A Consideration of Hemodynamic Criteria for Operability in Mitral Stenosis and in Mitral Insufficiency

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TEN years have elapsed since stenosis of the mitral valve was shown to be a surgically remediable lesion by Bailey and Harken and associates. Because effective surgery is now the province of a number of clinics, a great deal has been learned about rheumatic heart disease in its varied aspects and today there should be an unassailable hemodynamic formula or formulae for the selection of the patient for operation. Unfortunately there is still no simple answer.

The most direct approach to the assessment of a significantly stenotic mitral valve would appear to lie in the measurement of the diastolic pressure gradient across the mitral valve. Catheterization of the left heart using the method of Facquet and associates, Allison and Linden, or Bjorck and co-workers has rendered this feasible. It has been shown from this type of study and from those made in the operating room that a diastolic gradient does exist across a stenotic valve and that this gradient will diminish or disappear following successful surgery. It might therefore be expected that determination of the gradient would indicate which lesion demands commissurotomy.

However, the diastolic pressure gradient across the mitral valve is a reflection of at least 3 variables: the degree of stenosis, the blood flow across this valve, and the time during which this flow passes the valve. It has only been in the last 18 months that the diastolic gradient, blood flow, and heart rate have been simultaneously measured in a few clinics and since the ultimate results of surgery in this modest number of patients has not yet been ascertained, we are still in ignorance of what constitutes a significant gradient and of what conditions must be fulfilled.

A considerable body of data has been secured by right heart catheterization, although this information is less direct. Utilizing this technic and measuring heart rate, blood flow, and pressure, we have learned which hemodynamic alterations are found in patients with mitral stenosis and which of these variables will be returned toward normal by successful surgery.

MITRAL STENOSIS

This part of our discussion is limited to the findings in patients with isolated mitral stenosis. Therefore subjects with enlarged left ventricles, mitral regurgitation, or significant aortic or tricuspid lesions are specifically excluded.

There are at present 6 hemodynamic patterns that can be found in patients with the auscultatory findings of mitral stenosis. The individuality of each pattern becomes apparent when viewed in relation to the entire clinical picture.

The expected and most universally accepted picture of an obstruction at the mitral valve is one originally described by Dexter and associates in which at rest there is moderate to severe pulmonary hypertension, and elevation of the pulmonary wedge pressure, and a cardiac output that is slightly or moderately
reduced (fig. 1, group I). These findings occur at heart rates that fall within the accepted normal range of 60 to 100 beats per minute.

In this group of patients the diastolic pressure in the pulmonary artery usually lies between 20 and 30 mm. Hg, the systolic pressure between 40 and 75 mm. Hg, and the mean between 30 and 50 mm. Hg. The pulmonary artery pulse pressure is strikingly increased. The mean pulmonary wedge pressure is quantitatively the same as the pulmonary artery diastolic pressure.

The inference from these data is that significant or severe obstruction to left atrial outflow has occurred at the mitral valve and that there is a consequent increase in the volume of blood in the left atrium. This in turn causes a rise in pressure in this chamber that is reflected in the elevated pulmonary artery diastolic pressure. In these individuals diastolic run-off from the pulmonary arterial tree is influenced chiefly by the obstruction of the mitral valve. The pulmonary artery systolic and pulse pressures rise more strikingly than the diastolic because they are influenced not only by the elevation of the left atrial pressure but also by the distensibility characteristics of the vessels themselves, i.e., the caliber and elasticity of the vessels, the volume of blood in them, and pulsatile flow. In reviewing the available data one is struck by the tremendous variation in the level of cardiac output which is recorded in this type of patient; markedly reduced as well as normal values have been found. Even if one takes into consideration that all patients were not studied in the basal state nor were all free of apprehension or medications, nevertheless, in individual series a wide range of blood flow is apparent. It is known that atrial arrhythmias, fibrillation or flutter, can reduce cardiac output, but even in their absence low levels of blood flow are found. Attempts at correlation with pulmonary artery pressures or wedge pressures yield no consistent results. Correlations with such calculations as "pulmonary vascular resistance" and "mitral orifice size" prove little as the level of blood flow is an in-
integral part of these calculations. If the size of the mitral orifice is not the sole determinant of cardiac output, what other modality is? It is suggested that the integrity of the ventricular pump may well play a role.

