A Study of the Dynamic Relations Between the Mitral Valve Echogram and Phasic Mitral Flow

By Shlomo Laniado, M.D., Edward Yellin, Ph.D., Morris Kotler, M.D., Leonard Levy, M.D., Jona Stadler, M.D., and Reuven Terdiman, M.Sc.

SUMMARY
Echocardiographically recorded mitral valve motion was compared with phasic transmitral flow in 17 open chest dogs.

The normal mitral valve opening started with the onset of mitral flow and reached its full excursion while flow was still accelerating. Complete valve opening occurred .044 sec (± .002 SEM) before peak flow, during which time an average of 17.6% of total mitral filling volume had passed through the valve.

In contrast to the opening movement, the closing motion of the anterior mitral valve cusp lagged behind the deceleration of mitral flow. The E-F phase of the mitral valve echogram started while mitral flow was still increasing and resulted from a combined posterior motion of the cusp and the ring. The E-F slope of the normal valve was found to decrease with reduced cardiac output. The amplitude of the anterior cusp excursion did not reflect the amount of mitral flow.

Prolonged P-R interval may induce a mid-diastolic reversal of mitral flow which, in turn, may be accompanied by partial or complete valve closure, occurring before the onset of ventricular contraction. Such premature closure of the mitral valve may be accompanied by a certain amount of regurgitant flow.

Additional Indexing Words:
Echocardiography Mitral valve ring Diastolic closure slope

ECHOCARDIOGRAPHY, as a noninvasive method, affords a unique opportunity of studying mitral valve motion. The characteristic pattern of movement of the anterior mitral cusp, as recorded in the echogram, was first described by Edler.1 Although abnormal patterns of mitral valve motion have been described in a variety of conditions,2-10 the mitral valve echogram has proved to be of particular diagnostic value in mitral stenosis.11,12 In mitral stenosis the degree of reduction of the diastolic closure slope of the E-F segment of the mitral valve echogram has provided valuable information relating to the severity of the obstruction.13-18 Reduction of the diastolic closure slope was also found to exist in other pathological conditions in which the cardiac output and the rate of left ventricular filling were reduced.19-22

Although transmitral flow measurement in dogs23 and man24 has been proven successful, to date there have been no reports of studies which correlate phasic mitral valve flow with echograms of mitral valve motion. The two aims of this study were to compare total and phasic changes in transmital flow with mitral valve motion, and to determine the factors responsible for closing movements of the anterior cusp, and particularly the diastolic closure speed (the E-F slope), of the normal valve.

Methods
Seventeen adult mongrel dogs weighing 28-40 kg were anesthetized with pentobarbital 30 mg/kg. The chest was opened by two incisions in the mid-sternum and through the left fourth intercostal space. Short stiff catheters were placed in the left atrium and in the aorta, and Statham P23Db pressure transducers were used to measure the corresponding pressures. Left ventricular pressure was measured with a high fidelity catheter-tipped transducer (Micro-Tip model PC-350, Millar instruments) placed in the ventricle via an apical puncture. All three pressure transducers were adjusted for equal sensitivity and common zero. An intracardiac phonocardiogram was derived from the left ventricular pressure transducer by a method which has been described previously.25 During cardiopulmonary bypass, an electromagnetic flow probe was sutured to the mitral annulus in a suprannular position, and the wires were brought out through the left atrial appendage. A second flow probe was placed around the ascending aorta. Phasic mitral and aortic flows were measured with a two channel electromagnetic

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flowmeter (model 501, Carolina Medical Electronics).

The mitral flow probe is of toroidal shape with an inner diameter of 18 mm, and is similar to the one described by Nolan et al. Although precalibrated by the manufacturer, we have frequently checked its calibration by comparing the calculated stroke volume from the aortic probe with the mitral filling volume, and found the probe quite stable. Because of the large probe size and because the electrodes are in direct contact with the blood rather than the vessel wall, circulatory red cell mass is of little consequence and the probe can be calibrated in vitro using saline. Zero flow is easily determined during ventricular systole if the valve is competent, and is checked by cardiac fibrillation or arrest at the termination of the experiment. Vagal stimulation leading to acute bradycardia with prolonged diastasis and zero flow is sometimes used during an experiment to check zero flow. The frequency response of the flowmeter is selected at 30 Hz, thereby filtering the high frequency noise without significantly altering the flow wave form.

