Isolated Congenital Mitral Insufficiency with Particular Reference to Left Heart Volumes

By Graham A. H. Miller, B.M., B.Sc., Richard Brown, M.D., and H. J. C. Swan, M.B.

MITRAL insufficiency is well recognized in association with certain congenital cardiac anomalies. Reports of congenital mitral insufficiency as an isolated anomaly, however, are rare; 1-3 review of the literature reveals only 20 such cases. The pathologic anatomy of the condition has been described by Edwards and Burchell.4

This report concerns clinical, hemodynamic, and angiocardiographic findings in seven patients in whom the age of onset and the absence of a history of carditis indicate isolated congenital mitral insufficiency. In each of the cases reported here, left ventricular angiocardiograms were made. The volumes of the left atrium and ventricle were calculated according to the method of Arvidsson,5 and the degree of regurgitation has been quantitated. Absolute measurement of chamber volumes and regurgitant flow extends significantly the description of the hemodynamics in such conditions and allows for more meaningful interpretation of the criteria used for diagnostic purposes.

Methods

Cardiac Catheterization

Cardiac catheterization was performed as described by Wood and Swan6 with premedication as described by Moffitt and associates.7 The right axillary vein and artery were isolated under local anesthesia. The left ventricle was entered by passing the catheter retrograde through the aortic valve from the axillary artery. Calculations of the RV/VT ratio were made from the wedged pulmonary artery tracings according to the method of Owen and Wood.8

Angiocardiography

During angiocardiography, patients were anesthetized with nitrous oxide and oxygen. Halothane, in concentrations of less than 1 per cent, was used for brief periods. In all cases, 100 per cent oxygen was administered for at least 60 seconds prior to angiocardiography. Contrast medium—sodium and methylglucamine diatrizoate (Renovist), 1.3 to 1.7 ml. per Kg.—was injected mechanically through a no. 6, 7, or 8 Rodriguez catheter in 0.9 to 3.4 seconds. The injection was made into the sinus of the left ventricle in each case, but an additional angiocardiogram was made with injection into the right ventricle in case 7. Simultaneous anteroposterior and lateral exposures were made at six frames per second during left heart opacification, with a roll-film or cut-film changer,4 The electrocardiogram, arterial pressure, and the time of x-ray exposures were recorded simultaneously to permit correlation of the radiographic appearance with the events of the cardiac cycle.

Measurements of Angiocardiograms for Calculation of Volumes

Only those films showing complete opacification of the left ventricle were measured. Measurements were made as indicated in figure 1, and read to the nearest 1 mm. Estimation of chamber volume was carried out by the method of Arvidsson.5 The volume of the left atrium (V1A) is

\[ V_{1A} = \frac{a}{f_1} \cdot \frac{b}{f_1} \cdot \frac{c}{f_2} \cdot \frac{4}{3} \cdot \pi \]

and of the left ventricle (V1V) is

\[ V_{1V} = \frac{L}{2} \cdot \frac{B}{2f_1} \cdot \frac{C}{2f_2} \cdot \frac{4}{3} \cdot \pi \]

where L, the true long axis of the ventricular ellipsoid, is

\[ L = \sqrt{\left(\frac{D \cos \beta}{f_2}\right)^2 + \left(\frac{A}{f_1}\right)^2} \]

and f1 and f2 are the anteroposterior and lateral

From the Mayo Clinic and the Mayo Foundation, Rochester, Minnesota.


Circulation, Volume XXIX, March 1964

356
CONGENITAL MITRAL INSUFFICIENCY

Values for the volumes of left atrium \( (V_{LA}) \) and ventricle \( (V_{LV}) \) were plotted both in sequence (fig. 2a) and against time expressed in fractions of a second after the R wave of the electrocardiogram (fig. 2b) to form a composite curve. In general, three to four complete cycles were available for study during sinus rhythm.

Values for left ventricular end-diastolic \( (V_{ED}) \) and end-systolic \( (V_{ES}) \) volumes were obtained from the composite volume curves so constructed. The total volume ejected by the left ventricle is given by \( V_{ED} - V_{ES} \). In patients with no valvular insufficiency, the value \( V_{ED} - V_{ES} \) is the stroke volume \( (SV) \) and can be compared with the value for SV obtained from indicator-dilution curves to test the validity of angiocardio-phonographic volume measurements. This comparison was made in 26 patients, from 7 weeks to 20 years old, with no valvular insufficiency. Agreement was close; the relationship between angiocardio-phonographic estimates of ejection volume \( (Y) \) and estimates from indicator-dilution curves \( (X) \) being given by the linear regression equation:

\[
Y = 7.3 + 0.991 \times X, \quad (r = 0.91),
\]

from this

**Figure 1**

Paired angiography (anteroposterior and lateral projections). Calculations of heart volumes are made from the dimensions indicated on the line drawings. Lowercase symbols refer to semi-axes and uppercase symbols to axes.

