Mitral Anulus Motion
Relation to Pulmonary Venous and Transmitral Flows in Normal Subjects and in Patients With Dilated Cardiomyopathy

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The dynamics between mitral anulus motion, and, thus, motion of the base of the heart, and filling of the left atrium and ventricle were studied by Doppler echocardiography in 12 normal subjects and 28 patients with dilated cardiomyopathy. The normal motion of the mitral anulus is associated with two phases of inflow from the pulmonary veins. The first phase (J) of pulmonary venous inflow occurs during ventricular systole, concomitant with the descent of the mitral anulus toward the ventricular apex, the extent of which is 12.8 ± 1.4 mm. The end of the descent of the anulus occurs at the cessation of aortic ejection. About 100 msec later, a rapid recoil of the mitral anulus toward the atrium coincides with the onset of transmitral filling. This rapid recoil contributes to the displacement of blood from the atria into the ventricles in early diastole. The second phase (K) of pulmonary venous flow begins in early diastole, with its peak occurring about 50 msec after the peak of transmitral flow. During atrial contraction, the mitral anulus moves slightly (2.4 ± 0.7 mm) toward the atrium and then returns toward its initial position within 120 msec. This motion coincides with the A wave of transmitral flow. In patients with dilated cardiomyopathy, pulmonary venous flow and mitral anulus motion are markedly altered in comparison with normal subjects. In all patients, motion of the mitral anulus is either reduced or absent. In 10 patients with some residual motion of the mitral anulus and a competent mitral valve, who were in sinus rhythm, the profile of pulmonary venous flow maintained a normal biphasic pattern. In the remaining 18 patients, the systolic (J) phase of pulmonary blood flow was either reduced or absent. This abnormal pattern of pulmonary venous flow was associated with either absence of mitral anulus motion, atrial fibrillation, or significant mitral regurgitation. In patients with severe mitral regurgitation, a systolic regurgitant flow was observed in the pulmonary veins. Thus, both atrial contraction and normal motion of the mitral anulus that is produced by left ventricular systolic function contribute to the normal biphasic filling from the pulmonary veins into the atria. Dysfunction of either atrial or ventricular systolic emptying results in abnormal filling from the pulmonary veins during ventricular systole and leaves one major phase of pulmonary venous flow in late diastole. (Circulation 1988;78:621–629)

Passage of blood from the lungs to the left ventricle involves pulmonary venous flow, left atrial filling and emptying, and transmitral valve flow. The normal pulmonary venous flow has two phases that reflect changes in left atrial pressures.1–3 Recent studies have emphasized the importance of both atrial contraction and relaxation in generating pulmonary venous flow.3,4 The early phase (J) of pulmonary venous flow occurs during ventricular systole and starts with the relaxation of the atrium. In the absence of synchronous atrial contraction and relaxation, only the diastolic phase (K) of pulmonary venous flow occurs.1–3 The diastolic phase (K) of pulmonary venous flow occurs during rapid filling of the ventricle, and it depends on mitral valve dynamics and on changes in ventricular stiffness and relaxation.5

The normal pattern of the mitral anulus echocardiogram has been reported previously.6–10 Although its relation to left atrial and ventricular filling has been studied in dogs, it has not been defined in humans.11,12 The present study evaluates the relation between mitral anulus motion and pulmonary venous flow in normal subjects and in patients with dilated...
cardiomyopathy. In patients with reduced ventricular systolic function, mitral anulus motion is reduced or absent, and this dynamic factor on atrial and ventricular filling affects pulmonary venous and transmirtal blood flows. Moreover, functional mitral regurgitation and atrial fibrillation, which occur commonly in patients with dilated cardiomyopathy, should affect pulmonary and transmitral flow patterns.13–16

Subjects and Methods

Two-dimensional echocardiography and Doppler flow techniques were used to study pulmonary venous flow, mitral valve motion, and mitral and aortic flows. The relations between mitral anulus motion and left atrial and ventricular filling were studied in normal subjects and in patients with dilated cardiomyopathy.

Study Population

Normal subjects. Nine men and three women were studied. Their ages ranged from 26 to 49 years (and averaged 32 years). They were all in sinus rhythm, and all had a normal physical examination, exercise tolerance, and echocardiogram.

