BRITISH MEDICAL JOURNAL

LONDON SATURDAY JUNE 3 1950

VALVULOTOMY FOR MITRAL STENOSIS

REPORT OF SIX SUCCESSFUL CASES

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It is now a quarter of a century since a number of attempts were made to relieve mitral stenosis by operation. The most sustained efforts to solve this problem by direct attack on the valves were made by Cutler and his associates (Cutler and Beck, 1929). Their first patient survived four years and was thought to have been improved; six others died soon after operation, as also did single cases reported by Allen and Graham (1922) and by Pribram (1926). Souttar (1925) alone has published a further success in an important paper from this country.

These early efforts were succeeded by a long period of inaction, and many thought that direct surgery of the valves of the heart was too dangerous to be practicable. The need for reconsidering this has become increasingly clear during recent years, because great advances in thoracic surgery and anaesthesia and in the aftercare of the patient have entirely changed the prospects of success. That successful operations for the direct relief of valvular stenosis are possible was shown in the case of the pulmonary valve (Brock, 1948); and that successful resection of infundibular stenosis was also possible was shown in the following year (Brock, 1949). We have performed in all over 45 direct operations on the heart for the relief of these types of stenosis.

While this work was being developed during the last four years our attention was also directed towards the relief of mitral stenosis by direct operation on the mitral valve. We are now able to report eight such cases, six of which are successful. These clinical results show that operation is not only possible but holds out hope of relief for a number of sufferers from this crippling condition.

That we have tried to select our cases with proper caution, recognizing the inherent dangers and difficulties, is shown by the fact that out of the many patients seen during this time only a few were specifically considered for surgery. In addition, the first patient selected was observed for more than a year before operation was finally decided on and performed in September, 1948.

At the same time that we were engaged with this problem several teams in America were similarly occupied. With some workers the approach has been indirect: Bland and Sweet (1949) have devised and practised a venous-shunt operation in which an anastomosis is made between the azygos vein and a branch of the inferior pulmonary vein, with the intention of relieving the high pressure in the pulmonary circulation. D'Allaines and his colleagues (1949) have used a similar operation in Paris. Harken, Ellis, Ware, and Norman (1948, 1950) have used both direct and indirect septal defect in two patients, and operation upon the mitral valve itself in two patients with one death. Smithy (1949), before his untimely death, operated directly upon the mitral valve in seven patients with two deaths. Murray (1949), of Toronto, mentions two patients in whom he has resected one cusp of a stenosed mitral valve and inserted a section of cephalic vein to function as a new valve.

The largest number of operations upon the valvular stenosis itself have been done in Philadelphia by Bailey, Glover, and O'Neill, who have developed a technique similar to the one we have used. Up to February, 1949 (Bailey, 1949), they had operated upon 10 patients with three successes, but in a later report (Bailey, Glover, and O'Neill, 1950) they mention 22 patients with 11 survivals; when we visited their clinic they had already passed this figure with more successes and a lower mortality.

Selection of Cases for Operation

This is difficult, as substantial reasons on which to base our opinions can come only as more patients are operated on. From many patients with mitral stenosis only a few have been selected as suitable for valvulotomy; in this we have been conservative and have waited until it is clear that the patient is deteriorating and that prognosis without operation is bad. The decision to operate earlier, before changes are so far advanced, and a widening of the field of indications, will depend on the results of surgery, and so far they are encouraging. The possibility of surgery should, we think, be remembered so that the right type of case may be helped at the right time.

The therapeutic problem presented by mitral stenosis involves many more features than the narrowed valvular orifice. Treatment must be considered in relation to the natural history of the disease; the liability of rheumatic carditis to recur or to smoulder; the involvement of the other valves; the usual coexistence of some slight or gross degree of incompetence of the valve; calcification of the valve; the development of pulmonary hypertension with secondary changes in the pulmonary arteries and the lungs; the onset of auricular fibrillation; and, above all,

the extent to which the damaged myocardium can compensate for the obstructed valve. Most of these are interrelated, and elucidation of their relative importance is likely to be difficult and often incomplete.

The following are some of the factors that need consideration.

1. *Presence of Active Rheumatism.*—This is of first importance, and is naturally a contraindication to operation. Smouldering activity is difficult to detect, as the absence of rheumatic pains, chorea, or obvious ill-health does not rule out the possibility, and in fact it should be suspected in young people whose heart size is steadily increasing. The rheumatic process is commonest in the first two or three decades and tends to burn itself out, so that there is less danger of experiencing this in the third decade and after. It is not only the risk of active carditis that has to be excluded but the chance in the younger patient of active carditis recurring spontaneously or even as a result of operation. For this reason patients over 25 or 30 are more likely to be suitable and those under 17 should at present be excluded.

2. *Involvement of Other Valves.*—This means particularly the aortic valves. Though free aortic regurgitation is at present regarded as a contraindication, many cases of mitral stenosis have some minimal involvement of the aortic valve hardly sufficient to cause embarrassment of the heart. A diastolic "whiff" behind the sternum alone would not exclude the patient, as with pulmonary hypertension this may be due to pulmonary incompetence—the Graham Steell murmur. Up to now we have rejected as unsuitable for surgery all cases with an associated aortic valvular lesion.

3. *Mitral Regurgitation.*—This is without doubt a factor of importance, for a high degree of it is a grave threat to operative success and possibly, at this stage, a contraindication to valvulotomy. We have therefore been suspicious of all cases with a loud systolic murmur in the mitral area. The diagnosis of mitral regurgitation with or without stenosis has fallen out of favour, but should be resumed—this time with greater accuracy. A large left ventricle and increased atrial pulsation in the right oblique with a barium swallow are important signs. Free mitral regurgitation will lead to an increasing size of the left atrium, and the association of aneurysmal dilatation of this chamber with a wide mitral valve has been stressed (Parsonnet, Bernstein, and Martland, 1946). In tight mitral stenosis with minimal regurgitation slight or moderate enlargement of the left atrium and some hypertrophy of the muscle will be the rule. A massive left atrium suggests that failure of this chamber has already occurred, due not only to regurgitation but probably to rheumatic involvement of its muscle, which is suggested by the high incidence of auricular fibrillation; it is another contraindication to valvulotomy.

4. *Calcification of the Mitral Valve.*—Most old mitral valves show calcification, which, in addition to interfering further with valvular function, makes surgery more difficult and more dangerous, especially in relation to the risk of thrombosis and embolism. Calcification should therefore be searched for, but it is not a complete contraindication to operation, as is shown by our Cases 5 and 6.

5. *Pulmonary Hypertension.*—The simplest effect of mitral obstruction is a rise of pressure in the left atrium and in the pulmonary bed. This obstruction to the return of blood from the lungs is followed by a rise of pressure on the arterial side as well; pulmonary hypertension and hypertrophy of the right ventricle follow. As time passes these become extreme, pressures near or even above the systemic arterial pressure being reached. Ultimately, secondary sclerotic changes occur in the pulmonary arterial bed. In the early stages relief of the mitral obstruction should relieve the pulmonary hypertension, and even in the later stages it may reduce the pulmonary blood pressure (see Cases 1 and 4). When severe secondary changes have occurred in the pulmonary blood vessels and parenchyma (Parker and Weiss, 1936; Larrabee, Parker, and Edwards, 1949) relief of the mitral obstruction may help, but it cannot bring about a complete reversal of the lung damage.

On the other hand, early hypertension is a strong indication for operation. The association of a heart of mitral contour, with no great enlargement but with prominent vascular markings, either at the hilum or towards the periphery, suggests the development of pulmonary hypertension. These changes correspond to the clinical course of progressive lung symptoms and signs without congestive failure (see below) and in such cases the possibility of operation should at least be considered.

6. *Onset of Auricular Fibrillation.*—The presence of fibrillation is not so much a contraindication to operation as an indication that the optimum time has passed (see Case 5). If this arrhythmia has been present for any time, thrombus formation within the auricular appendage is likely and will constitute an additional hazard as a source of emboli both at operation and after. If auricular fibrillation has been followed by few symptoms and little congestive failure it may well indicate a relatively sound myocardium, and should not then be a bar to the consideration of mitral valvulotomy.

7. *Secondary Right-sided Heart Failure.*—This may be added to the clinical picture, and, although in the early stages it may strengthen the indication for operation, in the later stages it makes success unlikely and must increase the operative risk to to a degree that may be prohibitive.