All tracings were recorded by a multichannel oscillographic recorder (DR-8, Electronics for Medicine) at paper speeds of 50, 75 or 100 mm/sec. Mitral valve echograms were recorded utilizing a commercially available ultrasound device (Unirad Corp. Series 100) using a 2.25 MHz transducer which measured 8 mm in diameter. The depth of the recorded field was selected at 5 cm. The transducer was placed lightly on the anterior surface of the right ventricle close to its apex, directed to record the characteristic signal of the anterior cusp, and was held rigidly in place by the operator, thereby minimizing the relative motion between the transducer and the base of the heart. Whenever possible the respirator was turned off during the recording periods. The echocardiogram was recorded simultaneously with the hemodynamic data through an interface channel (model UDA-22, Electronics for Medicine).

Measurements and Calculations

Figure 1 is a schematic representation of the relationship between the anterior mitral cusp echogram and phasic mitral flow, in which the measured parameters are defined. We differentiated between mitral volume and mitral flow. Volume was defined as the total amount of blood which had passed through the valve during any certain period of time, while flow showed the amount of blood passing through the electromagnetic probe (and thus through the annulus) at any particular time. Since the area circumscribed by the flow probe was constant, the measured mitral flow, which is derived from the velocity of blood and the cross-sectional area of the probe, was the true amount of blood flowing into the valve at any given time.

Mitral volumes were calculated by planimetry of the area under the calibrated mitral flow curve. Cardiac output was obtained from aortic or mitral flow measurement and heart rate. Each parameter obtained was the mean measurement of ten consecutive beats. Statistical analysis was done by the nonparametric method of Van Der Waerden. Differences were considered significant when \( P < 0.05 \).

Results

The hemodynamic and echographic results of the different dogs are presented in tables 1 and 2. Table 3 compares the results obtained from a group of dogs with normal cardiac output, and with low output and/or arrhythmia.

Figure 2 is an original record of hemodynamic data recorded simultaneously with the mitral valve echogram. This record confirms our previous findings that flow across the mitral valve starts as soon as left atrial pressure exceeds left ventricular pressure, but continues beyond the systolic crossing point of the atrial and ventricular pressures, and that valve closure does not occur at the time of pressure equalization but after an additional period of time.

Temporal Relation Between the Maximal Amplitude of the Anterior Cusp Movement and Peak Mitral Flow

There is a striking similarity in the configuration of the recorded mitral flow and the anterior cusp echogram (figs. 2-5). The opening movement of the anterior cusp starts simultaneously with the onset of mitral flow, but reaches its maximal amplitude of excursion significantly earlier (.044 sec ± .002 SEM) than peak mitral flow (table 1). The time interval between the point of maximal valve opening and peak mitral flow was greater when peak flow was larger, or when it was delayed because the atrial augmentation coincided with the rapid augmentation coincided with the rapid
phenomenon is clearly shown in the second beat of figure 3 and in the second and fifth beats of figure 4. In these beats the peaks of the flows were increased by improperly timed atrial contractions generated by atrial premature beats. A constant relationship was found between the volume of blood necessary to induce full cusp opening and the total diastolic filling volume (table 1). In dogs with normal cardiac output the mitral opening volume consisted of about 18% of the total filling volume (group A, table 3). This value was increased to 23% in the dogs with low cardiac output (group B, table 3).

**Correlation of the Diastolic Motion of the Anterior Cusp Echogram with Changes in Mitral Flow**

In contrast to the opening movement, the posterior closing motion of the anterior cusp lagged behind the

