SUMMARY Although mitral valve prolapse is often associated with a systolic click or murmur, it is not widely appreciated that a sound or murmur may also occur in diastole. Nine patients with a systolic click or murmur and echocardiographic evidence of mitral prolapse had, in addition, a diastolic sound or an early diastolic murmur best heard at the apex or left sternal border. The sound, which was of high frequency and easily audible, followed A2 by 70–110 msec (mean 94 ± 5 msec), and coincided with the point where the prolapsed posterior leaflet returned from the left atrium and recoapted with the anterior mitral leaflet. The diastolic sound occurred 40–60 msec (mean 53 ± 4 msec) before the E point of the echocardiogram and O point of the apexcardiogram, and even longer before the rapid-filling wave. The diastolic murmur, also of high frequency, was brief and decrescendo, and simulated aortic regurgitation in two patients. Thus, mitral prolapse may be associated with a sound or murmur in diastole. When a diastolic sound or murmur is best heard apically, even if accompanied by a systolic murmur, mitral valve prolapse should be considered.

MITRAL VALVE PROLAPSE, a common and generally benign condition in which serious problems occur occasionally,1–8 is often diagnosed on the basis of characteristic auscultatory findings. The auscultatory features associated with this syndrome include a mid-systolic click that may be followed by a late systolic murmur, a late systolic or holosystolic murmur without a click, or the absence of both click and murmur.9–11 However, a diastolic sound or murmur may also be a part of the auscultatory features of mitral valve prolapse.12 We studied nine patients with mitral valve prolapse who also had a prominent diastolic sound or murmur that appeared to be related to motion of the prolapsing leaflet. These results show that mitral valve prolapse may be associated with sounds and murmurs in diastole as well as systole. The presence of diastolic findings, therefore, should not exclude the possibility of mitral prolapse. The diastolic sound bore a consistent relationship to the time of valvular recoaptation in all nine patients.

Methods

This study included all patients evaluated at the Johns Hopkins Hospital over the past 3 years who had a click or murmur in systole, echocardiographic evidence of mitral valve prolapse, and an early diastolic sound or murmur. Of approximately 150 patients with auscultatory and echocardiographic evidence of mitral prolapse, nine patients met all three criteria. In each patient we obtained a phonocardiogram, an apexcardiogram, carotid pulse tracing and the simultaneous recording of these techniques combined with echocardiography. These tracings were analyzed in detail and correlated with the physical findings.

The echocardiographic examination was performed with the patient in the supine position, rotated slightly leftward, using a Smith-Ekoline 20A Ultrasonoscope with a 2.25-MHz, 1.25-cm-diameter transducer. The echocardiograms, phonocardiograms and pulse

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tracings were recorded on a Cambridge strip-chart recorder or a Honeywell direct-writing recorder. All recordings were made at the same respiratory phase of held midexpiration. In addition to routine examination of the intracardiac structures, aorta and pericardial space, the mitral valve was studied in detail. Special attention was paid to the posterior mitral leaflet, and care was taken to ensure that the gain was not too low lest the faint posterior prolapsing echo be missed. Mitral stenosis was included in each patient by the presence of a normal EF slope and normal diastolic movement of the thin posterior leaflet. Right ventricular volume overload was similarly excluded by normal systolic ventricular septal motion and normal right ventricular internal dimensions.18 Phonocardiographic and pulse recordings were performed with the patient in the supine position. Simultaneous lead II ECGs were recorded. The sound recordings were obtained from the four standard auscultatory areas using midfrequency filters and Cambridge microphones, during quiet respiration and at held midexpiration. The apexcardiogram was performed with the patient in the left lateral decubitus position.

The following measurements were made from the combined graphic records: time from aortic valve closure to diastolic sound ($A_2X$), aortic closure to peak opening movement of the mitral valve ($A_2E$), aortic closure to coaptation of the mitral leaflets ($A_2D$), aortic closure to peak of rapid-filling wave of the apexcardiogram ($A_2R$), and aortic-pulmonic splitting on inspiration and expiration ($A_2P_2$). All data are summarized as mean ± SEM. The hypothesis that $A_2X$ was not different from the $A_2P_2$, $A_2D$, $A_2E$ or $A_2R$ was tested using the unpaired $t$ test.19 A linear regression of $A_2D$ vs $A_2X$ was obtained to delineate the relationship of the diastolic sound to the valvular recoaptation point.

