Doppler-Derived Rate of Left Ventricular Pressure Rise
Its Correlation With the Postoperative Left Ventricular Function in Mitral Regurgitation

Ramdas G. Pai, MD, MRCP, Ramesh C. Bansal, MD, and Pravin M. Shah, MD

A new Doppler-derived index of the rate of left ventricular (LV) pressure rise (ΔP/Δt) was evaluated for the prognostic stratification of patients with chronic mitral regurgitation. The index is derived from the continuous wave Doppler mitral regurgitation signal by dividing magnitude of LV—left atrial pressure gradient rise (Δp) between 1 and 3 m/sec of the mitral regurgitation velocity signal by the time taken (Δt) for this change. We studied the LV ΔP/Δt and other echocardiographic indexes of LV function before and after mitral valve surgery in 25 patients with chronic, severe mitral regurgitation in the absence of significant coronary artery disease. There was a good correlation between postoperative ejection fraction (EF) and the derived LV ΔP/Δt (r=0.75, p<0.001). The other echocardiographic parameters that correlated with postoperative EF were LV end-systolic dimension (r=−0.7, p<0.001), end-systolic volume (r=−0.69, p<0.001), end-diastolic dimension (r=−0.58, p<0.01), end-diastolic volume (r=−0.57, p<0.01), preoperative EF (r=0.69, p<0.001), end-systolic wall stress (r=−0.61, p<0.01), and end-systolic wall stress normalized for end-systolic volume index (r=−0.45, p<0.05). With multiple regression, the LV ΔP/Δt and LV end-systolic dimension (ESD) were shown to be independent predictors of postoperative EF. The postoperative EF could be defined by the equation: 43+0.8ΔP/Δt−0.53 ESD (mm) (r=0.86). We conclude that the Doppler-derived index of LV ΔP/Δt and end-systolic dimension are afterload-independent predictors of postoperative EF in patients with chronic, severe mitral regurgitation. (Circulation 1990;82: 514–520)

Chronic, severe mitral regurgitation, if not corrected in time, results in irreversible myocardial damage and dysfunction.1–3 The precise timing of mitral valve surgery is not well defined.4 Several preoperative parameters of left ventricular function have been used to predict left ventricular performance after surgery.1,5–7 Left ventricular ejection fraction has not proved to be a reliable index of ventricular dysfunction in the presence of severe mitral regurgitation.2 It may be normal despite advanced ventricular dysfunction, because in the presence of mitral regurgitation, the left ventricle empties into a low impedance left atrium. Some patients show unsatisfactory postoperative outcome despite a normal ejection fraction. Other parameters that have been investigated include left ventricular end-systolic volume and dimension, left ventricular end-diastolic volume and dimension, end-systolic wall stress, mean velocity of circumferential fiber shortening, and the ratio of end-systolic wall stress to end-systolic volume index.1,5–7 Most of these parameters are afterload dependent and are not indicative of early myocardial dysfunction in the presence of severe mitral regurgitation.

Hatle and Angelsen6 described the influence of left ventricular function on the continuous wave Doppler velocity profile of mitral regurgitation, a slower acceleration being associated with poor function. Bargiggia and associates9 calculated the left ventricular rate of pressure rise (ΔP/Δt) from the continuous wave mitral regurgitation signal and validated the findings during cardiac catheterization. A preliminary observation in our laboratory has demonstrated a good correlation between ΔP/Δt derived from the mitral regurgitation velocity profile and traditional parameters of left ventricular function (i.e., ejection fraction and end-systolic wall stress) in patients with mild or moderate mitral regurgitation.10 We hypothesize that left ven-
tricular $\Delta P/\Delta t$ during the preejection phase of systole, being afterload independent, may be a useful parameter to predict ventricular ejection fraction after surgical correction of chronic, severe mitral regurgitation. The present study examines a correlation between the left ventricular $\Delta P/\Delta t$ derived from the preoperative continuous wave Doppler signal of mitral regurgitation and postoperative left ventricular ejection fraction in symptomatic patients with chronic, severe mitral regurgitation. It compares this correlation with that observed with other parameters used in clinical practice, such as preoperative end-diastolic and end-systolic dimensions and volumes, ejection fraction, and systolic wall stress.