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**Table 1**

<table>
<thead>
<tr>
<th>Dog</th>
<th>Dog</th>
<th>Heart rate</th>
<th>P-R Interval (sec)</th>
<th>LV systolic pressure (mm Hg)</th>
<th>Mitral volume (ml/beat)</th>
<th>Cardiac output L/min</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Filling</td>
<td>Closing</td>
</tr>
<tr>
<td>1</td>
<td>28</td>
<td>90</td>
<td>0.10 ± 0.03</td>
<td>75 ± 1.75</td>
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<tr>
<td>2</td>
<td>30</td>
<td>82</td>
<td>0.12 ± 0.02</td>
<td>109 ± 3.31</td>
<td>24.7 ± 0.40</td>
<td>3.56 ± 0.44</td>
</tr>
<tr>
<td>3</td>
<td>35</td>
<td>93</td>
<td>0.09 ± 0.08</td>
<td>110 ± 2.58</td>
<td>26.7 ± 0.37</td>
<td>2.17 ± 0.04</td>
</tr>
<tr>
<td>4</td>
<td>35.5</td>
<td>87</td>
<td>0.10 ± 0.04</td>
<td>114 ± 3.10</td>
<td>27.9 ± 1.21</td>
<td>2.74 ± 0.22</td>
</tr>
<tr>
<td>5</td>
<td>32</td>
<td>83</td>
<td>0.18 ± 0.01</td>
<td>103.7 ± 0.87</td>
<td>23.4 ± 0.98</td>
<td>3.07 ± 0.39</td>
</tr>
<tr>
<td>6</td>
<td>30</td>
<td>88</td>
<td>0.13 ± 0.05</td>
<td>85.3 ± 2.11</td>
<td>23.0 ± 0.46</td>
<td>3.69 ± 0.27</td>
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<tr>
<td>7</td>
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<td>112</td>
<td>0.17 ± 0.03</td>
<td>99.1 ± 2.94</td>
<td>22.1 ± 0.58</td>
<td>3.81 ± 0.06</td>
</tr>
<tr>
<td>8</td>
<td>34</td>
<td>100</td>
<td>0.14 ± 0.02</td>
<td>80.2 ± 2.16</td>
<td>22.9 ± 0.89</td>
<td>3.72 ± 0.11</td>
</tr>
</tbody>
</table>

Mean: .13 97.10 24.09 3.32 13.80 4.28 17.6 2.22
Mean: .01 5.29 .82 .20 1.10 .45 .91 .06

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**Figure 2**

Original record at a paper speed of 100 mm/sec demonstrating the relationship between pressure, flow, sound and mitral valve cusp motion. Closure of the mitral valve (MVE) was completed 35 msec after the crossover of left atrial (LAP) and left ventricular (LVP) pressures. Note that peak amplitude of opening of the anterior cusp (E point) occurs 40 msec before peak flow. The positive spike at the downward slope of the mitral flow trace which occurs simultaneously with the R wave of the electrocardiogram (ECG) is an artefact. The negative deflection of the flow curve at the beginning of systole represents a small amount of closing volume presumably due to the movement of the sealed cusps (with the blood behind them) into the atrium and/or possibly a minimal amount of mitral regurgitation. AoP = aortic pressure.

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**Figure 3**

In this record the second beat is a premature atrial contraction with a prolonged P-R interval. In this beat the atrial contraction contributes to the rapid mitral filling wave. Following the peak flow there is a rapid deceleration of flow accompanied by delayed posterior movement of the cusp towards closure. Paper speed is 75 mm/sec.

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deceleration of mitral flow (figs. 2-5). With approximately 75% reduction in flow, the cusp achieved only 30% of its total posterior deflection, and when flow reached zero, the cusp was still midway, reaching only 40-60% of its total posterior excursion (tables 1 and 2).

The Effect of Low Cardiac Output on the D-E Amplitude and on the E-F Slope of the Echogram

Tables 1 and 2 demonstrate that low cardiac output did not cause any decrease in the maximal amplitude of opening of the anterior cusp. This is demonstrated in figures 6 and 7. In these records it is clear that the cusp was fully open with markedly reduced flow, and the cusps were held in a widely open position despite no apparent flow (fig. 7). Figures 6 and 7 show that the valve orifice area, as reflected by the area described by the anterior cusp echogram, was practically constant while cardiac output varied significantly.

A significant relationship was found to exist between the diastolic closure speed (the E-F slope) of the anterior cusp and the cardiac output. Figure 8 demonstrates the relationship between the E-F slope and the cardiac output in 17 dogs. As seen in table