**Results**

The nine patients were 23–64 years old (mean 37 ± 5 years), and five were women (table 1). Six of the patients had a midystolic click. Five had a mid- or late systolic murmur that continued into diastole as an early diastolic decrescendo murmur best heard at the left sternal border or apex. Eight patients had midystolic and one had pansystolic mitral valve prolapse; they had no other abnormality of the echocardiogram. One patient had pansystolic mitral prolapse with a dilated left atrium and ventricle. The ECGs revealed no evidence of conduction delay. Left ventricular ejection time (corrected)18 was available in five (range 342–462 msec, mean 369 ± 19 msec) and was within normal limits.

A phonocardiogram with external carotid pulse tracing of one of the patients is shown in figure 1. Normal respiratory splitting of the aortic and pulmonic components of $S_2$ during inspiration was noted. A high-frequency diastolic sound ($X$) separated from $A_2$ by 100 msec was well appreciated in both the pulmonic and apical areas. There was also a midystolic click (not seen here) followed by a crescento

<table>
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<tr>
<th>Table 1. Clinical Features of Patients with Mitral Valve Prolapse and Diastolic Sound or Murmur</th>
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<td><strong>Pt (years)</strong></td>
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*Cardiac catheterization with ventriculography showed moderately severe mitral regurgitation, prolapsing mitral leaflet, and significant narrowing of the distal left anterior descending and mid-right coronary arteries.

Abbreviations: SC = systolic click; SM = systolic murmur; DC = diastolic click; DM = diastolic murmur; Dec = decrescendo; LLSB = left lower sternal border; PVC = premature ventricular complex; WNL = within normal limits; LA = left atrium; LV = left ventricle.
A phonocardiogram with external carotid pulse tracing in a patient with mitral valve prolapse. The top two lines represent middle-frequency (MF) sound tracings from the pulmonary (PA) and apical (APEX) areas. During inspiration (Insp) there is normal respiratory splitting of the aortic (A2) and pulmonic (P2) components of S2. A loud, high-frequency diastolic sound (X) is widely separated from A2 and is well appreciated at both the pulmonary area and apex. In addition to a midsystolic click (Cl), a late-systolic murmur is also present. ECG = lead II electrocardiogram; 1, 2 = first and second heart sounds.

late systolic murmur. Figure 2 shows a phonocardiogram with an apexcardiogram from the same patient. The diastolic sound (X), also well appreciated in both the aortic and left sternal border areas, occurred earlier than the O point and the rapid-filling wave of the apexcardiogram. A simultaneous recording of the phonocardiogram from the left sternal border, carotid pulse tracing, and mitral valve echocardiogram is shown in figure 3. There was marked midsystolic mitral prolapse, which reached maximal posterior displacement at S2 and continued into early diastole. As the arrow indicates, the timing of the diastolic sound coincides with the D point, where the returning prolapsed posterior leaflet recoapted with the anterior mitral leaflet. The sound occurred well before the E point, which is the peak mitral valve opening, where an opening snap would occur.

A phonocardiogram with carotid pulse from another patient, who was referred for evaluation of a diastolic murmur thought to be due to aortic regurgitation, is shown in figure 4. The A2P2 components split normally with inspiration. A late systolic click introduced a crescendo late systolic murmur. A diastolic decrescendo murmur that ended before the diastolic sound was also well demonstrated. There was a loud diastolic sound, widely separated from A2, that was recorded in both the pulmonic and apical areas. In this same patient, a simultaneous study of echocardiogram, phono-, and apexcardiogram combined (fig. 5) showed that this diastolic sound again coincided with the D point of the echocardiogram, where the posterior leaflet rejoins the anterior leaflet. Marked midsystolic mitral prolapse continued beyond S2 into early diastole. The diastolic murmur was a continuation of the late systolic murmur, and was a high-frequency, decrescendo murmur that persisted while the leaflet was still prolapsed, and ended before the diastolic sound occurred.

