v wave in mitral stenosis based on the mean of eight observations. The Ry/v ratio is 28/24 or 1·17. $\bar{x}$ is the mean of eight observations and s the standard deviation.
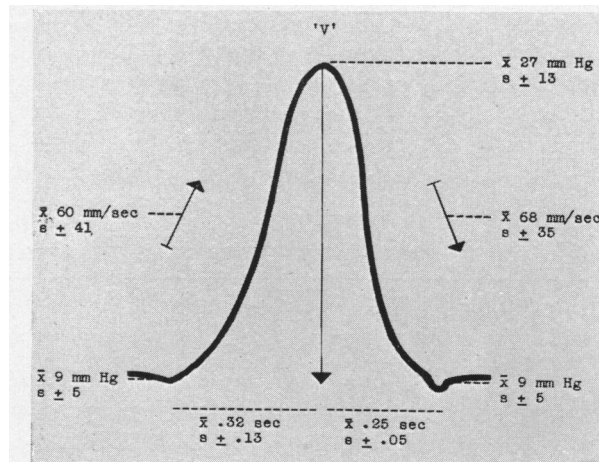

FIG. 3.—Drawing of a typical v wave in mitral incompetence based on the mean of six observations. The Ry/v ratio is 68/27 or 2·5. $\bar{x}$ is the mean of six observations and s the standard deviation.

The atrial pressure pulse thus appears to reflect the pattern of ventricular filling. In the presence of obstruction to forward flow at the mitral orifice, the left ventricle fills slowly and inadequately despite development of a large pressure head, and flow tends to continue throughout diastole (Wiggers, 1923). When records showing atrial fibrillation are examined, the y descent is seen to continue even during the longest diastolic intervals (Fig. 4, upper), confirming that a diastolic pressure gradient across the mitral valve never ceases to exist. In mitral incompetence, the combination of a high atrial pressure at the end of systole with no forward obstruction produces rapid and early filling of the left ventricle and a correspondingly rapid y descent; the form of the latter and the presence of the subsequent isotonic plateau suggests that atrio-ventricular pressure equalization is achieved shortly after the opening of the valve and that atrial pressure thereafter follows that in the relaxing ventricle. Typical examples of the two patterns in indirect left atrial tracings are illustrated (Fig. 4 and 5).
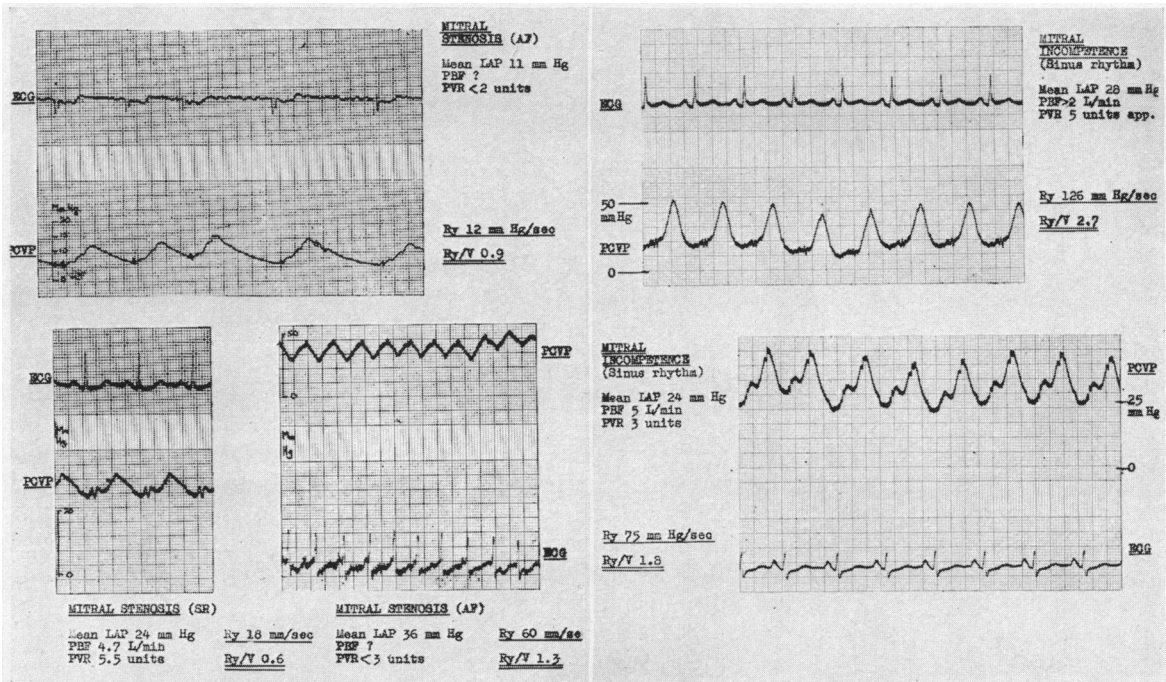

FIG. 4.—Indirect left atrial pressure tracings in three cases of mitral stenosis showing low Ry/v ratios.

FIG. 5.—Indirect left atrial pressure tracings in two cases of mitral incompetence with normal rhythm showing high Ry/v ratios.

