Haemodynamics after mitral valvotomy

Reasons for unsatisfactory clinical results

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Right and left ventricular haemodynamics were analysed in 54 patients (43 women, 11 men) with pure or predominant mitral stenosis before and 34 to 40 months after valvotomy. The patients were divided into 3 groups: pure mitral stenosis without increased pulmonary vascular resistance (group I, $n=33$), pure mitral stenosis with abnormal increase of pulmonary vascular resistance (group II, $n=12$), and predominant mitral stenosis with mild insufficiency (group III, $n=9$; all patients undergoing additional annuloplasty). In all 3 groups operation was followed by a significant decrease in mean left atrial pressure, a and v wave, and mean pulmonary artery pressure. A significant increase in cardiac index was observed only in group II, accompanied by a significant decrease of the raised pulmonary vascular resistance to almost normal levels. Effective working capacity (bicycle ergometry) increased for all 3 groups; yet this was significant only for groups I and III. The mild postoperative resting gradient with an average of less than 6 mmHg, observed in almost all patients, was not related to unsatisfactory clinical results which were found mainly in patients with mitral valve calcification (5 of 15 patients not improved), whereas latent myocardial insufficiency or severe pulmonary hypertension was of lesser importance, as well as mitral restenosis (1 patient) or valvotomy combined with annuloplasty. Thus, closed valvotomy still seems indicated for the majority of patients with pure mitral stenosis, even those with severe pulmonary hypertension. In the presence of moderate or extensive calcification, preference should, however, be given to mitral valve replacement.

The significantly higher survival rate of patients with severe mitral stenosis undergoing mitral valvotomy than of those who were not operated on is generally accepted today (Rowe *et al.*, 1960; Kawai and Ogata, 1962; Ellis and Harken, 1964). The reasons for improvement were shown by various postoperative haemodynamic studies (Basu and Gupta, 1962; Hugenholz *et al.*, 1962; Werkö, 1964; Granath, 1965; Feigenbaum, Linback, and Nasser, 1968). In contrast, the causes for unsatisfactory results, based on a comparison between postoperative clinical symptoms and haemodynamics, are still not fully defined or clearly understood (Harken *et al.*, 1961; Kay *et al.*, 1964; Irmer, Obladen, and Delfino, 1966; Kitchin and Turner, 1967; Gobel *et al.*, 1969). Furthermore, the improvement in valve replacement, i.e. the continuing reduction of operative mortality and postoperative complications through the use of more advanced types of prostheses (Björk, 1971; Starr, 1971), necessitates a re-evaluation of

the indications especially of closed mitral valvotomy.

Patients and methods

One hundred and eighty-seven patients with pure or predominant mitral stenosis were operated on from 1961 to 1968 at the Department of Surgery of the University Hospital, Zürich, Switzerland (Professor A. Senning). The following investigation is based on the results of 54 patients (43 women and 11 men), 43 of them undergoing closed mitral valvotomy with the Dubost-dilator; in 2 cases digital commissurotomy was performed. Furthermore, in 9 patients – with concomitant mild mitral regurgitation – in addition to valvotomy an annuloplasty was done. The 54 patients undergoing postoperative catheterization were re-examined because of clinically unsatisfactory results or discrepancies between objective clinical signs and subjective symptomatology. All patients were submitted to a preoperative right, and half of them to an additional left, heart catheterization.

The patients were divided into three groups according to their preoperative haemodynamics.

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Group I (n=33): pure mitral stenosis without increasing pulmonary vascular resistance.
Group II (n=12): pure mitral stenosis with increase in pulmonary vascular resistance of more than 230 dyn sec cm⁻⁵.
Group III (n=9): combined mitral valve disease with predominant stenosis. (Predominant or pure mitral regurgitation has not been included in this study.)

The clinical classification has been made in accordance with the criteria of the New York Heart Association (1953).

Haemodynamic studies Before operation, all patients were submitted to a right heart catheterization, an additional retrograde left heart catheterization was performed in 22 cases; 10 patients underwent transseptal left atrial catheterization. Postoperatively, right heart as well as transseptal and retrograde left heart catheterizations were performed in 48 patients in order to assess the postoperative mitral valve gradient. A typical example is shown in Fig. 1. Six patients were submitted to right heart catheterization only. For pressure measurements Statham P23Db strain gauge transducers were used, the zero reference point being set 5 cm below the sternal angle.