Patients. Twenty-four men and four women with dilated cardiomyopathy and congestive heart failure, in the New York Heart Association’s functional Classes III and IV, were studied. Their ages ranged from 43 to 76 years (and averaged 61 years). The origin of the cardiomyopathy was coronary artery disease in 13 patients and was unknown in the remaining 15 patients. M-mode echocardiography revealed that all patients had a left ventricular end-diastolic dimension greater than 60 mm and a left ventricular fractional shortening less than 25%. All patients were treated with digitalis and diuretics. Seventeen patients were treated with captropril. One patient was in atrial fibrillation and had a permanent VVI pacemaker.

Echocardiographic Examination

All patients underwent M-mode, two-dimensional, and pulsed-Doppler echocardiography. A Hewlett-Packard Ultrasound Imaging System (77020AC) (Palo Alto, California) was used for both imaging and Doppler flow studies. The system has a phased-array sector scanner and a movable Doppler cursor that allows sampling along a line within the image when the system is in the pulsed-Doppler mode. Images were obtained with either a 2.5- or 3.5-mHz transducer, whichever provided optimal visualization of the endocardium.

M-mode echocardiograms were spatially oriented from the two-dimensional image, preferably from the short-axis view according to a standard technique. Motion of the mitral anulus during the cardiac cycle was obtained with the M-mode cursor directed from the apical four-chamber view. The cursor was oriented toward the bright septal margin of the anulus (fibrous trigone) and then toward the lateral margin (Figure 1). On each side, the beam was oriented so that it was perpendicular to the descent motion of the anular structure. Multiple M-mode recordings of the septal and lateral margins of the mitral anulus were made. The motion of the septal and lateral margins was similar, and, thus, only the motion of the septal margin was reported.

Pulsed-Doppler Cardiographic Examination

Mitril and pulmonary venous flows were determined from the apical four-chamber view. Mitril flow velocity was obtained by sampling the volume between the tips of the mitral leaflets in the left ventricle. Pulmonary venous flow was obtained by rotating the transducer to visualize the orifices of the pulmonary veins opening into the left atrium. The right upper pulmonary vein was generally used for flow velocity recording.

Mitril insufficiency was searched for by scanning the atrium near the mitral valve for regurgitant flow. When detected, a qualitative description of the regurgitant mitral flow was obtained by pulsed Doppler.17,18

Aortic flow at the level of the aortic anulus was recorded from the apical long-axis view. The sample volume was placed in the middle of the left
Analysis of Pulmonary Venous Flow

The following measurements were made: 1) time from onset of the QRS complex to the onset of pulmonary venous flow (BJ), to the peak of the first phase of pulmonary venous flow (J), to the peak of the second phase (K), and to the end of pulmonary venous flow (EK) and 2) peak velocity of the first (J) and second (K) phases of pulmonary venous flow.

Analysis of Mitral Flow

From each record, five beats were chosen for analysis. The following variables were measured for each beat time from the onset of the QRS complex of the electrocardiogram: 1) to the onset of mitral flow (D, line 5 in Figure 2); 2) to the peak of the rapid-filling wave (E); 3) to the peak of atrial contribution (A); and 4) to the end of mitral flow (C). Peak mitral flow velocity was measured at the rapid-filling wave (E) and atrial contribution (A wave).

Analysis of Aortic Flow

The following measurements were made from the onset of the QRS complex to the: 1) onset of aortic flow (OAF); 2) peak of aortic flow (PAF); 3) end of aortic flow (EAF); and 4) peak aortic flow velocity.

Results

Mitral Anulus Motion in Normal Subjects: Relation to Pulmonary Venous, Mitral, and Aortic Flows

Pulmonary venous flow, transmitral flow, aortic flow, and mitral anular motion are shown in Figure 2. To permit analysis of concomitant events, vertical lines have been inserted in a redrawing on the right of the phenomena shown on the left.

