Mitral Valve Area in Combined Mitral Stenosis and Regurgitation

JOSEPH ASKENAZI, M.D., C. JEFFREY CARLSON, M.D., JOSEPH S. ALPERT, M.D., AND LEWIS DEXTER, M.D.

SUMMARY Eight patients with mixed mitral stenosis and regurgitation underwent hemodynamic and angiographic study prior to mitral valve replacement. The stenotic orifice of the mitral valve was calculated employing the total left ventricular stroke volume by cineangiography as the numerator of the Gorlin Formula. Excellent agreement with the measured orifice of the mitral valve was obtained using a value of 37.9 (0.85×44.5) for the constant in the Gorlin formula as recommended by Cohen and Gorlin. Recalculation of this constant independently by our data yielded a value that was almost identical. Regurgitant orifices were measured using the same constant as for the stenotic orifices.

CALCULATION OF THE CROSS-SECTIONAL AREA of the mitral valve by the Gorlin formula is remarkably accurate when the valve is stenotic. It has been emphasized, however, that the calculation underestimates the true size of the valve when mitral regurgitation coexists. The use of quantitative cineangiography makes it possible to measure diastolic mitral valve flow and hence calculation of the stenotic as well as regurgitant size of the orifice. Despite this method having been available since 1960, such measurements have seldom been made and the value of the constant in the Gorlin formula has never been determined. This study was undertaken to evaluate the accuracy of calculation of the mitral valve area in patients with mixed mitral stenosis and insufficiency utilizing quantitative cineangiography to obtain the value for flow across the mitral valve in diastole.

Methods

Surgically excised mitral valves were obtained in eight selected patients with mixed mitral stenosis and insufficiency (MS-MR) undergoing valve replacement. Six of the eight patients were operated on less than one week following cardiac catheterization (table 1) and in all but one patient (4), the mitral valve was obtained intact. In this patient, the mitral valve was reconstructed postoperatively. The fresh excised valves were flattened on a plate of glass which fixed them in a standard maximum diastolic position. They were then photographed from the ventricular and atrial aspects alongside a centimeter ruler placed in the plane of the valve orifice (fig. 1). The actual area of the valve orifice was measured by planimetry. The largest planed area

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was accepted as the actual valve area. In the patient in whom the mitral valve was reconstructed (4), the valve area was also measured with calipers at the time of surgery.

**Hemodynamic Studies**

All eight patients were considered to have satisfactory hemodynamic and angiographic studies. Pressures were measured with Statham P23d manometers and recorded with an E for M 8-channel recorder. Left atrial pressures were recorded as pulmonary capillary wedge pressures confirmed by appropriate wave form, greater than 95% saturation of withdrawn blood sample, and constancy of pressure at several sites. Mitral valve pressure gradients were of sufficient magnitude to be accurately and easily planimetered. Cardiac outputs were obtained by the Fick principle by collecting expired air for 3 min in a Douglas bag, measuring its volume in a Tissot spirometer, and measuring the PO2 with a Pauling oxygen meter. Midway during the collection of expired air, bloods were withdrawn from pulmonary and brachial arteries for determination of oxygen content. Pressures and flows were obtained simultaneously.

**Angiographic Studies**

The method of Dodge et al. and Kennedy et al. was followed scrupulously. High quality left ventricular angiograms were obtained in each case in the 30 degree right anterior oblique position. In each patient, the rhythm was stable throughout the cineangiographic recording. The ventricular volumes were averaged from at least three beats. Occasional extrasystolic and postextrasystolic beats were excluded. Heart rates were similar during Fick cardiac output and ventriculograms (Table 1).

Calibration of left ventricular volume was performed with a cm grid placed at the level of the apex of the left ventricle with the same image-to-intensifier distance as employed during the ventriculogram.

