CARDIODYNAMIC EFFECTS OF MITRAL COMMISSUROTOMY

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During commissurotomy for stenosis of the mitral valve, it has been possible to record the moment to moment changes in left auricular and pulmonary arterial pressures, using an electronic manometer system. The left auricular pulse patterns have varied depending on the degree of stenosis and the presence or absence of auricular fibrillation or unsuspected regurgitation. The degree of success attending operative intervention on the mitral valve has been predictable by a study of the postcommissurotomy tracings.

During the past few years, it has become technically feasible to attack the mitral valve directly to relieve mitral stenosis. Bailey and his associates have used the term “commissurotomy” to describe what appears to be the ideal procedure, that of cutting between the fused anterior and posterior cusps at one or both ends of the valve so that although the opening is enlarged, insufficiency is not produced. Others have called the procedure “valvuloplasty” or “valvulotomy.” A prominent feature in mitral stenosis with or without regurgitation is pulmonary hypertension, which can be measured in the intact subject by cardiac catheterization. The primary area of high pressure, however, is in the left auricle and this is accessible for pressure studies only at operation. The operative exposure of the heart and great vessels has given a good opportunity for a study of the pulse patterns of the left auricle and pulmonary artery before and after incision of the stenotic valve. Since mitral commissurotomy is aimed at the restoration of function of the mitral valve, it has been found that an evaluation of these pressure curves taken during the course of operation is helpful in ascertaining the adequacy of this procedure.

At the beginning of this century, MacCallum and McClure were among the first in this country to study the pressure changes in various regions of the vascular system in the presence of acute mitral stenosis or insufficiency. They employed levers attached to mercury manometers, a method which recorded mean pressures satisfactorily, but which was unavoidably associated with considerable damping of the pressure pulses. It was found that the immediate result of acute stenosis of the mitral valve was a lowering of the general arterial pressure, and great elevation of the pressure in the pulmonary artery, the pulmonary veins and the left auricle. They also produced insufficiency of the mitral valve by cutting chordae tendineae and measured the pressures with more sensitive tambours. There was lowering of the arterial pressure depending on the extent of the insufficiency. The pressure in the pulmonary artery was relatively little altered; in fact, with extreme insufficiency, it usually sank with the general arterial pressure. With minimal insufficiency, it rose slightly. In 1922,
Wiggers and Feil\(^1\) studied the pulse patterns of acute mitral insufficiency, using a photographic kymograph and sensitive optical manometers of adequate frequency responses. Reference will be made to some of their observations in connection with the interpretation of the tracings of our patients with insufficiency. Using the same manometer system, Katz and Siegel\(^6\) recorded certain pressure waves in acute mitral stenosis. Among their observations was an increase in the magnitude of the left auricular contraction.

Other groups\(^5\) operating on mitral stenosis have made some observations on the pressures in the pulmonary artery and left auricle, but no simultaneous pressure tracings obtained by a sensitive manometer system have been published.

**Apparatus and Methods**

An impedance gaging system,* developed for recording biologic pressure variables, was used to obtain the pulse patterns in the study. The apparatus has been described in detail by Schafer and Shierer.\(^7\) The gage is a pressure sensitive element designed to fit into a modified 2 cc. syringe. A tiny diaphragm is mounted in the end of the syringe plunger and an electrical element inside the plunger measures the movements of the diaphragm when pressure is applied. Previous response studies of the apparatus have indicated that the static and dynamic responses are fairly satisfactory and that it is relatively stable. In this investigation the gages were activated by inserting an 18 gage needle attached directly to the gage into the vascular chamber to be studied. The needle in the pulmonary artery was curved to 90 degrees so that end pressures were obtained. Moment to moment changes in pressure were observed at operation on a monitoring oscilloscope and tracings made on a photographic recording oscillograph for later consideration. At the termination of the operation the system was calibrated with a mercury manometer.

The clinical material consists of 12 patients with severe mitral stenosis who were selected for commissurotomy by the method of Bailey and his associates.\(^1\) The left third rib is resected anteriorly from the sternum to the midaxillary line, and additional exposure is obtained by cutting the second and fourth costal cartilages. The pericardium is incised longitudinally posterior to the phrenic nerve, exposing the auricular appendage. After a purse-string suture of heavy silk is placed around the base of the appendage, simultaneous pressure recordings are taken from the left auricle and pulmonary artery. The tip of the appendage is then amputated and the right index finger, accompanied by the Bailey guillotine knife, is introduced into the auricle. Digital exploration reveals the degree of stenosis, and if regurgitation is present, it is felt as a definite jet of blood. One or both commissures are then cut, after which the finger and the knife are withdrawn and the auricle closed by drawing the purse-string suture tight. Tracings are again taken of the pressures in the left auricle and pulmonary artery.