After atrial systole, which is signaled by the P wave of the electrocardiogram (Figure 2, line 1), the mitral anulus moves toward the atrium (Figure 2, lines 1 to 2). This atrial motion is observed consistently in normal subjects and averages 2.4 ± 0.7 mm (range, 2.0–4.0 mm; Table 1). The end of atrial phase of mitral anulus motion corresponds to mitral valve closure (Figure 2, line 2). The mitral anulus remains immobile for about 90 msec after the onset of the QRS (Figure 2, lines 2 to 3), and then moves toward the left ventricular apex (Figure 2, lines 3 to 4). This descent of the mitral anulus motion precedes aortic ejection and coincides with left ventricular emptying and the systolic phase (J) of pulmonary venous flow (Figure 2). The displacement of the mitral anulus toward the apex averages 12.8 ± 1.4

ventricular outflow tract, immediately proximal to the leaflets of the aortic valve. Slight adjustments were required to optimize the orientation between the sample volume and flow.

Analysis of Data

While describing the relation between mitral valve motion and flows, the following terms will be used (Figures 1, 2): descent, motion of the mitral anulus toward the apex; and recoil, movement of the mitral anulus toward the atrium.

The following time intervals were measured from the onset of the QRS complex: 1) to the onset of anulus displacement during atrial contraction; 2) to the end of displacement during atrial contraction; 3) to the onset of descent of the anulus toward the apex; 4) to peak descent toward the apex; 5) to the onset of rapid recoil of the anulus toward the atrium; and 6) to the end of rapid recoil toward the atrium.

Mitral valve echocardiograms were analyzed, and the following time intervals were measured from the onset of the QRS complex: 1) to the opening of the mitral valve (D, line 5); 2) to the peak opening of the mitral valve at the rapid-filling wave (E); 3) to the peak opening of the valve at atrial contraction (A); and 4) to closure of the mitral valve (C, point of closure of mitral valve).

**FIGURE 2.** Echocardiograms and composite figure of pulmonary venous, mitral, aortic flows (PVF, MiF, AoF, respectively), and mitral anulus motion (MAM) in a normal subject. Arrow 1, onset of mitral anulus motion due to atrial contraction; arrow 2, end of mitral anulus motion due to atrial contraction; arrow 3, onset of mitral anulus descent consequent to ventricular contraction; arrow 4, end of mitral anulus descent due to ventricular contraction; arrow 5, onset of mitral anulus recoil due to ventricular relaxation; and arrow 6, end of mitral anulus recoil due to ventricular relaxation. Lines on the schematic illustration on the right correspond to these arrows. J, ventricular systolic phase of PVF; K, diastolic phase of PVF; E, mitral rapid-filling wave; A, mitral flow due to atrial contraction. The J phase of PVF occurs during ventricular contraction and descent of the mitral anulus before aortic ejection (between lines 3 and 4). Onset of MiF coincides with the onset of anulus recoil (line 5).
### Table 1. Timing of Mitral Anulus Motion and Aortic, Mitral, and Pulmonary Venous Flows in Normal Subjects

| Timing (msec)* | Ventricular phase | Atrial phase |
|----------------|------------------|-------------|
|                | Descent          | Recoil      |                |
| Line 1         |                  |             | 936±183       |
| Line 2         |                  |             | 1,055±180     |
| Line 3         | 91±17            |             |                |
| Line 4         | 380±33           |             |                |
| Line 5         |                  | 470±38      |                |
| Line 6         |                  | 579±42      |                |
| Duration (msec)| 286±26           | 108±13      |                |
| Displacement (mm)| 12.8±1.4      | 10.3±1.6    | 2.4±0.7       |

| Doppler echocardiogram | OAF* | EAF* | ET | Peak velocity |
|------------------------|------|------|----|---------------|
| Aortic flow            |      |      |    |               |
| 105±15 msec            | 397±31 msec | 291±25 msec | 88±14 cm/sec |
|                         | D*   | E*   | DFP| E velocity    |
| Mitral flow            | 465±35 msec | 545±25 msec | 598±150 msec | 66±10 cm/sec | 1,015±193 msec | 34±8 cm/sec | 1,065±173 msec |
| Pulmonary venous flow  |      |      |    |               |
|                       |      |      |    |               |
| Systolic (J) phase     |      |      |    |               |
| 94±34 msec            | 250±40 msec | 369±60 msec | 48±8 cm/sec |
| Peak*                 | End* |       |     |               |
| Diastolic (K) phase    | 603±37 msec | 799±56 msec | 49±11 cm/sec |

All values are mean±SD.

