Quantitative angiographic analysis of the left ventricle in patients with isolated rheumatic mitral stenosis¹

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It has been suggested that impaired left ventricular performance in patients with rheumatic mitral stenosis results from a localized abnormality of wall motion. Accordingly, in 10 patients with isolated mitral stenosis who had no evidence of coronary arterial disease, the ejection fraction and the mean rates of circumferential fibre shortening (mean Vcf) both at the minor equator and at the base of the left ventricle were analysed. Ejection fractions ranged from 0.42 to 0.86 and were abnormal (<0.56) in 3 subjects. At the minor left ventricular equator mean Vcf ranged from 0.60 to 4.30 circumferences (circ)/sec and was abnormal (<1.2 circ/sec) in 4 patients; mean Vcf at the base was abnormal in 6 of the 10 patients. Radiographic projection did not affect the separation of normal from abnormal mean Vcf. Reduction of mean Vcf confined to the base of the left ventricle was seen in 2 patients, both of whom had a normal ejection fraction and a normal mean Vcf at the minor equator. However, of the remaining 4 patients with a reduced value for mean Vcf at the base, all had reduced mean Vcf at the minor equator and 3 also had a depressed ejection fraction. These data are consistent with the view that a generalized abnormality of myocardial mechanical performance is responsible for the occurrence of left ventricular dysfunction in some patients with mitral stenosis.

That some patients with mitral stenosis have abnormal left ventricular performance has long been suspected on clinical grounds (Harvey *et al.*, 1955; Fleming and Wood, 1959), but little quantitative information is available regarding myocardial wall function in such patients. Accordingly, the present study was undertaken: (1) to measure left ventricular myocardial function as compared with haemodynamic analysis of left ventricular performance in patients with mitral stenosis; and (2) to see whether abnormal left ventricular function in these patients was due to a regional or to a generalized abnormality in contraction.

Subjects and methods

The study group comprised 7 women and 3 men with isolated rheumatic mitral stenosis (Table). These 10 patients were selected from a larger group of 17 subjects solely on the basis of having had cineangiocardigrams suitable for analysis, i.e. absence of premature beats and adequate opacification of the left ventricle. None of these

patients had aortic valve disease and none had more than a trace of mitral regurgitation. No patient had systemic hypertension or a history suggestive of coronary heart disease. The 2 men over age 40 were studied by selective coronary angiography and neither had significant coronary arteriosclerosis. Six patients were in sinus rhythm and the remaining 4 had atrial fibrillation.

Right and left heart catheterization studies were performed in the postabsorptive state after administration of sodium pentobarbitone (100 mg) intramuscularly. Left heart catheterization was performed by the retrograde arterial and transseptal techniques, and the left ventricular cavity was opacified by left ventricular or left atrial injection of radiographic contrast material over a 2- to 3-second period. Satisfactory biplane cineangiograms were obtained in 6 patients, and 4 patients were studied in single plane (lateral or frontal projection only). The ventriculograms were filmed at 80 frames a second (8 patients) or at 200 frames a second (2 patients). The brachial arterial pressure, electrocardiogram, and cine frame pulses were recorded simultaneously at 200 mm/sec on a photographic recorder. Mitral valve areas were calculated from the mitral valve pressure gradient determined by planimetry from records obtained during simultaneous left atrial and left ventricular catheterization.

For purposes of the angiographic analysis, end-diastole was assumed to occur at the time of the peak of QRS

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TABLE

Case No.	Age	Sex	Rhythm	Cardiac index (l./min/m ²)	RV end-diastolic pressure (mmHg)	Pulmonary arterial pressure (S/D) (mmHg)	LV end-diastolic pressure (mmHg)	Mitral valve area index (cm ² /m ²)	End-diastolic volume (ml/m ²)	Ejection fraction
1	38	F	Normal sinus	2.8	5	24/12	2	1.30	59	0.67
2	40	F	Atrial fibrillation	2.2	7	29/10	5	1.00	81	0.47
3	37	F	Normal sinus	2.3	8	40/25	11	0.54	33	0.86
4	51	M	Atrial fibrillation	1.8	2	25/11	0	0.79	68	0.58
5	32	F	Normal sinus	3.1	7	45/25	10	0.78	—	0.56
6	42	M	Atrial fibrillation	2.3	8	27/16	16	0.93	114	0.45
7	38	F	Normal sinus	3.8	9	31/17	10	0.67	78	0.63
8	21	F	Normal sinus	2.6	6	48/24	10	0.58	76	0.58
9	39	M	Atrial fibrillation	2.2	8	40/20	6	0.60	118	0.42
10	41	F	Normal sinus	2.3	5	42/18	9	0.62	67	0.56

* Basal chord projected into aortic outflow tract.

† Right anterior oblique projection.