The majority of patients who demonstrate this pattern should have a successful result from mitral surgery, and indeed they do (fig. 2). The mean wedge pressure and pulmonary artery diastolic pressure return toward normal. The pulmonary artery systolic and pulse pressures fall even more strikingly, thereby supporting the importance of the state of overdistention of the pulmonary arterial tree prior to surgery. The cardiac output does not, however, show the same striking change. In most series, the resting level of blood flow is much the same as preoperatively, although it may rise during exertion, when preoperatively it remained fixed. It appears to us that the best explanation for this lack of change in output, despite a marked fall in pressure, lies in the fact that existing myocardial damage has not been reversed by surgery and that mitral block is not the sole regulating factor in determining the level of cardiac output.

Another hemodynamic pattern that may be encountered is similar to the one previously described except in the magnitude of pulmonary hypertension, which is much greater and may be formidable in this second group (fig. 1, group II). The pulmonary wedge pressure is not much greater and indeed may lie within the same range as in the first group. Pedersen, who has studied this pressure in many types of heart disease, has commented on the fact that one rarely encounters a wedge pressure of over 40 mm. Hg under the usual conditions of study. A review of the literature so strongly supports this view that one can probably say that those which have been recorded above this level are probably the result of manifest pulmonary edema as previously suggested by Gorlin and associates or reflect a technical error. What factor is responsible for the finding that the pulmonary hypertension is much more severe in this second group although the wedge pressure is not, if any, higher than in the first group? It may well be a consequence of anatomic changes in the walls of the pulmonary vascular tree. In support of this argument one may cite the fact that in this group one rarely sees an almost normal resting level of pulmonary arterial pressure following commissurotomy even when the wedge pressure has fallen satisfactorily. Furthermore, serial observations in the same patient over a period of months may show a progressive fall in pulmonary artery pressures, which most reasonably is ascribed to progressive change in the pathologic lesions of the arterial tree. Indeed, one may see striking changes in pressure and in the electrocardiogram over a prolonged period of time (fig. 3). Similar serial changes have not been noted in heart size as seen by the x-ray.

Perhaps, too, the high pulmonary artery pressures are an indication that the limits of distensibility of the system have been reached.
This conclusion is based on the observation that the pulmonary artery pressures, particularly the pulse pressure, do fall early and strikingly following surgery even if they do not return to the same level as in the previous group; hence, all this hypertension is not solely on the basis of pathologic anatomy.

There is evidence then for at least 2 factors that are responsible for the striking rise in pulmonary artery pressures in this second group: one, the pathologic changes in the vascular tree, which may be in part reversible after surgery; and the other, overdistention of the vascular system, which responds immediately to successful opening of a stenosed valve.

The third and fourth groups to be described may resemble each other hemodynamically at rest, but clinically, particularly historically, they may be distinguishable.

The first of these represents mild but significant mitral block (fig. 1, group III). The patients often complain of dyspnea only when under more than usual duress. Cardiac size is slightly increased and the electrocardiogram is within normal limits. Catheterization studies reveal either normal pressures or only minor elevations in pulmonary artery and wedge pressures at rest. The cardiac output may be normal or strikingly reduced. On exercise blood flow is increased normally, but the pulmonary artery pressures rise briskly, achieving levels not unlike those encountered in the first group at rest. Certainly the valve orifice is not so small as encountered in the previous 2 groups, but under conditions of stress, as in exercise or pregnancy, when there may be an increase in heart rate, cardiac output or blood volume, the stenosis becomes important. Surgery in these individuals with a mild but significant degree of stenosis results in a normal level of pressure on exercise (fig. 4). The resting level of blood flow may not be materially affected.

The fourth group (fig. 1, group IV) is hemodynamically not dissimilar from the third at rest—yet, clinically there is little doubt that we are dealing with another entity. In these individuals disability is as great as is encountered in those with moderate or severe resting hypertension. Indeed a story of repeated bouts of congestive failure is often

**Fig. 3.** The right precordial V leads and right ventricular systolic and diastolic pressures in a patient from group II before (1953) and after (1954, 1958) mitral commissurotomy.
elicited. The heart size is large, sometimes even larger than those with far greater pressures, and atrial fibrillation is often present. Although this group does not differ at rest from those with early mitral block, their hemodynamic response to exercise is not the same. In these individuals blood flow does not increase normally and the pulmonary artery pressures either do not rise, or do so modestly. Surgery does not change either the clinical course or the hemodynamic picture (fig. 5). It is easy to incriminate the surgeon for the lack of success but it is more likely that myocardial insufficiency is the responsible agent for both the hemodynamic and clinical picture and that valvular stenosis is not the predominant lesion.\(^{12, 13}\)