8. *State of the Myocardium.*—There are few cases of mitral stenosis in which some of the disability is not due to the mechanical effect of the obstruction and some to the damaged muscle; the relative rôle of these two factors will vary and may be difficult to assess. The importance of a damaged muscle as an inevitable contraindication to operation can be overemphasized; it may indeed be an urgent reason for relieving it from its overwhelming burden of forcing blood through the stenosed valve. The correlation between compensatory muscle force and the existence of an obstruction is no new problem in surgery, and some analogy may be drawn with this problem elsewhere in the body—for example, in the bladder or stomach. The surgeon knows from experience that the success of operation for the relief of an obstruction depends in great part on how early it is done, and that the correct time to operate is as soon as a chronic irreversible obstruction is present but before decompensation threatens.

The Surgical Problem

Before deciding upon tactics it is necessary to settle the strategic plan. In trying to relieve the effects of mitral stenosis by operation we must decide two broad principles. Should we use an indirect method, seeking by some form of shunt operation to relieve the pressure effects of the obstruction; or should we use a direct method, seeking to relieve the valvular obstruction itself? The first policy is really that of symptomatic relief only; it does not cure. The second aims not only at symptomatic relief but also at some degree of cure of the underlying disorder. Our policy has been the direct relief of the valvular obstruction. This does not mean that there is no place for indirect methods in certain types of case—probably those with advanced or permanent hypertensive changes in the pulmonary circulation.

The major strategy having been decided, we must consider the tactical or technical details necessary to solve the surgical problems involved. The two chief ones to be discussed here are the route of approach to the mitral valve and the method of dealing with the valvular stenosis.

Route of Approach to the Mitral Valve

The mitral valve may be approached either through the cavity of the left ventricle or across the left atrium, in which case the auricular appendage is convenient. The auricular approach is the method of choice. Cutler and Beck used the left ventricular route, as also did Pribram (1926) and more recently Smithy (1949). It has several grave disadvantages. The approach for adequate exposure

has to be more extensive, and the necessary manipulations may involve much dislocation of the position of the heart, which is liable to be followed by arrhythmias or cardiac arrest—a well-known fact of which we have personal experience in operations through the right ventricle for pulmonary stenosis. The thick muscle wall of the ventricle has to suffer the insertion of stay sutures and then incision, and is further interfered with by the passage of instruments into its interior; bleeding is more likely to be severe. The identification of the mitral valve is more difficult and uncertain from the ventricular aspect, and the chordae tendineae form a closely set obstruction to the approach to the narrow mouth of the valve. This is clearly shown in the latest paper by Smithy, Boone, and Stallworth (1950). It is also difficult to relieve the valvular obstruction efficiently from this aspect, as will be shown in the next section.

In contrast, the atrial route is much simpler. The operative exposure is easy and well tolerated and no dislocation of the heart is involved. This route was first suggested by Allen and Graham (1922). Allen and Barker (1926) showed by electrocardiographic studies on dogs that the ventricular approach caused ventricular arrhythmias, including fibrillation and even cardiac arrest; but cutting, clamping, or suturing the auricular appendage or section of the mitral valve produced little or no disturbance. Although Smithy (1948) and others have shown that the ill-effects of direct disturbance of the ventricular muscle can be lessened by the use of procaine solution, the ventricular route involves greater disturbance to the heart and has other inherent disadvantages. Our own operative experiences impress us that the heart is very tolerant of the auricular approach.

Allen and Graham introduced a cardioscope with an attached cutting knife through the left auricular appendage; it remained for Souttar (1925) to report a case in which the introduction of a finger was used with success. His use of the finger as the basic instrument is a contribution of fundamental importance and forms the basis of what would seem to be the safest and most practicable procedure in use to-day; for this he deserves full credit.

The approach to the mitral valve from its atrial surface is undoubtedly more natural than from its ventricular surface; the finger, once within the atrium, rapidly finds the mitral orifice; its shape, the consistency of its edges and of the valve cusps, and the presence or absence of calcification can all be noted; it is almost as if one sees with the finger. In addition, the presence and degree of mitral regurgitation may be detected as soon as the finger approaches the valve. The finger can then be used, or can carry the instrument, to relieve the valvular stenosis. Equally important is the fact that by this approach alone can the actual relief of the stenosis be done in the most mechanically efficient manner.

Relief of Valvular Stenosis

It is often assumed that relief of a valvular obstruction causes regurgitation. It is, of course, true that severe regurgitation can be caused in this way and can seriously aggravate the condition and even prove fatal. It is not an inevitable accompaniment if the valve is divided properly; indeed, we think the regurgitation may even become less. For instance, if the mitral orifice is a small rigid hole in the middle of a firm diaphragm with free regurgitation, a transverse incision in the correct plane replaces the rigid diaphragm by two more mobile flaps that can certainly function no less and possibly more efficiently.

Cutler and Beck, and more recently Smithy, Boone, and Stallworth (1950), excised or attempted to excise a round piece of the edge of the valve with a cardio-valvulotome. This enlarges the mitral orifice only slightly and causes regurgitation. It is a procedure that should not be used. Consideration of the normal anatomy of the mitral valve and the secondary changes caused by rheumatic valvulitis reveals the proper method of correction of the stenosis.

The mitral valve consists of a larger antero-medial flap and a smaller postero-lateral one; the axis of the valve is not transverse but is directed obliquely forwards and to the left (Fig. 1). As a result of the rheumatic infection

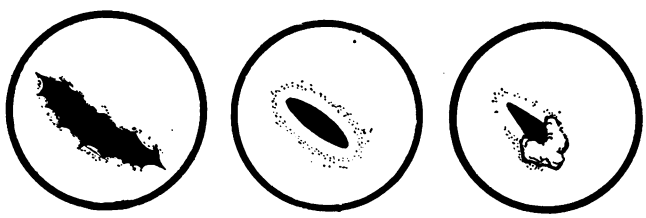

FIG. 1. FIG. 2. FIG. 3.

FIG. 1.—Showing the formation and disposition of the normal mitral valve. Note the oblique direction of the orifice and that the antero-medial cusp is much larger than the postero-lateral one.

FIG. 2.—Stenosis of the mitral valve; the classical buttonhole is surrounded by a zone of thick fibrous tissue. The two cusps are fused so as to form a medial and a lateral commissure.

FIG. 3.—Although exuberant calcification on the medial part of the valve orifice has resulted in a small rigid opening, the basic oval structure with two commissures is apparent.

the valve edges become thickened, deformed, and adherent, and the orifice becomes contracted owing to the partial fusion of the cusps, which themselves suffer a varying degree of thickening and fibrosis. In its simplest form the stenosed orifice is a narrow oval, the classical "buttonhole" stenosis; the axis of the orifice corresponds to that of the original valve (Fig. 2). Even in the severest forms, including those with calcification, this basic pattern exists, but it may not be apparent owing to the orifice being rounded, irregular, or triangular (Fig. 3).

In the severer forms the two valve cusps are thickened throughout and the contracture affects the whole mitral ring, which is smaller than normal; the greatest thickening occurs around the edges of the valve orifice. Sometimes there is partial fusion between the cusps across the opening, so that two, three, or more small apertures are seen. The mitral ring is not always much reduced in size: the valve cusps may be only slightly thickened and still retain much of their pliability, and the fibrous thickening and rigidity is almost entirely confined to the edges of the stenosed orifice. In Case 5, although the medial half of the orifice was calcified, the valve cusps immediately outside the fibro-calcareous margin were thin and supple.

These considerations show that the obstruction should be corrected by enlarging the orifice along the line of the original stoma—that is, antero-laterally and postero-medially (Fig. 4); the original structure of the valve is thus reconstituted and two functioning flaps are provided. Such a manœuvre, far from interfering with the efficiency of the valve and allowing regurgitation, is more likely to make the valve more efficient, since the freed portions of the cusps are larger and more mobile, especially if the cusps are thin and still supple. Even if the valve has a small rigid orifice (Fig. 3) which cannot close in ventricular systole, releasing the cusps enables them to come together.

At the same time that we were forming our own plans on the correct anatomical method to use, Harken and his

colleagues and Bailey and his colleagues had come to essentially similar conclusions. The portions of the fused valve on each side of the oval orifice have been termed the "commissures of the valve" by Bailey, and the operation of their division "commissurotomy."

