Hemodynamics of Mitral Stenosis with Special Reference to Coronary Blood Flow and Myocardial Oxygen Consumption

By George G. Rowe, M.D., George M. Maxwell, M.D., M.R.C.P., Cesar A. Castillo, M.D., John H. Huston, M.D., and Charles W. Crumpton, M.D.

Although there are excellent articles concerning the clinical and hemodynamic features of mitral stenosis,1-3 information concerning the coronary blood flow and the myocardial metabolism of oxygen and carbon dioxide in such subjects is inadequate. This report describes hemodynamic observations in 20 female subjects with mitral stenosis who underwent cardiac catheterization with determinations of the cardiac output and coronary blood flow.

Material and Methods

The 20 female subjects of this study were selected from the general medical wards of the University of Wisconsin General Hospital because of mitral stenosis. Many of the subjects were candidates for mitral valvulotomy and the diagnosis and degree of stenosis were confirmed at operation in 18 who underwent operation. One subject was not operated upon, and one (no. 14) had no clear estimate at operation of the mitral valve size. This subject has not done well postoperatively, continuing to show clinical and radiologic evidence of mitral valve obstruction.

Cardiac catheterization was done in the routine fashion on the fasting subjects. The reference point for zero pressure was half way between the anterior and posterior surfaces of the chest, measured in the region of the heart. Pressures were measured by Statham strain gages, and means were determined by electrical integration of the pressure curve. Cardiac output was measured by the Fick principle, and the coronary blood flow by the nitrous oxide saturation technic. A partition coefficient of 1 was assumed between blood and myocardium. Blood gas analyses were done by the Van Slyke-Neill technic. Expired air was analyzed for oxygen and carbon dioxide by the Scholander apparatus.

A suitable group of controls is difficult to obtain for any study such as this, but for lack of a better group we have chosen 15 normal women studied in this laboratory and previously reported.4 Furthermore, the group of subjects with mitral stenosis were divided for comparison into those with atrial fibrillation (cases 1-7) and those with sinus rhythm.

Results

The results are summarized in table 1 for the subjects with mitral stenosis, and in the separate columns at the bottom of the page are listed the mean figures for the group of normal women along with the statistical comparison of the two groups. Although there is some overlapping, the mean age is significantly different in that our control group was younger than the group with mitral stenosis. In the absence of specific data about the influence of age on coronary blood flow no statements can be made of how this would affect the results. Surface area of the two groups was within the same range, as were the body respiratory quotient and the cardiac rate. The mean systemic arterial blood pressure was lower in the group with mitral stenosis than in the control group (p<0.02) and the mean pulmonary arterial blood pressure of those with mitral stenosis was higher (p<0.01). The wedge pressure of the patients with mitral stenosis was elevated by usual standards. The arteriovenous difference of the group with mitral stenosis was slightly greater than normal (p<0.001), their coronary sinus oxygen content was reduced (p<0.02), and their arterial-coronary sinus oxygen difference was increased (p<0.001). The cardiac
**Table 1**

### Female Patients with Mitral Stenosis

| Study no. | Age | S.A. | O₃ | Card. rate | P.R. | M₁ | M₂ | Wedge | M₂-D | AV. | Card. index | R.V. total | M₂-D | AV. | Card. index | R.V. total | M₂-D | AV. | Card. index | R.V. total | M₂-D | AV. | Card. index |
|-----------|-----|------|----|-----------|-----|----|----|-------|------|-----|-------------|------------|------|----|-------------|------------|------|----|-------------|------------|------|----|-------------|------------|------|----|-------------|
| 1*        | 43  | 1.7  | 151| 0.67      | 48  | 97 | 26 | 20    | 5.9  | 2.6 | 1890        | 3.5        | 507 | 0.9 | 45          | 2.1        | 3.8  | 13.9 | 6.3         | 0.78       | 0.55 | 1  |
| 2*        | 44  | 1.7  | 151| 0.67      | 48  | 97 | 26 | 20    | 5.9  | 2.6 | 1890        | 3.5        | 507 | 0.9 | 45          | 2.1        | 3.8  | 13.9 | 6.3         | 0.78       | 0.55 | 1  |
| 3*        | 44  | 1.7  | 151| 0.67      | 48  | 97 | 26 | 20    | 5.9  | 2.6 | 1890        | 3.5        | 507 | 0.9 | 45          | 2.1        | 3.8  | 13.9 | 6.3         | 0.78       | 0.55 | 1  |
| 4*        | 44  | 1.7  | 151| 0.67      | 48  | 97 | 26 | 20    | 5.9  | 2.6 | 1890        | 3.5        | 507 | 0.9 | 45          | 2.1        | 3.8  | 13.9 | 6.3         | 0.78       | 0.55 | 1  |
| 5*        | 44  | 1.7  | 151| 0.67      | 48  | 97 | 26 | 20    | 5.9  | 2.6 | 1890        | 3.5        | 507 | 0.9 | 45          | 2.1        | 3.8  | 13.9 | 6.3         | 0.78       | 0.55 | 1  |