S, systolic; D, diastolic; Vcf, rate of circumferential fibre shortening; circ/sec, circumferences/second.

deflection; end-systole was determined by visual inspection as the earliest maximum inward excursion of the endocardial surfaces. End-diastolic and end-systolic volumes were calculated by the area-length method (Dodge *et al.*, 1960; Sandler and Dodge, 1968). Stroke volume was taken as the difference between end-diastolic volume and end-systolic volume, and ejection fraction was calculated as the ratio of stroke volume to end-diastolic volume. In one patient (Case 5) an appropriate grid was not available for correction of magnification (Karliner, Bouchard, and Gault, 1971a). Therefore, in this patient the ejection fraction was determined by incorporating the absolute values of the areas measured by planimetry into the area-length calculation.

The mean rate of circumferential fibre shortening (mean Vcf) was estimated as described previously (Karliner *et al.*, 1971b). For this calculation the left ventricular cavity silhouette was outlined at end-diastole and end-systole, and a long axis was drawn from the midpoint of the aortic (frontal and RAO projections) or mitral (lateral projection) valve plane to the left ventricular apex. The minor equatorial diameter was then constructed perpendicular to this axis at its midpoint and a basal chord was constructed at a point one-third the distance from either the aortic or mitral valve plane to the apex (Fig. 1). Each cineangiographic analysis was performed in duplicate. The ejection time was taken as the time from end-diastole to end-systole, less 50 msec for the pre-ejection period (Karliner *et al.*, 1971a). The velocity of circumferential fibre shortening was then calculated as the end-diastolic circumference minus end-systolic circumference divided by the ejection time.

Mean Vcf was then expressed as circumferences/second (circ/sec) by dividing this result by the end-diastolic circumference.

$$\text{Mean Vcf} = \frac{D_{ED} - D_{ES}}{D_{ED} (ET)}$$

where D_{ED} = end-diastolic diameter, D_{ES} = end-systolic diameter, and ET = ejection time. Since velocity is expressed per unit length of circumference, this technique allows comparison among patients.

In each patient several beats were analysed (range 2–7, average 4) and representative values used. In patients with sinus rhythm the first well-opacified, non-postextrasystolic contraction was chosen as the representative beat. For patients in atrial fibrillation the first contraction with the two preceding cycle lengths between 0.5 and 1.0 sec was chosen in order to minimize the effects of changes in inotropic state, ventricular filling, and afterload which occur with variations in RR interval (Karliner *et al.*, 1972).

Results

Haemodynamic data are summarized in the Table. The reduction in mitral valve area index ranged from moderate to severe, and in 7 patients the valve area index was less than 0.8 cm²/m². The end-diastolic volume index was within the normal range in 6 patients, above 110 ml m⁻² in 2 patients, and less than 40 ml m⁻² in 1 patient.

The effect of different projections during filming on mean Vcf was examined by comparing calcula-

FIG. 1 The cardiac silhouettes at end-diastole and end-systole are depicted in the frontal and lateral projections in a patient with rheumatic mitral stenosis. Line AB represents the basal chord and line CD the chord at the left ventricular minor equator. For methods of calculating ejection fraction and the mean rate of circumferential fibre shortening (see text).

Mean Vcf (circ/sec) Minor equator		Mean Vcf (circ/sec) Basal chord	
Frontal	Lateral	Frontal	Lateral
—	1.6	—	0.7
0.9	0.9	0.7	0.9
—	4.3	—	2.9
1.9	2.3	1.2	*
2.2	—	2.8	—
1.2	1.0	1.0	1.1
1.2	1.2	1.3	1.2
1.6†	—	0.9†	—
0.6	0.6	0.4	0.6
0.9	0.7	0.9	0.8

tions obtained in the frontal and lateral views at the minor equator in the six patients having biplane cineangiograms (Table). To demonstrate the range of variation, all contractions analysed are depicted in Fig. 2, including some postextrasystolic beats and beats with widely varying RR intervals in patients with atrial fibrillation. The encircled points are the selected representative contractions from each patient. Despite the wide differences in mean Vcf, due to the above physiological variables and differences due to projection, particularly at higher values, the radiographic projection did not substantially affect the separation of normal from abnormal mean Vcf (Table, Fig. 2).

Three patients had an abnormally low ejection fraction (<0.56 , Kennedy *et al.*, 1966), while 4 patients had a reduced mean Vcf (<1.2 circ/sec, Karliner *et al.*, 1971b, Table). No patient with a

FIG. 2 Comparison of the mean rate of circumferential fibre shortening (mean Vcf) calculated in circumferences/second (circ/sec) at the left ventricular minor equator in the frontal and lateral projections. Shown are all analysed beats from the 6 patients with biplane cineangiograms. All data points fall in the upper right or lower left quadrants, suggesting that radiographic projection is not an important factor in the calculation of mean Vcf. The crossed lines define the lower limits of normal for mean Vcf (1.2 circ/sec). The encircled points depict representative beats (see text).

reduced ejection fraction had a normal mean Vcf. Thus 4 of the 10 patients had depressed left ventricular myocardial mechanics when characterized by mean Vcf.

