Left Atrial and Left Ventricular Sound and Pressure in Mitral Stenosis

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With the technical assistance of George F. Rieser

SUMMARY

Left atrial and left ventricular pressure and sound were recorded at the time of mitral commissurotomy in 18 patients with severe, isolated, noncalcific mitral stenosis and sinus rhythm. Catheter tip micromanometers were used, and in eight studies, two equisensitive micromanometers were employed to examine pressure crossover relationships. Analysis of the left atrial and left ventricular sound and pressure crossover relationships is presented; viewed in the perspective provided by cineangiographic studies and surgical observations, a unifying concept of the auscultatory events in mitral stenosis is proposed.

Beginning with left ventricular pressure rise, the left ventricle drives the mitral complex through its ascent (or eversion) phase toward the left atrium, clearing the anterior leaflet from the left ventricular outflow tract. The ascent (eversion) terminates abruptly at the first heart sound (S). Following systole, left ventricular and left atrial pressure fall together after peak, during and after pressure crossover, until the point where left atrial pressure fall ceases abruptly (opening snap notch), left atrial pressure exceeding that in the left ventricle, and the mitral opening snap occurs. During this interval, the mitral valve complex descends or inverts toward the left ventricle and terminates abruptly with the mitral opening snap. Thus, the mitral opening snap may be considered as the reciprocal of the delayed, accentuated in noncalcific mitral stenosis in sinus rhythm.

Additional Indexing Words: Intracardiac phonocardiography Auscultation Hemodynamics

The most remarkable and consistent auscultatory events associated with mitral stenosis are the accentuated, delayed first heart sound, the mitral opening snap, and the characteristic diastolic murmur.

Basic to the understanding of these auscultatory events is the correlation of auscultatory, hemodynamic, radiographic, anatomic, and pathological phenomena in mitral stenosis.

It is the purpose of this paper to describe left atrial and left ventricular pressure pulse and sound relationships in patients with isolated, severe, noncalcific mitral stenosis and sinus rhythm, recorded at thoracotomy with catheter tip micromanometers and viewed in the perspective of cineangiographic observations and surgical findings.

Methods

Eighteen patients with severe, isolated, noncalcific mitral stenosis and sinus rhythm were studied; 14 had undergone right and left heart catheterization (Division of Cardiology) and Surgery (Division of Thoracic Surgery), the Ohio State University College of Medicine, Columbus, Ohio.

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Direct left atrial pressure pulse in a case of mitral stenosis. (Top to bottom) Intracardiac phonocardiogram, left atrium; left atrial pressure pulse; electrocardiogram. $S_1$ and $S_2 =$ first and second heart sounds; OS = opening snap. Time lines, 0.04 sec; paper speed, 50 mm/sec.

terization; 11 had received digitalis prior to surgery.

Direct left atrial pressure pulses and intracardiac sound were recorded at thoracotomy prior to closed mitral commissurotomy with the Allard-Laurens micromanometer mounted at the tip of a no. 8 French cardiac catheter. The micromanometer$^1$ (manufactured by Telco of Paris) is a variable inductance transducer from which low frequency vibrations are recorded as pressure, and the high frequency vibrations (above 30 cycle/sec) are recorded as sound. The manometer has a uniform amplitude response to frequencies up to 200 cycle/sec. Both events are recorded simultaneously from the catheter tip without transmission delay.

The micromanometer was introduced into the left atrium prior to mitral valvulotomy through the atrial appendage or a small incision in the left atrium.

Using two micromanometer systems (previously calibrated with a mercury manometer) without concern for an absolute zero point, pressure crossover studies were obtained by placing one micromanometer in the left atrium, balancing pressure against the second micromanometer.
introduced through the atrial appendage, then advancing the second catheter through the mitral valve. At times the surgeon's exploring finger was used to pass the micromanometer through the stenotic valve. After recording left atrial and left ventricular sound and pressure, the ventricular catheter was withdrawn into the left atrium. Eight studies were used to determine crossover relationships; on these records pressure recordings from both catheters were tracked within 1 to 2 mm Hg after withdrawal of the ventricular catheter to the atrium.

The indirect left atrial pressure pulse (esophageal) was recorded in four patients to obtain time relationships with the intact thorax for comparison with the direct left atrial pressure pulse.