The actual method to be used in enlarging the orifice along the lines of the commissures is a matter of technical expediency, provided that it does not involve punching out a circular portion of the valve, which would inevitably lead to severe regurgitation (Fig. 5). The enlargement can often

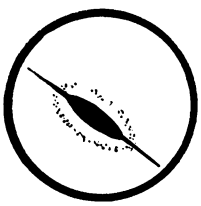

FIG. 4.

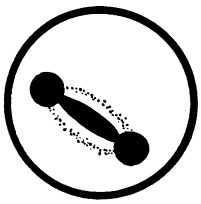

FIG. 5.

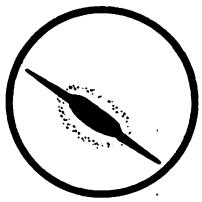

FIG. 6.

FIG. 4.—Illustrating that the only correct way to incise or split the stenosed valve is along the line of the lateral and medial commissures; in this way the original structure of the valve is, in some part, reproduced. Far from regurgitation being caused or aggravated, the valve cusps are probably more efficient, since some of their mobility is restored.

FIG. 5.—If circular portions of the valve are removed, even at the site of the commissures, regurgitation will certainly follow.

FIG. 6.—A thin sliver can be excised along the line of the commissures and may confer even greater valvular mobility and efficiency.

be made by splitting along the line of the commissures with the finger; or by cutting along this line with a suitable knife or guillotine; or by punching out a thin sliver of the commissures (Fig. 6), which might favour greater mobility of the flaps.

Harken *et al.* (1948) have used a curved cardio-valvulotome designed to punch out a wedge-shaped portion at the commissures; the instrument used is, however, small, and is passed blindly through the auricular appendage in an attempt to engage the mitral orifice by blind manipulation. Bailey and his colleagues have used various forms of knife and guillotine adapted to the curve of the index finger, and have evolved an instrument of considerable efficiency; earlier they used only the finger, following Souttar's technique, but later they have cut the valve along one or both commissures with their own valvulotome.

We also have designed a flat knife, thin and adapted to the curve of the index finger, that can be introduced into the atrium with the finger. We have found it necessary to use this in two cases only; in all the others it was possible to split the valve along the line of the commissure by using the finger.

It is not entirely accurate to describe this manœuvre as "dilatation" of the valve, which implies that the orifice is merely stretched. The valve is split, and in most cases the split is begun and continued with considerable accuracy and can be prolonged until the palpating finger detects that the circular fibres of the mitral ring itself have been reached. The chief disadvantage of using the finger alone is the difficulty of splitting the medial commissure, although this is not always necessary. One must have a suitable knife or guillotine that can be passed in with the finger to divide the thickened margin of the stenosed orifice quickly and efficiently if the least difficulty is experienced in splitting with the finger.

The antero-medial cusp of the mitral valve is larger than the postero-lateral cusp; it is also called the "aortic" cusp, and this will remind us that it exercises an important function in directing the blood in systole away from the atrio-ventricular orifice and towards the aortic orifice; in fact, it may well be regarded as a functional part of the approach to the aorta.

Harken and his colleagues have shown that damage of this cusp is much more harmful than that of the postero-lateral one. An incision across it (at right-angles to the axis of the valvular orifice or to the line of the commissures) inevitably produces severe acute mitral regurgitation and in the experimental animal is apt to prove rapidly fatal. They thought that twice as many animals died from destruction of the anterior cusp as from a corresponding destruction of the posterior cusp. They also showed that when an anterior defect was produced the rise in pressure in the left atrium from regurgitation was roughly twice as high as after production of a posterior defect. It is therefore quite certain that the integrity of the antero-medial aortic cusp must be preserved and that it must neither be cut into nor injured by punching with a cardio-valvulotome.

The Operation

In all cases anterior thoracotomy was done through the third left interspace with division of the third or fourth or both costal cartilages. Intravenous procaine was at first given only as occasion arose, but we now use it as a routine. Procaine solution 4% is instilled into the pericardium and left for at least five minutes before the pericardium is opened; swabs soaked in the same solution are then applied to the base of the auricular appendage. We have not injected procaine solution into the wall of the atrium, and have so far observed no disturbance when a clamp is applied to the base of the auricle or when the finger is introduced into the atrial cavity. When the mitral orifice itself is obstructed by the finger, which is never for more than two or three heart beats, there is, of course, disturbance of the heart's action, but this is corrected as soon as the finger is removed from the orifice.

A curved clamp is placed across the base of the auricular appendage and two opposing purse-string sutures are then inserted immediately distal to it. The auricular appendage is incised along one side, leaving it attached medially; the end of the appendage is not amputated at once, as it is felt that it might prove useful to seize if the appendage should slip away during later manipulations. Any cross bands are divided so that the auricular cavity is completely freed; any clot is of course removed. When an adequate orifice has been obtained the index finger is slid forwards into the atrial cavity as the clamp is loosened; in this way no haemorrhage should occur. If the fit is not snug enough the purse-string sutures can be slightly tightened. After the valve has been split or cut, the finger is withdrawn and the clamp simultaneously reapplied. The tip of the auricular appendage is removed and the opening closed by interrupted sutures and reinforced by tying the two purse-string sutures. The operative findings in Case 1 are important and may be taken as representative.

The pulmonary artery was found to be very large—much larger than the aorta of an adult man. The index finger was easily introduced into the left atrium, but on this, the first occasion on which we had performed this manœuvre, the state of affairs within the heart was very different from what was expected from post-mortem observation. The chief impression gained was of the powerfully contracting left ventricle; instead of the lower part of the atrial cavity forming a funnel leading to the mitral orifice, this part was found to be almost flat in diastole, and in systole it became convex towards the finger like a sail in the wind; the whole base of the heart rose towards the finger in

systole. Actually the mitral orifice was located at once, but was so much smaller than expected that it was not appreciated at first that the orifice was certainly that of the mitral valve; one anxiety was that it was the opening of a pulmonary vein.

The mitral orifice just admitted part of the tip of the finger and measured about 0.75 by 0.25 cm.; the mitral ring itself seemed to be little more than 2.5 cm. in diameter; the cusps were not very rigid. There was no difficulty in splitting the opening laterally and medially along the line of the commissures until the whole index finger passed readily into the left ventricle as far as the apex; the splitting and enlargement of the valve was not done in one movement but with a series of pauses during which the finger was withdrawn from the valve orifice so that the circulation was not obstructed for more than two or three beats at a time. Moreover, it was felt that it was better not to enlarge the orifice too rapidly, but to allow the circulation time to accommodate to the relief of the obstruction.

The diameter of the surgeon's index finger at the proximal interphalangeal joint is just over 2 cm., and the valve orifice was now so near the mitral ring that it was thought to be unnecessary and unwise to incise the commissures. The finger was within the atrium for about 10 minutes—a much longer time than in any subsequent operation when familiarity with the local conditions had been gained. Whereas when first exposed the atrium was very tense, at the end of the valvulotomy the pressure within it was obviously very much lower. The heart's action was undisturbed by the manipulations except when the mitral orifice was completely blocked; the heart then reacted violently and the blood pressure fell towards zero, but recovery occurred as soon as the finger was removed from the valve.

We have not taken records of intra-atrial pressures before and after valvulotomy, because we wished to do nothing that was not strictly therapeutic in these earlier operations, when we were trying to assess what the heart could tolerate. In addition, with the chest open and many other factors causing a drop in pressures, the changes observed might not give an accurate picture.

Cardiotomy and relief of valvular stenosis has been done in eight patients; in two of these a cutting valvulotome was used, but in the others the valve was split with the finger. The actual operation was well tolerated by all. Two patients died—one on the day after operation, and the other four days after, following a haemorrhage complicating heparin therapy, which was unwisely begun 24 hours after operation because of a cerebral embolus; we believe that without the heparin she would not have lost her life. One other patient suffered a cerebral embolus (Case 1), but made a complete recovery.

Notes of the eight cases follow. To save space some details that are given in Tables I and II are not repeated in the text. The clinical picture has been given in more detail so that the reader can judge the type of case operated upon and the degree of improvement.

Case 1

Pulmonary symptoms for seven years and recurrent pulmonary oedema for three years; complete incapacity; normal rhythm. Good result of operation maintained for 20 months; able to walk three miles (4.8 km.) instead of 100 yards (90 metres).