FIG. 1 Pre- and postoperative mitral valve gradient in a patient undergoing closed mitral valvotomy. Five months postoperatively a mild residual gradient is present. Abbr.: *m diast. Gr.* = mean diastolic gradient, *LA mean* = left atrial pressure.

TABLE I Pre- and postoperative haemodynamics in patients undergoing closed mitral commissurotomy

Age	mLA (mmHg)	a- mmHg	v- mmHg	HR min ⁻¹	CI (l./m/m ²)	SVI (ml/m ²)	mPA (mmHg)	mAo (mmHg)	mRA (mmHg)
Group I: Pure mitral stenosis without increase in pulmonary vascular resistance (33 patients)									
Preop.	37.6	21.5	28.6	25.0	79.8	3.07	39.5	28.0	87.5
	± 9.1	± 5.1	± 5.6	± 8.4	± 15.9	± 0.57	± 10.6	± 6.3	± 9.5
Postop.	40.7	9.9	16.4	16.4	75.0	3.20	44.0	19.2	96.5
	± 9.4	± 5.0	± 4.8	± 8.6	± 13.9	± 0.57	± 10.0	± 4.9	± 18.2
Difference		-11.6	-12.2	-8.6	-4.8	+0.13	+4.5	-8.8	+9.0
P <		0.0005	0.0005	0.0005	NS	NS	0.05	0.0005	0.005
Group II: Pure mitral stenosis with abnormal rise of pulmonary vascular resistance (more than 230 dyn) (12 patients)									
Preop.	38.2	24.0	30.6	29.7	78.5	2.07	27.8	40.4	92.3
	± 10.9	± 6.5	± 3.8	± 8.0	± 19.2	± 0.33	± 5.7	± 12.4	± 17.8
Postop.	41.2	13.5	22.0	18.6	74.0	2.78	36.6	25.1	102.8
	± 11.2	± 5.7	± 5.2	± 8.3	± 12.2	± 0.60	± 6.7	± 8.7	± 11.2
Difference		-10.5	-8.6	-11.1	-4.5	+0.71	+8.8	-15.3	+10.5
P <		0.0005	0.01	0.0025	NS	0.005	0.005	0.0005	0.05
Group III: Combined mitral valve disease with predominant stenosis and minimal insufficiency (9 patients)									
Preop.	41.5	24.8	—	34.4	81.6	2.70	33.2	36.3	98.3
	± 9.1	± 6.4	—	± 12.6	± 18.0	± 0.62	± 7.1	± 12.2	± 14.9
Postop.	43.8	12.9	—	21.2	75.0	2.60	35.1	25.7	97.3
	± 9.6	± 4.7	—	± 7.5	± 11.5	± 0.48	± 8.9	± 6.4	± 20.2
Difference		-11.9	—	-13.2	-6.6	-0.10	+1.9	-10.6	-1.0
P <		0.005	—	0.025	NS	NS	NS	0.01	NS

mLA = mean left atrial pressure, HR = heart rate, CI = cardiac index, SVI = stroke volume index, mPA = mean pulmonary artery pressure, mAo = mean aortic pressure, PVR = pulmonary arteriolar vasc. resistance, SVR = arteriolar systemic vasc. resistance, Work cap. = working capacity (bicycle ergometry).

Cardiac output was determined by the Fick principle, oxygen saturation being assessed both by Haldane principle and oximetry (American Optical) as well as gas chromatography. Oxygen uptake was registered by a Godard-spirometer. Cardiac index, stroke volume index, arteriolar pulmonary and peripheral vascular resistance were calculated in the usual way. In order to study the anatomy of the mitral valve and to show the presence or absence of mitral insufficiency, cineangiography of the left ventricle and left atrium was performed in 5 pre- and 21 postoperative patients.

Ergometry Thirty-eight patients underwent pre- and postoperative bicycle ergometry. This involved the use of two levels of work load, each lasting for 5 minutes, assessing the effective working capacity at a pulse rate of 170/min (Sjöstrand, 1960). The values of the working capacity were compared with those obtained from the normal population matched for age, sex, and height (Bühmann, 1965).