**Figure 2**

a. Example of left ventricular (solid circles) and atrial (open circles) volumes calculated from paired angiography exposures plotted in sequence during three cardiac cycles (case 7, angiography made with injection into main pulmonary artery). b. Composite left ventricular (solid circles) and atrial (open circles) volumes plotted against time expressed in fractions of a second after the R wave of the electrocardiogram. Constructed from the data in a.
### Table 1

**Summary of Clinical Findings**

<table>
<thead>
<tr>
<th>Clinical history</th>
<th>Case</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>yr.</td>
<td>9</td>
<td>5½</td>
<td>8½</td>
<td>8</td>
<td>7</td>
<td>9</td>
<td>5½</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td>M</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>Age at onset of exercise intolerance</td>
<td>yr.</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>4 mo.</td>
</tr>
<tr>
<td>Age when murmur first detected</td>
<td>yr.</td>
<td>3</td>
<td>7 mo.</td>
<td>2 yr.</td>
<td>5 yr.</td>
<td>2 yr.</td>
<td>2 yr.</td>
<td>3 mo.</td>
</tr>
<tr>
<td>Physical examination</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height, percentile</td>
<td>2</td>
<td>&lt;3</td>
<td>25-50</td>
<td>90</td>
<td>&lt;10</td>
<td>10</td>
<td>95</td>
<td>10-25</td>
</tr>
<tr>
<td>Weight, percentile</td>
<td>2</td>
<td>Edema</td>
<td>50</td>
<td>25</td>
<td>10</td>
<td>10</td>
<td>60</td>
<td>3-10</td>
</tr>
<tr>
<td>Apical systolic thrill</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Pulmonic valve closure</td>
<td>Accentuated</td>
<td>Accentuated</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td></td>
</tr>
<tr>
<td>Pansystolic murmur</td>
<td>Grade</td>
<td>4/6</td>
<td>3/6</td>
<td>3/6</td>
<td>3/6</td>
<td>3/6</td>
<td>2/6</td>
<td>3/6</td>
</tr>
<tr>
<td>Position</td>
<td>Apex</td>
<td>Aorta; LLSB</td>
<td>Apex</td>
<td>Apex</td>
<td>Apex</td>
<td>LLSB</td>
<td>Apex</td>
<td></td>
</tr>
<tr>
<td>Transmission</td>
<td>Axilla</td>
<td>Axilla; axilla</td>
<td>Axilla</td>
<td>Axilla</td>
<td>Back</td>
<td>Axilla; back</td>
<td>Axilla</td>
<td></td>
</tr>
<tr>
<td>Mid-diastolic murmur, position</td>
<td>Apex</td>
<td>Apex</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Apex</td>
<td></td>
</tr>
<tr>
<td>Thoracic roentgenogram</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiotoracic ratio</td>
<td>0.82</td>
<td>0.80</td>
<td>0.46</td>
<td>0.50</td>
<td>0.44</td>
<td>0.56</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>Enlargement of pulmonary artery</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Enlargement of left atrium</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Electrocardiogram</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhythm</td>
<td>Atrial fibrillation</td>
<td>Sinus</td>
<td>Sinus</td>
<td>Sinus</td>
<td>Sinus</td>
<td>Sinus</td>
<td>Sinus</td>
<td></td>
</tr>
<tr>
<td>AQRS, degrees</td>
<td>+120</td>
<td>+75</td>
<td>+20</td>
<td>+70</td>
<td>+25</td>
<td>+40</td>
<td>+50</td>
<td></td>
</tr>
<tr>
<td>Left atrial enlargement</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Left ventricular hypertrophy</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Remarks</td>
<td>Heart surgery</td>
<td>Heart surgery</td>
<td>Marfan's syndrome</td>
<td>Marfan's syndrome?</td>
<td>ECG compatible with corrected transposition</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Cardiomyotomy by Dr. J. W. Kirklin; attempted replacement of mitral and tricuspid valves by Starr-Edwards ball valve prostheses.
† Cardiomyotomy by Dr. D. C. McGoon was successful in the repair of a cleft of the anterior mitral valve leaflet.
‡ Electrocardiogram showed inverted T waves in leads II, III, and aV_3, and slight elevation of the ST segment in V_6.
### Table 2