From these preliminary observations, it seemed possible that an expression of the behaviour of the y descent might assist in the evaluation of wedged pulmonary arterial records. Although the time occupied by the inscription of the y descent had yielded a highly significant difference between the stenosis and incompetence groups (Table I), the tracings analysed had been selected to some extent for clarity of diastolic interval; and when applied to unselected examples of mitral stenosis, this measurement itself was dependent on the length of the diastolic intervals available for study. The calculated average slope of the y descent (Ry) was not so dependent, but was a more variable quantity and separated the groups less sharply. Moreover, it failed to remain constant even in the same record, tending to vary with the height of the preceding v wave during the pressure fluctuations associated with respiration (Fig. 6) or induced by exercise. As might be expected, it proved necessary to relate Ry to the left atrial diastolic pressure head in order to obtain
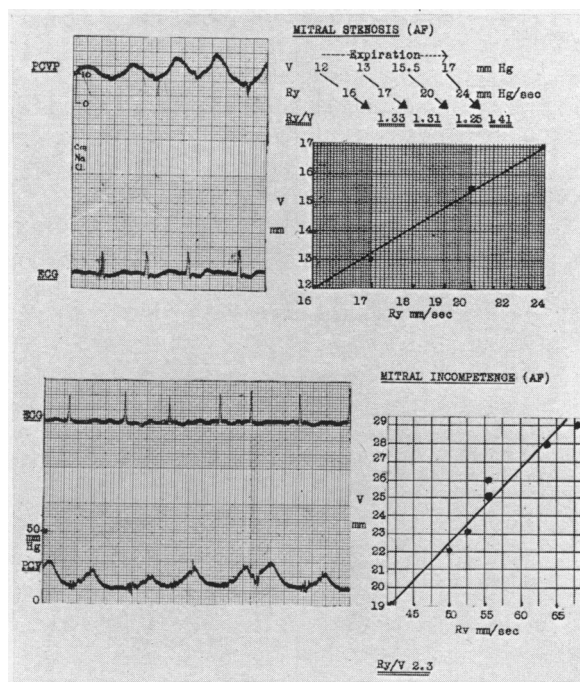
Fig. 6.—Graphs showing the effect of the height of the v wave on the rate of y descent. It will be seen that the rate of y descent is directly proportional to the height of v in any given tracings.

a stable expression. The simple ratio Ry/v was derived since this appeared to depart little from linearity in individual records. A series of 57 repeated observations made on tracings from 19 cases confirmed the reproducibility of Ry/v, which was more than twice that of Ry by itself (respective coefficients of variation approximately 9% and 19%). As the value also yielded a highly significant difference between the initial test groups, the possibility that it might prove a useful index of the situation at the mitral valve was further explored.

RESULTS

Ry and Ry/v were calculated for all cases available for the present study. When Ry is plotted against v, the general correlative trend of the two and the consistently higher value of their ratio in the presence of incompetence are confirmed (Fig. 7). With one exception (Case N. 347, $Ry/v=2.4$), the ratio was less than 1·5 in examples of pure stenosis, whereas it invariably exceeded this figure in the presence of moderate incompetence ; in all the 8 cases where incompetence was the only significant lesion the ratio was greater than 2·2. If the single outlying observation (which is un-explained) is excluded, the mean Ry/v values are as follows.

Group 1.   Pure mitral stenosis (22 cases), 0·81 (SD±0·36).
Group 2.   Mitral stenosis with trivial mitral incompetence (5 cases), 1·06 (SD±0·43).
Group 3.   Mitral stenosis with moderate mitral incompetence (8 cases), 1·8 (SD±0·73).
Group 4.   Mitral stenosis with considerable mitral incompetence (10 cases), 2·3 (SD±0·56).
Group 5.   Mitral incompetence with insignificant mitral stenosis (8 cases), 3·1 (SD±1·2).

That is, Ry/v increases with the presence and degree of mitral incompetence (Fig. 8). The difference between the first two groups is small and not statistically significant; the ratio in these 27 cases considered together yields a mean value of 0·85 (±0·38) about which it tends to form a normal
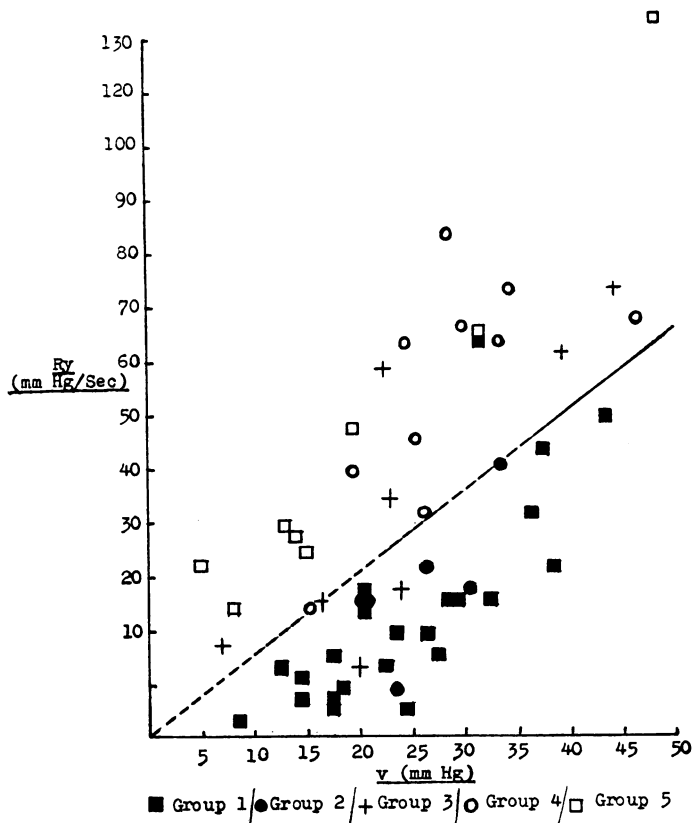
FIG. 7.—Graph showing the relationship of Ry to v in the five
groups of mitral valve disease mentioned in the text. The
open squares or circles represent cases with pure or
dominant mitral incompetence; the black squares or circles
represent pure or dominant mitral stenosis; group 3 is
borderline. In addition to the general correlative trend
between Ry and v, the consistently higher values for the Ry/v
ratio in the cases with incompetence is well shown.

