Mechanism of diastolic rumble and presystolic murmur in mitral stenosis

Pavlos Toutouzas, Antonios Koidakis, Anastasios Velimezis, and Demetris Avgoustakis

From the Department of Cardiology, Medical School of the University of Athens - Hippokration Hospital

The mechanism of the murmurs heard in mitral stenosis was studied in 61 patients by using simultaneous recordings of the mitral valve echocardiogram, phonocardiogram, and apex cardiogram.

It was observed that: (a) the diastolic rumble began just after the E point of the echocardiogram, clearly related to the diastolic closure of the valve, and was never recorded during the opening motion of the valve, which in 49 patients was completed (E point) 20 to 60 msec after the opening snap; (b) the presystolic murmur was recorded at the time the mitral valve was closing during preisometric contraction of the left ventricle.

It is suggested that both murmurs probably originate from impact between increased velocity of forward blood flow and the backward closing motion of the mitral valve. This mechanism explains (1) the frequently noted gap between the opening snap and the onset of the diastolic rumble; (2) the reduction in amplitude or disappearance of the diastolic rumble in calcified mitral stenosis; and (3) the occasional presence of a presystolic murmur in atrial fibrillation.

The mechanism of the diastolic rumble and presystolic murmur in mitral stenosis is still unclear. Until recently these murmurs were attributed to the increased blood flow velocity through the narrowed mitral orifice, caused by the diastolic gradient between the left atrium and the left ventricle. However, in the past few years it has been thought that mitral valve motion itself is responsible for certain mitral diastolic murmurs. In combined cineangiographic and phonocardiographic studies (Criley, Feldman, and Meredith, 1971; Criley and Hermer, 1971), it was observed that the presystolic murmur was related to the closing motion of the mitral leaflets; it is suggested that the progressive decrease in orifice size, engendered by the closure of the valve, is the cause of the murmur. This observation was confirmed in the echocardiographic studies of Fortuin and Craige (1973). These investigators, in addition, noted a similar time relation between the diastolic closing motion of the anterior mitral leaflet and the appearance of mid-diastolic murmurs heard in aortic regurgitation (Austin-Flint murmur), mitral regurgitation, and congenital heart diseases with large left-to-right shunt. They suggested that in such cases the closing motion of the mitral valve against an increased velocity of forward flow might be a contributory

factor in the production of these murmurs (Fortuin and Craige, 1972, 1973).

This study investigates the pathogenesis of the presystolic murmur and the diastolic rumble in mitral stenosis by using simultaneous recordings of the mitral valve echocardiogram, phonocardiogram, and apex cardiogram.

Subjects and methods

Studies were made on 61 patients, 12 men and 49 women, whose ages ranged from 16 to 65 years (average 42). In all patients the physical findings of mitral stenosis were present and the mitral valve echocardiogram demonstrated an abnormally slow diastolic closure from E to F, of less than 35 mm per second (Edler, 1967). The stenosis was confirmed by cardiac catheterization and angiocardiography; in 12 patients it was combined with insignificant mitral regurgitation. In 8 cases the mitral valve was calcified. Twenty-five patients were in sinus rhythm and the remaining 36 in atrial fibrillation. Echocardiograms of the mitral valve were obtained using a Hewlett-Packard 7214A ultrasound device, with attached Polaroid camera for film recording. Phonocardiograms from the apex, where the murmurs were best heard, and left ventricular apex cardiograms were obtained using an Electronics for Medicine multi-channel recorder and transducer (PS-IB). The gated mitral valve echo signal and lead II of the electrocardiogram were recorded simultaneously with the phonocardiogram and apex cardiogram. The recordings

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were made at a paper speed of 100 mm per second with time lines at 20 msec intervals.

In each patient the morphology of the diastolic rumble as well as the time relation of this murmur and the opening snap to the echocardiographic curve of the anterior mitral leaflet were studied. The morphology of the presystolic murmur and its time relation to the P and Q waves of the electrocardiogram, the C point of the apex cardiogram, and echocardiographic closing curve of the mitral valve, were also defined.

Results

A: Opening snap and diastolic rumble (Tables 1 and 2)

The opening snap was recorded 40 to 120 msec after the aortic component of the second sound. In patients with a calcified mitral valve the opening snap was inconspicuous. In 49 patients it coincided with the X point of the echocardiogram in which an abrupt deceleration of the opening valve motion

occurred (Fig. 1, 2, 3, 6, and 7). In these patients the interval X-E on the echocardiogram varied from 20 to 60 msec. In the remaining 12 patients there was no point X; in these cases the valve rapidly moved to the completely open position, i.e. the E point of the echocardiogram, which coincided with the opening snap (Fig. 4 and 5).