Recordings were made with a Sanborn 550M recording system (frequency response flat to 450 cycle/sec) at a paper speed of 100 mm/sec.

**Results**

**Left Atrial Events**

The left atrial pressure pulse (fig. 1) showed a positive a-c wave, a brisk descent following c peak, and a broader, occasionally taller v wave. The first heart sound (S₁) began with the c peak and accompanied the rapid fall in atrial pressure following the c peak. The aortic component of the second sound (S₂) occurred with a notch at the v peak.

The y descent was interrupted by a characteristic notch; the mitral opening snap coincided with this notch. Frequently there was a rebound immediately following the break in the pressure pulse. The diastolic murmur was not recorded in the left atrium. These observations were consistent and reproducible, although the morphology of the left atrial pressure pulse was variable. Similar left atrial pressure pulse and sound relationships exist with the thorax intact, as illustrated in the esophageal recording in figure 2.

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**Figure 2**

Indirect (esophageal) left atrial pressure pulse in a case of mitral stenosis. (Top to bottom) Indirect left atrial pressure pulse, intra-esophageal phonocardiogram; electrocardiogram. For abbreviations in this and other figures see figure 1. Time lines, 0.04 sec; paper speed, 100 mm/sec.
**Left Ventricular Events**

The time of onset of left ventricular pressure rise was normal (table 1). The left ventricular pressure rise (fig. 3) consisted of two phases: a slow and prolonged period (line A) which ended with the first heart sound, followed by a change in the slope of pressure pulse with a shorter, more rapid rise (line B) prior to ejection. The diastolic portion of the ventricular pressure pulse was unaffected by atrial systole (absence of “atrial kick”).

The delayed, accentuated first heart sound was recorded in the left ventricle with the break in ventricular pressure pulse rise. The aortic component of the second sound and the mitral opening snap were also recorded within the ventricle.

The diastolic murmur began with the mitral opening snap, was of variable amplitude in the ventricle, appeared to be maximal in the jet stream and the immediate infravalvular region, and disappeared abruptly on withdrawal of the catheter through the mitral orifice. There were areas in the ventricle where no murmur was recorded although heart sounds were recorded in these areas. Lack of visualization of the micromanometer tip precludes further precision in description. In areas where the atriosystolic (presystolic) murmur was recorded, this portion of the diastolic murmur extended to the first sound.

**Left Ventricular-Left Atrial Pressure Crossover Relationships**

Two equisensitive micromanometer systems were used to study pressure crossover relationships. Figure 4 shows two superimposed left atrial pressure pulses prior to advancing one catheter into the left ventricle. Figure 5, from the same patient, illustrates pressure and sound with one catheter in the left ventricle, and one catheter remaining in the left atrium.

Left ventricular pressure crossed left atrial pressure on the upstroke of the c wave. The

![Figure 3](image-url)

**Figure 3**

Left ventricular pressure pulse in mitral stenosis. (Top to bottom) Intracardiac phonocardiogram; left ventricular pressure pulse; electrocardiogram, lead II. Line A represents the slope of the initial portion of the left ventricular pressure pulse; line B, the slope of the second portion of the left ventricular pressure pulse; dotted line C, the approximate point of change in the rise of the ventricular pressure pulse. DM = diastolic murmur. Paper speed, 100 mm/sec.
first sound occurred after pressure crossover when left ventricular pressure was appreciably higher than pressure in the atrium (fig. 6). The change in direction of left ventricular pressure rise, the maximal vibrations of S1, and the rapid atrial pressure fall after c peak were practically simultaneous (fig. 7).

The aortic component of the second sound occurred with ventricular pressure fall, at a time when atrial pressure pulse was at or near v wave peak. Ventricular-atrial pressure crossover occurred between the v peak and the opening snap notch. Left ventricular and left atrial pressure continued to fall together until left atrial pressure fall was checked at the time of the mitral opening snap. The pressure in the left atrium was appreciably higher than ventricular pressure at the time of the mitral opening snap (fig. 8).