**Summary of Hemodynamic and Volume Data**

<table>
<thead>
<tr>
<th></th>
<th>Cases</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Normal*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface area, M.²</td>
<td>0.87</td>
<td>0.73</td>
<td>1.02</td>
<td>0.85</td>
<td>0.74</td>
<td>1.10</td>
<td>0.72</td>
<td>–</td>
</tr>
<tr>
<td>Cardiac output, L./min./M.² (awake)</td>
<td>2.9</td>
<td>3.6</td>
<td>3.7</td>
<td>4.4</td>
<td>3.8</td>
<td>3.6</td>
<td>3.6</td>
<td>–</td>
</tr>
<tr>
<td>Pressures, mm. Hg:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left ventricle</td>
<td>115/10-30</td>
<td>110/10-13</td>
<td>110/12</td>
<td>100/5-11</td>
<td>90/6-10</td>
<td>104/10</td>
<td>90/7</td>
<td>–</td>
</tr>
<tr>
<td>Pulmonary artery wedge</td>
<td>–</td>
<td>32/20</td>
<td>18/11</td>
<td>13/7</td>
<td>15/10</td>
<td>12/4</td>
<td>14/9</td>
<td>–</td>
</tr>
<tr>
<td>Pulmonary artery</td>
<td>125/60</td>
<td>38/24</td>
<td>32/19</td>
<td>22/7</td>
<td>25/15</td>
<td>18/5</td>
<td>30/10</td>
<td>–</td>
</tr>
<tr>
<td>Pulmonary resistances, units/M.²:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>28</td>
<td>6.5</td>
<td>6.3</td>
<td>2.7</td>
<td>4.8</td>
<td>2.6</td>
<td>4.6</td>
<td>–</td>
</tr>
<tr>
<td>Vascular</td>
<td>–</td>
<td>2.4</td>
<td>2.5</td>
<td>0.45</td>
<td>1.7</td>
<td>0.35</td>
<td>1.8</td>
<td>–</td>
</tr>
<tr>
<td>Regurgitation indices:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ry/Vᵗ</td>
<td>–</td>
<td>4.3</td>
<td>–</td>
<td>2.2</td>
<td>1.6</td>
<td>3.5</td>
<td>3.07</td>
<td>–</td>
</tr>
<tr>
<td>Cₑ/Cᵣ</td>
<td>0.68</td>
<td>&gt;1.0</td>
<td>0.36</td>
<td>0.33</td>
<td>0.35</td>
<td>0.26</td>
<td>0.44</td>
<td>–</td>
</tr>
<tr>
<td>Volumes from angiocardiogram, ml./M.²:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left atrium, maximum</td>
<td>170</td>
<td>573</td>
<td>–</td>
<td>71</td>
<td>55</td>
<td>–</td>
<td>90</td>
<td>24 ± 4.7</td>
</tr>
<tr>
<td>Left atrium, minimum</td>
<td>78</td>
<td>319</td>
<td>–</td>
<td>21</td>
<td>22</td>
<td>–</td>
<td>67</td>
<td>12 ± 4.2</td>
</tr>
<tr>
<td>Change in volume, ml./M.²</td>
<td>92</td>
<td>254</td>
<td>–</td>
<td>50</td>
<td>33</td>
<td>–</td>
<td>23</td>
<td>12 –</td>
</tr>
<tr>
<td>Change in volume, per cent</td>
<td>46</td>
<td>44</td>
<td>–</td>
<td>70</td>
<td>60</td>
<td>–</td>
<td>26</td>
<td>50 ± 14.7</td>
</tr>
<tr>
<td>Left ventricle:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vₑ₋₅₀</td>
<td>320</td>
<td>367</td>
<td>147</td>
<td>149</td>
<td>130</td>
<td>132</td>
<td>171</td>
<td>85 ± 11.7</td>
</tr>
<tr>
<td>Vₛ</td>
<td>132</td>
<td>131</td>
<td>61</td>
<td>55</td>
<td>49</td>
<td>66</td>
<td>74</td>
<td>28 ± 8.8</td>
</tr>
<tr>
<td>Vₑ₋₅₀⁻⁻Vₛ</td>
<td>188</td>
<td>236</td>
<td>86</td>
<td>94</td>
<td>81</td>
<td>66</td>
<td>97</td>
<td>56 ± 8.9</td>
</tr>
<tr>
<td>Vₑ</td>
<td>181</td>
<td>231</td>
<td>80</td>
<td>86</td>
<td>72</td>
<td>59</td>
<td>88</td>
<td>49 –</td>
</tr>
<tr>
<td>Vₑ₋₅₀⁻⁻Vₛ as per cent of Vₑ₋₅₀</td>
<td>59</td>
<td>64</td>
<td>59</td>
<td>63</td>
<td>62</td>
<td>50</td>
<td>57</td>
<td>67 ± 8.2</td>
</tr>
<tr>
<td>Stroke volume, SV, from dye dilution curve, ml./M.² (asleep)</td>
<td>8</td>
<td>27</td>
<td>34</td>
<td>42</td>
<td>41</td>
<td>34</td>
<td>59</td>
<td>43 ± 10.2</td>
</tr>
<tr>
<td>Regurgitation, Vₑ:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>As ml./M.²/beat</td>
<td>173</td>
<td>204</td>
<td>46</td>
<td>44</td>
<td>31</td>
<td>25</td>
<td>29</td>
<td>6†</td>
</tr>
<tr>
<td>As per cent of Vₑ</td>
<td>96</td>
<td>88</td>
<td>58</td>
<td>51</td>
<td>43</td>
<td>42</td>
<td>33</td>
<td>12†</td>
</tr>
</tbody>
</table>