<table>
<thead>
<tr>
<th>Peak Mitral flow (ml/sec)</th>
<th>Percent opening</th>
<th>Peak amplitude of anterior cusp movement (Cm)</th>
<th>Maximal amplitude of cusp motion (Cm)</th>
<th>Time from start of opening to peak motion (Sec)</th>
<th>Time interval from peak motion to peak flow (Sec)</th>
<th>Diastolic closure rate (E-F speed) (mm/sec)</th>
<th>Percent of closing movement at time of zero flow</th>
</tr>
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<tbody>
<tr>
<td>105 ± 2.8</td>
<td>88 ± 2.21</td>
<td>78 ± 1.66</td>
<td>.14 ± .01</td>
<td>.16 ± .006</td>
<td>.03 ± .003</td>
<td>1.04 ± 1.20</td>
<td>44 ± 1.21</td>
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<tr>
<td>39.6 ± .98</td>
<td>38.1 ± 1.04</td>
<td>83 ± .83</td>
<td>1.71 ± .03</td>
<td>.13 ± .006</td>
<td>.17 ± .008</td>
<td>.04 ± .007</td>
<td>52.1 ± 1.08</td>
</tr>
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<td>85.7 ± 1.97</td>
<td>75.2 ± 2.32</td>
<td>87 ± 1.10</td>
<td>1.71 ± .01</td>
<td>.18 ± .008</td>
<td>.21 ± .008</td>
<td>.046 ± .006</td>
<td>45.1 ± 1.38</td>
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<td>83.8 ± 1.60</td>
<td>74.3 ± 1.81</td>
<td>88 ± .63</td>
<td>1.73 ± .02</td>
<td>.19 ± .007</td>
<td>.24 ± .006</td>
<td>.051 ± .006</td>
<td>66.5 ± 2.03</td>
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<td>73.0 ± .41</td>
<td>55.5 ± 1.23</td>
<td>78 ± 1.40</td>
<td>1.56 ± .05</td>
<td>.11 ± .007</td>
<td>.15 ± .005</td>
<td>.049 ± .005</td>
<td>62.5 ± 1.09</td>
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<td>56.2 ± 1.70</td>
<td>40.5 ± 1.54</td>
<td>77 ± .72</td>
<td>1.44 ± .03</td>
<td>.08 ± .003</td>
<td>.12 ± .002</td>
<td>.043 ± .006</td>
<td>59.9 ± 1.21</td>
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<td>139 ± 6.90</td>
<td>110 ± 3.80</td>
<td>79 ± .87</td>
<td>1.50 ± .03</td>
<td>.11 ± .004</td>
<td>.14 ± .002</td>
<td>.048 ± .007</td>
<td>73.2 ± 2.47</td>
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<td>110 ± 4.21</td>
<td>82.4 ± 2.30</td>
<td>74 ± 1.27</td>
<td>1.80 ± .09</td>
<td>.11 ± .005</td>
<td>.15 ± .002</td>
<td>.051 ± .006</td>
<td>74.2 ± 1.59</td>
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<table>
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<td>.11</td>
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<td>.16</td>
<td>.044</td>
<td>.64.4</td>
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<tr>
<td>1.74</td>
<td>.04</td>
<td>.01</td>
<td>.002</td>
<td>2.53</td>
</tr>
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</table>

Figure 4

In this tracing the occurrence of atrial premature beats, with prolonged P-R intervals (the second and fifth beats) changes the pattern of mitral flow and anterior cusp echogram. In the premature beats, atrial contraction coincided with the period of accelerating mitral flow, causing peak flow to be of greater magnitude and delayed appearance; 90 msec following complete valve opening as compared with 45 msec in the regular beats. In the two premature beats flow had already reversed its direction (arrow) while the anterior cusp was still in a mid-open position. The left atrial and left ventricular pressure gradient throughout diastole is due to a recording error. Paper speed is 50 mm/sec and time lines are 1 sec apart.
Hemodynamic and Echographic Data from Nine Dogs with Low Cardiac Output

<table>
<thead>
<tr>
<th>Dog</th>
<th>Heart rate (beats/min)</th>
<th>P-R Interval (sec)</th>
<th>LV systolic pressure (mm Hg)</th>
<th>Filling</th>
<th>Closing</th>
<th>Percent closing</th>
<th>Opening</th>
<th>Percent opening</th>
<th>Cardiac output (ml/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>60</td>
<td>.14 ± .003</td>
<td>58.0 ± 1.14</td>
<td>15.17 ± .40</td>
<td>2.72 ± .25</td>
<td>17 ± .87</td>
<td>3.56 ± .27</td>
<td>23.4 ± 1.08</td>
<td>91 ± .004</td>
</tr>
<tr>
<td>10</td>
<td>38</td>
<td>.15 ± .004</td>
<td>52.3 ± 1.3</td>
<td>15.60 ± .41</td>
<td>2.95 ± .23</td>
<td>18 ± 1.12</td>
<td>3.43 ± .15</td>
<td>23.1 ± 1.37</td>
<td>.90 ± .008</td>
</tr>
<tr>
<td>11</td>
<td>81</td>
<td>.13 ± .003</td>
<td>46.4 ± .74</td>
<td>12.91 ± .31</td>
<td>2.45 ± .24</td>
<td>19 ± .40</td>
<td>2.69 ± .19</td>
<td>21.4 ± .79</td>
<td>.86 ± .006</td>
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<tr>
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<td>.14</td>
<td>52.2</td>
<td>14.56</td>
<td>2.71</td>
<td>18.0</td>
<td>3.16</td>
<td>22.97</td>
<td>.92</td>
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</table>