**Methods**

**Patient Selection**

Patients who underwent mitral valve replacement or repair for chronic, severe mitral regurgitation between 1984 and 1988 at Loma Linda University Medical Center were selected for the study if the following criteria were met: 1) symptomatic patients with chronic, severe mitral regurgitation defined by clinical, Doppler echocardiographic, and angiographic criteria, who underwent surgical correction,1-12 2) presence of predominant mitral regurgitation without associated mitral stenosis, aortic stenosis or regurgitation, and congenital heart disease, 3) absence of significant coronary artery disease (>50% reduction in luminal diameter of a major epicardial artery) according to coronary arteriography, 4) absence of left bundle branch block, and 5) adequate preoperative and postoperative echocardiographic and Doppler recordings.

Only one patient was excluded on the basis of inadequate preoperative Doppler recordings. Nine were men, and 16 were women. The mean age was 66.2 (range, 26-82) years. The etiology for mitral regurgitation was mitral valve prolapse syndrome in 15 patients, rheumatic heart disease in four, and degeneration of the bioprosthetic valves in six patients. Seventeen patients were in sinus rhythm, and seven had atrial fibrillation. One patient had paced rhythm with pacing electrode in the right ventricle. Twenty-one patients underwent mitral valve replacement, and four had mitral valve repair with quadrilateral resection of the mitral leaflet and implantation of a Duran ring. The body was cooled to 28°C on cardiopulmonary bypass, and the bypass time varied from 66 to 173 minutes.

**Preoperative Echocardiography**

M-mode, two-dimensional, and Doppler echocardiograms were obtained with an Aloka 880 or Irex Meridian imaging systems with a 2.5- or 3.5-MHz transducer. The M-mode recordings were obtained by placing a cursor through the left ventricle from parasternal two-dimensional cross-sectional views on strip chart paper at a speed of 50 mm/sec. These were generally obtained in the parasternal short-axis view, although when technically inadequate, a carefully maximized long-axis view was used. The end-diastolic dimension, end-systolic dimension, diastolic thickness of the left ventricular posterior wall, and diastolic thickness of the ventricular septum were measured according to the recommendations of the American Society of Echocardiography.14 The systolic thickness of the posterior wall was measured during the maximum posterior motion of the interventricular septum.

The continuous wave Doppler mitral regurgitant signal was obtained from the left ventricular apex using a duplex or nonimaging transducer with a frequency of 2.0 MHz. A complete velocity envelope was obtained in all patients, and the recordings were made at a paper speed of 50, 75, or 100 mm/sec. None of the patients had oblique or eccentric mitral regurgitant jets that would have given rise to poorly delineated signal and erroneous estimate of left ventricular $\Delta P/\Delta t$. Care was taken to align the continuous wave beam along the mitral regurgitant jet in patients with color flow studies. The method of measuring left ventricular $\Delta P/\Delta t$ is illustrated in Figure 1. The time taken ($\Delta t$) in milliseconds for the mitral regurgitation velocity to increase from 1 to 3
m/sec was carefully measured to the nearest 5 m/sec and averaged for three to five beats for patients in sinus rhythm and for seven to 10 beats for those in atrial fibrillation. With the simplified Bernoulli equation, the increase in velocity from 1 to 3 m/sec corresponds to an increase of the pressure gradient between the left ventricle and the left atrium from 4 to 36 mm Hg. Assuming that no significant change in the left atrial pressure occurs during the early pre-ejection phase of systole, the $\Delta P$ of 32 mm Hg would represent the left ventricular $\Delta P$. Hence, rate of left ventricular pressure rise ($\Delta P/\Delta t$) is ($\Delta P$ or 32 mm Hg$/\Delta t$ msec$^1$) $\times$ 1,000 mm Hg/sec.