Results (Fig. 2 and 3, Table 1)

Group I: pure mitral stenosis without increase in pulmonary vascular resistance This group includes 33 patients with a preoperative average age of 37.6 years, postoperative catheterization being performed

FIG. 2 Pre- and postoperative clinical classifications according to the New York Heart Association standardisation. MS = pure mitral stenosis; MS + PH = pure mitral stenosis and abnormal elevation of pulmonary vascular resistance to more than 230 dyn sec cm^{-5} ; MS > MI = mitral stenosis with mild regurgitation, necessitating in addition to valvotomy and annuloplasty.

at an average of 34 months after closed valvotomy. According to the New York Heart Association classification, 14 patients belonged preoperatively to class II, 17 to class III, and 2 to class IV (Fig. 2). Postoperatively, 1 patient improved by three classes, 8 by two classes, and 19 by one class. Five patients remained unchanged. Postoperative haemodynamics (Fig. 3) showed a significant decrease in the mean left atrial pressure by 11.6 mmHg, i.e. from 21.5 to 9.9 mmHg; the left atrial a wave was reduced by 12.2 mmHg and the v wave by 8.6 mmHg. Further, there was a reduction in the mean pulmonary pressure by 8.8 mmHg and from 28 to 19.2 mmHg ($P < 0.0005$). In addition, a small, yet significant increase in mean aortic pressure (+9 mmHg) and stroke volume index (+4.5 ml/m²) could be observed, corresponding to a rise in working capacity from a preoperative value of 81.5 watts (504 kg m/min) (61% of the expected value) to 112.1 watts (698 kg m/min) (88% of the expected value) ($P < 0.005$). Heart rate, cardiac index, mean right atrial pressure, pulmonary, and peripheral vascular resistance remained essentially unchanged.

Group II: pure mitral stenosis with an abnormal rise in arteriolar pulmonary vascular resistance (greater than 230 dyn/sec cm^{-5}) The mean preoperative age of the 12 patients of this group was 38.2 years, and catheterization was performed 32.5 months after operation. Preoperatively,

PVR (dyn sec cm^{-5})	SVR (dyn sec cm^{-5})	Effective work cap. (watts)	Calculated work cap. (watts)
126.3 ± 46.9 142.7 ± 67.4 + 16.4 NS	1409 ± 266 1420 ± 374 + 11.0 NS	81.5 ± 31.9 112.1 ± 34.7 + 30.6 0.0005	133.9 ± 28.8 128.5 ± 30.6
384.3 ± 231 235.2 ± 16.0 - 149.1 0.01	2140 ± 579 1709 ± 309 - 431 0.025	60.0 ± 18.9 74.4 ± 19.9 + 14.4 NS	130.0 ± 24.5 126.7 ± 26.9
230.0 ± 128.9 235.4 ± 139.6 + 5.1 NS	1713 ± 439 1702 ± 374 - 11 NS	68.3 ± 19.1 95.8 ± 28.5 + 27.5 0.01	117.5 ± 20.2 114.1 ± 17.4

FIG. 3 Pre- and postoperative haemodynamics. LA=mean left atrial pressure, CI=cardiac index, SVI=stroke volume index, HR=heart rate, work cap.=working capacity, PA=mean pulmonary artery pressure, Ao=mean aortic pressure, RA=mean right atrial pressure, PVR=arteriolar pulmonary vascular resistance, SVR=arteriolar systemic vascular resistance, LV syst.=systolic left ventricular pressure, LVED=left ventricular end diastolic pressure. Other abbreviations as in Fig. 2.