**Results**

The pressure curves of 6 patients have been selected for special consideration. These are: (1) a person with a normal heart who had a left thoracotomy for a noncardiac condition; (2) a patient with regular rhythm who had a satisfactory commissurotomy; (3) a patient with auricular fibrillation and a good commissurotomy; (4) a patient with an unsatisfactory commissurotomy; (5) a patient with an unsuspected large amount of mitral regurgitation; and (6) a patient whose mitral insufficiency was first aggravated and then partially corrected during the operative procedure.

(1) For orientation to the analysis of the cardiodynamics of commissurotomy it is desirable to consider first the pulse contour of the pulmonary artery (upper curve) and left auricle (lower curve) of a man of 56 without clinical evidence of heart disease during thoracotomy for the removal of a small lung tumor (fig. 1). The pulmonary artery pressure measures 25/15

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* Hathaway Instrument Company, Denver, Colo.
mm. Hg. At the beginning of ventricular ejection, the pressure rises gradually to a rounded peak and falls more slowly. The dicrotic notch indicating closure of the pulmonary valve occurs when the pressure has almost reached diastolic level. The auricular tracing is of more interest. During auricular systole a rounded somewhat peaked wave is invariably present (A–C). The pressure rises to a summit (B), but before ventricular systole starts, it has fallen to a variable extent (C). Near the onset of ventricular systole the pressure first rises sharply to a peak (D) and then abruptly falls (E). The closure of the aortic valve and the opening of the mitral valve is not clearly signalled. From the low point at (E), the pressure with the partial opening of the mitral valve. The absence of any appreciable elevation of pressure during ventricular ejection indicates the absence of any significant insufficiency of the valve. This auricular tracing is believed to be typical for pure mitral stenosis.

Following lateral commissurotomy, the pulmonary artery pressure measures 35/25 mm. Hg. Left auricular pressure has been reduced to 8/5 mm. Hg. The rounded wave near the onset of ventricular systole is followed by no increase in auricular pressure signifying the absence of regurgitation. Clinically this patient was restored from invalidism to normal health.

(3) Figure 2 is an example of the records obtained from a patient with mitral stenosis

![Figure 2](http://circ.ahajournals.org/)

**Fig. 2.** Pressure curves in the pulmonary artery (upper) and left auricle (lower) in a patient with mitral stenosis and regular rhythm. A. Before commissurotomy. B. After opening the stenotic valve. Time lines = 0.1 second. For discussion, see text.

in the auricle gradually rises until the next auricular systole begins. The pressure in the auricle varies between 2.5 mm. and 10 mm. Hg.

(2) Figure 2 is an example of the pressure waves in the pulmonary artery (upper curve) and left auricle in a patient with a regular rhythm at the time of commissurotomy and an excellent operative result (case 12 in the series, C. K., female, age 30). Although the rise in pressure in the pulmonary artery is not abrupt with the occurrence of right ventricular ejection, the pressure is elevated to 65/50 mm. Hg. The dicrotic notch is prominent, signifying the absence of pulmonary insufficiency. Auricular systolic pressure is high (25 mm. Hg) and the sharply peaked wave is followed by a rounded wave of lower amplitude during ventricular systole, falling rapidly to lower levels and auricular fibrillation (case 10 in the series, L. B., male, age 41). The initial pulmonary artery pressure (upper curve) was 95/65 mm. Hg. The abrupt rise in pressure with right ventricular ejection signifies the increased resistance to outflow imparted by the stenotic mitral valve. The notch made by the closure of the pulmonary valve is noted. The low amplitude pulse shown at the right of the precommisurotomy tracing indicates a weak right ventricular ejection occurring in the course of auricular fibrillation. Since this patient was fibrillating, no definite changes in the auricular pressure curve due to contraction of the auricle are demonstrable. The auricular pressure rises near the onset of ventricular ejection and remains as a plateau until after the closure of the semilunar valve, the reduction of ventricular
pressure and the flow of blood from auricle to ventricle. This pressure was registered as 25/10 mm. Hg.