The diastolic rumble was decrescendo in type and its vibrations were always greater in sinus rhythm than in atrial fibrillation. In the patients with a calcified mitral valve this murmur was quiet or virtually absent (Fig. 6). The diastolic rumble always began immediately after the mitral valve was completely open, i.e. after the E point of the echocardiogram. Thus, in 12 patients the murmur began at the time the opening snap was recorded, and in 49 patients 20 to 60 msec after the opening snap. The diastolic slope of the echocardiogram in patients with a pliable mitral valve frequently presented distortions or 'dents' (Fig. 2, 4, and 5) which were not observed in cases with calcified valve.

TABLE 1 Data derived from 25 patients with mitral stenosis in sinus rhythm

Case No.	Sex	Age (yr)	Heart rate	Pre-systolic murmur	PR interval	P wave - PSM onset	PSM onset - C (ACG) (msec)	A2-OS interval (msec)	Mitral valve echocardiograms		
									D-X interval (msec)	X-E interval (msec)	Diastolic slope rate (mm/sec)
1	F	38	67	C-D	240	180	60	70	*	*	15
2	F	40	61	C-D	240	140	130	70	20	20	30
3	F	38	75	C-D	240	160	120	40	20	40	15
4	M	48	67	C	200	230	0	60	40	60	15
5	F	39	64	C	160	160	40	60	30	60	25
6	F	40	65	C	140	140	40	70	40	50	20
7	M	34	74	C	180	220	0	90	40	60	22
8	F	35	89	C	180	160	40	80	*	*	28
9	F	32	78	C	140	130	40	70	*	*	27
10	M	53	63	C	180	220	0	65	40	50	8
11	F	24	100	C	140	150	20	100	40	40	35
12	F	32	70	C	160	160	20	70	40	60	15
13	M	43	65	C	140	180	0	80	*	*	20
14	F	37	72	C	180	220	0	70	40	20	15
15	F	16	80	C	180	140	60	60	20	30	14
16	F	33	61	C	140	140	40	70	*	*	25
17	F	42	56	C-D	240	220	60	120	*	*	35
18	F	50	80	C	160	160	30	110	30	30	26
19	F	47	65	C	140	180	0	80	*	*	18
20	M	42	86	C	210	210	30	60	40	50	12
21	F	24	82	C	200	160	140	80	30	60	29
22	F	36	75	C	180	180	40	110	40	40	26
23	F	35	73	C	140	160	20	100	30	40	22
24	F	16	58	C	160	160	30	50	40	60	15
25	F	33	65	C	140	160	0	75	30	40	20

C-D = Crescendo-decrescendo.

C = Crescendo.

* = Patients with no X point on the echocardiogram; in these cases the opening motion of the valve was completed rapidly in one phase D-E.

FIG. 1 Mitral stenosis with atrial fibrillation. The mitral valve echocardiogram (MVE) shows two distinct phases of the opening motion of the anterior leaflet: a rapid one (D-X) lasting about 40 msec and a slow one (X-E) lasting about 60 msec. The opening snap (OS) coincides with the X point of the echocardiogram (arrow). The diastolic rumble (DR) appears after the E point, corresponding with the diastolic closing motion of the mitral valve. A presystolic murmur (PSM) appears after short diastolic periods (M_1 = mitral component of the 1st sound: A_2 = aortic component of the 2nd sound).

B: Presystolic murmur (Tables 1 and 2)

This murmur was recorded in all patients with sinus rhythm and in 10 of the 36 with atrial fibrillation (Fig. 1, 5, and 7). It was crescendo in type in 21 of the patients with sinus rhythm, beginning 130 to 230 msec after the onset of the P wave of the electrocardiogram. When the PR interval was normal the beginning of the murmur coincided with the onset of the QRS complex. However, in 4 out of 5 patients with a prolonged PR interval the presystolic murmur began before the onset of the QRS complex and was crescendo-decrescendo in type. In atrial fibrillation the presystolic murmur was always crescendo and louder in the cardiac cycles following short diastolic periods (Fig. 1 and 7). It began after the onset of the QRS complex and its vibrations were always of less amplitude than in sinus rhythm.

The presystolic murmur always began at or just after the peak of the A wave of the echocardiogram of the mitral valve. The progressive increase in amplitude of the crescendo murmur was clearly related to the closing motion of the valve (Fig. 1, 5, and 7).

The peak of crescendo-decrescendo murmurs also corresponded with the closing movement on the echocardiogram, and its final vibrations, just before the echocardiographic B point, were of significant amplitude (Fig. 3).

On the apex cardiogram it was found that in patients with sinus rhythm the presystolic murmur began before (18 patients) or at the C point (7 patients), but the peak of the murmur was always noted after this point. In atrial fibrillation the presystolic murmur was constantly recorded after the C point (Fig. 5 and 7).