### Notes:
- Those patients whose cardiac rhythm was atrial fibrillation.
- SEM, standard error of the mean.
- 1. Body surface area in square meters.
- 2. Oxygen consumption in ml. per min./M.² of body surface area.
- 3. Systemic arterial mean blood pressure in mm. Hg.
- 4. Pulmonary arterial mean blood pressure in mm. Hg.
- 5. Mean pulmonary artery wedge ("pulmonary capillary") pressure in mm. Hg.
- 6. Arterio-venous oxygen difference in ml. per 100 ml. of blood.
- 7. Total peripheral resistance in dynes cm.⁻⁴ per second.
- 8. Left ventricular work in kilograms meters per minute.
- 9. Total pulmonary resistance in dynes cm.⁻⁴ per second.
- 10. Right ventricular work in kilogram meters per minute.
- 11. Coronary blood flow in ml. per 100 Gm. of myocardium per minute.
- 13. Coronary sinus blood oxygen content in ml. per 100 ml. of blood.
- 14. Arterial-coronary sinus blood oxygen difference in ml. per 100 ml. of blood.
- 15. Cardiac metabolic rate for oxygen in ml. per 100 Gm. of myocardium per minute.
- 16. Cardiac respiratory quotient.
- 17. Index of efficiency in kilogram meters of work done per ml. of CMRO₂.
- 18. Surgeon's estimate at operation of the diameter of the mitral valve in centimeters.
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index in the patients with mitral stenosis was less than in the normal group \((p<0.001)\), and the left ventricular work index was reduced \((p<0.001)\). The right ventricular work index, on the other hand, was increased \((p<0.05)\). The total peripheral resistance in the patients with mitral stenosis was higher than in the normal subjects \((p<0.01)\), and the total pulmonary resistance was likewise elevated \((p<0.01)\).

As compared with the group of normal women, coronary blood flow in the subjects with mitral stenosis was reduced \((p<0.001)\) as was the cardiac metabolic rate for oxygen \((p<0.01)\), whereas coronary vascular resistance was increased \((p<0.01)\). The cardiac respiratory quotient on the other hand was identical in the two groups and the index of efficiency, which relates the left ventricular work index to left ventricular oxygen consumption, revealed that if the left ventricular weights are presumed to be comparable, subjects with mitral stenosis had no significant difference in efficiency from the normal subjects.

The 7 subjects with mitral stenosis who had atrial fibrillation were compared statistically by the t test for each valve in table 1 with those who had a sinus rhythm. Those with atrial fibrillation were older \((42 \text{ years versus } 34 \text{ years, } p<0.05)\), their coronary blood flow was somewhat less \((52 \text{ versus } 69 \text{ ml./100 Gm. L.V./min., } p<0.05)\), their arterial-coronary sinus oxygen difference was greater \((13.6 \text{ versus } 12.4 \text{ ml./100 ml. of blood, } p<0.05)\), and their coronary vascular resistance was increased \((1.8 \text{ versus } 1.2 \text{ arbitrary units, } p<0.01)\). There were no other statistically significant differences.