To characterize this diastolic sound further, time intervals between A2 and X were compared with other similar time intervals (table 2). The sound occurred 70–110 msec (mean 94 ± 5 msec) after A2. The A2P2
FIGURE 3. Mitral valve echocardiogram (MVE) with the simultaneous phonocardiogram (PCG) from lower left sternal border (LSE) and the carotid pulse tracing. The marked midsystolic prolapse reaches maximal excursion at S₂ and continues into early diastole. The diastolic sound (X) clearly coincides with the D point of the echocardiogram (arrow), where the valve leaflets recoapt. This is well before the E point, which is the peak mitral valve opening, where an opening snap would occur.

FIGURE 4. Phonocardiogram with carotid pulse from a patient who was referred for evaluation of a diastolic murmur thought to be due to aortic regurgitation. During inspiration (INSP), normal splitting of S₂ (A₂ and P₂) is seen in the middle-frequency (MF) sound tracing from the pulmonary area (PA). A midsystolic click (CI), followed by a systolic murmur (SM) is demonstrated at the apex. There is also a diastolic murmur (DM), which ends before a loud diastolic sound (X). ECG = lead II electrocardiogram.

Table 2. Echocardiogram and Phonocardiogram Timing in Eight Patients with Mitral Valve Prolapse and Diastolic Sound

<table>
<thead>
<tr>
<th>Interval</th>
<th>Range (msec)</th>
<th>Mean ± SEM (msec)</th>
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<tr>
<td>A₂X (diastolic sound)</td>
<td>70–110</td>
<td>94 ± 5</td>
</tr>
<tr>
<td>A₂P₂ (exp)</td>
<td>20–28</td>
<td>26 ± 2</td>
</tr>
<tr>
<td>A₂P₂ (insp)</td>
<td>40–55</td>
<td>48 ± 2</td>
</tr>
<tr>
<td>A₂D point</td>
<td>70–114</td>
<td>93 ± 8</td>
</tr>
<tr>
<td>A₂E point</td>
<td>125–170</td>
<td>146 ± 7</td>
</tr>
<tr>
<td>A₂diff (n = 3)</td>
<td>150–220</td>
<td>188 ± 38</td>
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*Compared with A₂X interval by unpaired t test.

Expiration and inspiratory intervals were significantly shorter. The time from A₂ to the E point, which is the echocardiographic peak open position of the anterior mitral leaflet, was 125–170 msec (mean 146 ± 7 msec) and was significantly longer than A₂X. However, the A₂D interval, i.e., the time from A₂ to valvular recoap-
tion alone, it was sometimes difficult to define this as a diastolic murmur. The phonocardiograms, however, showed that this murmur persists beyond $A_2$. In the case illustrated in figure 4, the diastolic murmur could be defined by auscultation. One patient who had a loud early systolic murmur and a decrescendo diastolic murmur that was best heard at the left sternal border was referred for evaluation of aortic stenosis and aortic regurgitation. He underwent cardiac catheterization and angiography, which showed no valvular gradient or incompetence of the aortic valve but did show mitral regurgitation and pansystolic mitral valve prolapse, which was also shown by M-mode and two-dimensional echocardiography.

**Discussion**

Eight of the nine patients had, in addition to typical auscultatory and echocardiographic evidence of mitral valve prolapse, a loud, high-frequency sound in early diastole. The diastolic sound occurred when the returning prolapsed posterior mitral leaflet recoapted with the anterior leaflet, after the onset of mitral valve opening. Thus, in effect, this diastolic sound may represent the "closing" of an opening that was transiently created by the prolapse. The temporal relationship between the sound and valve motion does not prove that recoaptation is the cause of the sound, but the precise correlation in each patient in this series strongly supports this mechanism. In each case, prolapse occurred in late systole and the posterior leaflet was displaced into the left atrium at the onset of diastole. We postulate that the force of early left ventricular relaxation may be sufficient to draw the leaflet rapidly back to the normal opening position and that the sound occurs as anterior and posterior leaflets are transiently brought into reapposition.