FIG. 2 Mitral stenosis with atrial ectopic beats. The echocardiogram shows an abrupt deceleration of the opening motion of the valve at the X point which coincides with the opening snap. The diastolic rumble appears about 60 msec later and just after the E point. The decrescendo murmur corresponds with the 'dented' diastolic slope of the echocardiogram. A presystolic murmur (PSM) appears at the time of valve closure. The atrial ectopic beat shows that the murmurs are related only to the closing motion of the valve. The presystolic murmur follows the C point of the apex cardiogram (vertical dotted line).

Discussion

The presence of a presystolic murmur in some cases of mitral stenosis with atrial fibrillation raised doubts about the accuracy of the classical view according to which the atrial contraction is responsible for its genesis. Some authors thought that the presystolic murmur in these cases, usually present in short diastolic periods, was caused by interruption of the diastolic rumble by the following first sound (Ongley, Sprague, and Rappaport, 1955). Others suggested that it was produced by vibrations of a pliable mitral valve (Nichols *et al.*, 1956) or that it was caused by tricuspid closure (Leo and Hultgren, 1959).

Criley *et al.* (1971) and Criley and Hermer (1971), in cineangiographic and phonocardiographic studies, showed that the presystolic murmur in mitral stenosis was recorded after left atrial systole, while the mitral valve was closing. This observation led them to think that the murmur was caused by increased blood flow velocity through the progressively narrowing mitral orifice during valve closure. Fortuin and Craige (1973) showed a clear relation between the presystolic murmur and the closing movement of the anterior leaflet (after the A wave of the echocardiogram). These authors suggested that, as well as the progressive narrowing of the mitral orifice, the valve motion itself contri-

FIG. 3 Mitral stenosis with sinus rhythm and prolonged PR interval (240 msec). The pre-systolic murmur is clearly related to the closing phase (A-B) of the echocardiogram. The quiet diastolic rumble related to the diastolic slope of the echocardiogram begins about 60 msec after the opening snap. The rapid filling wave (RF) in the apex cardiogram (after the O point) is recorded during the opening motion of the valve (D-E).

buted to the production of the murmur; the movement of the valve leaflets in an opposite direction to the continued forward blood flow provides a mechanism for vortex shedding, i.e. conditions for the production of a murmur.

Our findings are in agreement with the observations of Fortuin and Craige (1973). In all patients the increase of the amplitude of the presystolic murmur occurred with the progressive closing motion of the anterior leaflet. In 5 patients with sinus rhythm and prolongation of the PR interval, in whom the murmur was usually crescendo-decrescendo in type, its maximal amplitude corresponded with the closing phase of the mitral valve echocardiogram. Furthermore, the presystolic murmur or the greater part of it was recorded during preisometric systole. In some patients with sinus rhythm the C point of the apex cardiogram, which

is a reliable sign of the onset of left ventricular contraction (Willems, De Geest, and Kesteloot, 1971), coincided with the beginning of the pre-systolic murmur; in others with sinus rhythm the C point followed the onset of the murmur, whereas in cases with atrial fibrillation it was always recorded before the onset of the murmur. In addition we found that the C point of the apex cardiogram appeared simultaneously with the beginning of the closing motion of the mitral valve. This is in agreement with the statement of Lakier *et al.* (1972) that in mitral stenosis the mitral valve starts to close after the onset of the contraction of the left ventricle. These observations suggest that in most cases the presystolic murmur in mitral stenosis is predominantly systolic, and can be well explained by the mechanism postulated by Fortuin and Craige, that is impact of the valve leaflets moving

FIG. 4 Mitral stenosis with sinus rhythm. In this patient the valve opening motion is rapidly completed at the E point, which coincides with the opening snap. The diastolic rumble follows immediately and is recorded simultaneously with the diastolic slope of the echocardiogram, which presents dents in its initial part. The presystolic murmur is clearly related to the closing motion of the valve.

backwards and the blood flowing forwards. We think that, in addition to the mitral valve motion, left atrial systole contributes to production of the murmur by increasing the flow velocity through the mitral orifice; thus, the mechanism of the impact of the blood flow against the valve motion is reinforced and begins earlier, just after the peak of the A wave in the echocardiogram. This explains the fact that the presystolic murmur is a constant finding and begins earlier in sinus rhythm than in atrial fibrillation.