The left ventricular $\Delta P/\Delta t$ derived in this manner is a measure of the average rate of left ventricular pressure rise during the pre-ejection period and has been reported to correlate well ($r=0.89$) with the left ventricular $dP/dt$ derived from micromanometer-tipped high-fidelity catheters.9

Postoperative Echocardiography

Routine echocardiography was performed at an average of 6.5 (1–22) weeks after surgery. None of the patients had postoperative mitral regurgitation by clinical or Doppler criteria, and none had segmental left ventricular wall motion abnormalities.

Echocardiographic Calculations

Percent fractional shortening (%FS) was measured as $\%FS=\{(EDD-ESD)\times 100\}/EDD$, where EDD is end-diastolic dimension, and ESD is end-systolic dimension. Left ventricular mass (LVM) was calculated according to the recommendations of Troy et al16: $LVM=1.05\times[(EDD+PW+VS)^3-EDD^3]$ g, where PW is left ventricular diastolic wall thickness, and VS is diastolic thickness of the ventricular septum. End-diastolic volume (EDV) and end-systolic volume (ESV) were derived with the formula of Teicholz et al17: $\text{volume}=(7\times D^3)/(2.4+D)\text{ml}$, where D is the left ventricular dimension in centimeters. Ejection fraction (EF) was calculated from the standard formula with the EDV and ESV derived by the method of Teicholz et al18: $\text{EF}=[(EDV-ESV)/EDV]\times 100$.

The endocardial definition was fully visualized in the apical cross-sections in only 12 of the 25 patients. The volumes and ejection fraction were measured by both Simpson’s biplane method and the method of Teicholz et al18 in these 12 patients. The ejection fraction by the two methods correlated well ($r=0.91$). The ejection fraction obtained by the method of Teicholz et al18 is used in the analysis of results for all 25 patients.

End-systolic wall stress (ESWS) was calculated according to the method described by Grossman et al19 and Colan et al20 with the mean arterial blood pressure (MBP) in place of the end-systolic pressure: $\text{ESWS}=(1.35\times \text{MBP}\times \text{ESD})/\{4\times \text{PWs}\times (1+\text{PWs}/\text{ESD})\}$ g/cm², where PWs is thickness of the posterior left ventricular wall in systole, and 1.35 is the conversion factor to change mm Hg to g/cm². $\text{MBP}=\frac{(\text{SBP}+2\text{DBP})}{3}$, where SBP is systolic blood pressure, and DBP is diastolic blood pressure. Mean systolic wall stress (MSWS) was calculated as $\text{MSWS}=(1.35\times \text{MSP}\times \text{ESD})/\{4\times \text{PWs}\times (1+\text{PWs}/\text{ESD})\}$ g/cm². $\text{MSP}=\frac{(2\times \text{SBP}+\text{DBP})}{3}$, where MSP is the mean systolic blood pressure.21

Statistical Methods

Means were compared by the Student’s $t$ test. The variables were correlated by least-squares linear regression or multiple regression.

Reproducibility of Measurements

The Doppler-derived left ventricular $\Delta P/\Delta t$ values were measured independently by two observers and twice by the same observer. Good interobserver ($r=0.91$) and intraobserver ($r=0.93$) agreement were obtained.

Results

The data for individual patients are provided in Table 1.

Figure 2 shows examples of a high and a low $\Delta P/\Delta t$ from the mitral regurgitant signals of two representative patients.