To compare regional myocardial performance, mean Vcf calculated at the minor equator was

plotted against mean Vcf calculated at the basal chord. In Fig. 3 all beats analysed from all patients are depicted in each projection. In only 2 patients were contractions clearly discordant, i.e. a reduced mean Vcf at the base but a normal value at the minor equator (lower right quadrants, Fig. 3). It is of

FIG. 3 Panel A: The relation in the frontal (and right anterior oblique) projection between the mean rate of circumferential fibre shortening (mean Vcf) at the basal chord and mean Vcf at the left ventricular minor equator is depicted for all beats analysed. With the exception of only three beats from the same patient analysed in the right anterior oblique projection all measurements in the other 9 patients were concordant. Panel B: Here the relation between mean Vcf measured both at the base and at the left ventricular minor equator in the lateral projection is shown for all beats analysed. Only two beats (both from the same patient) are discordant. The crossed lines in each panel represent the lower limits of normal for mean Vcf (1.2 circ/sec).

interest that each of these patients had a normal ejection fraction, while the 3 patients with a reduced ejection fraction also had a reduced value for mean Vcf in both chords in both projections (lower left quadrants, Fig. 3). Thus, in our patients with mitral stenosis whose left ventricular performance was depressed, a generalized rather than only a regional impairment of myocardial function was more common.

Discussion

Several haemodynamic studies have indicated that left ventricular performance may be abnormal in patients with rheumatic mitral stenosis. Despite apparently complete left ventricular filling in 25 patients with mitral stenosis, Heller and Carleton (1970) reported an ejection fraction more than 2 SD below their normal mean in 20 of 25 subjects. By contrast, Chatterjee and his coworkers (1971) reported a normal ejection fraction in 4 patients with mitral stenosis. Feigenbaum and his coworkers (1966) noted an increased left ventricular end-diastolic pressure at rest in 6 of 32 patients with mitral stenosis. Though these same workers reported a decrease in left ventricular compliance during exercise, simultaneous measurements of pressure and dimensions were not obtained, and volume changes were not measured directly. Befeler, Kamen, and MacLeod (1970) suggested that co-existent coronary artery disease might account for wall-motion abnormalities in some patients with mitral stenosis, but they also reported qualitatively abnormal left ventricular contraction patterns in 7 of 13 patients with mitral stenosis and normal coronary arteriograms.

There is little information relative to quantitative regional analysis of myocardial wall function in patients with pure rheumatic mitral stenosis. In the present study the angiographically determined mean Vcf has been used to measure the performance of the left ventricular myocardium. Previously, it has been shown that this measure correlates well with instantaneous Vcf at maximum calculated wall tension, a more complex method of assessing the contractile state of the left ventricle (Gault, Ross, and Braunwald, 1968; Karliner *et al.*, 1971b). The data obtained in the present study show that mean Vcf was reduced in 4 of the 10 patients studied, indicating that there is impairment of left ventricular myocardial wall function in some patients with mitral stenosis. Abnormalities in mean Vcf were seen in both the frontal and lateral projections and in both equatorial and basal chords, indicating that myocardial impairment is usually generalized (Fig. 3).

Heller and Carleton (1970) postulated that the impaired left ventricular function observed in some patients with mitral stenosis is due to a localized posterior basal wall motion abnormality which they noted cineangiographically using the right anterior oblique projection. However, these investigators did not measure regional myocardial performance. We also observed a localized basal contraction abnormality in the right anterior oblique projection in one patient, but such an abnormality was not seen in the frontal projection in any patient, and in the lateral projection in only 1 of 7 patients. The present data are more consistent with a generalized myocardial disorder which could be the result of previous rheumatic myocarditis. Supporting this contention are the observations of Horwitz and his associates (1972) who noted a reduced ejection fraction along with consistent hypokinesis of both the posterobasal and anterolateral wall in 7 patients with mitral stenosis.

In a recent study, a reduction in the extent of fibre shortening of both the basal and the anterolateral walls of the left ventricle was observed in 12 patients with mitral stenosis (Curry, Elliott, and Ramsey, 1972). Eight of the patients were over 40 years of age, but significant coronary heart disease was not excluded in these subjects. Moreover, the criteria used for the selection of analysed beats and the cardiac rhythm were not specifically stated. Of our 10 patients, 4 had impairment of anterolateral wall contractility, but in the other 6 subjects it was normal. Though Curry *et al.* (1972) filmed in the right anterior oblique view, while we used the biplane mode, it is unlikely that radiographic projection accounts for the differing results of the two studies. It is possible that patient selection, including the presence or absence of coronary disease, may have significantly influenced the patterns of wall motion observed.

Of 3 patients with a reduced value for mean Vcf, 2 were premenopausal women and 1 was a 39-year-old man. Though coronary artery disease cannot be ruled out definitively in this group, these patients had no clinical evidence of coronary heart disease and were not subjected to coronary arteriography. The fourth patient was a 42-year-old man with a reduced ejection fraction who had normal coronary arteriograms. As indicated earlier, 2 other men over age 40 also had normal coronary arteriographic studies.

In summary we believe that a generalized abnormality of myocardial mechanical performance accounts for the occurrence of left ventricular dysfunction in some patients with rheumatic mitral stenosis, who do not have significant coronary artery narrowing.

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