### Time and Pressure Relationships

In the eight crossover studies with two micromanometers the following time and

**Table 1**

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<th>Patient</th>
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<th>F.M.</th>
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**Figure 4**

Study of patient M.M. with two equisensitive micromanometers in the left atrium. (Top to bottom) Intracardiac phonocardiogram, left atrium; intracardiac phonocardiogram, left atrium; superimposed left atrial pressure pulses; electrocardiogram, lead II. Paper speed, 100 mm/sec.
pressure relationships were observed (tables 1 and 2):

The Q-S₁ interval was subdivided into:
(a) Q-crossover interval, that is, Q-LV pressure rise plus LV pressure rise to crossover (average value, 0.079 sec) and (b) crossover-S₁ interval (average value, 0.025 sec). The interval from LV pressure rise to S₁, designated as the mitral complex ascent phase (see Discussion), averaged 0.07 sec. The pressure differential at S₁, that in the left ventricle being greater than that in the left atrium, averaged 14.6 mm Hg (range, 8 to 22 mm Hg).

The S₂-OS interval (average value, 0.066 sec) was subdivided into the S₂ to crossover interval (average value, 0.03 sec), and the crossover to OS interval (average value,
0.036 sec). The pressure differential at OS, that in the left atrium being greater than that in the left ventricle, averaged 14.0 mm Hg (range, 10 to 18 mm Hg). The interval from v peak to OS notch was designated as the descent phase of mitral complex.

The average value for the ascent phase (LV upstroke to S₁), 0.07 sec, was comparable to the average value for the descent phase (S₂ to OS), 0.066 sec. When the ascent phase was compared to descent phase in the same patient (eight studies) the intervals were either identical or within 0.01 sec. Comparative values for the pressure differential at S₁ and the pressure differential at OS in the same patient agreed within 4 mm Hg.

Figure 6

Study of patient E.B. with two equisensitive micromanometers. (Top to bottom) Intracardiac phonocardiogram, left atrium; intracardiac phonocardiogram, left ventricle; left atrial pressure pulse; left ventricular pressure pulse; electrocardiogram, lead II. Paper speed, 100 mm/sec. See text for details.
Figure 7
Study of patient C.M. with two equisensitive micromanometers. (Top to bottom) Intracardiac phonocardiogram, left atrium; intracardiac phonocardiogram, left ventricle; left atrial pressure pulse; left ventricular pressure pulse; electrocardiogram, lead II. Paper speed 100 mm/sec.

Figure 8
Study of patient B.H. with two equisensitive micromanometers. (Top to bottom) Intracardiac phonocardiogram, left atrium; intracardiac phonocardiogram, left ventricle; left atrial pressure pulse; left ventricular pressure pulse; electrocardiogram, lead II. ASM = atriosystolic murmur. Paper speed, 200 mm/sec. See text for details.
DISCUSSION

In this study observations were limited to patients with severe mitral stenosis, sinus rhythm, and noncalcific, mobile mitral valves, since mitral stenosis is a broad spectrum disease process with varying pathology and multiple clinical syndromes.2

LEFT ATRIAL SOUND AND PRESSURE

The atrial contraction wave was increased in height with a prolonged ascent phase, the relaxation phase was interrupted by c wave ascent, and the z point was elevated. The changes in the atrial contraction wave are consistent with prolonged atrial systole. The fusion of a and c waves is a reflection of the overlap of atrial and ventricular contraction in mitral stenosis. The interruption and break in the y descent at an appreciable interval after v peak was consistent with earlier observations by Rich,3 Nixon,4 and Ross and Criley.5 that mitral valve flow begins at a significant interval after v peak. Details of these observations are the subject of another study.

LEFT VENTRICULAR PRESSURE PULSE AND SOUND

The slow initial rise in left ventricular pressure following normal onset of contraction is probably not isovolumetric as noted earlier6 since the atriosystolic murmur suggests ventricular filling during this interval.

Piemme and associates7 used the Allard-Laurens micromanometer to record intracardiac sound and pressure in dogs. Differentiation of the left ventricular pressure revealed a subtle change in slope in early isometric ventricular contraction coincident with the first component of the first heart sound in all cases. This was not discernible by inspection of the pressure tracing since the amplitude was sufficiently low as to be hidden within the width of the rapidly rising electron beam inscription. The change in slope of the left ventricular pressure pulse at elevated pressure in mitral stenosis may be a delayed, exaggerated manifestation of the same process.