Table 2 summarizes the correlations between the preoperative and the postoperative ejection fractions for the whole group along with the regression coefficient, level of statistical significance, the value of the parameter derived from the regression equation predictive of postoperative an ejection fraction of 50%, sensitivity, specificity, positive predictive value, negative predictive value predictive of a postoperative ejection fraction of less than 50%, and the standard error of the estimate. The correlations between left ventricular $\Delta P/\Delta t$ and postoperative ejection fraction are depicted in Figure 3. The left ventricular $\Delta P/\Delta t$ showed the best correlation ($r=0.75$) with postoperative ejection fraction compared with all the other parameters tested. The ratios of $\Delta P/\Delta t$ to end-diastolic volume and to end-diastolic dimension did not improve the correlation. As seen in Figure 3, the correlation is not strictly linear, and it improved on using $\sqrt{\Delta P/\Delta t}$ ($r=0.79$).

The variables of age, left ventricular end-diastolic pressure, end-diastolic volume/left ventricular mass ratio, end-systolic volume/left ventricular mass ratio, and end-diastolic dimension/posterior wall thickness did not yield a statistically significant correlation with the postoperative ejection fraction.

With multiple regression, the left ventricular $\Delta P/\Delta t$ and end-systolic dimension had an independent predictive value, and postoperative ejection fraction (EF) could be determined by the equation ($r=0.86$): $\text{Postoperative EF}=43+0.8\sqrt{\Delta P/\Delta t}-0.53\text{ ESD}$ in millimeters. The addition of other preoperative variables irrespective of their level of significance by univariate analysis did not improve the predictive value of the model (see Table 2).

The means and standard deviations of some of the above parameters for the patients who had a postop-
would appear from these ventricular postoperative previously reported parameters multivariate cardiopulmonary bypass correction of mitral end-systolic dimension; EDV, 23 21* 20 17 29.9 35.6 3.32 1,067 51
5 79 F 1.70 90 SR 312 62 35 197 51 44 74 51.0 59.9 1.70 3,200 67
6 75 F 1.70 80 SR 197 47 37 118 70 21 41 63.0 73.4 1.53 800 42
7 64 M 1.70 70 SR 478 61 40 187 70 35 63 62.0 70.6 1.51 320 38
8 65 M 1.77 80 SR 431 67 32 232 41 54 82 35.1 44.5 1.52 914 49
9 35 F 1.52 72 SR 202 42 22 79 16 48 80 25.3 33.0 2.53 1,185 57
10 71 F 1.54 90 AF 254 59 17 174 10 71 94 21.7 27.7 3.61 1,600 58
11 60 F 1.76 90 SR 232 62 42 197 79 32 60 151.6 171.3 3.44 914 42
12 64 F 1.87 86 SR 255 60 36 180 55 40 69 66.4 77.8 2.28 914 57
13 64 F 2.03 96 SR 198 48 26 107 25 46 77 39.4 46.2 3.28 3,200 64
14 60 F 1.70 80 SR 170 48 26 107 25 46 77 30.0 37.5 2.14 1,600 64
15 56 M 2.05 64 SR 377 62 50 197 118 19 40 75.3 84.8 1.32 800 20
16* 69 M 1.92 90 AF 330 55 37 148 59 33 60 57.3 65.9 1.91 3,556 70
17 80 M 1.95 80 AF 337 62 40 197 70 35 64 63.3 74.2 1.80 800 31
18* 73 F 1.63 90 SR 325 62 42 197 79 32 60 76.9 92.6 1.60 1,600 59
19 62 M 2.01 75 AF 657 83 68 372 240 18 35 153.1 172.6 1.28 582 26
20 82 F 1.83 90 AF 244 50 25 118 22 50 81 34.8 43.6 2.90 1,600 57
21* 59 M 1.72 85 AF 312 62 37 232 59 37 75 52.6 61.3 1.54 2,284 74
22* 68 M 1.59 74 SR 326 57 30 159 35 47 78 39.0 46.5 1.77 2,000 66
23 68 F 1.58 80 RV paced 208 42 18 79 11 57 86 18.3 22.9 3.05 3,556 74
24 48 F 1.68 91 SR 169 50 36 118 55 28 53 71.9 84.6 2.24 1,231 62
25 61 F 1.67 96 SR 323 71 51 265 123 28 50 118.4 139.0 1.62 533 35