4 patients were classified in New York Heart Association class II, 5 in class III, and 3 in class IV. Postoperatively, 2 patients improved by two classes, 8 by one class, and 2 remained unchanged (Fig. 2). Pre-operative arterial pulmonary vascular resistance averaged 384 dyn/sec cm⁻⁵, with a range from 230 to 1060 dyn/sec cm⁻⁵. Arteriolar pulmonary vascular resistance diminished from 384 to 235 dyn/sec cm⁻⁵, and 149 dyn, with a maximal decrease from 1060 to 441 dyn. In addition, a decrease in mean pulmonary artery pressure from 40.4 to

25.1 mmHg (-15.3 mmHg) could be observed ($P < 0.05$) (Fig. 4). Mean left atrial pressure again showed a significant reduction by 10.5 mmHg, the a wave was reduced by 8.6 and the v wave by 11.1 mmHg (Fig. 3); this was accompanied by a significant increase in stroke volume index (+8.8 ml/m²), cardiac index (+0.7 l./min/m²), and mean aortic pressure (+10.5 mmHg) ($P < 0.05$). The average working capacity increased from a pre-operative value of 60 watts (372 kg m/min) (46% of the expected value) to a postoperative value of 74 watts (461 kg m/min) (59% of the

expected value). This increase was, however, statistically not significant.

Group III: Combined mitral valve disease with predominant stenosis (mitral commissurotomy and annuloplasty)

The mean preoperative age of these 9 patients amounted to 41.5 years; 3 patients were preoperatively classified into class II, 4 into class III, and 2 into class IV (Fig. 2). Two patients improved by two classes, 5 by one class, while the condition of 1 patient remained unchanged and that of another deteriorated. The postoperative haemodynamic follow-up (Fig. 3) demonstrated again a significant decrease of the mean left atrial pressure by 11.9 mmHg, of the v wave by 13.2 mmHg, and of the mean pulmonary artery pressure by 10.6 mmHg. Heart rate, stroke volume index, cardiac index, mean right atrial pressure, mean aortic pressure, as well as pulmonary and peripheral arterial vascular resistance remained essentially unchanged. Working capacity increased significantly from

68.3 watts (423 kg m/min) (58% of the expected value) to 95.8 watts (594 kg m/min) (48% of the expected value) ($P < 0.01$).

Discussion

In general, patients with severe mitral stenosis undergoing closed mitral valvotomy present a good correlation between postoperative clinical improvement, increase in effective working capacity, and postoperative haemodynamics. However, in the presence of unsatisfactory haemodynamic and clinical results, all factors responsible for failure should be carefully analysed in order to re-evaluate the indications for closed or open instrumental valvotomy and valve replacement. This seems of primary importance due to the remarkable improvement recently achieved in the development of artificial valves or homografts (Björk, 1971; Ionescu, 1971; Starr, 1971). Thus, in contrast to other studies, in the present investigation including 54 of 187 patients submitted to mitral valvotomy, re-

FIG. 4 Pre- and postoperative pulmonary vascular resistance and mean pulmonary artery pressure in patients of group II (abnormal elevation of PVR). (The patient decreasing from 1000 to 400 dyn sec cm^{-5} is not included in the average changes of Fig. 3 and Table 1) Abbr. as in Fig. 3.

examination was undertaken only when special indications were present. The reasons for recatheterization therefore were the following: (1) the presence of a clinical symptomatology suggesting an unsatisfactory result, accompanied by corresponding findings at bicycle ergometry, mechanography, or chest x-ray, and (2) a discrepancy between the postoperative subjective symptoms and the objective signs as revealed by the above-mentioned examinations. Thus, though 83 per cent of these patients showed clinical improvement of one or more classes according to the New York Heart Association criteria, the study was outlined to analyse the factors responsible for failure rather than to give an overall view of the haemodynamic changes after closed valvotomy. For the same reasons, the investigation includes a small group of patients suffering from mild mitral insufficiency in addition to severe stenosis, submitted not only to instrumental valvotomy, but also to annuloplasty and open commissurotomy.