The close agreement between Fick outputs and ventriculographic outputs in patients without valvular regurgitation and with normally contractile left ventricles is seen in Table 2. In 16 patients the average Fick cardiac output was 5.84 ± 1.25 L/min (± SD), and left ventriculographic output was 5.80 ± 1.36 L/min. (r = 0.94).

**Calculations**

The area of the stenotic orifice of the mitral valve (MVA) was calculated as follows using the hydraulic formula of Gorlin and Gorlin:

$$MVA = \frac{MVF \times \sqrt{P_{CWdm} - LV_{dm}}}{C \times 44.5 \times PR \times Dfp}$$

where $MVF$ (ml/min) = flow across mitral valve in diastole; $LV_{dm}$ = total left ventricular output (Ft) obtained by cineangio-

**Table 1. Hemodynamics and Calculation of Stenotic Orifice in Patients with Mitral Stenosis - Mitral Regurgitation**

<table>
<thead>
<tr>
<th>Age/Sex</th>
<th>Time to Surgery (days)</th>
<th>Fp (L/min)</th>
<th>HR (beats/min)</th>
<th>Dfp (sec)</th>
<th>MVA (ml/sec)</th>
<th>MDG (mm Hg)</th>
<th>MVA (cm²)</th>
<th>Fp (beats/min)</th>
<th>MVA (ml/sec)</th>
<th>MVA (cm²)</th>
<th>Empirical constant of Gorlin formula</th>
<th>C</th>
<th>calculated</th>
<th>Empirical constant of Gorlin formula</th>
<th>C</th>
<th>calculated</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/58/F</td>
<td>4</td>
<td>3.3</td>
<td>86</td>
<td>0.35</td>
<td>109</td>
<td>17</td>
<td>0.7</td>
<td>5.4</td>
<td>85</td>
<td>182</td>
<td>1.2</td>
<td>1.2</td>
<td>0.83</td>
<td>36.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2/51/F</td>
<td>3</td>
<td>2.8</td>
<td>75</td>
<td>0.38</td>
<td>98</td>
<td>15</td>
<td>0.7</td>
<td>6.4</td>
<td>78</td>
<td>169</td>
<td>1.4</td>
<td>1.3</td>
<td>0.89</td>
<td>39.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/52/F</td>
<td>5</td>
<td>2.7</td>
<td>100</td>
<td>0.31</td>
<td>88</td>
<td>22</td>
<td>0.5</td>
<td>4.4</td>
<td>98</td>
<td>211</td>
<td>1.2</td>
<td>1.2</td>
<td>0.84</td>
<td>37.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4/35/F</td>
<td>2</td>
<td>3.2</td>
<td>105</td>
<td>0.32</td>
<td>95</td>
<td>24</td>
<td>0.5</td>
<td>6.4</td>
<td>102</td>
<td>230</td>
<td>1.2</td>
<td>1.3</td>
<td>0.88</td>
<td>39.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5/61/F</td>
<td>11</td>
<td>5.9</td>
<td>105</td>
<td>0.27</td>
<td>208</td>
<td>25</td>
<td>1.1</td>
<td>6.8</td>
<td>105</td>
<td>240</td>
<td>1.3</td>
<td>1.3</td>
<td>0.83</td>
<td>38.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6/47/F</td>
<td>2</td>
<td>1.6</td>
<td>92</td>
<td>0.42</td>
<td>42</td>
<td>22</td>
<td>0.5</td>
<td>6.7</td>
<td>92</td>
<td>173</td>
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<td>1.0</td>
<td>0.83</td>
<td>36.9</td>
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<td></td>
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<tr>
<td>7/52/F</td>
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<td>3.6</td>
<td>140</td>
<td>0.22</td>
<td>117</td>
<td>52</td>
<td>0.4</td>
<td>13.7</td>
<td>140</td>
<td>445</td>
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<td>1.5</td>
<td>0.92</td>
<td>40.9</td>
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<tr>
<td>8/45/F</td>
<td>30</td>
<td>4.7</td>
<td>60</td>
<td>0.58</td>
<td>135</td>
<td>11</td>
<td>1.1</td>
<td>5.7</td>
<td>60</td>
<td>164</td>
<td>1.3</td>
<td>1.3</td>
<td>0.86</td>
<td>38.3</td>
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<tr>
<td>Average</td>
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<td>0.7</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>1.3</td>
<td></td>
<td>1.3</td>
<td>1.3</td>
<td>0.86</td>
<td>38.3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Same for Fick and ventriculographic studies.
Abbreviations: Fp = forward (aortic blood flow); Ft = total left ventricular output; HR = heart rate; Dfp = diastolic filling period; MVA = rate of flow across mitral valve during diastole; MVA = size of stenotic orifice or mitral valve; MDG = mean diastolic gradient.

