Diastolic Mitral Regurgitation

Haemodynamic and Angiographic Correlation

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A better understanding of the factors involved in ensuring competence of the mitral valve based on knowledge of the function of the leaflets, chordae tendineae, and papillary muscles has expanded the clinical range of systolic mitral regurgitation. For all this, diastolic mitral regurgitation remains a curiosity. Late diastolic mitral regurgitation has been described together with reversal of the left atrioventricular pressure gradient in experimental and clinical studies (Williams *et al.*, 1968; Rutishauser *et al.*, 1966; Lochaya, Igarashi, and Shaffer, 1967). In these reports the mitral valve was established or judged to be normal, and, therefore, incomplete closure of the valve was a causal factor of mitral regurgitation. A diseased mitral valve unable to close tightly during systole might be regurgitant during diastole as well if left ventricular pressure were to exceed left atrial pressure. In the past year we have recognized systolic and diastolic reflux across abnormal mitral valves in 4 patients who represent a spectrum of valvular heart disease. We wish to present the haemodynamic and angiographic evidence for diastolic mitral regurgitation. Its incidence in 4 of 50 consecutive patients studied for rheumatic heart disease is frequent enough to make it something to consider in any patient with mitral valve disease.

SUBJECTS AND METHODS

Each patient was selected for pre-operative cardiac catheterization on the basis of his clinical condition. The need for premedication was decided individually, and Cases 1, 2, and 3 received hydroxyzine hydrochloride ("Vistaril" 100 mg.) intramuscularly before the study. Right heart catheterization was performed using No. 7 Goodale-Lubin catheters passed from an antecubital vein. The left heart was catheterized with No. 8

Lehman or Gensini catheters introduced from a brachial arteriotomy or percutaneously from a femoral artery. Cardiac output was determined from either duplicate indocyanine-dilution curves or by the Fick method. Simultaneous pulmonary artery wedge and left ventricular pressures were measured immediately before and within two minutes after the injection of contrast media for angiography. The pressures were obtained using Statham P23D strain-gauges and were recorded by a Sanborn multichannel photographic recorder. The calibrations and sensitivities of the gauges were matched; and the zero levels of each gauge were referred to the mid-chest plane. Baselines were checked against the zero reference before and during each recording. Left ventriculograms were obtained on 35 mm. cinefilm at 30 or 60 frames per second with the patient lying in the right anterior oblique position. Aortograms were taken with the same technique with the patient lying in the left anterior oblique position. Injections of 70 to 100 ml. of 76 per cent Hypaque were used for each exposure and were delivered in 2 to 3 seconds with a Cordis injector.

RESULTS

In Table I the pertinent clinical data are summarized, and anatomical findings observed at open heart operation are indicated.

The reported auscultatory findings represent the agreed observations of several examiners. All the patients had atrial fibrillation.

At operation the mitral valves showed typical rheumatic changes with shrunken leaflets. In Case 1 the anterior leaflet was flail; in Cases 2 and 3 the valve was stenotic as well as regurgitant. All 3 patients required mitral and aortic valve prostheses. Operation was not recommended at the time of study for Case 4.

The catheterization and angiography data are listed in Table II. Two sets of heart rates and pressures are given for each patient. The upper sets are averaged values observed before the ven-

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TABLE I
DIASTOLIC MITRAL REGURGITATION—CLINICAL AND SURGICAL FINDINGS