OAF, onset of aortic flow; EAF, end of aortic flow; ET, ejection time; D, onset of mitral flow; E, peak of rapid-filling wave; DFP, diastolic filling period; E velocity, A velocity, velocity of the leaflets of the mitral valve; C, closure of mitral valve.

*All measurements are made from the onset of the QRS. Lines 1 through 6 refer to corresponding lines on Figures 1 and 2.

mm (Figure 2). The initial atrial filling phase (J) of pulmonary venous flow begins with both atrial relaxation and the start of descent of the anulus during ventricular systole. The peak velocity of the J phase of pulmonary venous flow occurs at 250±40 msec and subsides, but does not cease completely, before the onset of the second phase (K) of pulmonary venous flow (Figure 2, line 5).

The onset of mitral anulus recoil coincides with both the K phase of pulmonary venous flow and the onset of transmural flow (Figure 2, line 5). Thus, pulmonary venous flow continues even during the isovolumic ventricular relaxation period at which time the mitral anulus is maximally displaced toward the ventricular apex. During that period, either no motion or only slight recoil is detected (Figures 1 and 2, lines 4 to 5).

The time required for the mitral anulus recoil is brief (Figure 2, lines 5 to 6) and coincides with rapid ventricular filling. Peak velocity of rapid ventricular filling (E) occurs before the end of the recoil (Table 1, Figures 1 and 2, line 6). The relative velocity of blood moving from the atrium toward the ventricle during the rapid-filling wave is the sum of the absolute velocity of flow and the rate of recoil of the mitral anulus toward the flow of blood. The rate of recoil of the anulus toward the atrium in diastole was 10±2 cm/sec (Table 2). The peak velocity of mitral flow (E wave) at the anulus was 50±7 cm/sec. Thus, the relative velocity of blood flowing between the atrium and ventricle was 60±7 cm/sec.

**Mitral Anulus Motion in Patients With Dilated Cardiomyopathy: Relation to Pulmonary Venous and Mitral Flows**

Eighteen of the 28 patients with dilated cardiomyopathy exhibited an abnormal pulmonary venous flow that was characterized by a reduced or absent J phase and a prominent K phase that peaked early in diastole. In addition, a retrograde regurgitant flow in the pulmonary vein was observed during systole in a few patients (Figure 3). Nine of the 18 patients with predominantly monophasic pulmonary venous flow had mitral regurgitation. In three of these patients, the regurgitant flow was recorded in the pulmonary vein that obviated forward flow during the J phase (Figure 3). In the other patients, the mitral regurgitation was moderate with low velocity of the regurgitant flow. A gradual increase in pulmonary venous flow was then observed throughout systole with the major pulse of forward pulmonary venous flow in diastole. The peak velocity of this phase was 60±3 cm/sec and occurred 509±57 msec after the QRS.

Mitral anulus motion was absent in seven of the 18 patients who demonstrated a predominantly monophasic pulmonary venous flow (Figure 4). Six of the seven patients were in sinus rhythm, and two
TABLE 2. Rate of Mitral Anulus Descent and Recoil and Mitral Flow Velocity (Absolute, Relative) in Normal Subjects