distribution (Fig. 9). It may therefore be deduced that Ry/v will be less than 1·6 in 95 per cent of
cases * of serious mitral valve disease where incompetence is either absent or insignificant in degree
and that a greater value will imply the presence of appreciable regurgitation with equal probability.
Although in groups 4 and 5 all values were above this figure in the present series of observations,
the data are too few to permit estimation of a useful lower confidence limit beyond which incom-
petence may be expected to be absent, and are further limited by the fact that the diagnosis was
only controlled by surgery in a proportion. The 8 observations in group 3 range between 0·6 and
3·3 but in only two was the classification known with certainty to be correct; since clinical assess-
ment is most difficult in such cases the group was probably more heterogeneous than the others
and may include patients who would have been placed in another category after cardiotomy.
Further studies are required to elucidate the distribution of Ry/v in this borderline group.

The pulmonary vascular resistance was raised above normal in 23 of the 54 cases, in 5 to the
extreme grade (Table II). The results in these did not differ significantly from those in the remainder.

In 30 of the surgical cases the data are sufficient to allow comparison of the Ry/v ratio with the
degree of stenosis as estimated at operation on the one hand, and with that predicted from the
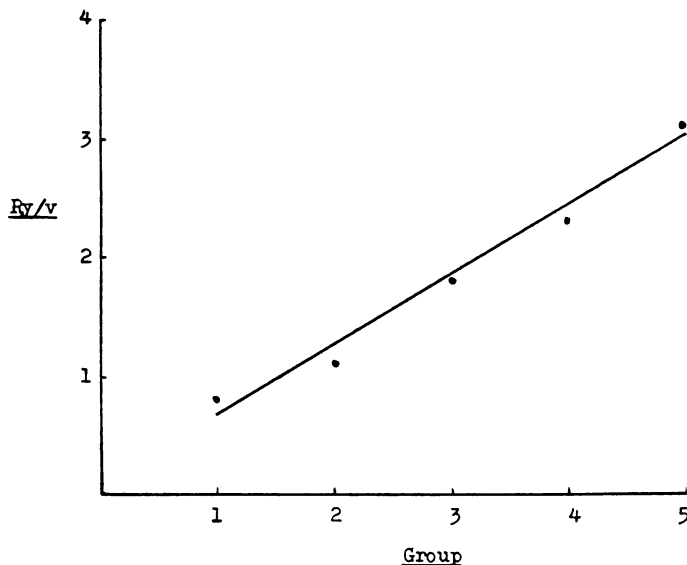
* Not greater than 1·7 with 99 per cent probability.

FIG. 8.—Composite graph showing that the Ry/v ratio increases with
the presence and degree of mitral incompetence. The five
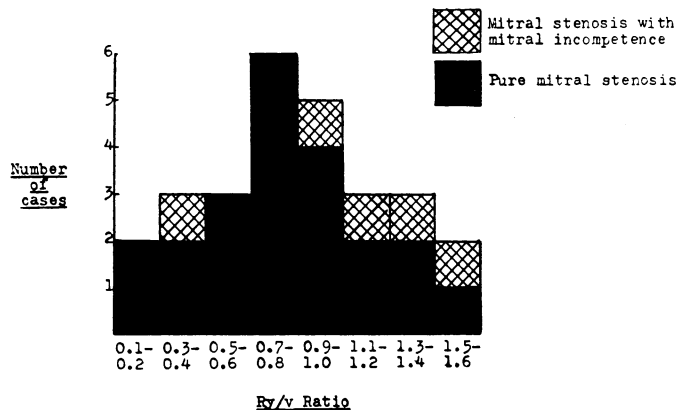groups are defined in the text.