2) Irregular supraventricular rhythm
(Multiple APC’s or atrial tachycardia or flutter with varying block)

<table>
<thead>
<tr>
<th>Dog</th>
<th>Heart rate (beats/min)</th>
<th>P-R Interval (sec)</th>
<th>LV systolic pressure (mm Hg)</th>
<th>Filling</th>
<th>Closing</th>
<th>Percent closing</th>
<th>Opening</th>
<th>Percent opening</th>
<th>Cardiac output (ml/min)</th>
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<tbody>
<tr>
<td>12</td>
<td>71</td>
<td>40.6 ± 2.17</td>
<td>13.50 ± .63</td>
<td>2.97 ± .26</td>
<td>22 ± .26</td>
<td>2.37 ± .19</td>
<td>26.2 ± 1.8</td>
<td>.96 ± .003</td>
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<td>13</td>
<td>78</td>
<td>37.0 ± 3.28</td>
<td>11.7 ± 1.50</td>
<td>2.88 ± .20</td>
<td>24 ± 1.07</td>
<td>2.61 ± .31</td>
<td>22.1 ± 1.44</td>
<td>.91 ± .004</td>
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<td>14</td>
<td>81</td>
<td>39.1 ± 2.16</td>
<td>12.96 ± .64</td>
<td>2.93 ± .37</td>
<td>22 ± .18</td>
<td>2.38 ± .10</td>
<td>19.5 ± 1.83</td>
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<tr>
<td>Mean</td>
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<td>38.9</td>
<td>12.73</td>
<td>2.93</td>
<td>22.6</td>
<td>2.45</td>
<td>22.6</td>
<td>.97</td>
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</tr>
<tr>
<td>± SE</td>
<td></td>
<td>.04</td>
<td>.53</td>
<td>.10</td>
<td>.06</td>
<td>.08</td>
<td>.20</td>
<td>.04</td>
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</table>

3) Idioventricular rhythm

<table>
<thead>
<tr>
<th>Dog</th>
<th>Heart rate (beats/min)</th>
<th>P-R Interval (sec)</th>
<th>LV systolic pressure (mm Hg)</th>
<th>Filling</th>
<th>Closing</th>
<th>Percent closing</th>
<th>Opening</th>
<th>Percent opening</th>
<th>Cardiac output (ml/min)</th>
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</thead>
<tbody>
<tr>
<td>15</td>
<td>78</td>
<td>42.0 ± 1.96</td>
<td>9.4 ± .36</td>
<td>3.07 ± .23</td>
<td>32 ± 1.32</td>
<td>2.27 ± .03</td>
<td>24 ± 1.06</td>
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<td>16</td>
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<td>41.2 ± .80</td>
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<td>2.85 ± .11</td>
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<td>1.68 ± .04</td>
<td>23 ± .97</td>
<td>.68 ± .002</td>
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<tr>
<td>17</td>
<td>75</td>
<td>46.3 ± .69</td>
<td>8.18 ± .27</td>
<td>2.93 ± .17</td>
<td>35 ± 1.40</td>
<td>2.05 ± .04</td>
<td>24 ± .71</td>
<td>.69 ± .003</td>
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<tr>
<td>Mean</td>
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<td>43.2</td>
<td>8.23</td>
<td>2.95</td>
<td>35.7</td>
<td>2.33</td>
<td>23.7</td>
<td>.67</td>
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<tr>
<td>± SE</td>
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<td>1.58</td>
<td>.66</td>
<td>.06</td>
<td>2.33</td>
<td>.17</td>
<td>.33</td>
<td>.03</td>
<td></td>
</tr>
</tbody>
</table>

3, the dogs with normal cardiac output had an average E-F slope of 64.4 mm/sec, while the animals with the lowest output had an average E-F slope of 26 mm/sec.