Laurens8 presented pressure pulses and intracardiac sound recordings by Soulié (from one patient with mitral stenosis) using two micromanometers, one introduced into the left ventricle by retrograde arterial catheterization, the second passed into the left atrium by transseptal catheterization. The atrial micromanometer recorded only "auricular sounds"; the left ventricular micromanometer recorded a diastolic rumble preceded by an opening snap under the mitral valve. The left ventricular pressure pulse from the retrograde catheter shows the change in slope of the pressure pulse occurring after pressure crossover, similar to our recordings obtained with the micromanometer across the mitral valve. In addition, the respective atrial and ventricular sound recordings are similar to those of the present study.

Grant8 commented upon architectural changes of the left ventricle in mitral stenosis; he noted "selective atrophy of the posterior wall of the heart in mitral stenosis" suggesting that mitral stenosis immobilized the posterior wall of the left ventricle.

Feigenbaum and associates10 used an index of ventricular diastolic function, obtained at left and right heart catheterization during modified exercise, and suggested the possibility of a left ventricular abnormality in some patients with mitral stenosis, perhaps related to decreased left ventricular compliance.

Kurz and associates11 studied left ventricular hemodynamics in mitral stenosis with standard catheters, Statham strain gauges, and intracardiac phonocardiograms from a fluid column transmission system. The mean interval from Q-wave onset to onset of left ventricular pressure pulse was 0.049 sec; the mean Q-S1 interval was 0.080 sec. The rate of rise of pressure was appreciably altered in patients with pure mitral stenosis compared to normals. Two phases in the curve of the first derivative of left ventricular pressure were observed: a slow phase "while the mitral valve was still open," and an extremely rapid phase "after mitral valve closure." The first group of vibrations of the first sound followed the early slow phase of the first derivative.
Hood and associates\textsuperscript{12} used biplane angiocardiography to examine force-velocity relations in the left ventricle and noted that subjects with mitral stenosis had normal end-diastolic volumes and normal peak stress with significant reduction of the velocity of contractile element shortening and lowered values for the ejection fraction.

The changes in the left ventricular pressure pulse and sound noted in the present study support the concept that alterations of left ventricular function occur in mitral stenosis, related to moving the abnormal mitral valve complex in the presence of elevated left atrial pressure, with the added possibility that the architectural changes described by Grant\textsuperscript{8} also contribute.

**Pressure-Crossover Relationships**

The hemodynamics of mitral stenosis were described in detail in a series of articles and monographs by Braunwald,\textsuperscript{6, 13} Gordon,\textsuperscript{14} Moscovitz\textsuperscript{15} and their associates. Left ventricular contraction was shown to consist of two distinct phases, from ventricular contraction to crossover and from crossover to the moment of aortic valve opening. The diastolic pressure gradient was described as the fundamental hemodynamic expression of mitral stenosis and the absence of diastasis was discussed. Many fundamental observations on the correlation of the electrical, mechanical, and sound events were presented in these studies.

Rich\textsuperscript{8} stated that the pressure crossover occurred before \( c \) upstroke, the maximum vibrations of \( S_1 \) corresponded to the \( c \) wave peak, \( S_1 \) occurred after crossover, left ventricular pressure exceeded left atrial pressure at \( S_1 \), and valve motion occurred during \( c \) upstroke. He also noted that the first part of the \( y \) descent took place before the opening snap and postulated that the initial fall of the \( y \) descent corresponded to the \( c \) wave in reverse.

Di Bartolo and associates\textsuperscript{16} performed left heart catheterization by the transthoracic method and recorded intracardiac phonocardiograms by the method of Luisada and Liu. Thirty-three patients were studied: 16 with sinus rhythm and 17 with atrial fibrillation. The average Q-S\(_1\) interval was 88 msec, and the average S\(_2\)-OS interval was 77 msec. Left ventricular pressure at \( S_1 \) averaged 25 mm Hg, left atrial pressure at \( S_1 \) averaged 20 mm Hg, and the average difference in 25 patients was 7 mm Hg. Left atrial pressure at opening snap averaged 18 mm Hg and left ventricular pressure averaged 13 mm Hg. In 10 patients the left atrial pressure exceeded the left ventricular by an average value of 5 mm Hg. The authors assumed that A-V valve closure took place at crossing of atrial and ventricular pressures, and concluded that \( S_1 \) “occurred some time after closure of the mitral valve.” Similarly, the occurrence of the opening snap at a time when left atrial pressure was lower than ventricular pressure provided “convincing evidence that this snap follows the opening of the valve and does not occur at the time of valvular opening.”