* Means and standard deviations of data from 18 subjects with no abnormality of the left heart.
† See text for discussion.
by guest on April 24, 2017 http://circ.ahajournals.org/ Downloaded from

The cardiographic data concerning curves derived from injection with contrast of the mitral regurgitation were presented as percentage of left ventricular stroke volume. a. left atrium. b. Left ventricle.

A correction factor has been derived: 

\[ V_E = 1.01 \times (V_{ED} - V_{ES}) - 7.37 \]

in which \( V_E \) is the corrected left ventricular ejection volume. This correction factor was applied to all values for \( V_{ED} \) and \( V_{ES} \) obtained angiographically.

**Arterial Indicator-Dilution Curves**

Arterial indicator-dilution curves for calculation of cardiac output were recorded, 1 to 3 minutes prior to angiography, at the femoral artery after injection of 2.5 or 5 mg of indicator* into the same chamber used for injection of contrast medium. Cardiac output was calculated according to the method of Hamilton and was divided by the heart rate during inspiration of the curve to give stroke volume, \( SV \), which was subtracted from the corrected left ventricular ejection volume, \( V_E \), to give a value for regurgitant flow, \( V_R \).

Cardiac output with the patient awake was obtained from indicator-dilution curves performed with injection into the main pulmonary artery. These curves were also used to obtain \( C_L/C_R \) ratios as an index of valvular insufficiency as described by Wood and Woodward.11

**Results**

The principal clinical features are given in table 1 and the hemodynamic and angiographic data are summarized in table 2. The mean pulmonary arterial wedge pressure was elevated in case 2 and at the upper range of normal for children in case 3. For cases 2 and 4, the \( R_y/v \) ratio was in the range found in cases of mitral insufficiency. Calculation of the \( R_y/v \) ratio in the remaining cases has little meaning, since the wedge pressures were not elevated. Pulmonary vascular resistance was normal in all instances in which it could be measured.

In cases 3 to 7, the contour of the indicator-dilution curve was within the range of normal, but, in cases 1 and 2, there was significant prolongation of the disappearance phase of the curve consistent with the presence of valvular insufficiency.

Maximal and minimal left atrial volumes were increased above the range of normal in all cases in which measurement was possible, as was the difference between maximal and minimal volumes (fig. 3a and table 2). Left atrial opacification was inadequate for measurement purposes in cases 3 and 6.

Left ventricular volumes (\( V_{ED} \) and \( V_{ES} \)) were calculated in all cases and all were increased significantly above the normal range (fig. 3b and table 2). The left ventricular ejection volume (\( V_{ED} - V_{ES} \)) was grossly increased in cases 1 and 2 and moderately in-

* Cardio-green, from Hynson, Westcott and Dunning, Baltimore, Maryland.

---

**Figure 3**

Volumes for seven patients with congenital mitral insufficiency plotted against calculated regurgitant flow expressed as percentage of left ventricular stroke volume. a. left atrium. b. Left ventricle.