Although it is possible that this diastolic sound may be associated with pulmonic valve closure, the association appears unlikely for several reasons. The absence of any clinical, electrocardiographic or echocardiographic evidence for a cardiac condition, such as atrial septal defect, that would give rise to a widely split and unusually loud $P_2$ makes it likely that this diastolic sound is not related to pulmonic closure.

Further, another sound that had the characteristics of a normal $P_2$ occurred regularly, following $A_2$ by an interval within the normal range and showing the normal inspiratory widening. Also, while $P_2$ is normally well appreciated in the pulmonary area but not at the apex, the diastolic sound of interest was widely transmitted throughout the precordium and was heard maximally at the apex, not in the pulmonary area. In addition, the temporal relationship between the dia-
stolic sound and the echocardiographic D point did not vary, but remained constant throughout the recordings, even at different heart rates, making it unlikely that this temporal relationship was coincidental.

Although the early diastolic sound associated with mitral valve prolapse simulates an opening snap and may be thought to have a similar origin, simultaneous echocardiogram and phonocardiogram tracings are helpful in evaluating this possibility. Although a similar sound described in earlier reports was thought to correspond to the E point of the mitral valve echocardiogram in one patient and to coincide approximately with the O point of the apexcardiogram in six other patients, simultaneous echocardiographic studies were not performed. Figures 2, 3 and 5 show that the diastolic sound clearly occurs well before both the E point of the mitral valve echocardiogram and the O point of the apexcardiogram.

The possibility that this early diastolic sound may be associated with rapid ventricular filling (S₂) or pericardial knock can also be excluded, as this sound occurs long before the rapid ventricular filling wave of the apexcardiogram and before any meaningful ventricular filling begins. Further, none of the patients had complete atrioventricular block or other cardiac conditions that might give rise to an exaggerated third sound. Although mitral regurgitation may be associated with an exaggerated third sound, a normal echocardiographic atrial dimension in the eight patients with the diastolic sound makes significant mitral regurgitation in these patients unlikely.

The prevalence of the diastolic sound in patients with mitral valve prolapse remains uncertain, but it is likely that this diastolic sound occurs more frequently than formerly though. Hancock and Cohn noted a diastolic sound in six of 40 patients (15%) with a midsystolic click. However, no simultaneous echocardiogram-phonocardiogram studies were available to delineate the relationship of this sound to other cardiac events. In the present study, the diastolic sound occurred in approximately 5-8% of patients with mitral valve prolapse. The exact incidence of this finding remains to be determined. The diastolic sound is likely to occur in patients who have prolapse in late systole so that the prolapsed leaflets are positioned well back in the left atrium at the onset of isometric relaxation.

Five of the nine patients had an early diastolic murmur that was decrescendo in character and appeared to be an extension of the systolic murmur. The exact mechanism of this diastolic murmur is uncertain, but it may be related to motion of the prolapsed leaflet. It is possible that this murmur represents a continuation of mitral regurgitation after aortic valve closure during isometric relaxation, when the pressure gradient between left ventricle and atrium persists. This would be more likely if the position of the leaflet were displaced markedly posteriorly, as in severe prolapse. The decrescendo character of this diastolic murmur may reflect a decreasing regurgitant orifice as the prolapsed leaflet returns and moves anteriorly. An alternate and perhaps more likely explanation is that the diastolic murmur may result from a reduction in the mitral orifice size due to posterior prolapse at the onset of left ventricular filling, and as the orifice widens with normal opening, the murmur disappears.

In conclusion, a striking early diastolic sound or murmur was noted in nine patients with auscultatory and echocardiographic evidence of mitral valve prolapse. The diastolic sound occurred when the prolapsed posterior mitral leaflet recoated with the anterior leaflet, when it may have "closed" the transient opening that resulted from the prolapse. These findings suggest that even when a diastolic sound or murmur best heard at the apex is accompanied by a systolic murmur, mitral valve prolapse may be considered. In patients with midsystolic mitral prolapse, an early diastolic sound may represent the point of valvular recoaptation of the anterior and posterior mitral leaflets.

Acknowledgment

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