FIG. 9.—Frequency of distribution of the Ry/v ratio in cases of pure
mitral stenosis and mitral stenosis with trivial incompetence
(groups 1 and 2).

cardiac output and the mean left atrial pressure on the other. On the basis of the surgical assess-
ment, they have been divided into four grades (Wood, 1954) : extreme stenosis (orifice about
0.5×0.3 cm.), stenosis tighter than average (about 0.75×0.4 cm.), average stenosis (about
1.0×0.5 cm.) and less than average stenosis (not less than 1.25×0.75 cm.). Although these figures
probably underestimate the true dimensions, it may be assumed that they bear a fairly constant
relation to them, and to each other. The results of the comparison are shown in Table III. In
the first three grades, the expected valve area from the hydrodynamic formula of Gorlin and Gorlin
(1951), the simple ratio of cardiac output to mean left atrial pressure (Wood, 1954), and Ry/v show

upward trends, the slope of which is strikingly similar in each (Fig. 10). Significant incompetence was absent in all but three instances. In the fourth grade, however, where examples of dominant incompetence were in the majority, Ry/v rises disproportionately to the other expressions. If the cases in this grade are considered individually (Table IV), both this increase and the greater variability of Ry/v appear to reflect orifice area more truly. While the data are few, they are consistent with the expected disparity between systemic output and valve flow in mitral regurgitation; they support the validity of both methods of assessment in uncomplicated stenosis, and suggest that in combined lesions the Ry/v ratio remains an index of forward area.

TABLE II

DISTRIBUTION OF RAISED PULMONARY VASCULAR RESISTANCE

Group	Pulmonary vascular resistance (PVR units)		
	4·0–5·8	6·0–9·9	10–30
1	4	4	3
2	–	1	1
3	4	1	–
4	2	1	–
5	–	1	1
Totals ..	10	8	5

TABLE III

COMPARISON OF ORIFICE AREA AGAINST Ry/v, CALCULATED MVA AND CO/LAP (MITRAL) INDEX

Surg. estimate (deg. of stenosis)	No.	Group 1 2 3 4 5	Ry/v Mean±SD	MVA cm.² Mean±SD	CO/LAP% Mean±SD
Extreme (0·5×0·3 cm.)	7	5 2 – – –	0·77 0·43	0·84 0·3	16 5·4
Tight (0·75×0·4 cm.)	4	2 1 1 – –	0·85 0·45	0·95 0·17	19 4·4
Average (1·00×0·5 cm.)	13	9 2 1 1 –	1·0 0·49	1·09 0·38	24 8·7
Mild (>1·25×0·75 cm.)	6	2 – – 1 3	2·9 1·96	1·4 0·61	31 13

MVA=Mitral valve area in cm.² calculated from hydrodynamic formula (Gorlin and Gorlin, 1951).
CO/LAP Index=Cardiac output (L/min.)×100/mean LA pressure (mm. Hg).

TABLE IV

LESS THAN AVERAGE STENOSIS: COMPARISON OF ORIFICE AREA AGAINST Ry/v, CALCULATED MVA AND CO/LAP INDEX

Case serial	Group	Surg. estimate * MV area (cm.²)	Ry/v ratio	Calculated MVA (cm.²)	CO/LAP Index
N 453	1	0·95 approx.	0·9	1·7	32
N 553	1	0·95 approx.	0·8	0·7	18
N 826	4	1·50 approx.	2·2	1·9	27
N 509	5	? (>1·0)	2·6	1·6	43
B 74	5	2·25 approx.	6·2	2·0	48
B 191	5	? (>1·0)	2·3	0·6	17
Correlation coefficient with surg. estimate of area in 4 cases where stated			$r=0·74$	$r=0·50$	$r=0·51$

* Arbitrary value obtained by multiplying estimated length and breadth of orifice: relation to true orifice area is unknown.
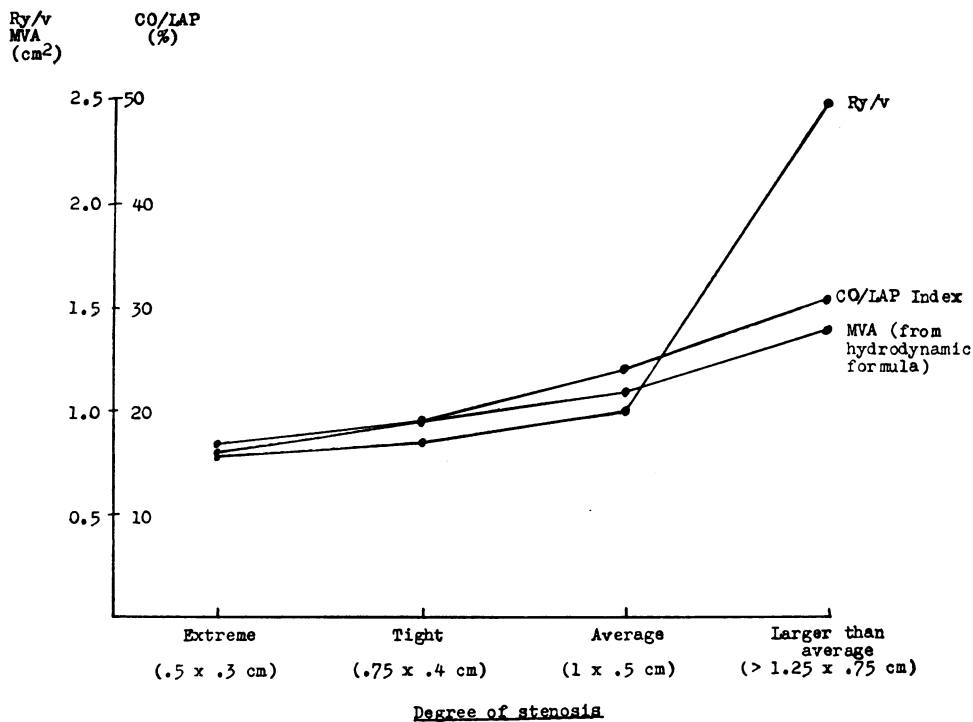
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FIG. 10.—Relationship of Ry/v ratios, calculated mitral valve area (Gorlin), mitral index (Wood), and surgically assessed degree of stenosis.