**Discussion**

The general effect upon hemodynamics from mitral stenosis have been described by others\(^1^3\) and reviewed recently.\(^3\) The changes constitute chiefly an elevated wedge pressure, elevated pulmonary artery pressure, increased right ventricular work, decreased cardiac output, and increased pulmonary vascular resistance. These general hemodynamic changes are confirmed in the present study. A normal or decreased coronary blood flow has been reported previously in small groups of subjects with mitral stenosis.\(^5^6\) It is of interest that the coronary blood flow is reduced significantly in the presently reported group of women with mitral stenosis as compared to the normal women studied in this laboratory, but not when compared to the normal men. It is not established whether the slower coronary flow in normal men is a sex-conditioned difference, but it seems possible that coronary flow in the human subject is related inversely to body size,\(^4\) as has been said to be the case in the dog.\(^7^8\) If this be true, two opposing factors would be at work in the mitral stenotic patients; their small size would tend to increase and mitral stenosis would tend to decrease coronary blood flow per unit weight of the heart. Another factor that makes it very difficult to compare subjects with mitral stenosis with each other or with any other group is that the degree of mitral stenosis varies from one subject to another. Therefore the hemodynamic effect varies, the group is not uniform and the data tend to scatter. The variability within the group has been emphasized already by comparing those with sinus rhythm to those with atrial fibrillation.

In the present group of subjects with mitral stenosis, coronary blood flow was positively correlated with cardiac index \((r=0.67, p<0.01)\), left ventricular work index \((r=0.65, p<0.01)\), and the coronary sinus oxygen content \((r=0.64, p<0.01)\). The left ventricular oxygen consumption was positively correlated with left ventricular work index \((r=0.66, p<0.01)\), and the cardiac index \((r=0.47, p<0.05)\), suggesting that the amount of oxygen consumed is related to the amount of work done. The results of these correlations compare favorably with those previously reported in the intact dog.\(^9\) Furthermore, the more hemodynamically significant is the mitral stenosis in reducing cardiac output and left ventricular work, the lower is the coronary sinus blood oxygen content, and hence, presumably, the myocardial oxygen tension.

A working hypothesis would seem to be that mitral stenosis, by producing obstruction to
filling of the left ventricle, reduces the left ventricular output and therefore the left ventricular work. As a result, coronary blood flow and myocardial oxygen utilization are reduced. Such a hypothesis is compatible with the present data. None of the subjects of this study had true angina pectoris, although the subject with the highest pulmonary artery pressure (no. 7) had very prolonged chest pain of the variety suggesting pulmonary hypertension. This particular patient had a higher mean pulmonary arterial pressure than systemic mean arterial pressure and a very reduced coronary blood flow. This flow, however, is measured per unit weight of left ventricle, and it is suspected that the pulmonary hypertensive anginoid pain may arise from right ventricular ischemia, especially when the systolic pressure generated by the right ventricle exceeds that in its perfusing coronary arteries.

Summary and Conclusions

Hemodynamic studies, including determination of coronary blood flow by the nitrous oxide method, have been reported in a group of 20 female subjects with mitral stenosis.

Pulmonary artery pressure and wedge pressure, as well as pulmonary vascular resistance and right ventricular work were increased. These subjects with mitral stenosis tended to have a lower cardiac index and left ventricular work index than did the normal subjects, and this was accompanied by a decrease in left ventricular coronary blood flow and decreased left ventricular oxygen utilization per unit of myocardial weight.

The arteriovenous oxygen difference was wider in both the systemic and coronary circulations of subjects with mitral stenosis and the coronary sinus oxygen content was lower, indicating the widespread effects of obstruction at the mitral valve.

Summario in Interlingua

Es reportate studios hemodynamic—incluse determinations del fluxo de sanguine coronari per le metodo a oxydo nitroso—effectuate in un gruppo de 20 femininas con stenosis mitral.

Le tension del arteria pulmonar e le tension cuneate, si ben como le resistentia pulmono-vascular e le trava-valio dextero-ventricular, esseva augmentate. Iste subjectos con stenosis mitral tendeva a haber un plus basse indice cardic e un plus basse indice de travalo dextero-ventricular que subjectos normal, e isto esseva accompaniante de un reduction in le fluxo de sanguine coronari sinistro-ventricular e in le utilisation de oxygeno sinistro-ventricular per unitate de peso myocardial.

Le differenza arterio-venose de oxygeno esseva plus considerabile tanto in le circulation major como etiam in le circulation coronari in le caso de subjectos con stenosis mitral, e le contenito de oxygeno in le sinus coronari esseva plus basse, reflectente le extense effectos de obstruction del valvula mitral.

References


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