Our observations also suggest that the mitral valve closure in early diastole may also contribute to the diastolic rumble in mitral stenosis. It was interesting to note that in all patients the diastolic rumble was not recorded during the time the mitral valve was opening. Like Friedman (1970), we found that the opening motion of the valve usually had two distinct phases. The first one, which is rapid, lasts

20 to 40 msec and ends at the X point, coinciding with the opening snap of the phonocardiogram; the second one is slow, lasts 20 to 60 msec, and ends at the E point, when the anterior leaflet has moved to the completely open position. This second phase of the opening motion appears simultaneously with the initial part of the filling wave of the apex cardiogram, beginning immediately after the O point (Fig. 1, 3, 6, and 7). Therefore, the diastolic rumble would be expected to appear at least during this phase of valve opening, when according to the classical view the prerequisites for production of a murmur exist, i.e. increased blood flow velocity through a narrow mitral orifice. Instead, we found that the diastolic rumble started after the E point of the echocardiogram, during the diastolic closing motion of the anterior leaflet. These observations suggest that in mitral stenosis the diastolic rumble is probably not caused by the blood flow through the

FIG. 5 Mitral stenosis with atrial fibrillation. The diastolic rumble begins with the opening snap and is recorded simultaneously with the 'dented' diastolic slope of the echocardiogram. The E point coincides with the opening snap. A presystolic murmur is more obvious in the cardiac cycle after a short diastolic period. Note the clear relation between the closing motion of the valve and the presystolic murmur which is recorded during preisometric systole (C-M₁, vertical dotted lines).

stenotic orifice, but is the result of the impact of the forward blood flow and the backward closing motion of the mitral valve in early diastole. This would explain the fact that in many patients with mitral stenosis the diastolic rumble begins some time after the opening snap (Tavel, 1972). This probably occurs because at that time there is no backward (closing) movement of the mitral valve. In other patients the beginning of the diastolic rumble coincides with the opening snap; we observed that this occurred in patients with a pliable mitral valve system, in whom the opening motion was completed rapidly at the time the

opening snap was recorded, so that again the diastolic rumble appeared only during the diastolic closing motion of the valve.

In calcified mitral stenosis the diastolic rumble is quiet and may disappear despite the increased flow velocity through the narrowed orifice. According to the proposed mechanism the murmur is quiet because the valve does not move sufficiently. Further evidence in favour of our view is that in patients with loud diastolic rumbles the diastolic slope of the mitral valve echocardiogram very often presents distortions or dents, which are always absent in calcified valves.

FIG. 6 Calcified mitral stenosis with atrial fibrillation. The echocardiogram is significantly amplified. A very inconspicuous opening snap is recorded simultaneously with the X point. A slow opening motion of the anterior leaflet is noted between the points X-E. The diastolic rumble is virtually absent.

FIG. 7 Mitral stenosis with atrial fibrillation. A quiet presystolic murmur is related to the closing motion of the mitral valve occurring during preisometric systole (after the C point of the apex cardiogram).

TABLE 2 Data derived from 36 patients with mitral stenosis in atrial fibrillation

Case No.	Sex	Age (yr)	Heart rate	Presystolic murmur (crescendo)	A ₂ -OS interval (msec)	Mitral valve echocardiogram		
						D-X interval (msec)	X-E interval (msec)	Diastolic slope rate (mm/sec)
1	M	50	61	+	100	30	50	10
2	F	43	85	—	50	40	60	25
3	M	48	83	+	60	40	30	13
4	F	53	87	+	75	30	20	19
5	F	32	65	—	90	40	60	17
6	F	50	80	—	50	30	20	20
7	F	45	62	—	50	30	30	17
8	F	46	59	+	60	40	20	17
9	M	38	60	+	60	40	40	18
10	F	43	85	—	75	30	40	13
11	M	50	82	—	60	40	60	20
12	F	44	63	—	100	40	60	11
13	F	45	63	—	110	30	40	15
14	M	54	86	—	60	20	60	12
15	F	31	62	—	70	20	30	10
16	M	35	58	—	55	40	40	8
17	F	35	65	+	90	40	40	10
18	F	44	67	—	90	40	30	15
19	F	25	72	—	80	30	50	18
20	F	55	82	+	95	20	60	8
21	F	65	78	+	100	20	50	10
22	F	57	60	—	100	20	60	15
23	F	50	85	—	80	40	40	21
24	M	53	81	+	110	—	—	25
25	M	46	92	—	80	40	60	8
26	F	50	95	—	85	40	40	33
27	F	65	88	—	80	20	40	19
28	F	35	76	—	50	40	40	32
29	F	57	80	—	95	—	—	18
30	F	47	85	—	70	30	50	12
31	F	46	65	+	85	—	—	15
32	F	42	72	—	75	20	60	16
33	F	59	85	—	65	40	40	8
34	F	36	82	—	80	30	40	30
35	F	49	73	—	120	—	—	14
36	F	51	70	—	75	—	—	8

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Requests for reprints to Dr. Pavlos Toutouzas, 10 Likiou Street, Athens T.138, Greece.