Separate determinations indicate that the mean of the Ry/v values from four wave complexes may be trusted within the limits of about ±0·17. Falsification of the y slope by respiratory pressure swing is occasionally revealed in anomalous observations; these were excluded in making this estimate, which otherwise takes account of all sources of error. The ratio is independent of the sensitivity at which the tracing is recorded, and therefore of inaccuracies in calibration; but precise determination of the zero reference level is essential, since manometer zero drift may involve appreciable error. In this connection it must also be emphasized that the present results are not comparable with those obtained from other records unless they are referred to sternal angle level, or unless the relevant corrections are made.

A number of tracings obtained by direct needle puncture of the left atrium during thoracotomy or bronchoscopy have also been examined. When both are technically adequate, the direct and indirect records in mitral valve disease differ only in respect of the transmission delay of 0·02–0·08 sec. (Epps and Adler, 1953) and the consistently more prominent sound deflections displayed by the latter (Fig. 11). The mean Ry/v values obtained from these direct tracings in four cases of stenosis and eight of incompetence were 1·2 (SD±0·4) and 2·8 (SD±1·4) respectively, not significantly different from the indirectly obtained figures, and the form of the diastolic pulse was entirely similar. An example of a direct left atrial pressure tracing in a case of mitral incompetence is shown in Fig. 12.

Good evidence concerning the difference in the rate of y descent in mitral stenosis and mitral incompetence is provided by Fig. 13: this shows the change that took place when incompetence was inadvertently caused by valvotomy (indirect P.C.V.P. tracings). That it is the relief of the obstruction rather than the incompetence which is responsible for the change is shown in Fig. 14, for in this case no incompetence was caused by valvotomy (direct operative tracings).
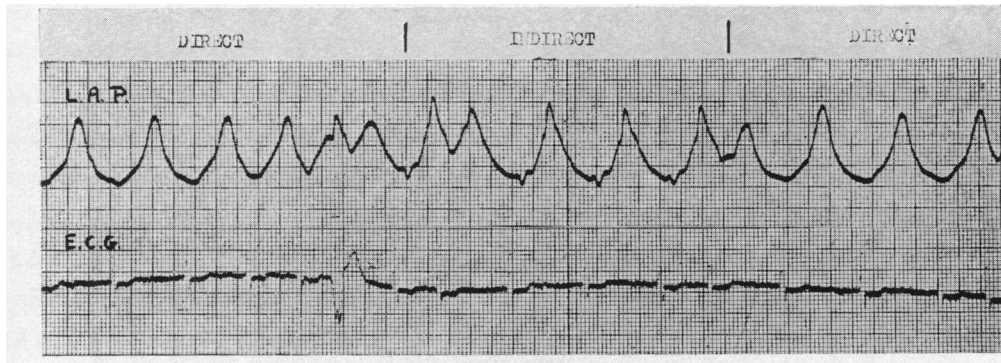
FIG. 11.—Direct and indirect left atrial pressure tracings taken in immediate succession from a case of mitral incompetence (Epps and Adler).
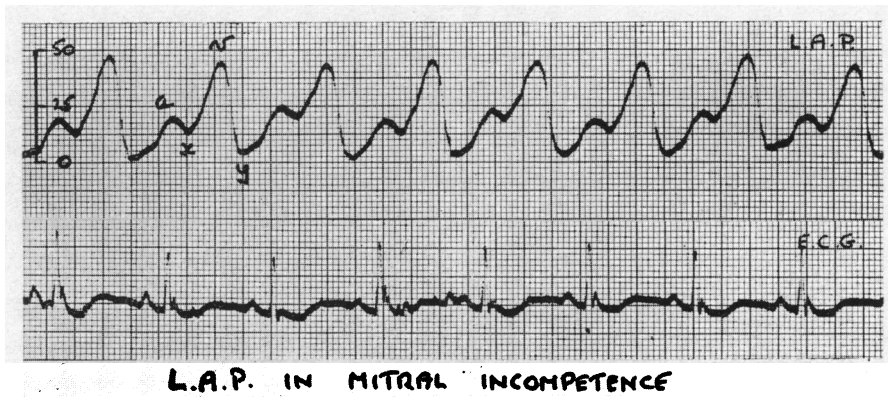