This fourth group is the most frequently confused clinically with those who have tight mitral stenosis because of the degree of their disability, but hemodynamically they can be separated. However, when these patients with myocardial insufficiency are in congestive failure (fig. 1, group V) pulmonary hypertension and an elevation of right ventricular diastolic pressure develop. Hence their resting pulmonary hypertension might lead one to suspect mitral block rather than advanced myocardial insufficiency. The true state of this fifth group can be clarified by the finding of an elevated right ventricular end-diastolic pressure and by the rigorous use of all medical therapies. If such patients are studied following the relief of congestive heart failure, marked falls in the lesser circuit pressures will be noted. In the absence of such studies or in the presence of chronic irreversible failure, the nature of the hypertension cannot be elucidated and such patients should be considered for surgery with caution, if at all. In our experience surgery has not altered the clinical or the hemodynamic picture (fig. 6).

Finally, in patients who display normal cardiodynamics at rest and during exercise (fig. 1, group VI) there is no indication for surgery as has been shown by Claps et al.\(^{15}\)
MitrP Insufficiency

While successful surgery in mitral stenosis has permitted a definition of the hemodynamic consequences of this lesion, to date, with few exceptions, mitral regurgitation has not proved amenable to operation. Hence, one is insecure in stating which patient with mitral insufficiency should be offered surgery. This, however, is not the only problem. We do not know what, if any, hemodynamic abnormalities may be properly attributed to mitral regurgitation and are also at a loss as to how to identify a significant lesion.

In 1922 Wiggers and Feil\textsuperscript{14} published a detailed analysis of the hemodynamic effects of experimentally produced mitral insufficiency. Among some of their conclusions are the following: 1. Mitral regurgitant flow occurs chiefly in the latter part of ventricular systole and in very early diastole causing a rise of pressure in the left atrium in this interval. With the opening of the mitral valve, the regurgitant volume passes into the left ventricle, so that during diastole, left atrial pressure is not increased. 2. Left ventricular diastolic volume and pressure are increased as a consequence of the return of the regurgitant volume. 3. The rise in ventricular filling pressure, by producing a greater systolic discharge, serves to maintain aortic flow at an almost normal level. They further inferred that right ventricular output is unaltered and found that pulmonary artery systolic and diastolic pressures were not elevated by the production of mitral insufficiency and conclude that "as long as cardiac muscle is efficient, the increased volume of blood contained in the left auricle during systolic ejection is accompanied by expansion of the left auricle and its venous tributaries. Consequently no 'back pressure' effects are produced in the pulmonary artery or right heart." Lesser circuit hypertension could be produced, however, if arterial resistance was increased in the systemic circulation as then regurgitation would be greater than could be accommodated in the left veno-atrial system. Braunwald, Welch, and Sarnoff\textsuperscript{15} have recently extended the observations in experimentally induced mitral insufficiency and have shown that the effect of any given regurgitant volume on left atrial pressure is a function of the filling pressure of the left ventricle.

Applying these considerations to man one could then predict that isolated valvular mitral regurgitation would cause no change in lesser circuit pressures, an elevation of left atrial pressure in late systole and very early diastole without much change in mean left atrial pressure, a minor increase in left ventricular end-diastolic pressure if the ventricle is not otherwise embarrassed, and a normal level of pulmonary and systemic blood flow.

The characteristic left atrial pressure curve of mitral insufficiency has been recorded on numerous occasions in man. Although recently, as would be predicted from experimental studies, normal levels of blood flow and lesser circuit pressures have been noted in man in the presence of isolated mitral insufficiency (fig. 7), these individuals were almost entirely asymptomatic.\textsuperscript{16} In contrast to the experimental animal and the asymptomatic subject, the symptomatic patient said to have isolated or predominant mitral insufficiency is usually found to have pulmonary hypertension, left atrial hypertension, and a reduced cardiac output. Measurements of left ventricular diastolic pressure are few but both normal and elevated levels have been recorded.\textsuperscript{17, 18}