After “finger fracture” of the lateral commissure to the ring of the mitral valve without recourse to the use of the knife, the pulmonary hypertension was reduced to 70/40 mm. Hg. Left auricular pressure was 12/9 mm. Hg and there was no evidence of mitral insufficiency. This man was brought from imminent retirement to active professional life as an engineer.

(4) The results of this series have not all been satisfactory and figure 4 illustrates the moment to moment changes in pulmonary arterial (upper curve) and left auricular pressures of pulmonary insufficiency. Left auricular pressure measured 10/5 mm. Hg. The resulting pulmonary arterial pressure (fig. 4B) remained at 75/55 mm. Hg and left auricular pressure rose to 20/10 mm. Hg. This patient expired 17 hours after operation. Autopsy findings of importance were acute pulmonary congestion and atelectasis.

(5) Figure 5 is an example of an unsuspected amount of mitral insufficiency (case 4 in the series, H. F., a male, age 42). This patient had been described as having only a questionable systolic murmur at the apex to indicate the insufficiency. At operation, the regurgitation was felt with the finger. There was also severe mi-

Before and after an operative failure (case 5 in the series, M. B., a woman, age 45). The patient had progressive heart failure, myocardial insufficiency, and auricular fibrillation. She was recognized as a poor risk; nevertheless, since she appeared to have pure mitral stenosis and since an early death seemed inevitable without intervention, she was accepted for operation. The lateral commissure was cut and an attempt was being made to cut the thick medial commissure when the ratchet came off the guillotine knife, leaving no way to control the cutting edge. The heart action was poor, and further efforts to cut the valve were discontinued. Prior to commissurotomy the pulmonary artery pressure was registered at 75/55 mm. Hg and the incomplete incisura suggests some degree of mitral stenosis, so it was thought that the regurgitation would be made no worse and might even be benefited by incising the commissures. The lateral commissure was flat and calcified and did not lend itself to cutting. A satisfactory incision was made in the medial commissure. After this, it was felt that the regurgitation was actually diminished. The precommisurotomy tracing is typical of mitral insufficiency. The rounded wave of auricular systole (upper curve) is followed by a rather sharp decrease in pressure and sharply peaking and falling waves preceding ventricular systole. With the beginning of ventricular ejection the pressure rises sharply and remains elevated until after closure of the aortic valve. This pressure was 30/15 mm. Hg. Pulmonary arterial pressure rose ab-

![Fig. 3. Blood pressure tracings in the pulmonary artery (upper) and left auricle (lower) in a case with mitral stenosis and auricular fibrillation. A. Prior to lateral commissurotomy. B. After successful commissurotomy. Time lines = 0.1 second. See text.](http://circ.ahajournals.org/doi/abs/10.1161/01.CIR.23.4.3206.1.1?journalCode=cir)
ruptly to 50 mm. Hg and then slowly declined to 15 mm. Hg at the end of diastole. Small high frequency waves in this tracing are artefact. The autopsy showed that death may have been due to an area of myocardial injury in the vicinity of a large exostosis of a vertebra.

Subsequent to medial commissurotomy, left auricular pressure was measured as 10.5 mm. Hg. This patient expired 37 hours after operation. 

(6) Figure 6 shows the tracing in another patient with mitral insufficiency (case 3 in the series, B. L., female, age 40). The patient was
FIG. 6. Blood pressure tracings from the left auricle (upper) and pulmonary artery (lower) in a patient with mitral stenosis and insufficiency. A. Prior to commissurotomy. B. After surgically increasing the mitral insufficiency. Upper curve is from the pulmonary artery. Lower curve is from the left auricle. Note range change. C. After partially correcting the insufficiency (left auricle only. Note range change). Time lines = 0.1 second. See text.

fibrillating and the rise in left auricular pressure (figure 6A, upper curve) during the later phase of ventricular ejection indicates mitral regurgitation. The pressure in this chamber was 30/15 mm. Hg. Unfortunately, the pulmonary arterial wave was damped and only a mean pressure of 45/40 mm. Hg was recorded. After inadequate incision of the lateral commissure and digital dilatation of the valve, pulmonary artery pressure rose to 75/60 mm. Hg (fig. 6B). The patient had reverted to a regular rhythm and left auricular pressure rose to 65/25 mm. Hg. During auricular systole the pressure rises acutely and following a rounded wave of small amplitude, continues the ascent to a profound degree which coincides with ventricular ejection. This indicated the production of a high degree of insufficiency of the mitral valve. It was obvious that the patient could not be expected to live long with these dynamics and an attempt was made to improve the incision in the commissure. Following incision of the lateral commissure, the pressure in the left auricle had fallen to 14/5 mm. Hg (fig. 6C). However, the pulse pressure remained high and the wave contour of insufficiency was still present. Pulmonary artery pressure was not obtained. This patient has shown little improvement since discharge from the hospital.