![Figure 1. Mitral valve in fresh form, photographed immediately after its removal from patient #5. Measured area was 1.3 cm². A) from the atrial aspect; B) from the ventricular aspect.](http://circ.ahajournals.org/Downloaded from http://circ.ahajournals.org)
Table 2. Fick and Ventriculographic Cardiac Outputs in Patients without Valvular Regurgitation

<table>
<thead>
<tr>
<th>Pt</th>
<th>Fick</th>
<th>LVgram</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.8</td>
<td>6.9</td>
</tr>
<tr>
<td>2</td>
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<td>7.4</td>
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<tr>
<td>3</td>
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<tr>
<td>14</td>
<td>7.5</td>
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<tr>
<td>15</td>
<td>3.2</td>
<td>3.4</td>
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<tr>
<td>16</td>
<td>5.4</td>
<td>5.3</td>
</tr>
<tr>
<td>Mean ± sd</td>
<td>5.84 ± 1.25</td>
<td>5.80 ± 1.36</td>
</tr>
</tbody>
</table>

A correlation coefficient of \( r = 0.94 \) is obtained between Fick and ventriculographic (LVgram) output, (single RAO plane) in patients without regurgitant valve. The standard error of estimate is 0.4 L/min.

gram of the LV according to the method of Dodge et al.:4

\[ C = 0.85, (C \times 44.5 = 37.9) \]

PR = pulse rate per minute;

Dfp = diastolic filling period (seconds per beat) obtained from simultaneous LV and PCW pressure tracings;

PCWdm = pulmonary capillary wedge diastolic mean pressure (mm Hg) obtained by planimetry; LVdm = left ventricular diastolic mean pressure (mm Hg) obtained by planimetry.

The regurgitant area of the mitral valve (MVA) was calculated as follows:

\[ \text{Regurgitant flow (Fr)} = \frac{\text{MVA}_r}{C \times 44.5 \times \text{PR} \times \text{SEP} \times \sqrt{\text{LVdm} - \text{LA}_{\text{am}}}} \]

where \( Fr = F_r - F_v \) (ml/min); \( F_r = \) total LV output (ml/min) determined by ventriculography; \( F_v = \) forward flow, i.e., Fick cardiac output (ml/min); \( C = 0.85 \) (assumed) = \( (C \times 44.5 = 37.9) \); SEP = systolic ejection period (sec per beat) = PR (ECG) minus Dfp; LVdm = left ventricular systolic mean pressure (mm Hg) obtained by planimetry; LAam = PCW systolic mean pressure (mm Hg) obtained by planimetry.

Hemodynamic and angiographic data for diastole and the calculation of stenotic valve orifices were compared with those measured directly and are shown in table 1.

When cardiac output was measured by the Fick principle, the calculated mitral valve area was consistently less than the true area (table 1). The difference was as little as 0.2 cm² (patients 5 and 8) when regurgitation was slight or as much as 1.1 cm² (patient 7) when regurgitation was considerably larger.