Case No., sex, age	Aetiology	Final diagnoses	Functional class	Auscultatory findings	Electrocardiograms	Surgical findings
1 M 43	Rheumatic heart disease	Aortic and mitral regurgitation	III-IV	S ₁ accentuated and palpable, S ₂ single and loud, S ₃ opening snap inconstant, ASM 1/6, ADM 3/6, MSM 2/6, MDM 2/6	Atrial fibrillation, QRS-60°, left ventricular hypertrophy, digitalis effect	Mitral valve: attenuation of both leaflets, flail anterior leaflet, nodular edges, no calcium Aortic valve: rolled inverted edges, no calcium
2 M 41	„	Aortic and mitral regurgitation and stenosis	III	S ₁ normal intensity, aortic closure absent, S ₃ no opening snap, ASM 4/6, ADM 3/6, MDM 1/6	Atrial fibrillation, QRS + 30°, digitalis effect	Mitral valve: fibrosis and heavy calcification of both leaflets, area 1.25 cm. ² Aortic valve: extensive calcification of all leaflets, area 1.0 cm. ²
3 M 34	„	„	III	S ₁ diminished, aortic closure absent, pulmonary closure loud, S ₃ no opening snap, ASM 4/6, ADM 3/6, MSM 2/6, MDM 1/6	Atrial fibrillation, QRS + 75°, left ventricular hypertrophy, digitalis effect	Mitral valve: fibrotic, thickened, and stenotic Aortic valve: fused cusps and inverted edges
4 M 44	„	Mitral regurgitation	II-III	S ₁ normal intensity, S ₂ widely split, pulmonary closure accentuated, S ₃ no opening snap, MSM 3/6, MDM 2/6, ASM 1/6 transmitted? no ADM	Atrial fibrillation, QRS + 60°, tall R waves, digitalis effect	Operation not performed

ASM, aortic systolic murmur; ADM, aortic diastolic murmur; MSM, mitral systolic murmur; MDM, mitral diastolic murmur; QRS, mean axis in frontal plane.

TABLE II
DIASTOLIC MITRAL REGURGITATION—CATHETERIZATION AND ANGIOGRAPHY FINDINGS

Case No.	Body surface area (m. ²)	Cardiac index (l./min./m. ²)	Heart rate* (beats/min.)	Pressures (mm. Hg)						Angiograms†			
				Rt. atrial	Rt. ventr.	Pulm. art.	Pulm. art. wedge	Lt. ventr.	Aortic	Lt. atrial vol.	Lt. ventr. vol.	Mitr. regurg. (syst.)	Aortic regurg.
1	2.14	1.7	67 72	18	86/25	88/35 (55)	54/22 (30) 62/22 (32)	155/26 153/25	155/57 153/60	3+	3+	2+	3+
2	1.80	2.4	48 56 53	14	57/8	55/24 (33)	31/16 (20)	124/24 198/44	85/52‡ 127/78	2+	2+	1+	2+
3	1.80	2.4	54 54 73	5	36/4	36/15 (24)	24/14 (18) 56/26 (35)	150/13 198/15	122/51‡ 156/54	2+	2+	2+	2+
4	1.66	2.5	81 83 85	6	31/5	31/15 (20)	12/4 (7) 24/10 (14)	121/5 141/11		1+	2+	2+	—

* Figures in left hand column refer to heart rates during left ventricular opacification.

† Chamber volume and severity of valvular regurgitation are graded on 1+ to 4+ scale.

‡ Brachial artery pressure.

triculographic studies; the lower sets, values observed after. Fig. 1 to 4 are representative of the tracings from which the upper set of pulmonary artery wedged and left ventricular pressures were derived. The pulmonary artery wedge was treated as a measurement of left atrial pressure, and compared with the left ventricular pressure tracing it is delayed by 0.04 to 0.08 second. All four tracings show that in at least one cardiac cycle in each, left ventricular pressure exceeded pulmonary artery wedge during late diastole. The reversal of the mitral diastolic gradient is less convincing in the

illustration from Case 3 because it is small and occurs in only one cycle; other tracings from the same patient recorded at four times greater sensitivity, however, also showed an occasional reversal of pressures during late diastole. High left ventricular end-diastolic pressures were recorded in only 2 patients. In Cases 3 and 4, end-diastolic left ventricular pressure was normal or only slightly raised before and after the injection of contrast media. Heart rate influenced the reversed gradient in all the patients; the slower the rate, the greater the reversal. The reversed mitral gradient per-

FIG. 1

FIG. 3

FIG. 2

FIG. 4

FIG. 1 to 4.—Simultaneous pulmonary artery wedge (PAWP) and left ventricular (LVP) pressure tracings recorded in Cases 1 to 4, respectively. See text.

sisted after angiography in Cases 1 and 4. In Case 2, though the post-injection pulmonary artery wedge pressure was not recorded, the reversed atrio-ventricular gradient probably remained in view of the continued slow heart rate and extremely high end-diastolic pressure of 44 mm. Hg. In Case 3 only, the heart rate accelerated after the angiographic study and pulmonary artery wedge pressure increased, producing a forward mitral gradient which persisted throughout diastole.