The Effect of Prolonged P-R Interval on the Mitral Flow and the Mitral Echogram

A frequent and interesting phenomenon was observed in situations where the P-R interval was prolonged in relation to the heart beat. This was usually observed with the occurrence of atrial premature contractions (figs. 3-4). Following prolongation of the P-R interval, the atrial contraction coincided with rapid mitral filling, and resulted in a transfer of a larger volume of blood from the left atrium to the left ventricle in a shorter time period. Rapid deceleration of mitral flow was then followed by partial or complete premature valve closure before ventricular systole. In addition, the abnormal valve closure was accompanied by a greater than normal amount of regurgitant flow. Figure 9 records three groups of beats from a continuous recording of a dog in which the P-R interval spontaneously increased during 20 consecutive beats. As the P-R interval lengthened, there was an obvious change in the configuration of the mitral flow trace, the anterior cusp moved towards closure long before ventricular systole and closure was accompanied by a larger regurgitant volume.

Determinants of the E-F Slope and the Contribution of Mitral Ring Movement to Cusp Echogram

In those records where echograms of the mitral ring could be obtained together with those of the anterior cusp (fig. 10), it was observed that the ring started its posterior movement at the onset of diastole, with a short phase of rapid motion that was subsequently
followed by a slower motion. The early phase of the E-F slope (measured from point E to the arrow), almost parallels the initial rapid posterior movement of the ring, both of which precede the peak of flow (fig. 10).

Discussion

The present study provides the first data correlating dynamic changes of mitral valve movement determined by echocardiography with phasic mitral flow. It demonstrates that the motion of the anterior cusp follows gross changes in mitral flow, but the relationship between the two is complex. With the onset of a positive atrioventricular pressure gradient at the beginning of diastole, the mitral valve starts its opening simultaneously with the increase in flow across the mitral valve. Complete valve opening always occurs before peak flow. The period of time from opening flow (corresponding to complete valve opening) to peak flow varies depending on the magnitude and configuration of the rapid filling wave.

Table 3
Comparative Hemodynamic and Echographic Results of the Different Groups of Dogs

<table>
<thead>
<tr>
<th>Cardiac output (L/min)</th>
<th>Percent of volume to filling volume</th>
<th>Percent of closing volume</th>
<th>Time interval from peak motion to peak flow (sec)</th>
<th>Diastolic closure rate E-F speed (mm/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.22</td>
<td>P&lt;.01</td>
<td>&lt;.05</td>
<td>13.8</td>
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<td>=.06</td>
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<td>Group B</td>
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<td>23.67</td>
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*P values between any two groups are given.
which in turn may be affected by the length of the P-R interval. While valve opening can be associated with minor increases in flow, the closing motion of the cusp is delayed following the rapid deceleration of flow. The valve may stay widely open despite the fact that minimal or even zero flow has occurred. These observations of opening and closing cusp motion and simultaneous early and late diastolic flow correlations indicate that mitral valve orifice area as derived from the echogram is a poor index of mitral flow.

Our study shows that the optimal closure of the mitral valve is achieved in dogs with regular sinus rhythm and normal cardiac output (table 1). In these cases the closing (‘regurgitant’) volume consisted of about 14% of the total diastolic filling volume. In dogs with low cardiac output (with apparently distended ventricles) and with irregular rhythm this ratio was increased, and was particularly high with the occurrence of idioventricular rhythm where up to 35% of the total mitral filling volume regurgitated back to the atrium.

With prolonged P-R intervals atrial contribution adds to ventricular filling during the rapid phase of mitral flow. Thus, the combination of ventricular overloading and atrial relaxation will result in a mid-diastolic pressure gradient reversal, and rapid deceleration of mitral flow. There is delay in valve closure following deceleration of flow and it is accompanied by mitral regurgitation. A possible mechanism for this imperfect closure may be due to undue tension of the chordae tendineae, created by an overdistended ventricle and absence of ventricular contraction at that point in time.