*Patients undergoing mitral valve repair; all others had mitral valve replacement.
BSA, body surface area; HR, heart rate; LVM, left ventricular (LV) mass; EDD, left ventricular end-diastolic dimension; ESD, LV end-systolic dimension; EDV, LV end-diastolic volume; ESV, LV end-systolic volume; FS:pre, LV preoperative fractional shortening; EF:pre, LV preoperative ejection fraction; ESWS, LV end-systolic wall stress; MSWS, LV mean systolic wall stress; ESWS/ESVI, LV ESWS to end-systolic volume index ratio; EF:po, LV postoperative EF; SR, sinus rhythm; AF, atrial fibrillation; RV, right ventricular.

Table 1. Preoperative Echocardiographic and Doppler Parameters and Postoperative Ejection Fraction for Each Patient

Discussion

This study demonstrates a good correlation between the Doppler-derived left ventricular ΔP/Δt and early postoperative ejection fraction after surgical correction of mitral regurgitation. A number of previously reported parameters of dimensions, volumes, and function also showed statistical correlations with postoperative ejection fraction.1,5,7 With multivariate analysis, the left ventricular ΔP/Δt ranked as the leading independent predictor of postoperative ejection fraction. When used in combination with preoperative end-systolic dimension, left ventricular ΔP/Δt provides an excellent prediction of postoperative ejection fraction (r=0.86). Thus, it would appear from these preliminary observations that this parameter could serve to help determine if patients undergoing surgery for mitral regurgitation are more likely to have a postoperative ejection fraction less than 50% and those who maintained an ejection fraction at 50% or more are listed in Table 3. Eight of the 25 patients had a postoperative ejection fraction less than 50%.

There was no correlation between the duration of cardiopulmonary bypass and the postoperative ejection fraction.

FIGURE 2. Panel A: Mitral regurgitation (MR) signal from a patient with good left ventricular function. Note rapid rise of mitral regurgitant velocity reflecting high left ventricular ΔP/Δt. Panel B: Continuous wave mitral regurgitation signal from a patient with poor left ventricular function. Note slow acceleration reflecting low left ventricular ΔP/Δt.
TABLE 2. Preoperative Parameters and Their Correlation With the Postoperative Ejection Fraction and Their Predictive Value
Postoperative Ejection Fraction of Less Than 50%