Quite a few explanations can be offered to reconcile the differences between the experimental and clinical observations. The experimental studies are acute and little is known of the chronic effects of mitral insufficiency. It is possible that ultimately left ventricular function may be disturbed by the continuing effects of a large diastolic inflow and that left ventricular failure ensues with a consequent rise in filling pressure and a further increase in regurgitant flow that cannot be contained solely by the left veno-atrial system. This train of events, as recently postulated by Edwards and Burchell,\textsuperscript{19} places the primary defect in the insufficient valve. It is also con-
ceivable that damage to the myocardium independent of the valve lesion is responsible for the aggravation of an otherwise innocent valvular lesion. This idea is strengthened by recent reports of open heart surgery on patients with mitral insufficiency\textsuperscript{20, 21} in a number of whom marked dilatation of the annulus was found with virtually normal valve leaflets. The mechanism by which annular dilatation occurs must therefore be considered separately. If one invokes left ventricular myocardial failure secondary to rheumatic myocarditis or aortic valvular lesions, then one can account for the elevated left ventricular diastolic and lesser circulation pressures as well as the reduced cardiac output. Experimental studies on chronic mitral insufficiency, as recently begun by Kuykendall et al.\textsuperscript{22} may eventually reveal whether the hemodynamics associated with mitral valvular insufficiency can in truth produce left ventricular failure and hence elevation of lesser circulation pressures and reduced output, or whether it is not myocardial failure that produces annular dilatation and aggravates an otherwise innocent valvular lesion.

A second explanation would stress that in the experimental preparation valvular incompetence is not so great as is encountered in man. There is no way to support or deny this at present.

Dexter and associates\textsuperscript{17} have recently offered a third possibility. In studies in man, they, as have Marshall et al.,\textsuperscript{23} found that a diastolic pressure gradient exists between the left atrium and left ventricle. This phenomenon has not been noted in animal experiments. The implication is that in man mitral regurgitation rarely exists in the absence of mitral stenosis. During diastole a large flow must cross a valve orifice that is not normal, albeit not markedly stenosed; this results in an in-

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**Fig. 6** Left. Comparison of hemodynamic data at rest and during exercise in a patient (E.B.) from group V before and after mitral commissurotomy.

**Fig. 7** Right. Hemodynamic data at rest and during exercise in a patient (H.Z.) with pure mitral insufficiency. (From the work of Claps, Kaltman, Harvey, and Koosmann.)

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*CLINICAL PROGRESS*
crease in left atrial volume and pressure which is reflected in the pulmonary vascular tree.

At present, then, it cannot be stated with certainty which hemodynamic abnormalities may be ascribed to mitral valve insufficiency, which laid to resulting or concomitant ventricular damage, or which reflect associated valve lesions.

Currently efforts are being directed at the documentation of the presence of mitral insufficiency and an estimation of its severity. Both the pulmonary wedge tracings and left atrial curves reflect the characteristic contour associated with this lesion. However, the same contour is seen if atrial fibrillation is present and little mitral regurgitation exists. Furthermore detailed analysis of these curves, including the height of the regurgitant wave, its slope, etc., do not permit a clear-cut definition between mild and severe degrees of regurgitation. Calculation of "mitral orifice size," particularly if insufficiency is suspected, requires measurement of the left atrial and left ventricular pressure levels and of both forward and regurgitant flow. Pressure levels and forward flow can be secured, but an estimation of regurgitant flow eludes us. Following the lead of Korner and Shillingford several clinics are now attempting this, but at present, theoretical as well as practical objections must be overcome before one can accept such data without question.

In conclusion, since the hemodynamic alterations produced by mitral insufficiency in man are not well defined and the hemodynamic assessment of the degree of the regurgitation is not yet possible, hemodynamic indications for repair of this lesion cannot be stated at present.

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Arthur Stanley Eddington
English astronomer, 1882-1944

It is with thoughts of the relation of man to the visible universe that the scientifically minded among us approach the problem of his relation to the unseen world. Scientific theories have blundered in the past; they blunder no doubt to-day; yet we cannot doubt that along with the error there come gleams of a truth for which the human mind is impelled to strive. We seek the truth; but if some voice told us that a few years more would see the end of our journey, that the clouds of uncertainty would be dispersed, and that we should perceive the whole truth about the physical universe, the tiding would be by no means joyful. In science as in religion the truth shines ahead as a beacon showing us the path; we do not ask to attain it; it is better far that we be permitted to seek.—Science and Unseen World. From Great Companions. Readings on the Meaning and Conduct of Life from Ancient and Modern Sources. Vol. II, Boston, The Beacon Press, 1953.
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