Angiographic estimation of left ventricular and left atrial volumes revealed a variation from marked enlargement in Case 1 to slight enlargement in Case 4. Aortic valvular regurgitation was shown in 3 patients but was severe only in Case 1. In Case 4 an aortogram was not performed because aortic

regurgitation was clinically absent. Systolic mitral regurgitation occurred in all 4 patients and was minimal to moderate. In all patients a small but definite jet of contrast media regurgitated across the mitral valve during late diastole in one to five cardiac cycles, and was not associated with ventricular premature beats. In Case 2, the diastolic regurgitant jet appeared to be larger than the systolic jet. The heart rates during ventricular opacification, translated from mean R-R intervals, approximated pre-injection heart rates. Fig. 5 illustrates the diastolic mitral regurgitation in Case 4.

DISCUSSION

Diastolic mitral regurgitation resulting from incomplete closure of a normal mitral valve has been

FIG. 5.—Case 4. Retrograde left ventricular cine-angiogram in RAO projections. *Late systole*: the left atrium is opacified by mitral regurgitation and is delineated anteriorly by the anterior mitral leaflet (AML); the regurgitant jet occurs near the postero-medial commissure. *Late diastole*, 0.3 sec. later: left atrial opacification is lighter due to the preceding rapid emptying of left atrial contents; the posterior fornx (PF), lying between the posterior mitral leaflet and basilar endocardium of the ventricle, is continuous with a small diastolic regurgitant jet in the left atrium.

demonstrated in experimental and clinical heart block. Williams *et al.* (1968) analysed, with a videodensitometer, left ventricular injections of contrast media, and detected small amounts of left atrial opacification. Similarly, Rutishauser *et al.* (1966), using thermodilution methods, injected cold saline into the ventricle and recorded temperature drops in the atrium. In both studies diastolic mitral regurgitation occurred after every atrial systole which was not followed after a normal interval by ventricular systole, when a reversed atrioventricular pressure gradient of 2 to 4 mm. Hg was recorded.

Reversal of late diastolic pressure between the left ventricle and atrium or wedged pulmonary artery has been recorded in patients with aortic regurgitation in normal sinus rhythm, first degree AV block, and atrial fibrillation (Meadows *et al.*, 1963; Oliver, Gazetopoulos, and Deuchar, 1967; Rees *et al.*, 1964). Distinctive features were severe aortic reflux and high left ventricular end-diastolic pressures. The reversal of the atrioventricular gradient was related by some authors to increased ventricular inflow and reduced ventricular distensibility. Its significance was thought to be that it would produce premature closure of the mitral valve. Again in patients with severe aortic regurgitation, Lochaya *et al.* (1967) demonstrated, angiographically, diastolic mitral regurgitation which was associated with a reversed atrioventricular gradient, and Aldridge, Lansdown, and Wigle (1966), in a published abstract, reported similar findings. The former group did not see systolic mitral reflux, and suggested that the diastolic mitral reflux was a consequence of incomplete valve closure.

In the past year, we have recognized late diastolic mitral regurgitation in 4 patients, and in each there was an associated reversal of the atrioventricular gradient. We have not seen the one without the other. Unlike the previous reports, aortic regurgitation was not uniformly severe in our cases, and the left ventricular end-diastolic pressures were not invariably or inordinately raised. Indeed, in 1 patient aortic regurgitation was clinically absent, and in 2 patients the end-diastolic pressures were normal, or nearly so. Notably, the mitral valves were anatomically abnormal in all 4 patients.