Ross and Criley\textsuperscript{6} correlated cineangiographic observations, intracardiac pressure, and external sound in mitral stenosis. The mitral opening snap occurred at the “moment of maximum descent of the valve, which is also the moment of first flow through the valve.” The beginning of the descent of the still closed mitral valve corresponded to the peak of the \( c \) wave; opening of the valve and mitral flow began an average of 67 msec later. (The average value for the descent phase in our study was 0.066 sec.) The moment of mitral valve opening was often associated with a notch or change in the slope of the \( y \) descent. Ventricular systole began while the dome formed by the fused leaflets of the mitral valve was still in the partially descended position; abrupt rise in ventricular pressure forced the mitral valve upward toward the atrium. These superb studies must be viewed to be appreciated, and the preceding comments represent only a fraction of the observations made in a series of studies by these authors.

McCall and Price\textsuperscript{17} performed cineangiographic studies and phonocardiograms in 10 patients with mitral stenosis; six were in sinus rhythm. They noted ascent of the mitral...
valve toward the left atrium 0.03 to 0.04 sec after the Q wave. The mitral component of the first sound occurred at the instant when upward movement of the valve into the left atrium stopped. No subsequent valve motion occurred until late in systole when descent of the mural portion of the annulus was noted, terminating before A₂ and v-wave peak. Shortly after A₂ the valve cusps moved downward into the left ventricle, and the opening snap coincided with the end of the downward movement of the valve. Upward movement of the mural portion of the annulus was noted in mid-diastole. These observations were incorporated into an explanation for the delay noted between crossover positions on atrial and ventricular pressure traces and the occurrence of S₁ and the opening snap.

Figure 9
Postulated time and pressure relationships for mitral valve ascent and descent phases. Study with two equisensitive micromanometers. (Top to bottom) Left atrial phonocardiogram; left ventricular phonocardiogram; left atrial pressure pulse; left ventricular pressure pulse. C.O. indicates crossover, OSN is opening snap notch. Time lines, 0.04 sec. Paper speed, 200 mm/sec. See text for details.
in mitral stenosis. In relation to the present study the interval McCall and Price noted between the Q wave and ascent of the mitral valve (0.03 to 0.04 sec) corresponds closely to our time interval from Q wave to onset of left ventricular pressure rise (average value, 0.033 sec), which we have designated as the beginning of the mitral complex ascent phase.

Unifying Concept

Analysis of the left atrial and left ventricular time-sound-pressure crossover relationships in the perspective provided by cineangiographic studies suggests the following concept (figs. 9 and 10):

The onset of left ventricular pressure rise is normal. Thereafter, left ventricular and left atrial pressures rise together, crossover occurs, left ventricular pressure exceeds rising left atrial pressure after crossover until the point where the slope of delayed left ventricular pressure rise abruptly changes, left atrial pressure falls, and S₁ occurs. S₁ occurs at the time of rapid ventricular and atrial pressure changes at the peak of the elevated left atrial pressure. Beginning with left ventricular pressure rise, the left ventricle drives the mitral complex through its ascent (or eversion) phase toward the left atrium, clearing the anterior leaflet from the left ventricular outflow tract. The ascent (eversion) terminates abruptly at S₁.

Following systole, left ventricular and left atrial pressures fall together after v peak, during and after pressure crossover, until the point where the left atrial pressure fall ceases abruptly (opening snap notch); the left atrial pressure then exceeds that in the left ventricle, and the mitral opening snap occurs. During this interval, the mitral valve complex descends or inverts toward the left ventricle and its descent terminates abruptly with the mitral opening snap.

Thus, the mitral opening snap may be considered as the reciprocal of the delayed, accentuated S₁ in noncalcific mitral stenosis in sinus rhythm.
Flexibility and mobility of the mitral valve complex is intimately related to timing and intensity of S1 and the opening snap, as are left atrial compliance and pressure, rate and vigor of left ventricular pressure rise and fall, and mitral valve flow. Extreme calcification of the mitral complex significantly modifies these sound events, although the other relationships persist.

Exact time of mitral valve opening or mitral valve closure, whether this is a real or functional event in mitral stenosis, is uncertain. The present study emphasizes the dynamic nature of pressure changes; although the sound events occur after pressure crossovers, they occur within the time range of movement of the mitral complex.

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References

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