This patient was 23 years old when seen in October, 1947. Dyspnoea was first noticed when she was 17 and working as a land girl; it increased steadily over the next six years. There was no history of congestive failure, but in the previous two years she had been admitted to her local hospital with attacks of "pneumonia." She was referred to us by Dr. E. D. Y. Grasby, of Pembury County Hospital.

The physical signs indicated mitral stenosis (see Table I). There were moist sounds at both bases, but no enlargement of the liver or systemic oedema. Cardiac catheterization showed an increase of pressure in the right ventricle and pulmonary artery (see Table II). Though it was thought that pulmonary oedema was probably the cause of such frequent attacks, an infective element could not be excluded, and it was decided to watch her to make sure she could not be improved by medical treatment.

During the next eight months her dyspnoea increased, and she had further attacks of "pneumonia" and lost another 13 lb. (5.9 kg.) in weight (to 89 lb.—40.4 kg.). She was not able to walk more than 100 yards (90 metres). She was never well enough to get up to the out-patient department, and when she finally came by ambulance in July, 1948, she was very much worse and was at once admitted to hospital.

She was breathless walking about the ward. She had a malar flush and cyanosis of the lips after exertion, but no congestive failure. At the apex there was a diastolic murmur typical of mitral stenosis, but no systolic; at the third left interspace a blowing systolic and diastolic murmur, thought to be evidence of pulmonary rather than aortic regurgitation, had appeared since she was last seen; the pulmonary second sound was loud and reduplicated.

Crepitations were heard all over the lungs, not confined to the bases as before. The heart had increased in size with blurred outlines; the vascular markings throughout the lung fields were more prominent than those usually seen in simple congestion. Both pulmonary branches were greatly dilated as in cases of

TABLE I.—*Clinical Data of Patients with Mitral Stenosis Submitted to Mitral Valvulotomy*

Case No.	Sex and Age	Duration of Dyspnoea	Duration of Pulmonary Oedema	Haemoptysis	Duration of Congestive Failure	Duration of Auricular Fibrillation	Apical Systolic Murmur*	Blood Pressure	Cardio-thoracic ratio
1	F 22	6 yrs.	3 yrs.	−	No	No	No	120/85	56%
2	F 36	10 ,,	Yes†	+	No	5 yrs.	No	110/70	60%
3	F 39	8 ,,	No	−	3 yrs.	3 ,,	Yes	115/75	68%
4	F 36	8 ,,	8 yrs.	+	1 yr.	1 yr.	Yes	100/70	64%
5	M 42	3 ,,	6 mths.	+	6 mths.	6 mths.	No	120/80	68%
6	M 31	2 ,,	Yes	+	No	3 ,,	Yes	102/74	51%
7	F 23	4 ,,	6 mths.	+	No	No	No	107/70	—
8	M 26	4 ,,	No	+	No	No	No	100/70	—

* All cases showed typical diastolic murmurs of mitral stenosis; all had accentuation of the pulmonary second sound. All had marked right axis deviation.
† Only when pregnant seven years previously.

TABLE II.—*Data Obtained by Cardiac Catheterization in Patients with Mitral Stenosis. Before and After Operation. The Figures in Parentheses Indicate the Results After Operation*

	Case 1*	Case 2	Case 3	Case 4*	Case 5*	Case 6	Case 8
Pressure in mm. Hg R.A.	16† (6)	10	11	7 (0)	12 (12)	3	12/0
Pressure in mm. Hg R.V.	68+ (23)	18	40	55/10 (35/0)	36 (65/13)	67/2	
Pressure in mm. Hg P.A.	68+ (40)	20·5‡	78	63/26 (35/10)	59 (70/30)	73/50§ (41/20)	130/78
Oxygen percentage—arterial	90·5 (96)	91	95	95 (94)	95 (95)	93·4	91
Oxygen saturation—mixed venous blood	45·5 (64)	43	49	54 (64)	53 (54)		44·7
Cardiac output in litres a minute	2·6 (3·3)	2·4	3·0	2·5 (3·3)	2·9 (2·7)	2·1‖ (2·3)	2·71¶

* Pre-operative figures 9 to 12 months before operation. † Reading may be too high owing to possible clotting in catheters. ‡ Pulmonary capillary pressure. § Rose to 100/78 on exercise. ‖ Rose to 2·6 on exercise. ¶ After exercise, 2·65.

atrial septal defect, but without pulsation. The right ventricle and left atrium were moderately enlarged in the oblique views.

Valvulotomy, September 16, 1948. Anaesthetist, Dr. Hutton. Thiopentone and curare with intratracheal cyclopropane and ether. Blood transfusion, 450 ml.

The findings inside the heart at operation in this case have already been detailed in the general description of the operation (see above). The general condition at the end of operation was good and the blood pressure was 95 mm. This continued for 48 hours, when she became drowsy with bilateral extensor plantar responses and a right-sided hemiplegia. Sir Charles Symonds diagnosed a succession of emboli to both middle cerebrals. A heparin drip was given for the succeeding eight days; there was no further extension and her hemiplegia gradually improved.

Her cardiac condition was remarkably good, the lungs remained dry, her pulse was steady at 80 by the fourth day, and her blood-pressure level gave no anxiety. For the first few days after operation no diastolic murmur at the apex was heard, though there was a roughish systolic murmur, but as her condition improved and her activity increased a low rumbling diastolic appeared. Her progress was steady and she was allowed to increase her exercise gradually until after five weeks she went up and down two flights of stairs without distress. Cardiac catheterization eight weeks after operation showed improvement. Mean pressures (measured from the skin of the back) and oxygen saturation figures are given in Table II. As will be seen, the cardiac output increased from 2.6 to 3.3 litres a minute.

The pre-operative pressures were probably much higher than those just before operation, as they were obtained almost a year before operation, when her condition had been much better.

The patient's subsequent course has been very encouraging. Two weeks after discharge from hospital she could walk half a mile (0.8 km.) slowly, climb stairs, and help in the house—which she estimated as equal to her capacity three or four years before operation. Six weeks after discharge she had walked a mile (1.6 km.) without symptoms, she had no cough, and was 7 lb. (3.2 kg.) heavier; the diastolic murmur was obvious, and the lung bases were clear.

Twenty months after operation she walked three miles (4.8 km.), her weight has increased by 14 lb. (6.4 kg.) and she is leading a normal quiet life at home.

Case 2

Severe disability with recurrent haemoptyses without right-sided congestive failure or gross enlargement. Successful valvulotomy, but cerebral embolism. Death from bleeding after heparin.

A married woman aged 36 was able to play some games at school, and later tennis, but was breathless compared with her friends. When she was 21 she began to notice breathlessness in her ordinary life, and at 26 she became much worse and had to be in bed for several months. When the war came she was able to work as an ambulance driver for a year.

In June, 1941, when she was 29 and was six months pregnant, she complained of severe nocturnal dyspnoea and coughed up some blood-stained sputum. Caesarean section and sterilization were performed in October, 1941.

From 1942 to 1945 she was worse and haemoptysis was frequent, lasting on and off for eight weeks in 1943, and returning two or three times a year. When seen in 1948, at the age of 36, she was very incapacitated and could hardly do any shopping or housework. She could walk only 200 yards (183 metres) and also complained of a tight feeling in the mid-sternum on walking, which was sometimes quite severe. The heart was a little larger—c.t.r. 60 (15/20 cm.); this being due to the right ventricle and left atrium. There was a long diastolic murmur and thrill and the diastolic murmur was heard up to the pulmonary area. Moist sounds could be heard in both lungs. The liver was not felt, and oedema of the ankles was not present. There was auricular fibrillation, but it was not easy to be sure when this had started—perhaps five years before.

Cardiac catheterization showed little if any increase of pressure in the right ventricle or pulmonary artery (see Table II).

Mitral valvulotomy, September 28, 1948. Anaesthetist, Dr. E. H. Rink. Thiopentone and curare, cyclopropane, and ether.