<table>
<thead>
<tr>
<th>Patient</th>
<th>Predictor</th>
<th>r</th>
<th>p</th>
<th>EF50 (Mean±SEE)</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>+PV (%)</th>
<th>−PV (%)</th>
<th>SEE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ESWS (g/cm²)</td>
<td>-0.61</td>
<td>0.01</td>
<td>65.5±70</td>
<td>50</td>
<td>76</td>
<td>50</td>
<td>76</td>
<td>12.3</td>
</tr>
<tr>
<td>2</td>
<td>ESWS/ESVI (g·m²/cm²)</td>
<td>0.45</td>
<td>0.05</td>
<td>2.15±4.8</td>
<td>88</td>
<td>53</td>
<td>47</td>
<td>90</td>
<td>13.8</td>
</tr>
<tr>
<td>3</td>
<td>LVM (g)</td>
<td>-0.58</td>
<td>0.01</td>
<td>305±93</td>
<td>75</td>
<td>71</td>
<td>55</td>
<td>86</td>
<td>12.6</td>
</tr>
<tr>
<td>4</td>
<td>EDD (mm)</td>
<td>-0.58</td>
<td>0.01</td>
<td>58±8</td>
<td>88</td>
<td>65</td>
<td>58</td>
<td>92</td>
<td>12.6</td>
</tr>
<tr>
<td>5</td>
<td>EDV (ml)</td>
<td>-0.57</td>
<td>0.01</td>
<td>176±55</td>
<td>88</td>
<td>76</td>
<td>64</td>
<td>93</td>
<td>12.7</td>
</tr>
<tr>
<td>6</td>
<td>EDVI (ml/m²)</td>
<td>-0.49</td>
<td>0.05</td>
<td>98±31</td>
<td>75</td>
<td>71</td>
<td>55</td>
<td>86</td>
<td>12.9</td>
</tr>
<tr>
<td>7</td>
<td>ESD (mm)</td>
<td>-0.70</td>
<td>0.001</td>
<td>37±8.2</td>
<td>75</td>
<td>88</td>
<td>75</td>
<td>88</td>
<td>11.1</td>
</tr>
<tr>
<td>8</td>
<td>ESV (ml)</td>
<td>-0.69</td>
<td>0.001</td>
<td>67±34.5</td>
<td>88</td>
<td>94</td>
<td>88</td>
<td>94</td>
<td>11.3</td>
</tr>
<tr>
<td>9</td>
<td>ESV (ml/m²)</td>
<td>-0.68</td>
<td>0.001</td>
<td>36±18</td>
<td>75</td>
<td>71</td>
<td>86</td>
<td>89</td>
<td>11.5</td>
</tr>
<tr>
<td>10</td>
<td>FS:pre (%)</td>
<td>0.60</td>
<td>0.01</td>
<td>38±10</td>
<td>88</td>
<td>71</td>
<td>58</td>
<td>92</td>
<td>12.4</td>
</tr>
<tr>
<td>11</td>
<td>EF:pre (%)</td>
<td>0.69</td>
<td>0.001</td>
<td>65±11</td>
<td>88</td>
<td>76</td>
<td>64</td>
<td>93</td>
<td>11.2</td>
</tr>
<tr>
<td>12</td>
<td>ESD/WTS</td>
<td>-0.56</td>
<td>0.01</td>
<td>2.6±0.73</td>
<td>75</td>
<td>75</td>
<td>60</td>
<td>86</td>
<td>12.8</td>
</tr>
<tr>
<td>13</td>
<td>MSWS (g/cm²)</td>
<td>-0.61</td>
<td>0.01</td>
<td>76±4.7</td>
<td>50</td>
<td>76</td>
<td>50</td>
<td>76</td>
<td>11.3</td>
</tr>
<tr>
<td>14</td>
<td>ΔP/Δt (mm Hg/sec)</td>
<td>0.75</td>
<td>0.001</td>
<td>1,343±623</td>
<td>100</td>
<td>71</td>
<td>62</td>
<td>100</td>
<td>10.3</td>
</tr>
<tr>
<td>15</td>
<td>ΔP/Δt/EDV (mm Hg/sec/ml)</td>
<td>0.7</td>
<td>0.001</td>
<td>9.9±7.2</td>
<td>100</td>
<td>76</td>
<td>67</td>
<td>100</td>
<td>10.4</td>
</tr>
<tr>
<td>16</td>
<td>ΔP/Δt/EDD (mm Hg/sec/mm)</td>
<td>0.76</td>
<td>0.001</td>
<td>25.0±13</td>
<td>100</td>
<td>76</td>
<td>67</td>
<td>100</td>
<td>10.3</td>
</tr>
<tr>
<td>17</td>
<td>√ΔP/Δt</td>
<td>0.79</td>
<td>0.001</td>
<td>34.9±9.7</td>
<td>100</td>
<td>76</td>
<td>67</td>
<td>100</td>
<td>10.1</td>
</tr>
<tr>
<td>18</td>
<td>LA (mm)</td>
<td>-0.44</td>
<td>0.05</td>
<td>60±9.5</td>
<td>50</td>
<td>50</td>
<td>56</td>
<td>77</td>
<td>11.5</td>
</tr>
<tr>
<td>19</td>
<td>EF (multivariate model)</td>
<td>0.86</td>
<td>0.001</td>
<td>...</td>
<td>88</td>
<td>88</td>
<td>78</td>
<td>94</td>
<td>7.9</td>
</tr>
</tbody>
</table>