The significant decrease or return to normal of mean left atrial pressure at rest, and the increase in calculated mitral valve area (average postoperative mitral valve area in 20 patients being 2.1 cm^2), accompanied by a significant reduction of mean pulmonary artery pressure and a considerable increase in the working capacity as assessed by bicycle ergometry, represents the most striking haemodynamic improvement seen in this study. These findings agree with those of other investigators (Basu and Gupta, 1962; Werkö, 1964; Kay *et al.*, 1964; Granath, 1965; Feigenbaum *et al.*, 1968; Gobel *et al.*, 1969). However, it seems that success or failure of instrumental mitral valvotomy is not primarily dependant on the normalization of the mean left atrial pressure; this is shown by the fact that in 7 patients mean left atrial pressure was decreased significantly without any clinical improvement (Fig. 5). In addition, there was no significant difference between the postoperative mean left atrial pressure of various clinical classes in all three groups. Furthermore, closed instrumental mitral valvotomy led to a complete restoration of left atrial haemodynamics in only a few cases, the great majority of patients revealing a small residual postoperative diastolic gradient, averaging 5.6 mmHg at rest. This has to be attributed to the operative technique, tolerating a somewhat incomplete opening of the mitral valve in order to avoid haemodynamically relevant mitral insufficiency (Fig. 1). Minimal residual mitral stenosis seems, however, not to be the cause of an unsatisfactory clinical result, as is shown by the

Clinical improvement in relation to LA pressure

FIG. 5 Pre- and postoperative clinical classification according to criteria of the NY Heart Association in relation to mean left atrial pressure. Abbreviations as in Fig. 2 and 3.

significant increase in working capacity, especially in patients with pure mitral stenosis without complications (group I), achieving an average of 90 per cent of the working capacity of the normal control group. Thus, the reasons for unsatisfactory improvement after mitral valvotomy – as suggested by this study – are briefly analysed.

(1) **Mitral restenosis** (Fig. 6 and 7) Mitral restenosis seems to occur rarely when the

diagnosis is based upon repeated left atrial catheterizations and assessments of mitral valve gradients (Fig. 7). Hence, no correlation was found between the level of postoperative mean left atrial pressure and the time interval between operation and haemodynamic re-evaluation (Fig. 6), the correlation factors being insignificant for each group ($r=0.1-0.3$). If restenosis were of relatively frequent occurrence – as suggested by earlier studies (Keith *et al.*, 1963) – a rise in postoperative mean left atrial pressure with increasing length of the postoperative interval might be expected. Based on the present results, true mitral restenosis therefore seems only rarely to be the cause for a lack of clinical improvement, a finding that is in agreement with an extensive survey from the American College of Chest Physicians; they observed restenosis in only 2.8 per cent of 8638 patients submitted to mitral commissurotomy (1959). Other investigators confirmed this observation (Harken *et al.*, 1961; Belcher, 1960; De Jesus, Breneman, and Keyes, 1962; Likoff, 1963; Logan, Lowther, and Turner, 1962; Wilhelmsen *et al.*, 1962; Harley, 1965; Irmer *et al.*, 1966).

(2) **Minimal mitral regurgitation, associated with severe stenosis** Sixteen patients presented before operation with trivial mitral regurgitation without haemodynamic significant changes, as observed by left ventricular cineangiography, dye dilution curves, or during operation. As a result of angiography and/or dye dilution studies, 27 patients showed minimal mitral regurgitation after operation (16 patients in group I, 4 in group II, 7 in group III). Thus postoperative mitral insufficiency seems to be of no haemodynamic significance for most of the patients; this is seen by the considerable postoperative decrease of the v wave in group I and group II ($P<0.005$ and 0.01). Annuloplasty was thought to be necessary in only 9 patients (group III) to correct additional mitral insufficiency. The mean left atrial pressure and v wave decreased significantly for 7 of the 9 patients, all of these patients being clinically improved (Fig. 5 and 6). The haemodynamic success of annuloplasty was further shown by the significant increase in working capacity during bicycle ergometry. The situation is, however, different in the presence of mitral regurgitation acquired during valvotomy, this

FIG. 6 Pre- and postoperative mean left atrial pressure, correlated to the postoperative interval (r =correlation factor between left atrial pressure and postoperative years). Abbreviations as in Fig. 2 and 3.

Correlation between mean postop. pressure and postop.interval

being the case for two patients in this study (one belonging to group I and the other to group II); both patients remained clinically unimproved. The incidence of 4 per cent of postoperative mitral insufficiency after instrumental valvotomy is in agreement with earlier findings (Granath, 1965). Thus, only in a few cases is the operative result jeopardized by postoperative mitral insufficiency, even in the presence of mild preoperative regurgitation.