The pulmonary artery was large, prominent, and tense; the auricular appendage was large and was occupied by a thrombus from which an indurated area about 2.5 cm. in diameter extended on to the lateral wall of the atrium; a slight yellowish discoloration could be seen over it. A clamp was applied to the base of the appendage, which on being opened disclosed yellow organized clot. A finger was inserted, but the way seemed to be completely blocked; it was withdrawn, and inspection showed it had been inserted between the myocardium and the clot. It was now inserted medial to the clot, and entered the atrium and passed down to the valve at once. The opening in the valve was very small, no more than 0.75 by 0.4 cm.; an adhesion could also be felt as a strand across the orifice. The orifice was slowly and steadily split with the finger, both laterally and medially, until the finger passed through as far as the proximal joint. The edges of the opening were now so rigid that further splitting was not possible; the finger was withdrawn and reinserted carrying a valvulotome, with which an incision was made in the lateral commissure. The orifice was much enlarged by this and the finger could be moved freely about; the orifice seemed to be about 2.5 by 2 cm. The intracardiac manipulations lasted seven minutes and were well tolerated except for the usual reaction when the orifice was completely blocked.

The patient's general condition on return to bed was satisfactory. Later it became clear that cerebral embolism had occurred, no doubt from the disturbance of the clot in the auricular appendage. On the following day she was still drowsy but could speak; she had a left-sided facial paralysis, weakness of left conjugate deviation, paralysis in the left half of the tongue, and some choking on swallowing water; she moved the left arm and elbow but not the left wrist or hand; movements of the left lower limbs were diminished. Sir Charles Symonds diagnosed an embolism of a branch of the middle cerebral artery. After much discussion heparin was given by intravenous drip 24 hours after operation. Her general condition was satisfactory apart from the embolus; the pulse rate was 90.

The decision to give heparin proved unfortunate, because the next morning a large effusion was found in the left chest; 2.5 litres of fluid blood was removed, and it was clear that massive oozing had occurred. In spite of blood transfusion and other treatment she did not rally, and died four days after operation. If heparin had not been given we think she would not have lost her life.

Necropsy showed infarction in the right cerebral hemisphere. The operation site in the heart was satisfactory; the mitral orifice easily admitted the whole length of the index finger, and its edges were clean and smooth, with the exception of a thin fibrin deposit on the lateral commissure where the incision in the valve had been made. The medial commissure was very short, less than 1 cm., and it would not have been possible to enlarge the orifice much further in that direction.

Case 3

Auricular fibrillation with attacks of congestive failure for three years; pulmonary hypertension, but lung symptoms not prominent; loud apical systolic murmur suggesting mitral regurgitation; death 36 hours after operation.

A housewife aged 39, without children, had had dyspnoea for the past eight years, but she worked until the last three years, when this symptom increased suddenly with the onset of auricular fibrillation. After rest in bed and treatment with digitalis she resumed her housework and shopping, but movement was very limited through dyspnoea and oedema of the ankles, and she slept propped up at night. She gave no history of haemoptysis. She lost 14 lb. (6.4 kg.) in weight during these three years.

On admission she was thin and asthenic. Her complexion was sallow, with a malar flush; she had poor peripheral circulation, with cold extremities and a faint cyanotic tinge. The neck veins were prominent even when she was sitting. The liver was slightly enlarged and oedema of the feet could be elicited by prolonged heavy pressure. There was slow fibrillation. There was a Grade 3 blowing systolic murmur, maximal at the apex but heard over a circle 7.5 cm. in radius. Air entry was good, with no adventitious sounds at the bases. Cardioscopy showed a very large heart (15/22 cm.) due to the right ventricle, the left ventricle being of normal size; the left atrium was moderately enlarged. Calcification of the mitral valve was not seen. (See Tables I and II for physical signs and results of catheterization.)

Valvulotomy, January 17, 1949. Anaesthetist, Dr. E. H. Rink. Thiopentone and curare followed by cyclopropane and ether. Blood transfusion of 600 ml.

The pulmonary artery was as large as a normal aorta and under high tension; the left auricular appendage was large and prominent and also under high tension. During all intracardiac manipulations the left common carotid artery was compressed by the anaesthetist to lessen the chance of cerebral embolism. The mitral valve orifice was easily found; it was about 1 by 0.75 cm., and its margins were heavily calcified. The lateral commissure was slowly and progressively split quite easily until the mitral ring was reached; the medial commissure was not split. The index finger readily passed through the enlarged orifice. The finger was within the heart for about 10 minutes; the whole manœuvre was well tolerated and the heart showed no disturbance. The pressure in the left atrium was obviously reduced.

The post-operative course for the first 12 hours was encouraging, but the blood pressure failed to rise above 90/60 despite methedrine and intravenous fluids. Twenty-four hours after operation 15 oz. (425 ml.) of blood was aspirated from the left chest. The patient was conscious, but her blood pressure gradually fell and, despite a rate generally under 100, her pulse became feebler until she lost consciousness and died 36 hours after operation.

At necropsy the myocardium showed no gross evidence of disease. There was a moderate degree of tricuspid stenosis and a large atrium. Ante-mortem thrombus filled the left auricular appendage and extended as a thin strand on the divided lateral commissure of the mitral valve. The anterior cusp of the mitral valve revealed pronounced calcification extending on to the chordae tendineae and the atrial surface. The lungs showed typical brown induration, but were not oedematous, infected, or infarcted. The liver was enlarged, tawny, and cirrhotic, and there was a scar from an old infarct in the right kidney.

Case 4

Severe mitral stenosis with seven years of increasing pulmonary symptoms, including repeated cardiac asthma, and one year of right-sided failure and auricular fibrillation; completely incapacitated. Successful operation with no complications. Able to work and walk two miles (3 km.).

A nursery governess aged 35 was a children's nurse until the age of 23, when she found difficulty in doing a full day's work. When 27, breathlessness on exertion increased and she had her first attack of cardiac asthma. After three months' rest she worked for the next three years, but was more breathless on exertion. Her second attack of cardiac asthma occurred when she was 32 and she was admitted to hospital; this happened on five subsequent occasions for periods up to seven weeks in different parts of the country where she was employed. In the earlier admissions there seems to have been no right-sided failure, but in the summer of 1948 she was admitted with congestive failure. She then had auricular fibrillation, but the time of onset of this is not known, though digitalis had been taken intermittently over the previous three years. She was admitted to Guy's in February, 1949, having been seen at the National Heart Hospital by Dr. Paul Wood, who thought that operation on her mitral valve should be considered.

On admission, she was small and slightly built. She was orthopnoeic, but showed no venous congestion or oedema. There was cyanosis in lips, ears, and extremities. She became breathless after walking 10 yards (9 metres). She had auricular fibrillation. Radiologically the heart showed enlargement of typical mitral conformation, measuring 16/25 cm.; the left atrium was enlarged.

She improved while in hospital and was discharged; she was given mersalyl injections and digitalis to see if this improvement might be maintained without operation. She was, however, clearly unfit to resume her work as a nursery governess, or even to do any light work. She was most anxious that operation should be attempted, as she had no home and no one to look after her.

Valvulotomy, June 30, 1949. Anaesthetist, Dr. Carnegie. Thiopentone and intratracheal nitrous oxide, oxygen and ether. Intravenous saline, 600 ml.

The pulmonary artery was the usual huge tense structure; the pulmonary veins were also large and tense, as also was the left atrium; the auricular appendage was small and barely large enough to be used with safety.

The stenosed mitral orifice was located as soon as the finger entered the heart; it was rather less than 1 by 0.5 cm. and the valve cusps were surprisingly thin; the only obvious induration was around the edge of the orifice; there was no calcification. It was a simple matter to split both commissures across with the finger as far as the mitral ring. The new orifice was much larger than one finger; the mitral ring seemed to be of normal size. At the end of the operation the general condition was satisfactory and her colour was much better. She made a good and rapid recovery.

In late September, 1949, she was readmitted for cardiac catheterization. She had been able to push a perambulator with two children for two miles (3 km.) without distress. She had gained 7 lb. (3 kg.) in weight. There had been no oedema of the ankles, but she still slept with three pillows. She still had auricular fibrillation. There was a soft systolic and a doubtful mid-diastolic murmur at the apex; the pulmonary second sound was still increased. The heart was slightly decreased in size 14.5/25 cm., and the pulmonary conus looked slightly less prominent. Cardiac catheterization gave the following information, the pre-operative findings being given in parentheses.

	Right Atrium	Right Ventricle	Pulmonary Artery
Percentage oxygen saturation	65 (60)	64 (54)	64 (54)
Pressure in mm. Hg ..	0 (7)	35–0 (55–10)	35–10 (63–26)

Cardiac output, 3·3 litres per minute (2·5)

There was therefore a significant decrease in the pressures in the right ventricle and the pulmonary artery, and 0.8 litre a minute more blood was passing through the mitral valve at rest.