EF50, numerical value of the preoperative parameter predictive of a postoperative ejection fraction (EF) of 50%; +PV, positive predictive value; −PV, negative predictive value of postoperative EF <50%; SEE, standard error of estimate of the postoperative EF; ESWS, left ventricular (LV) end-systolic wall stress; ESWS/ESVI, LV ESWS to end-systolic volume index ratio; LVM, LV mass; EDD, LV end-diastolic dimension; EDV, end-diastolic volume; EDVI, LV end-diastolic volume index; ESD, LV end-systolic dimension; ESV, LV end-systolic volume; ESVI, LV end-systolic volume index; FS:pre, LV preoperative fractional shortening; EF:pre, LV preoperative ejection fraction; WTS, systolic thickness of LV posterior wall; MSWS, LV mean systolic wall stress; LA, left atrial diameter.

that Doppler-derived left ventricular ΔP/Δt may be a clinically useful predictor of postoperative function. Although it correlated better with postoperative ejection fraction and had a higher predictive value for postoperative ejection fraction less than 50%, it remains to be demonstrated whether reduction in ΔP/Δt precedes deterioration of other predictive parameters. Left ventricular ΔP/Δt of more than 1,343 mm Hg/sec uniformly predicted a postoperative ejection fraction greater than 50%. Prospectively designed studies would be necessary to define the

FIGURE 3. Plot of postoperative ejection fraction (EF postop) and ΔP/Δt. □, Patients undergoing valve repair; ●, patients undergoing valve replacement. Standard error of estimate for correlation between EF postop and left ventricular ΔP/Δt is 10.3±1.

TABLE 3. Preoperative Parameters Associated With a Postoperative Ejection Fraction of Less Than and More Than 50%

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Postoperative ejection fraction &lt;50% (n=8) (Mean±SD)</th>
<th>&gt;50% (n=17) (Mean±SD)</th>
<th>p &lt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDD (mm)</td>
<td>64.38±10.20</td>
<td>52.41±7.45</td>
<td>0.01</td>
</tr>
<tr>
<td>ESD (mm)</td>
<td>45±11.22</td>
<td>29.18±7.97</td>
<td>0.001</td>
</tr>
<tr>
<td>EDV (ml)</td>
<td>220.63±74.02</td>
<td>138±47.60</td>
<td>0.01</td>
</tr>
<tr>
<td>ESV (ml)</td>
<td>101.38±62.17</td>
<td>86±35.01</td>
<td>0.001</td>
</tr>
<tr>
<td>FS:pre (%)</td>
<td>54.38±15.77</td>
<td>74.12±10.73</td>
<td>0.01</td>
</tr>
<tr>
<td>EF:pre (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ΔP/Δt (mm Hg/sec)</td>
<td>707.88±209.53</td>
<td>1,948.71±912.5</td>
<td>0.01</td>
</tr>
<tr>
<td>√ΔP/Δt (mm Hg/sec/mm)</td>
<td>11.37±4.22</td>
<td>38.04±19.36</td>
<td>0.001</td>
</tr>
</tbody>
</table>
| EDD, left ventricular (LV) end-diastolic dimension; ESD, LV end-systolic dimension; EDV, LV end-diastolic volume; ESV, LV end-systolic volume; EF:pre, preoperative ejection fraction.
temporal sequence of changes in the parameters of left ventricular function during longitudinal follow-up of mitral regurgitation patients before surgery.