(3) Abnormal increase in pulmonary vascular resistance Though an abnormal increase in pulmonary vascular resistance is not considered a contraindication to mitral valve operation any longer (Dickhaus and Rapaport, 1961; Emanuel, 1963), the question was raised whether preference should be given to valve replacement rather than to closed instrumental valvotomy (Braunwald *et al.*, 1965). In this study, 10 of the 12 patients with an abnormal increase in pulmonary resistance showed a good clinical result correlating with a considerable reduction in mean left atrial and pulmonary artery pressure as well as resistance, accompanied by a significant increase in stroke volume and cardiac index. In 2 patients (Fig. 4), one of whom was studied recently and not included in the overall results of this study, pulmonary resistance decreased from 1060 or 1000 to 440 and 400 dyn sec cm^{-5} . Thus, the contradictory results of other investigations (Dickhaus and Rapaport, 1961; Emanuel, 1963; Braunwald *et al.*, 1965; Granath, 1965) are not supported by the findings of the present study. Mitral valve replacement seems not to be justified in these patients, the decrease in mean left atrial pressure obtained by closed mitral commissurotomy being sufficient to assure a significant reduction of pulmonary vascular resistance. Yet, in order to prevent progression of right ventricular hypertrophy and right heart failure, tricuspid insufficiency, often present in these patients, should always be corrected (Fig. 7). Thus, persistence of a preoperative excessively high pulmonary resistance and right heart failure seems rarely to be the cause of an unsatisfactory clinical result.

(4) Myocardial disease leading to left ventricular failure The unrecognized presence of chronic rheumatic heart disease and its persistence after mitral commissurotomy, leading to progressive left ventricular failure after operation, have become well known (Murphy, 1960; Fleming and Wood, 1959). However, the preoperative diagnosis of latent myocardial insufficiency is still difficult, especially if left ventricular haemodynamics have

FIG. 7 Mitral restenosis in a 49-year-old woman: simultaneous left atrial (LA) and left ventricular (LV) pressure 1 and 5 years after closed mitral valvotomy. The patient presented considerable mitral valve calcification, but no clinical signs of chronic rheumatic disease. Before operation severe pulmonary hypertension and tricuspid insufficiency was found, pulmonary vascular resistance being 1060 dyn sec cm^{-5} , being postoperatively reduced to 440 dyn sec cm^{-5} and remaining unchanged during the following 4 years.

been assessed at rest only, end-diastolic pressure usually being within normal limits (average LVED = 7 mmHg in this study). The significant postoperative increase in left ventricular end-diastolic pressure observed in this study

(postoperative average LVED = 11.6 mmHg) has to be attributed to a better left ventricular filling. However, 6 patients had an abnormal rise in postoperative end-diastolic pressure, ranging from 14 to 44 mmHg, 5 of them with normal preoperative values. Though this probably is a case of latent myocardial insufficiency, only 2 of these patients remained clinically unimproved. Thus, one has to conclude that preoperative masked myocardial disease might lead to postoperative latent left ventricular failure, yet without severely affecting the clinical results.

(5) **Mitral valve calcification** Fifteen patients in this study had mitral valve calcification, 11 of them belonging before operation to class III or IV. Five of these patients, or one-third, remained clinically unchanged or deteriorated. This represents half of the patients with a clinical and/or haemodynamically unsatisfactory result, 9 of the 54 cases studied, or 17 per cent, showing no improvement. Thus, in the presence of considerable mitral valve calcification, valve replacement is most certainly indicated in order to obtain an adequate decrease in mean left atrial pressure, with a satisfactory opening of the mitral valve (Granath, 1965; Kitchin and Turner, 1967).

In conclusion, the lack of clinical improvement displayed by 17 per cent of these patients has to be attributed to a variety of causes, including mitral valve calcification, latent myocardial insufficiency, pulmonary hypertension with right heart failure and mitral restenosis, following this sequence of importance. Nevertheless, closed instrumental mitral valvotomy seems to lead to satisfactory results in the great majority of patients with pure or predominant mitral stenosis. In these patients, commissurotomy or valve replacement should therefore not be considered as a rule, but only for carefully selected patients.

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