She left hospital and her condition was satisfactory enough to approve of her taking a position as a "nanny" to travel to South Africa and back. After eight months she was doing a full day's work without distress and was able to push a baby in a perambulator three miles (4.8 km.). There had been no return of cardiac asthma, and she had successfully surmounted a heavy winter cold.

Case 5

Late onset of symptoms of pure mitral stenosis, but rapid progress of lung symptoms and signs over three years; right-sided failure with onset of auricular fibrillation; successful operation with temporary return to normal rhythm; much improvement with return to full working day.

A man aged 41 was first seen in April, 1948. The first evidence of mitral stenosis was a large haemoptysis 18 months before, though he had been slightly breathless for six months. He changed from heavy to clerical work, but was troubled by increasing dyspnoea and cough. The rhythm was normal and the heart small for the degree of disability.

He was admitted to Guy's in September, 1948. He was a well-built athletic type of man. There was no cyanosis nor any evidence of venous engorgement nor oedema. His heart was slightly enlarged, with a prominent pulmonary conus and main branches, and a granular mottling of the lung fields; the right ventricle and left atrium were moderately enlarged. He was still able to earn his living as a clerk, being conveyed to and from his office in a friend's car; but in April, 1949, with the onset of auricular fibrillation his dyspnoea suddenly increased, there was more orthopnoea and oedema of the ankles, and his heart had increased in size from 17 cm. to 19/29 cm. He was admitted to hospital, where his congestive failure was relieved and his heart decreased in size (17.5/28.5 cm.); but a month after admission he had his first attack of cardiac asthma and an embolism involving one toe. He attempted to return to work, but it was beyond him, and in one month he had four more attacks of cardiac asthma and could sleep only sitting up. It was decided to operate before further deterioration occurred.

FIG. 7.—Showing valvulotomy performed along the line of the lateral commissure in Case 5, in which the medial commissure was calcified.

Valvulotomy, September 5, 1949. Anaesthetist, Dr. Carnegie. Thiopentone and curare, cyclopropane and ether. Intravenous saline, 1,200 ml. The general condition was very unsatisfactory during induction of anaesthesia, with rapid and irregular pulse rate as high as 180, which was slowed to 140 by the use of intravenous procaine solution.

The pulmonary artery was the usual huge tense structure. A large long appendix projected from the tense left atrium. The finger was introduced without difficulty and at once a powerful jet of regurgitant blood could be felt with each ventricular systole; this was noteworthy, as no systolic murmur had ever been heard. The mitral orifice (Fig. 7) was grossly calcified around its medial two-thirds in front, medially, and behind. Lateral to this calcification was a small rigid triangular orifice through which the blood could be felt to regurgitate. The edge of this part of the opening was slightly thickened, but the valve cusps were thin and the lateral commissure was easily split open as far as the mitral ring. Although regurgitant blood could still be felt it seemed less and the jet had lost its power. The most dramatic event was an immediate slowing of the heart, which was also felt to become more regular. Almost at once Dr. Reynolds, who had been taking electrocardiographic tracings, reported that auricular fibrillation had ceased. By the time the auricular appendage had been closed there was slight dissociation between the ventricular and atrial rates, which were about 120 and 110 (Fig. 8). A few minutes later Dr. Reynolds reported that normal sinus rhythm was established (Fig. 8).

The patient's general condition at the end of the operation was much better than at the start, and he had a good colour; his pulse was 120 and regular.

The return to normal rhythm within one minute of the relief of the obstruction (Fig. 8) was most dramatic. His post-operative course was remarkably smooth. The pulse rate was steady at 90 with sinus rhythm, and the blood pressure showed no tendency to fall. On the second day there were frequent auricular extrasystoles and on the third day auricular fibrillation returned. An apical systolic murmur had appeared at the apex, and for the first week no diastolic murmur was heard, though it returned later. He was up in two weeks, and six weeks after operation his heart was again catheterized. The findings are summarized in Table II (with the pre-operative findings of one year before in parentheses).

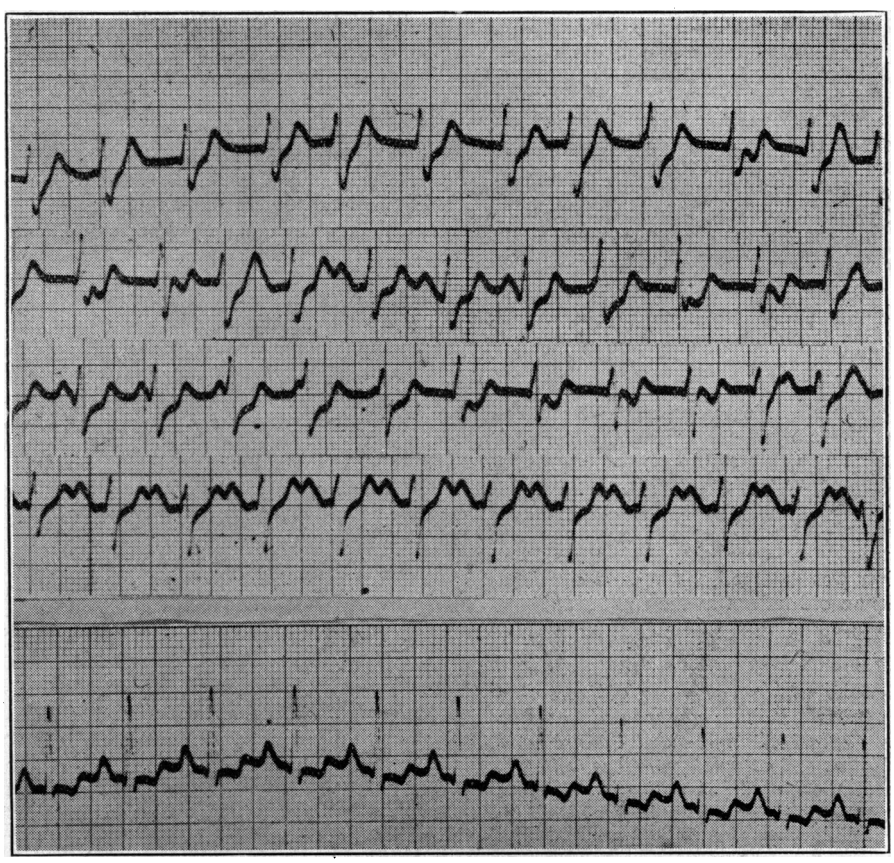

FIG. 8.—Showing the cessation of auricular fibrillation immediately after valvulotomy (Case 5). The upper curve shows auricular fibrillation with P waves appearing towards the end, though probably still with complete dissociation. In the second, third, and fourth curves, which were taken continuously, the P waves are present throughout and regular, but there is probably still complete dissociation until the fifth curve, where the relationship of P to QRS has become regular and there is a consistent response still with tachycardia. In the fifth curve, taken 40 minutes later, the rate is a little slower and the P waves are better separated from the T waves and show normal rhythm.

The cardiac output was 2.7 instead of 2.9 litres a minute. The pressure in the right ventricle and pulmonary artery was not greatly reduced—a disappointing finding in view of his striking clinical improvement.

He was discharged seven weeks after operation, and a fortnight later had walked a mile (1.6 km.) without discomfort, compared with his previous distress on walking about the ward. He was allowed to resume work and has continued since. Six months after operation his condition is satisfactory. He has walked a mile and a half (2.4 km.) without dyspnoea and feels he could do more; he sleeps with only one pillow and has had no further cardiac asthma; his colour is good, there is no oedema, and the lung bases are clear. There is no change in the size or shape of the heart on screening, though perhaps the pulmonary conus is less prominent: the mottled opacities in the lung fields are less marked.

	Right Atrium	Right Ventricle	Pulmonary Artery
Pressure in mm. Hg from skin of back	12 (12)	65–13 (30)	70–30 (59)

Case 6

Progressive dyspnoea and haemoptysis for two years. Auricular fibrillation. Severe pulmonary oedema and incapacity. Successful operation with immediate good result.

A draughtsman aged 31 had chorea and rheumatic fever as a child. He was seen in 1931 by Dr. Helen Taussig, and his heart was then normal. He continued under Dr. Taussig's observation, and it was due to her courtesy and to Dr. Alfred Blalock's that one of us was asked to operate on him and also upon Case 7 at the Johns Hopkins Hospital.