In contrast, when mitral valve flow during diastole was measured by ventriculography ( cineangiography ), there was an excellent correlation between calculated and measured size of the valve orifice \( (r = 0.98) \) (fig. 2). In six of the eight patients, the calculated and measured valve sizes were the same. In the other two, the difference was only 0.1 cm².

The empirical constant, C, was calculated for each case by using the actual valve area, the ventricular flow, the pulse rate, diastolic filling period and pressure gradient and solving for C in the Gorlin formula:

\[ C = \frac{\text{MVA}_d \times 44.5 \times \text{PR} \times \text{Dfp} \times \sqrt{\text{PCW}_{\text{dm}} - \text{LVdm}}}{\text{MVF}_d} \]

C averaged 0.86 for the eight patients. C × 44.5 averaged 38.3 with variations from 36.9 to 40.9.

The hemodynamics of mitral regurgitation are shown in table 3. The regurgitant flow varied from 1.0 to 10.1 L/min in different patients. The calculated sizes of the regurgitant orifice varied from 0.1 to 1.1 cm² in these patients.

Discussion

Gorlin and Gorlin¹ originally used an empirical constant of 31 (0.7 × 44.5) in their formula for calculating the size of the mitral orifice. This was before the time of left heart catheterization. The LV diastolic pressure was assumed to be 5 mm Hg and the Dfp was measured from the arterial pressure tracing as the time between onset of the dicrotic notch and the upstroke. This time is longer than the Dfp obtained from LV tracings because it does include the time of isometric contraction and relaxation. Cohen and Gorlin⁹ recently revised the constant to 37.9 (0.85 × 44.5) when the Dfp was measured from the LV – PCW pressure tracings. The present study confirms their use of this constant. In these eight patients, the average constant, calculated from measured size of valve, ventriculographic flows, and Dfp from LV – PCW pressures, was 38.3 (0.86 × 44.5), a value practically identical with that of Cohen and Gorlin.

For the ventriculographic method to be acceptable for use in calculating stenotic and regurgitant orifices in the presence of combined mitral stenosis and regurgitation, the technique must be such that there is good agreement between cardiac outputs obtained by ventriculography and by Fick or dye methods in the absence of regurgitation. This was true in this study as shown in table 2. It was only by the most scrupulous attention to the method of Dodge and

Figure 2. Relation between measured mitral valve area (MVA) and calculated MVA in eight patients.
Kassar and their associates⁶-⁷ that such agreement could be obtained.

When the size of the stenotic orifice of the mitral valve was calculated in these patients with combined stenosis and regurgitation, the Fick method yielded falsely low values for orifice size (table 1). Gorlin and Gorlin,¹ Selzer et al.,² and others have pointed out this fact. The reason is that the Fick output measures the flow going to the body, back to the lungs and through the mitral valve. This is an accurate method of measure of diastolic flow across the mitral valve in the absence of regurgitation but in its presence the Fick method is not. When mitral regurgitation is present, the diastolic mitral flow will be the forward flow (Fick) and the regurgitant flow; therefore the total left ventricular output (F₄) equals that which flows across the mitral valve during diastole and is used in the numerator of the Gorlin equation. The present study verifies this method, there being a remarkably close agreement between calculated and measured sizes of the stenotic orifices when the constant of Cohen and Gorlin⁴ is used (fig. 2).

There have been few reports of the calculation of regurgitant orifice sizes and volumes of regurgitation in mitral valve disease.⁴, ⁶-⁹-¹⁰ Because of the high head of pressure in the LV and the relatively low pressure in the LA, it is apparent that a small orifice (0.1 cm² in patient 8) can allow 1.0 L/min of regurgitation. The largest regurgitant orifice in our patients was 1.1 cm² with a regurgitant flow of 10.1 L/min (patient 7) — nearly three times more than the amount flowing out to the body via the aorta. Arvidsson and Karnell⁴ and Sandler, Dodge, et al.⁴ measured even larger flows and orifices.

### References

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