| Displacement of descent (cm) | Duration (sec) | Rate (cm/sec) | Displacement of recoil (cm) | Duration (sec) | Rate (cm/sec) | Doppler MiF E wave at anulus (cm/sec) | MiF relative velocity* (cm/sec) |
|-----------------------------|----------------|--------------|-----------------------------|----------------|--------------|------------------------------------|-------------------------------|
| 1.2                         | 0.27           | 4.2          | 1.0                         | 0.11           | 9.1          | 45                                 | 59                            |
| 1.3                         | 0.27           | 4.6          | 1.1                         | 0.12           | 8.4          | 60                                 | 68                            |
| 1.5                         | 0.27           | 4.1          | 0.8                         | 0.11           | 7.2          | 45                                 | 52                            |
| 1.5                         | 0.30           | 5.0          | 1.2                         | 0.085          | 14.2         | 50                                 | 64                            |
| 1.3                         | 0.27           | 5.5          | 1.2                         | 0.10           | 12.0         | 50                                 | 62                            |
| 1.2                         | 0.29           | 4.2          | 0.9                         | 0.10           | 12.0         | 65                                 | 72                            |
| 1.3                         | 0.29           | 4.5          | 1.0                         | 0.10           | 7.7          | 55                                 | 63                            |
| 1.4                         | 0.35           | 4.0          | 1.3                         | 0.12           | 10.8         | 55                                 | 66                            |
| 1.2                         | 0.32           | 3.8          | 1.1                         | 0.12           | 9.2          | 40                                 | 49                            |
| 1.1                         | 0.28           | 4.1          | 0.9                         | 0.09           | 10.0         | 45                                 | 55                            |
| 1.2                         | 0.27           | 4.4          | 1.0                         | 0.11           | 9.1          | 45                                 | 54                            |
| Mean ± SD                   | 1.28±0.14      | 0.28±0.03    | 4.5±0.5                     | 1.03±0.16      | 0.108±0.013 | 9.9±2.02                           | 50±7                          |

MiF, mitral inflow.
*Relative velocity is the sum of peak E wave of MiF at anulus and the rate of the recoil of the anulus (cm/sec).

patients had moderate mitral regurgitation, one of whom was also in atrial fibrillation. All seven patients demonstrated a small systolic J phase of pulmonary venous flow or a gradual increase in flow velocity throughout systole and a predominant K phase of flow. Peak velocity of the K phase was 54±15 cm/sec and occurred 516±87 msec after the onset of QRS. Thus, the lack of mitral anulus motion was associated with a monophasic pattern of pulmonary venous flow in five patients who were in sinus rhythm and who had a competent mitral valve.

Five of 18 patients who had a predominantly monophasic pulmonary venous flow were in atrial fibrillation. In three of these patients, a small forward J phase (peak velocity up to 10 cm/sec) was observed, and in the other two, the J phase was absent. Mild mitral regurgitation was also present in these patients with atrial fibrillation.

Ten patients with dilated cardiomyopathy demonstrated a normal biphasic pulmonary venous flow (Figure 5). They were all in sinus rhythm, and mitral anulus motion, although reduced when compared with normal subjects (5.1±2.0 vs. 12.8±1.4 mm, p<0.01), was present in all 10 patients. Four of the 10 patients had minimal mitral regurgitation. The peak velocity and timing of the J and K phases of pulmonary venous blood flow were similar to those of normal subjects (Tables 1, 4).

Discussion
This study supports the view that the mechanical events in the left ventricle contribute to the phasic characteristics of pulmonary venous flow and that motion of the base of the heart may be important in determining the pattern of pulmonary venous flow. Alternatively, the motion of the mitral valve anulus could be a passive phenomenon resulting from changes in transmitial blood flow. Our present data,
which describe a temporal relation between the motion of the mitral anulus and pulmonary venous flow, do not establish a causal relation between the two. Previously, we have shown that the first phase (J) of pulmonary venous flow occurs while the mitral valve is closed, and results from a reduced pressure in the left atrium that is due, at least in part, to relaxation of the atrium at the end of diastole.1,4 In the present study, we have shown that during systole the mitral valve descends toward the ventricular apex as a result of contraction and shortening of the left ventricle and thus adds to the fall in pressure in the left atrium.7,11,13,19 Thus, in addition to atrial contraction, mitral anulus motion may also contribute to atrial filling. Consequently, pulmonary venous flows due to isolated atrial contraction alone1 or isolated ventricular premature beats are reduced when compared with those observed with synchronous atrioventricular function (Figure 6).