In 1932 he had acute rheumatism again, and after this a systolic murmur developed; in 1935 he had established mitral stenosis. Several more attacks followed, and he entered hospital for the last one in 1937. He continued fairly well for the next ten years and worked as a draughtsman. He was unaware of any marked limitations until about two years ago, when he began to lose ground steadily; he coughed almost all the time and often brought up blood. Dyspnoea on exertion became progressive, and he found it increasingly difficult to get to and from his work, which was a 20-minutes walk. For three months he had noticed occasional bouts of palpitation, which would last for a few hours (presumably auricular fibrillation). He could just manage to walk about the room.

He was admitted to the Johns Hopkins Hospital on October 4, 1949. He was thin and pale, slightly dyspnoeic at rest, and orthopnoeic. Auricular fibrillation was present.

The heart was enlarged, the apex beat being almost in the anterior axillary line in the fifth interspace; a diastolic thrill could be felt at the apex; a rumbling diastolic and a blowing systolic murmur were heard. The liver was not enlarged. Radiography showed a heart of typical mitral appearance, with some enlargement of the left atrium. Calcification of the mitral valve, 1 cm. in thickness, was reported to be present.

In view of his steady deterioration, especially during the previous two months, and his present severe disability which confined him to the room, operation was recommended and eagerly accepted by the patient.

Valvulotomy was carried out on November 17, 1949. He was anaesthetized slowly by Miss Olive Burger with cyclopropane and became rather apprehensive and struggled; thiopentone was then administered and an intratracheal tube was passed. Almost at once acute pulmonary oedema developed and his condition became grave. Venesection, 250 ml., was done, tourniquets were applied to his limbs, and he was given a further dose of atropine and morphine; all this time his bronchi were being sucked clear of oedema fluid. He improved considerably, and by the end of 30 minutes the pulmonary oedema had gone.

The difficult decision now had to be made whether to proceed with operation or not. After some deliberation it was decided to proceed, as it was unlikely he would be much better on a later occasion. Curare was given and anaesthetization proceeded with; before the operation began he had two more episodes of pulmonary oedema, though these were less severe. The pulmonary artery was enormous and under great tension; the left pulmonary veins were also large and tense, as also was the left atrium. The left auricular appendage was large; distortion of its surface and irregular thickening on palpation indicated thrombus formation. Fortunately the clamp could be applied proximal to this clot, as was confirmed when the auricle was opened; much clot was removed, most of it buffy in colour; portions were polypoid, white, and smooth.

When the finger was inserted into the atrium an obvious stream of regurgitant blood could be felt. The mitral orifice was at once located and was a small oval about 1 by 0.5 cm.; the lateral part was lightly calcified in a thin layer on the atrial surface and on the valve rim; this calcification was not enough to contraindicate division of the valve at this site. The valve split easily along the line of the lateral commissure as far as the mitral ring, and the opening was now large enough to admit the finger freely and loosely, being estimated at 3 by 2 cm. The medial commissure was palpated but could not be split with the finger.

His condition was satisfactory at the end of the operation and the lungs seemed quite dry; the blood pressure was 110/80 and the pulse, although irregular, was about 100.

He made a smooth recovery, with immediate improvement in colour and relief of orthopnoea. He left hospital and was able to do much more than before operation.

Case 7

Increasing dyspnoea for four years. Acute pulmonary oedema for six months. Normal rhythm with no general cardiac enlargement. Successful valvulotomy with immediate improvement

This patient, a married woman aged 23, was always active in sports. When she was 18 a routine examination disclosed the presence of mitral stenosis, and soon after this she began to notice slight dyspnoea on exertion. She married at 19, and while on her honeymoon tried to ride a bicycle and for the first time noticed real limitation of her activities from dyspnoea. Since then the dyspnoea steadily increased until she became short of breath on climbing one flight of stairs; she noticed brief, sharp pain occasionally on exertion. She had slept with two pillows for the last three years. During the last six months she had four episodes of typical acute pulmonary oedema with extreme dyspnoea and cough with frothy blobs of sputum; each attack lasted eight to ten hours and ceased suddenly. Two of these attacks were brought on by coitus. She continued working as a stenographer, but had noticed mild oedema of the ankles at the end of the day for the last few years.

She looked well but pale. The pulse was regular. On radiography the heart was not generally enlarged, although the left atrium was moderately enlarged; the pulmonary artery was large and prominent, as also was the infundibular portion of the right ventricle. The lungs showed increased markings suggesting chronic passive congestion.

Cardiac catheterization (Dr. Richard Bing) showed a moderate rise in pressure in the pulmonary artery and right ventricle with a sharp rise of pressure on exercise and a fall in cardiac output.

Because of her recent deterioration with several attacks of acute pulmonary oedema a right-to-left venous-shunt operation had been suggested. Dr. Sanford, however, asked for valvulotomy, and this was agreed to and accepted by the patient.

Valvulotomy, November 26, 1949. Anaesthetist, Miss Olive Burger. The whole procedure went very smoothly; the mitral valve showed the typical contracted oval orifice about 1.5 by 1 cm.; it was split towards both commissures without difficulty, so that the finger passed through freely and easily. Recovery was uneventful and the patient was discharged from hospital in good condition. It is as yet too early for a full progress report.

Case 8

Steady deterioration for nine years; further deterioration during two years of observation. Severe dyspnoea on exercise, 20 yards (18 metres) being the limit in comfort and 150 yards (137 metres) absolute maximum. Severe pulmonary hypertension. Successful operation.

A clerk aged 26 had rheumatic fever at the age of 4 and mitral stenosis was diagnosed in 1938. In 1942 he had a haemoptysis. Radiographs showed very large pulmonary vessels and also scattered markings and calcified areas suggesting haemosiderosis. He led a very restricted life, being unable to run, and could walk only about 20 yards before becoming very breathless; 150 yards was his absolute maximum. The pulse was regular.

Valvulotomy, March 2, 1950. Anaesthetist, Dr. Hutton. Thiopentone, curare, nitrous oxide, and oxygen. The mitral orifice was a small narrow oval measuring about 1 by 0.4 cm.; the whole mitral ring was small, measuring little more than 3 cm. The lateral commissure was split with the finger to within 0.5 cm. of the mitral ring and the division completed with a valvulotome. The medial commissure was split with the finger. The operation was well tolerated.

Auricular fibrillation developed on the third day after operation, but was controlled by digoxin, and recovery was then rapid and uneventful. The operation is too recent for assessment of the final result.

Discussion

In the trial period of all major and potentially dangerous operations it is rarely possible to choose the ideal case. It is unfortunate, but true, that difficult surgery has often to be worked out first on the more advanced cases in which the risk of operation is greater and the chance of a good result smaller. Although our experience is limited it is enough to show that direct operation on the stenosed mitral valve is justifiable and helpful. It should now be recommended in suitable cases before they have deteriorated too far.

Ideally the most suitable case is a young adult with established mitral stenosis, without evidence of recent rheumatic infection or symptoms to indicate that failure is imminent.

We feel that it is wrong to attempt operation on middle-aged patients with gross cardiac enlargement and chronic heart failure. Many of these are beyond hope of relief by valvulotomy, but with greater experience it may prove possible to submit some of them to operation. Case 3, for example, tolerated the operation well, but after a promising first 24 hours forward failure overcame her : the large heart and the presence of a systolic murmur were pre-operative danger signals ; some degree of tricuspid stenosis, undiagnosed in life, and cardiac cirrhosis, which should have been suspected, were additional posthumous contraindications.

It will be seen from our cases that the various adverse factors mentioned earlier are not absolute contraindications ; some degree of them may have to be accepted ; it is the advanced degree of these changes that counts against operative success. Those that need special mention are gross cardiac enlargement, of the right ventricle because it foreshadows failure, or of the left ventricle because it may indicate aortic regurgitation or free mitral regurgitation ; aneurysmal dilatation of the left atrium ; gross enlargement of the pulmonary artery ; gross secondary vascular changes within the lungs shown radiologically ; severe pulmonary hypertension observed by catheterization ; and continued congestive heart failure. One attack of mild congestive failure is no bar to operation, as is shown by Cases 4 and 5.

In contrast, we prefer the heart that is not much enlarged and without evidence, indirect or direct, of gross pulmonary hypertension. Auricular fibrillation is undesirable, but it is in itself no contraindication, though it increases the risk of intra-auricular thrombosis. In fact, the onset of fibrillation, like the onset of congestive failure, may serve as a stimulus to make the decision in favour of operation.