Anatomical incompetence of the mitral valves in these patients is adequate basis for the defective valve closure during late diastole. Atrial fibrillation excludes an atrial mechanism producing the diastolic mitral regurgitation. Therefore, the mechanism of the diastolic reflux in our patients becomes a question of the validity of the atrioventricular gradient. Strict equivalence of pulmonary artery wedge pressure and left atrial pressures,

recorded through catheter-manometer systems of identical dynamic characteristics, is precluded by the transmission of the pulmonary artery wedge pressure through the pulmonary vessels. Pressures recorded through a wedged catheter-manometer system tend to be overdamped and the amplitude between the peaks and valleys of the pulmonary artery wedge pressure compared to the left atrial pressure may be less (Connolly, Kirklin, and Wood, 1954). The "y" point of the pulmonary artery wedge pressure would then be falsely high and more likely to conceal a reversed gradient than to produce one as an artefact. For these reasons we feel that if left ventricular end-diastolic pressure exceeds pulmonary artery wedge pressure, it very likely exceeds left atrial pressure.

Large injections of contrast media made into the left ventricle under pressure alter ventricular performance immediately (Hallermann, Rastelli, and Swan, 1964). It is, therefore, speculative to consider that atrioventricular pressure relationships are comparable before and during the angiographic study. However, we are arguing from the position that despite any probable alteration, the angiographic events agreed with the pressure data measured immediately before the injection. In addition, soon after the injection the reversed mitral gradient persisted in 2 patients and probably did in a third whose heart rates did not change significantly. Furthermore, if forceful left ventricular injections of contrast media alone produced artefactual diastolic mitral reflux, we should see it more frequently than we do.

The appearance and magnitude of the reversed diastolic atrioventricular gradient are dependent in part upon the diastolic pressure-volume characteristics or distensibility of the ventricle. To what point on its pressure-volume curve the ventricle progresses in diastole is determined by the ventricular filling rate and the length of the diastolic filling period. Recent observations in experimental ventricular asystole have shown that the left ventricular diameter reaches its maximal dimension within one second of asystole and does not increase further even when asystole is prolonged to 30 seconds (Van Citters and Ruttenberg, 1967). In patients with increased ventricular filling rates due to either aortic regurgitation or systolic mitral regurgitation, the distension limits of the ventricle may possibly be reached at normal heart rates. The reversed atrioventricular gradients are also influenced by the ability of the atrium to empty and to relax. In this regard the reversed mitral gradient observed with completely normal pressures in Case 4 is pertinent. The smallness of the left atrium plus its rapid

evacuation by cine-angiographic estimation probably effected the low "y" point of the pulmonary artery wedge pressure. We presume that both rapid ventricular filling and rapid atrial emptying must concur in reversing the atrioventricular gradient at normal levels of pressure.

The studies from these 4 patients show that anatomically incompetent mitral valves permit regurgitation whenever, in the cardiac cycle, systole or diastole, left ventricular pressure even minimally exceeds left atrial pressure. Left ventricular end-diastolic pressure need not be greatly increased to reverse the atrioventricular gradient. The feasibility of a small gradient producing mitral regurgitation illustrated in these patients is consistent with the earlier studies on heart block.

Our inability to quantify the diastolic mitral regurgitation makes its haemodynamic and clinical significance conjectural. In these patients the reversed atrioventricular gradients were small and the amount of diastolic reflux was not large, and probably did not compromise effective stroke volume. However, in Case 2, the amount of diastolic regurgitation appeared to be at least equivalent to the systolic reflux and, therefore, the reduction of forward stroke flow from diastolic mitral regurgitation is potentially important in patients with high end-diastolic pressures. Additionally, in patients with severe aortic regurgitation, mitral valve incompetence in diastole allows raised diastolic pressures to be reflected into the lungs (Welch, Braunwald, and Sarnoff, 1957). The possible detriment of diastolic mitral reflux in patients with normal ventricular pressures and volumes would be a decrease in ventricular end-diastolic fibre stretch, with resultant loss in stroke volume.

SUMMARY

Late diastolic mitral regurgitation associated with a reversal of the left atrioventricular pressure gradient occurred in 4 patients with mitral valve disease. Aortic regurgitation was severe in only one patient and absent in another. Left ventricular end-diastolic pressures were not invariably and inordinately raised. The incidence of diastolic mitral

reflux in this experience was 4 in 50 patients consecutively studied for rheumatic heart disease.

It is concluded that anatomically incompetent mitral valves permit regurgitation in both systole and diastole whenever left ventricular pressure exceeds left atrial pressure.

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