**Figure 4**

Left ventricular end-diastolic (\( V_{ED} \)) and end-systolic (\( V_{ES} \)) volumes for seven patients with congenital mitral insufficiency. The proportion of total left ventricular stroke volume (\( V_{ED} - V_{ES} \)) which forms forward flow (\( SV \)) and that which forms regurgitant flow (\( V_R \)) is indicated (\( V_R = (V_{ED} - V_{ES} - SV) \)).

_Circulation, Volume XXIX, March 1965_
creased in the remaining cases. Expressed as a percentage of end-diastolic volume ($V_{ED}$), the volume ejected by the left ventricle ($V_{ED}-V_{ES}$) varied between 50 and 64 per cent. Values for stroke volume (SV) varied between 8 and 59 ml. per square meter per beat. Regurgitant volumes ($V_{R}$) ranged between 25 and 204 ml. per square meter per beat (fig. 4).

Angiocardiographic Appearances

In each case, contrast medium injected into the left ventricle was seen to regurgitate into the left atrium. Regurgitation occurred before aortic opacification in case 1, when only the root of the aorta had opacified in cases 2 and 4, and when the aortic arch was opacified in cases 3, 5, 6, and 7. In case 2, the left atrium was enormously enlarged (fig. 5a) but no regurgitation of contrast medium into pulmonary veins was seen, a finding present in cases 1, 4, and 7 (fig. 6). An abnormal ridge of muscle was seen posteriorly in the left ventricle in case 7 (fig. 5b). Cases 3 and 6 both exhibited dilatation of the sinuses of Valsalva and aortic root (fig. 5c and d).

Discussion

Clinical Observations

Since the hemodynamics of isolated congenital mitral insufficiency are similar to those of mitral insufficiency from any other cause, the physical signs and roentgenologic and electrocardiographic findings are identical (table 1). Enlargement of the left atrium may reach aneurysmal proportions; this was a feature of the first case of congenital mitral insufficiency reported in the literature and of case 2 reported here.

A congenital basis for the lesion may be established at operation or at necropsy. Failing this, and in the absence of associated congenital heart lesions, such an etiology may be assumed when the murmur is heard very early in life prior to the age when acquired valvular lesions are expected. In six of the seven cases reported here, the murmur was detected at 2 years of age or less and none of the patients had a history of carditis.

There was operative evidence as to the anatomic nature of the lesion in cases 1 and 2.
logic evidence of previous carditis. We have been unable to find a similar case reported in the literature.

In case 2, the patient was found to have a cleft in the anterior leaflet of the mitral valve and no atrial or ventricular septal defect. This type of lesion probably results from faulty embryogenesis of the endocardial cushions and may be a variant of common atrioventricular canal. Three similar cases have been reported.3, 14, 15

Mitral insufficiency occurs in the Marfan syndrome.16 Heart disease associated with this syndrome can be classified as degenerative, since the diastasis, but not the defect, is present at birth.16 Mitral murmurs in the Marfan syndrome have been heard at birth,17 however, and the valvular involvement may, in such instances, be truly congenital. Two of the patients described here (cases 3 and 6) had body features suggestive of the Marfan syndrome and both were demonstrated to have dilatation of the ascending aorta at angiocardioangiography, a finding common in this syndrome. The electrocardiogram in case 6 resembled, in certain respects, that described in some cases of the Marfan syndrome.18

Volume Calculations

The accuracy of determinations of volume of left heart chambers by biplane angiocardiography is well established. Errors arise when there is an abnormal rhythm during filming or when atrial opacification is inadequate for measurement purposes. Injection of contrast medium into the pulmonary artery reduces these complications. In the present study, contrast medium was injected into the left ventricle but an additional injection was made into the pulmonary artery in case 7. Both sets of films were measured with respect to left heart volumes and showed good agreement. Other potential errors in the determination have been recognized19, 20 and tend to result in an overestimate of ventricular volume. Dodge and co-workers21 used contrast-filled postmortem hearts and models to investigate five methods based on the ellipsoid5 for calculating left ventricular volume angiocardiographically. For the best model, the calculated volumes exceeded the measured volumes by approximately 10 per cent and a regression equation was derived to eliminate the overestimate.