FIG. 12.—Direct left atrial pressure tracing taken at operation in a case of mitral incompetence showing a very rapid *y* descent followed by a diastolic rise of pressure during the latter half of left ventricular filling.
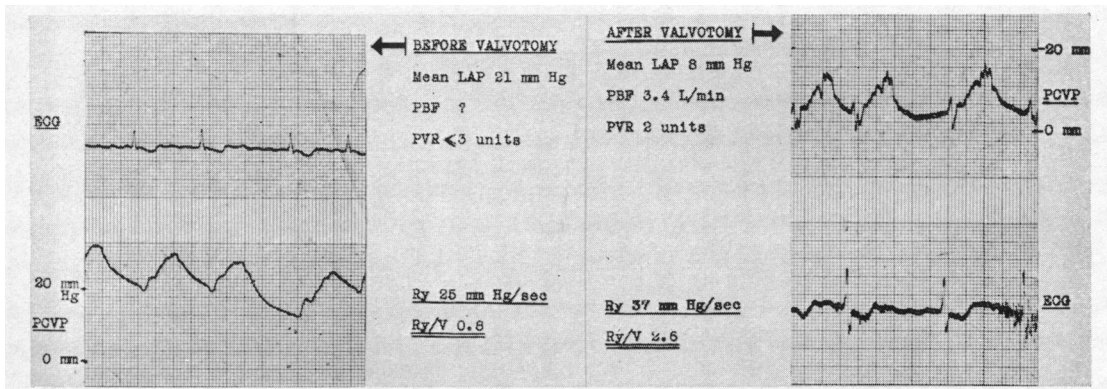

FIG. 13.—Indirect left atrial pressure tracings from a case of mitral valve disease before and after incompetence had been inadvertently induced by valvotomy; the R*y*/*v* ratio rose from 0·8 to 2·6.
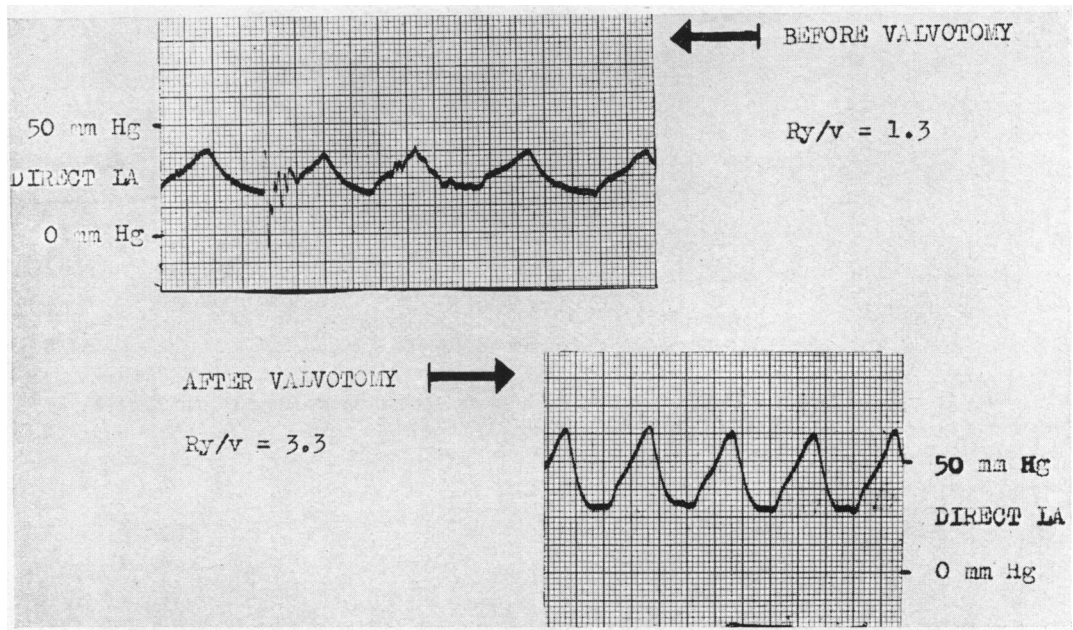
FIG. 14.—Direct left atrial pressure tracings before and after valvotomy in a case of mitral stenosis showing a change
in Ry/v ratio from 1·3 to 3·3 after relief of the obstruction.

DISCUSSION

Occasional difficulty continues to arise in correctly apportioning functional significance between
stenosis and incompetence of the mitral valve (Baker *et al.*, 1952); clinical evidence may fail to
put the issue beyond doubt and assistance must then be sought from right heart catheterization.
Despite the intense interest the problem has aroused, the value of this investigation has, however,
remained uncertain, and no clearly defined criteria for separating stenosis and incompetence by
means of indirect left atrial pressure records have emerged.   Attention has centred on the systolic
phase in these records: the correlation of high amplitude *v* or systolic waves with regurgitation has
been denied (Eliasch, 1952; Biörck *et al.*, 1953; Logan and Turner, 1953; Venner and Holling,
1953) as often as it has been asserted (Lagerlöf and Werkö, 1949; Dexter *et al.*, 1950; Gorlin
et al., 1952; Wade *et al.*, 1952), a difference of opinion which accords with the present findings
that the relationship has little diagnostic value.   Nor has analysis been aided by the presence of
sinus rhythm, since pure mitral stenosis is as likely to be associated with a dominant systolic as
with a dominant presystolic deflection (Wood, 1954).