The displacement of the mitral anular ring begins during the isovolumetric ventricular contraction before aortic ejection and peaks with the end of ejection and the end of the J phase of pulmonary venous flow. Tsakiris et al11 and others6,20,21 have also noted an anular ring motion toward the ventricular apex during the isovolumic contraction period. Subsequent to ventricular contraction, the mitral anulus springs back, or recoils, during the rapid phase of mitral blood flow into the ventricle. This increases the net velocity of mitral flow and augments the left ventricular filling process.22 Indeed, we would estimate an approximate 20% increase in relative velocity of blood from the left atrium to the left ventricle due to the recoil motion of the mitral anulus (Table 2). The rapid fall in left atrial pressure in early diastole is associated with the onset of mitral flow and the ensuing second (K) phase of diastolic flow from the pulmonary veins. We have previously shown that with early mitral flow deceleration, the pulmonary veins refill the atrium; this restores a positive pressure gradient between the veins and, thereby, in the left atrium and ventricle, which causes the mitral valve to open (L motion) and to reaccelerate mitral flow (L wave).3 This phase occurs early in diastasis after the rapid ascent of the ring. The active phase of atrial systole was consistently observed in sinus rhythm and was associated with a 2–4-mm displacement of the anulus, confirming observations by Tsakiris et al11 in the dog and by Zaky et al6 in humans.

The contribution of both atrial contraction and mitral ring displacement in determining pulmonary venous flow is corroborated by our findings in patients with dilated cardiomyopathy. Three different patterns of altered pulmonary venous flow are observed in patients with congestive heart failure. The first pattern is a normal biphasic pattern associated with normal sinus rhythm and a competent mitral valve, despite a reduced displacement of
the mitral anulus in systole. The second pattern is monophasic, whereby the J flow associated with ventricular systole is reduced or absent, and thus, most or all of the flow from the pulmonary veins into the left atrium occurs in diastole. This is observed in patients with atrial fibrillation or in patients with sinus rhythm with either a completely immobile mitral anulus or mild-to-moderate mitral regurgitation. The third pattern is one of severe mitral regurgitation with only regurgitant flow detected in ventricular systole in the pulmonary vein and a forward flow occurring only in diastole. The lack of synchronized atrial contraction in patients with atrial fibrillation, sinoatrial block, or atrioventricular block results in reduction or complete disappearance of the normal J portion of biphasic pulmonary venous flow. 

Cardioversion in patients with atrial fibrillation and atrioventricular sequential pacing in patients with complete heart block restore the J flow. 

Left ventricular function is also clearly implicated in determining pulmonary venous flow into the left atrium. Inotropic stimulation in the dog heart with isoproterenol augments both phases of pulmonary venous flow. Experimentally, when atrial contraction is inhibited by stimulation of the left vagus, the A wave in the left atrial pressure is depressed, and the pulmonary venous flow is altered so that the bulk occurs during ventricular diastole rather than in systole. 

In patients with dilated cardiomyopathy, ventricular dysfunction results in disturbed filling from the pulmonary veins through development of atrial fibrillation or by immobilization of the mitral systolic ring. Both result in a significant reduction in the amount of filling of the left atrium during ventricular systole, that is, the J phase of flow. Because pulmonary venous flow normally continues throughout both systole and diastole, mitral regurgitation vitiated this phase of flow. Accordingly, either net forward blood flow will be reduced, or the amount of flow that occurs during diastole will be greatly augmented. The latter would require a substantial rise in left atrial pressure that may help to explain the detrimental effect of functional mitral regurgitation in dilated cardiomyopathies.

In summary, we have shown that during ventricular systole, pulmonary vein flow fills the left atrium (J phase) because of both left atrial relaxation and caudal displacement of the atrioventricular junction (mitral