The use of the simplified Bernoulli equation to estimate pressure gradient during flow acceleration may be questioned. Wong et al.\textsuperscript{23} examined the accuracy of this approach in in vitro studies and showed accurate reproducibility of the pressure gradient profile with the simplified Bernoulli equation. Bargiggia et al.\textsuperscript{26} validated the use of the mitral regurgitation velocity profile to estimate rate of left ventricular pressure rise with the manometer-tipped catheter. The left ventricular \(\Delta P/\Delta t\) is subject to the influence of heart rate, preload, and inotropic state.\textsuperscript{22,24–26} The heart rates in all 25 patients at the time of echocardiographic studies varied narrowly between 60 and 96 beats/min. The attempts to correct for preload by examining the ratios of left ventricular \(\Delta P/\Delta t\) and end-diastolic dimension or end-diastolic volumes failed to improve the correlations.

A potential for error in estimation of \(\Delta P/\Delta t\) exists in cases of poor alignment between the continuous wave Doppler beam and the regurgitation jet. This may be minimized by requiring a complete unidirectional signal with sharply delineated boundaries and the largest signal obtained by audio and visual guidance. Generally, patients with markedly eccentric jets would be unsuitable for such analysis. A recent independent study compared \(dP/dt\) values derived by Doppler and micromanometer-tipped catheters at baseline and after inotropic stimulation in seven patients with dilated cardiomyopathy.\textsuperscript{27} A good correlation \((r=0.84)\) was observed. A similar study in our laboratory analyzed 38 heartbeats in four patients under different loading conditions and showed a good correlation \((r=0.88)\) between simultaneously derived left ventricular \(\Delta P/\Delta t\) from Doppler tracings and from catheter-tipped manometers.\textsuperscript{28}

An assumption is made in this study that left atrial pressure does not change in the pre-ejection phase of systole and, thus, does not contribute to the increase in the left ventricular and left atrial pressure difference in early systole. This may not hold true in acute, severe mitral regurgitation, where even the early systolic component of regurgitation may result in elevations in atrial pressures because of a small noncompliant left atrium. The present study included only patients with chronic, isolated mitral regurgitation, in whom the left atrial pressures during the preejection period probably remain unchanged. The good correlations with catheter-derived \(dP/dt\) support such an assumption.

The left atrial size, which may indirectly reflect preload, also showed a negative correlation with postoperative ejection fraction. A larger left atrium indicative of higher preload before operation was associated with a lower postoperative ejection fraction. This correlation is the inverse of that noted with left ventricular \(\Delta P/\Delta t\).

A major shortcoming of this study is a short follow-up period of a mean of 6.5 weeks for postoperative evaluation. The routine postoperative evaluation was performed either just before hospital discharge or during early postoperative follow-up. A possible late continued improvement in ejection fraction cannot be assessed in the present study. However, the correlates examined do permit evaluation of influence of surgical correction of mitral regurgitation on early and intermediate functional recovery. Conclusions based on these results can only be considered preliminary until the correlations are extended to late postoperative outcome. An additional drawback of the study is that the ejection fraction was calculated by the M-mode method in the postoperative state, where interventricular septum motion is frequently abnormal. However, it correlated well with that derived by the two-dimensional planimetered method in patients in whom the latter method was technically possible.

**Conclusions**

On the basis of this preliminary study, a new noninvasive parameter of left ventricular function, namely left ventricular \(\Delta P/\Delta t\) derived from Doppler signal of mitral regurgitation, correlates with postoperative ejection fraction after surgical correction of mitral regurgitation. Furthermore, a predictive assessment of postoperative ejection fraction can be made with the square root of left ventricular \(\Delta P/\Delta t\) and end-systolic dimension. A correlation with late clinical and functional recovery needs to be assessed to determine further usefulness of this parameter.

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KEY WORDS • mitral valve surgery • ejection fraction • end-systolic diameter • left ventricular function
Doppler-derived rate of left ventricular pressure rise. Its correlation with the postoperative left ventricular function in mitral regurgitation.

R G Pai, R C Bansal and P M Shah

Circulation. 1990;82:514-520
doi: 10.1161/01.CIR.82.2.514

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1990 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

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