Attacks of recurrent " bronchitis," cardiac asthma, and pulmonary oedema (Cases 4, 5, 6, and 7), particularly in a case with little increase of heart size, are strong indications for considering operation. This group of " oedematous mitral stenosis " with regular rhythm, without great enlargement of the left atrium, and without oedema of the legs, was clearly defined by Gallavardin (1921, 1934), and it is this type that shows the advanced pulmonary vascular changes described by Parker and Weiss (1936). The development of pure mitral stenosis in its early stages and its clinical course have been described by Walsh, Bland, and Duckett Jones (1940) among the large group of well-observed cases of rheumatic heart disease in Boston, and they found that the course was generally mild and the prognosis relatively good. This is, however, by no means the rule, and some of these patients with pure stenosis and rapidly progressive lung symptoms and signs are much more incapacitated than those who show a slower progression from passive congestion in the lungs to right-sided failure, often ushered in by auricular fibrillation. They present as lung failure rather than heart failure, their prognosis is poor, they respond poorly to medical treatment, and they often die from acute pulmonary oedema.

It is in this type with clinically pure and pathologically tight mitral stenosis that surgery is most indicated, for the lungs are mechanically gripped between the compensating force of a hypertrophied right ventricle and the increased pressure in the obstructed left atrium ; the heart muscle is good, and it is primarily the stenosed valve that is at fault. Such cases have been selected for the venous-shunt operation ; they are much more likely to get lasting improvement from mitral valvulotomy. The shunt operations that create a right-to-left venous fistula are certainly no less severe operations than valvulotomy ; they offer no more than symptomatic relief, and do nothing to relieve the valvular obstruction and impaired efficiency of the right heart. Our successful cases all had these severe pulmonary episodes.

Recurrent severe haemoptysis may also be an indication for operation. Haemoptysis in mitral stenosis may be due to pulmonary embolism, most often associated with auricular fibrillation and failure. In cases without pulmonary infarction and with normal rhythm it may be an indication of the " cardiac lung." Massive haemoptysis may occur through rupture of dilated bronchial vessels which may be found in the pulmonary hypertension of mitral stenosis, or may be associated with attacks of pulmonary oedema due to left atrial failure (Bramwell and Jones, 1944). That it indicates a poor prognosis in cases of mitral stenosis without large hearts was shown by Wolff and Levine (1941) ; this stresses its importance as a symptom for considering surgery. In Case 5 it was the first indication of mitral stenosis, and was a feature of five of our eight cases.

Naturally, the degree of disability will be one of the main criteria in deciding if the risk of operation is justifiable. The younger patient is more likely to be suitable, provided recurrent or smouldering rheumatic carditis is absent. We have, however, operated successfully on one patient aged 42 and one aged 36 ; sometimes the older patients have been well compensated until recently—for example, the man aged 42 (Case 5) whose symptoms had been present for only three years.

The information obtained by cardiac catheterization is of great importance (see Table II). The changes following moderate exercise should also be measured. Thus Case 6 showed a rise in pulmonary arterial pressure after exercise (100/78 mm. Hg) even though the pressure had been high at rest (79/44 mm. Hg) ; his cardiac output on exercise rose only from 2.2 to 2.8 litres a minute. In Case 7 the pulmonary pressure was moderately raised at rest but rose sharply after exercise, with a fall in cardiac output.

Changes in these data after mitral valvulotomy should provide valuable information. Apart from the clinical improvement that follows operation it is important to study the changes that can occur in the secondary pulmonary hypertension. If this can be lowered and kept low by operation it will say much for the success of valvulotomy. If it remains high the later results of the operation will be disappointing.

It is in cases such as Case 7, in which the resting pressure in the pulmonary artery is low but there is a sharp rise

after exercise, that we can expect the best results. Such a finding is an indication for operation, since a permanent rise in pulmonary pressure is likely unless the mitral obstruction is relieved.

We feel that the immediate good results in all the six successful cases and the maintenance of the good result in those which have been followed up for the longer times show that the operation is fully justified. It has been well tolerated even in those who were bad risks (Cases 1, 4, 5, 6, and 8). The evidence provided by this experience is as yet small, but it is large enough to justify recommending and performing the operation in other selected patients.

Summary

The attempts of 25 years ago to relieve mitral stenosis by direct operation upon the valve were followed by such bad results that the procedure fell into disfavour. The great advances in thoracic surgery since then, and the recently demonstrated feasibility of direct operation upon the pulmonary valves of the heart, have pointed to the time being ripe for reconsideration of this important problem.

From a large number of patients with mitral stenosis careful selection has been made of eight who were seriously incapacitated and deteriorating. These eight have been submitted to mitral valvulotomy, with six successes and two deaths. The first was operated upon in September, 1948.

Direct relief of the valvular obstruction has been preferred to the various indirect methods, usually some form of venous shunt. These indirect operations aim only at symptomatic relief and are at least as severe as valvulotomy, which aims at achieving some degree of cure.

The valve is better approached through the left auricular appendage than through the left ventricle.

The contraction of the stenosed valve is discussed and the importance of enlarging the opening along the line of the commissures is demonstrated. In this way it is possible, in addition to increasing the opening, to reconstruct, in some degree, two valve flaps; these by virtue of their increased mobility are not likely to encourage regurgitation, but may even reduce it. The manipulations are well tolerated and in most cases the valve can be split with the finger, or the finger can be used to carry a valvulotome.

The most suitable cases are those with pure mitral stenosis and a reasonably good myocardium, with progressive lung symptoms and signs, but before pulmonary hypertension is too far advanced.

Contraindications are rheumatic activity or the likelihood of this, associated aortic regurgitation or much mitral regurgitation, gross enlargement of the heart or of the left atrium, or auricular fibrillation or congestive failure, when these are of long standing.

Cardiac catheterization gives valuable help in the assessment of these patients, especially as regards the pressure in the pulmonary artery and the changes in this and in cardiac output, with and without exercise, before and after operation.

The six survivors have all been much improved and have been able to walk farther and do more without provoking cardiac asthma or pulmonary oedema; some have already returned to work that they could not manage before.

The results in this small series are good enough to show that valvulotomy for mitral stenosis is a thoroughly practical procedure and can now be justifiably recommended in suitable cases.

Only patients with a grave outlook have so far been selected, but the encouraging results make us hope that surgery may be indicated in some less advanced cases.

[Since this paper was written another successful case has been operated on for Dr. Paul Wood. The patient, a woman aged 34, had severe secondary pulmonary hypertension. This makes a total of nine cases with seven successes.]

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PHARMACOLOGY OF D-O.O-DIMETHYL TUBOCURARINE IODIDE IN RELATION TO ITS CLINICAL USE

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The preparation from D-tubocurarine of its dimethyl ether, D-O.O-dimethyl tubocurarine iodide, was first described by King (1935). In recent years a number of workers have investigated the properties of this compound in experimental animals, and several groups of authors have reported its administration to man (Marsh *et al.*, 1948; Stoelting *et al.*, 1948; Pelikan *et al.*, 1950; Wilson *et al.*, at p. 1296 of this issue).

TABLE I.—*Ratio of Potency of* D-*O.O-dimethyl Tubocurarine Iodide to* D-*Tubocurarine Chloride*

Reference	Mouse	Rat	Guinea-pig	Rabbit	Cat	Man
Dutcher (1946) ..				9 (HD)		
Glock *et al.* (1948)	0·5 (LD)	3 (LD)	2 (LD)	9 (LD)		
Collier *et al.* (1948)	0·7 (RR50)	4 (RR50)		10–11 (RR50)		
Marsh *et al.* (1948)		8 (LD50)		7·5 (HD)	7 (SG)	5 (HD)
Swanson *et al.* (1949)	0·6 (LD50)	5 (SG)		8 (HD)	5–7 (SG)	
Pelikan *et al.* (1950)	0·7 (LD50)			8 (HD)	6·5 (RR)	2·3 (GD)

HD = Head-drop; GD = decline in grip strength; LD = lethal dose; RR = loss of righting reflex; SG = sciatic-gastrocnemius preparation.

As will be seen from Table I, which summarizes results in the published literature, D-dimethyl tubocurarine iodide is considerably more active than D-tubocurarine chloride in all mammals tested, except the mouse.