Elucidation of combined lesions is further complicated by the disparity between calculated
cardiac output and mitral valve flow in the presence of incompetence.   Since the Fick output then
represents an unknown fraction of actual atrio-ventricular flow, hydrodynamic calculation of valve
area (Gorlin and Gorlin, 1951) yields falsely low values imitating stenosis; other and simpler
expressions of the relationship between cardiac output and mean atrial pressure (Silber *et al.*, 1951;
Werkö *et al.*, 1953; Wood, 1954) and that derived from the output alone (Ravin *et al.*, 1952) are
similarly invalidated.   In such cases, moreover, the observed mean left atrial pressure diverges
still farther from the true diastolic pressure head.   However formulæ and data are manipulated,
no estimate of the amount of regurgitant flow is possible unless both the fact of regurgitation and
the forward area of the mitral orifice are already known (Gorlin and Dexter, 1952), conditions
implying autopsy or cardiotomy: such calculations have therefore only an academic interest.

The results of the present study suggest that an expression of the resistance to diastolic flow

imposed by the mitral valve may be derived directly from the atrial pressure pulse. If this suggestion is confirmed, then this constant will possess the important advantage of being neither less accurate nor less valid in the presence of regurgitation since the pressure/flow relationship is not thereby altered (Gorlin, 1953). It may therefore be expected to separate stenosis and incompetence on the basis of their differing forward areas, since both theoretical considerations (Gorlin *et al.*, 1952) and recent experience (Wood, 1954) suggest that severe mitral incompetence and more than mild mitral stenosis are mutually exclusive.

Theory predicts that the rate of blood flow through a stenotic valve orifice will vary not linearly but as the square root of the pressure gradient across it (Rodrigo, 1953); and this relationship has been confirmed in patients with mitral stenosis (Gorlin and Gorlin, 1951). Were the rate of atrial diastolic pressure fall itself a linear function of mitral valve flow rate, the empirical conclusion that Ry/v tends to remain constant would be surprising. No information about the volume-elasticity characteristics of the human left-atrial—pulmonary-venous system is available, but Little (1949) has shown that in dogs pressure is linearly related to values only while it remains in the normal range; when this is exceeded, the rises in pressure in response to constant increments in volume become progressively greater (Fig. 15). If a similar situation is assumed to obtain in man
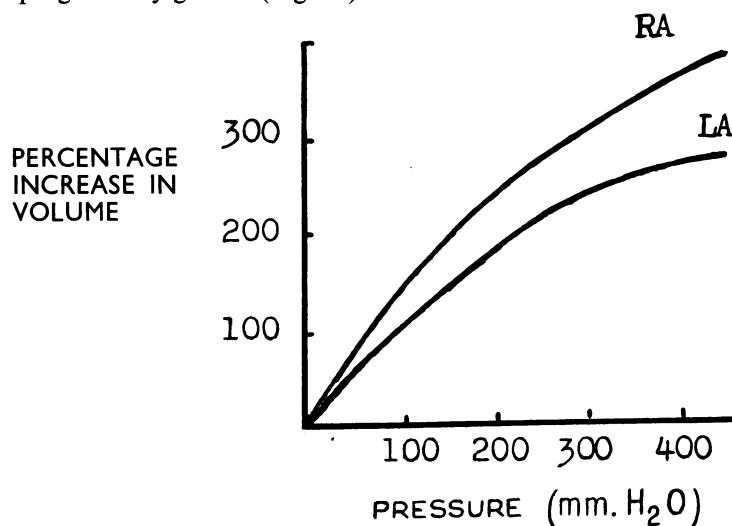

FIG. 15.—Pressure volume curves for right and left atria in dogs (after Little,
E. C., 1949; *Amer. J. Physiol.*, **158**, 237).

under the conditions imposed by mitral valve disease, it follows that the ratio of pressure change to volume change will increase as the pressure level rises. The resultant effect will be to approximate the Ry/v ratio to linearity.* That this is in fact the case is suggested by the influence of pressure fluctuations on Ry/v: in face of a rising pressure, if it does not remain absolutely constant, then it may alter slightly in *either* direction.

While these considerations rationalize the observed stability of Ry/v, it follows also from them that the magnitude of the ratio will be influenced by the volume elasticity coefficient of the left atrial system and that it will depart from a sole expression of orifice area to the extent of such influence. The importance of this is at present uncertain; but the high correlation of the ratio with group classification in the present study suggests that it may not be great. It is clear from comparing radiological size of the left atrium with mean atrial pressure in cases of mitral valve disease, that volume-elasticity characteristics are by no means constant from individual to individual.

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* If $Ry\sqrt{MVF} \propto \sqrt{v}$ (where MVF = mitral valve flow rate)
then since $MVF \propto \sqrt{v}$, it follows that $Ry/\sqrt{v} \propto \sqrt{v}$
That is, $Ry \propto v$

That anomalous deviation of Ry/v may occur as a result of wide variations in this respect remains an unexcluded possibility (patient N 247 may represent such an anomaly). A firm conclusion as to whether this factor will invalidate finer quantitative application of the ratio must await the accumulation of data adequate to determine its true correlation with orifice area: the present results (Tables III and IV) do not deny that such correlation may be good.