### Table 3. Timing of Mitral, Pulmonary Venous, and Aortic Flows in Patients With Dilated Cardiomyopathy

|                  | Mitral flow (msec) | Pulmonary venous flow (msec) | RR (msec) | Aortic flow (msec) |
|------------------|--------------------|-----------------------------|-----------|-------------------|
|                  | D*                 | E*                          | C*        | DFP               | BJ*       | J*       | BK*     | K*     | OAF* | PAF* | EAF* | ET   |
| Sinus rhythm     |                    |                              |           |                   |           |          |         |        |       |      |      |      |      |
| Biphasic flow    | 443 ± 62 512 ± 64  | 684 ± 108                   | 271 ± 86  | 102 ± 59 232 ±  | 65 395 ±  | 90 578 ±  | 83 677 ± | 110 115 | ± 27 | 182 ±  | 34 352 ± | 37 226 ± | 22 |
| (n = 10)         |                    |                              |           | 65 ± 65 | 395 ± 90 | 578 ± 83 | 677 ± 110 | 115 ± 27 | 182 ± 34 | 352 ± 37 | 226 ± 22 | |
| Mitral regurgitation | 411 ± 51 476 ± 52 | 725 ± 126                   | 310 ± 113 | 509 ± 57 691 ± | 125 118 ± 21 | 217 ± 45 | 349 ± 39 | 231 ± 35 | |
| (n = 9)          |                    |                              |           | 125       | 118 ± 21 | 217 ± 45 | 349 ± 39 | 231 ± 35 | |
| Atrial fibrillation | 434 ± 42 510 ± 54 | 645 ± 82                    | 211 ± 44  | 414 ± 46 519 ± | 34 766 ± | 147 133 ± 14 | 209 ± 12 | 344 ± 34 | 211 ± 25 | |
| (n = 5)          |                    |                              |           | 414 ± 46 | 519 ± 34 | 766 ± 147 | 133 ± 14 | 209 ± 12 | 344 ± 34 | 211 ± 25 | |
| Without mitral  | 419 ± 67 499 ± 77  | 709 ± 91                    | 290 ± 80  | 516 ± 87 739 ± | 90 122 ± 35 | 243 ± 30 | 243 ± 56 | 240 ± 29 | |
| anulus motion   | (n = 7)            |                              |           | 516 ± 87 | 739 ± 90 | 122 ± 35 | 243 ± 30 | 243 ± 56 | 240 ± 29 | |

Values are mean ± SD.

D, onset of mitral flow; E, peak of rapid-filling wave; C, end of mitral flow; DFP, diastolic-filling period; BJ, onset of the first phase of pulmonary venous flow; J, peak of the first phase of pulmonary venous flow; BK, onset of the second phase of pulmonary venous flow; K, peak of the second phase of pulmonary venous flow; OAF, onset of aortic flow; PAF, peak aortic flow; EAF, end of aortic flow; ET, aortic ejection time; biphasic flow, patients in sinus rhythm with biphasic pulmonary venous flow.

*All measurements are made from the onset of the QRS.

### Table 4. Mitral, Aortic, and Pulmonary Venous Flow Peak Velocities in Patients With Dilated Cardiomyopathy

|                  | Mitral flow E wave (cm/sec) | Aortic flow (cm/sec) | Pulmonary venous flow (cm/sec) |
|------------------|-----------------------------|----------------------|-------------------------------|
|                  |                            |                      | J                             | K                             |
| Sinus rhythm     |                            |                      |                               |                               |
| Biphasic flow    | 74 ± 21                     | 82 ± 13              | 45 ± 8                        | 48 ± 10                       |
| Mitral regurgitation | 76 ± 8                     | 67 ± 12              | ...                           | ...                           |
| Atrial fibrillation | 74 ± 15                     | 72 ± 15              | ...                           | ...                           |
| Without mitral anulus motion | 62 ± 14                   | 77 ± 6               | ...                           | 54 ± 15                       |

Values are mean ± SD.

J, systolic phase of pulmonary venous flow; K, diastolic phase of pulmonary venous flow; biphasic flow, patients in sinus rhythm with biphasic pulmonary venous flow; mitral regurgitation, patients in sinus rhythm with mitral regurgitation.
valve ring). During the onset of ventricular relaxation, recoil of the mitral anulus and base of the left ventricle occurs, and during the rise in the pressure in the left atrium, the mitral valve opens, and the diastolic K phase of pulmonary venous flow ensues. In patients with congestive heart failure, loss of atrial contraction and immobilization of the mitral anulus due to reduced ventricular systolic function result in reduced systolic inflow into the left atrium. Dysfunction of the mitral anulus in these patients, which results from reduced ventricular contraction, may result in functional mitral regurgitation that abolishes the systolic first phase of pulmonary venous flow. This mitral regurgitation will then tend to augment left atrial pressure by not only increasing left atrial blood volume from the regurgitation but also by vitiating the systolic phase of atrial filling so that all atrial filling by the pulmonary veins must occur during diastole. Thus, the left ventricle plays a central role in its filling as well as emptying, and disorders of systolic function will significantly affect diastolic ventricular filling.

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