Clinical Results

The clinical results in the 12 patients have been as follows: There were three deaths; two of these were explained above, one being in a poor risk patient who had inadequate commissurotomy because of failure of the instrument, and the other in the patient with marked regurgitation who developed the myocardial injury. In addition, there was another patient with marked unsuspected mitral insufficiency who was not benefited by a small cut in the lateral commissure. The immediate results were good in 8 patients, but one of these has developed symptoms which are believed to be largely based on pulmonary fibrosis and emphysema. A diastolic rumble is present but is not as prominent as before the operation. Another patient was unimproved; the tracings showed regurgitation before and after the commissurotomy.
DISCUSSION

By means of a sensitive electronic manometer system records have been made of the pulse pattern in the normal human heart; these were compared with the changes in the pulse wave contours of the pulmonary artery and left auricle resulting from rheumatic disease of the mitral valve. It is possible to point to what is probably a typical tracing for mitral stenosis with and without associated auricular fibrillation. Following commissurotomy, the pressure curves should show a marked decrease in the auricular pressure and some decrease in the pulmonary artery pressure. Furthermore, the postcommissurotomy tracing should show that no significant insufficiency has been created by the incision.

Interestingly enough, the left auricular pulse patterns in a patient without heart disease and in these patients suffering from the effects of rheumatic mitral valvular disease are similar to those obtained in acute experiments in the laboratory. Moreover, since the functional result of this pathologic process is a combination of stenosis and incompetence of the mitral valve, an aspect in which pressure studies have not been made in the laboratory, the left auricular wave forms in this investigation have frequently revealed resultant wave contours that have not been reported previously.

Some of the theories of the cardiodynamics of mitral insufficiency proposed by other investigators can be checked against these records of the condition in human cases. For example, MacCallum and McClure believed that they demonstrated a back flow in the pulmonary artery due to the regurgitant stream, which made itself evident by a small secondary peak in the pulmonary artery pressure. Inspection of the record in figure 5 shows that the slope of the diastolic decline of the pulmonary artery pressure is comparatively smooth, except for the notch made by the closure of the semilunar valve. However, the ascending part of the curve is quite steep, a picture which was noted by Wiggers and Felb and interpreted by them as being possibly due to the wave front effect of the regurgitation. These investigators also noted that regurgitation was continued over into diastole for a period (0.08 second). Again, in figure 5 it is seen that the peak of the regurgitation is reached about 0.02 second after the height of pulmonary artery systole and continues into diastole.

Pulmonary arterial pulse patterns have been recorded without the presence of artefacts noted by cardiac catheterization. Because these waves have in general had adequate reproduction, the condition of the pulmonary valve has also been evaluated. In 5 of this group a soft diastolic murmur along the left sternal border was interpreted as representing the Graham-Steell murmur of pulmonary insufficiency. However, only one of the pulmonary arterial pulse patterns disclosed the presence of a small amount of incompetence of the pulmonary valve. The mechanism of this murmur in the presence of a competent pulmonary valve is not entirely clear at this time.

Some of the conditions of this investigation, as is the case in many clinical studies, were beyond the control that can be maintained in laboratory experiments. The pressure waves taken after commissurotomy are presumably due to the effects of incision of the commissures and the relief of the stenosis, rather than changes in systemic blood pressure. It would be technically possible to take a tracing also from the aorta to obtain systemic pressures, but it did not seem to be advisable to subject the patient to this maneuver, since a fairly satisfactory estimate of this pressure was available from the ordinary aneroid sphygmomanometer and wrap-around cuff on the arm. Comparison of these cuff pressures (taken at the time of pressure recording), before and after commissurotomy, revealed no change in systolic pressure in 7 of the patients and a fall up to 20 mm. Hg in 5 patients with no change in diastolic pressure. Blood pressure was maintained by the replacement of any blood loss by whole blood transfusions.

CONCLUSION

Oscillograph tracings of the left auricular and pulmonary artery pressures in patients undergoing commissurotomy for mitral stenosis have been of academic interest as well as practical value in indicating the accuracy of the diagnostic methods used in selecting patients
for the operation and in demonstrating the adequacy of the incisions of the valves.

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