In none of the cases analysed was the mean left atrial pressure less than 8 mm. Hg above the sternal angle. It is unlikely that the conclusions would prove transferable to normal records, since not only is the Ry/v ratio the numerical expression of an abnormal situation, but it is dependent on that situation for its correlation with the pressure/flow relationship across the mitral valve. From the observations of Little already quoted, it follows that Ry/v is not normally a constant since it will still vary with the rate of flow. Under normal conditions, too, small deflections and disproportionately large sound artefacts imply considerable inaccuracy of measurement, while the supposition that the height of v was related to the pressure-gradient would involve a further large error. These considerations are reinforced by the doubt that exists as to the validity of wedged pulmonary arterial records when pulmonary venous pressure is not raised (Epps and Adler, 1953). The use of the word " normal " has therefore been avoided in referring to the Ry/v ratio, and no attempt has been made to establish a normal range of values for the expression.

CONCLUSIONS

The limitations of this study are realized, especially that imposed by the relative lack of surgical data from cases of frank mitral incompetence. It is possible that in this group the bias of catheterization records towards borderline and doubtful cases has not been entirely eliminated. Progress in surgical treatment will enable appropriate extension of observations. At present, it may be concluded that the pattern of the left atrial pressure pulse during diastole is determined by the presence and degree of mitral stenosis. With reservations in respect of the excluded outlying observation and the possible influence of varying volume-elasticity characteristics, the Ry/v ratio appears to provide a useful expression of this pattern.

SUMMARY

An attempt has been made to correlate the form of the indirect left atrial pressure record in mitral valve disease with the presence and relative importance of stenosis and incompetence respectively. In pure or dominant stenosis, the time taken for inscription of the y descent is significantly prolonged. The most stable expression of this proved to be the quotient of the calculated rate of fall (mm. Hg per sec.) divided by the height of the preceding v wave (mm. Hg above the sternal angle), the value so obtained remaining relatively independent of individual fluctuations in mean pressure and diastolic length. It is suggested that when the left atrial pressure is raised, this simply calculated ratio varies as the pressure-flow relationship across the mitral valve. On the basis of the results reported, a value greater than 1·6 is unlikely to occur if stenosis is pure or associated with only trivial incompetence. While such a value is not in itself positive evidence of mitral incompetence, it may become so under appropriate clinical circumstances by denying the existence of a significant degree of stenosis.

REFERENCES

Baker, C., Brock, R. C., Campbell, M., and Wood, P. (1952). *Brit. med. J.*, **1**, 1043.
Biörck, G., Axen, O., Krook, H., Andren, L., and Wulff, H. B. (1953). *Amer. Heart J.*, **45**, 13.
Bloomfield, R. A., Lauson, H. D., Cournand, A., Breed, E. S., and Richards, D. W., (1946). *J. clin. Invest.*, **25**, 639.
Dexter, L., Gorlin, R., Lewis, B. M., Haynes, F. W., and Harken, D. E. (1950). *Trans. Amer. Clin. Climatological Ass.*, **62**, 1.

Dow, J. W., and Gorlin, R. (1950). *Fed. Proc.*, **9**, 33.
Eliasch, H. (1952). *Scand. J. Clin. Lab. Invest.*, Suppl., **4**, 1.
——, Lagerlöf, H., and Werkö, L. (1950). *Nord. Med.*, **44**, 1128.
Epps, R. G., and Adler, R. H. (1953). *Brit. Heart J.*, **15**, 298.
Friedreich, N. (1864). *Virchows Arch. path. Anat.*, **29**, 296.
Gorlin, R. (1954). *Brit. Heart J.*, **16**, 375.
——, and Dexter, L. (1952). *Amer. Heart J.*, **43**, 88.
——, and Gorlin, S. G. (1951). *Amer. Heart J.*, **41**, 1.
——, Lewis, B. M., Haynes, F. W., and Dexter, L. (1952). *Amer. Heart J.*, **43**, 354.
Hansen, A. T. (1949). *Pressure Measurement in the Human Organism.* Copenhagen.
——, Eskildsen, P., and Gotzsche, H. (1951). *Circulation*, **3**, 881.
Hellems, H. K., Haynes, F. W., and Dexter, L. (1949). *J. appl. Physiol.*, **2**, 24.
Lagerlöf, H., and Werkö, L. (1949). *J. clin. Invest.*, **1**, 147.
Little, R. C. (1949). *Amer. J. Physiol.*, **158**, 237.
Logan, A., and Turner, R. (1953). *Lancet*, **1**, 1007.
Mackenzie, J. (1902). *The Study of the Pulse.* Pentland, Edinburgh and London, 1902.
Ravin, A., Slonim, N. B., Balchum, O. J., Dressler, S. H., and Grow, J. B. (1952). *J. Amer. med. Ass.*, **149**, 1079.
Rodrigo, F. A. (1953). *Amer. Heart J.*, **45**, 1.
Silber, E. N., Prec, O., Grossman, N., and Katz, L. N. (1951). *Amer. J. Med.*, **10**, 21.
Venner, A., and Holling, H. E. (1953). *Brit. Heart J.*, **15**, 205.
Wade, G., Werkö, L., Eliasch, H., Gidlund, A., and Lagerlöf, H. (1952). *Quart. J. Med.*, **31**, 361.
Wiggers, C. J. (1923). *Modern Aspects of the Circulation in Health and Disease.* Lea and Febiger, Philadelphia, 1923.
Wood, P. (1952). *First European Congress of Cardiology, Abstracts of Scientific Communications*, p. 25.
—— (1954). *Brit. med. J.*, **1**, 1015 and 1113.
——, and Gibson, R. V. (1954). In preparation.