Zaky and his colleagues were the first to draw attention to the significance of recognizing the pattern of mitral ring motion in the echogram. They concluded that the echocardiographic recording of the anterior cusp consists of both cusp and ring motion. The E-F slope in the mitral valve echogram seems therefore to be a composite of two different

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**Figure 6**

This tracing is from a dog with low cardiac output. The amplitude of motion of the mitral cusp is 17 mm but the E-F slope is reduced to 28 mm/sec. The bottom part of the mitral echo tracing was retouched.

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**Figure 7**

This tracing, from the same dog as figure 6, was recorded during a bout of ventricular tachycardia. There were no effective ventricular contractions or mitral flow, but the cusps remained widely opened.
the cusps are attached to the myocardium by the chordae tendineae and the papillary muscles. Another possible influence on valve motion may be due to the tension on the cords during diastole (unpublished data).

In normal individuals in whom the anterior mitral cusp is very pliable, the E-F slope is predominantly a result of cusp motion and to a lesser extent ring movement. In mitral stenosis, however, the initial posterior movement of the ring accounts for the E-F slope, during which time the cusps remain in a relatively stable open position. This was suggested by Zaky et al. and supported subsequently by the study of Chakhorn et al.

In the normal mitral valve echogram, the A point, which results from atrial contraction, is usually of smaller amplitude than the protodiastolic E point. In a previous investigation in which the degree of valve opening was determined from the cinefluorograms of opacified cusps, it was demonstrated that during normal sinus rhythm the cusps achieved the same full separation from each other following atrial systole as during early diastole. The present data demonstrate that reduced mitral flow can still induce the valve to reach complete or near complete opening. It is therefore suspected that in the normal echogram point A is lower than point E, not because the anterior cusp has not reopened completely, but because the ring moved posteriorly during the latter part of diastole.

Based upon the experimental findings in our report

Figure 8

Relationship of the E-F slope measurement and the cardiac output obtained in 17 dogs.

movements, the cusp moving toward closure and the ring receding away from the ventricular apex at the time of rapid ventricular filling. The cusp motion is also determined by the anatomy of the ventricle since

Figure 9

This figure demonstrates the relationship between mitral valve flow and the mitral valve echogram in three groups of beats with varying P-R intervals, all occurring during a period of about fifteen seconds. A fourth heart sound becomes prominent during the periods of atrial augmentation to the rapid mitral filling phase. For clarity the mitral valve echogram has been retouched. A dense echo recorded during systole and diastole adjacent to the mitral valve echogram may represent echoes originating from the flow probe. Time lines are 0.2 sec apart. Paper speed is 30 mm/sec.
Two factors are probably responsible for this phenomenon: 1) slower deceleration of flow during the later phase of the rapid filling wave, and 2) reduction in the posterior movement of the ring.

Thus, it is not surprising that in certain patients with mitral stenosis, the recorded diastolic closure slope may be a poor index of the severity of the stenosis. It is possible that altered left ventricular compliance, reduced left ventricular filling and significant reduction in mitral ring motion may be the major determining factors in the reduced diastolic closure slope, rather than the actual mitral valve orifice size. In addition, these observations may help explain the unusual finding of reduced diastolic closure rates in patients with pure mitral regurgitation.31

References


Circulation, Volume 51, January 1975

Figure 10

Echogram of mitral valve ring (R) was obtained together with the anterior cusp (AC). Arrow marks the time of peak flow. The E-F slope starts while mitral flow is still increasing and is a combination of the posterior motion of the anterior cusp and the ring in early diastole.

it is possible to understand certain echocardiographic findings in various clinical situations. The diastolic closure rate was found to be reduced in other conditions besides mitral stenosis, i.e., aortic stenosis, idiopathic hypertrophic subaortic stenosis, left ventricular hypertrophy, atrial myxoma and right ventricular pressure overload.3 This diastolic closure (E-F slope) has been regarded as a hemodynamic function of the duration of a positive gradient across the mitral valve and the rate of left ventricular filling during diastole.19

A recent report has revealed a discrepancy between recorded rates of diastolic closure slope and mitral valve orifice dimension obtained at surgery.20 Our studies demonstrate clearly that with the reduction of cardiac output and the diminution of mitral flow, the E-F slope of the echogram will decrease significantly even in a normal valve.
MV ECHOGRAM AND PHASIC MITRAL FLOW

A study of the dynamic relations between the mitral valve echogram and phasic mitral flow.
S Laniado, E Yellin, M Kotler, L Levy, J Stadler and R Terdiman

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