Perhaps the strongest evidence for the accuracy of volume measurements in vivo lies in the agreement between estimates of stroke volume by angiocardiography on the one hand and by the Fick22 and the dye methods23 on the other. In the group of 28 subjects with no valvular insufficiency studied in this laboratory, however, the regression equation, 

\[ Y = 7.30 + 0.991X, \]

indicates an overestimate of 12 per cent (table 2), which is similar in direction and magnitude to that found by others.23

Quantitation of Regurgitant Volume

The presence of mitral insufficiency is established when injection of contrast medium into the left ventricle is followed by significant regurgitation in the absence of abnormality of cardiac rhythm. Quantitation of such regurgitation has been attempted by estimating the intensity of left atrial opacification24, 25 or by comparing the time relationship of left atrial and aortic opacification.26 On the basis of such methods, cases 1 and 2 would be classified as having severe, case 4 as moderate, and cases 3, 5, 6, and 7 as mild, mitral insufficiency. Recently Sandler and associates,27 using the technic reported here, found regurgitant flows of up to 14.2 L. per minute in 19 adult patients with aortic and mitral valve disease; the regurgitant flow in the cases reported herein ranges from 2.0 to 29 L. per minute per square meter. In the most severe case (case 1), 96 per cent, and in the least severe case (case 7), 33 per cent of the total left ventricular ejection volume regurgitated into the left atrium. Such estimates of regurgitation \((V_R)\) are affected by the accuracy of indicator-dilution determinations of forward flow \((SV)\). Theoretically, valvular insufficiency should not affect calculation of SV, providing systemically recirculated indicator is not included in the computation. However, data available28 suggest that indicator-dilution curves performed with injection into the left ventricle may underestimate SV in the presence of mitral in-
sufficiency. Regurgitant flows calculated in these patients are still surprisingly large and represent a high output state of the left ventricle. Yet, in cases 3 to 7, the lesion was considered, on clinical grounds, to be mild and not to require operation despite regurgitant flows of 30 to 60 per cent—a situation in marked contrast to patients with ventricular and atrial septal defects in whom left-to-right shunts of this magnitude would indicate consideration for surgical repair of such defects.

Relationship of Regurgitation to Ventricular Volume

In the absence of a marked increase in heart rate and in the presence of a regurgitant flow, a normal cardiac output can be maintained by (1) an increase in the proportion of end-diastolic volume ejected as total stroke volume or (2) an increase in end-diastolic volume, the proportion ejected by the ventricle remaining approximately the same. Our results show that it is the latter mechanism which is operating. Thus, while there were considerable increases in end-diastolic volume, the total left ventricular ejection volume \( V_{ED} \) averaged 59 per cent of end-diastolic volume \( V_{ED} \), which is, in fact, a somewhat smaller proportion than that found by us (67 per cent) in 18 subjects with normal left ventricles who were studied under identical conditions. Similar values for per cent ejection can be derived from data reported in adults, by Dodge and associates,\textsuperscript{23, 24} and in children without insufficiency, by Bunnell and co-workers,\textsuperscript{25} in regard to the proportion of end-diastolic volume ejected. Similar results have been obtained in normal dogs.\textsuperscript{31} Thus, the children described herein were able to maintain a reasonable forward flow as a result of a substantial increase in end-diastolic volume (figs. 3 and 4). The increases in end-diastolic, end-systolic, and regurgitant volumes serve effectively to categorize the severity of insufficiency.

Left Atrial Volumes

In the present series, both absolute atrial volumes and changes in atrial volume were, like the ventricular volumes, significantly increased above the normal range (fig. 4). In conjunction with the abnormal ventricular volumes, these changes in atrial volume reinforce the diagnosis of mitral insufficiency and categorize its severity. In normal subjects or in patients with mitral stenosis, the magnitude of the change in atrial volume is less than the stroke volume. In mitral insufficiency, the change in atrial volume, although greater, still may not equal the total volume of blood ejected by the left ventricle (regurgitant plus forward flow).\textsuperscript{5} Since the atrium is never a closed chamber, part of the regurgitant flow can be accommodated in pulmonary veins and, in cases 1 and 7, in which the change in atrial volume was less than ventricular stroke volume, contrast medium was seen to pass from the left ventricle into the pulmonary veins (fig. 6). Minimal regurgitation into pul-

Figure 6

Case 1. Angiocardiogram during systole, showing regurgitation into pulmonary veins.
monary veins was also seen in case 4, in which atrial volume change was nearly equal to left ventricular stroke volume.

**Diagnostic Implications**

Assessment of regurgitant volume on the basis of left atrial pressure pulses, whether direct or indirect (pulmonary arterial wedge pressure), is notoriously susceptible to error. Of the measurements available, the By/v ratio \(^8\) commonly is regarded as the least unreliable.\(^{32}\) However, in cases 4 to 7, left atrial pressure was not increased sufficiently to make such calculations meaningful, despite significant regurgitation.

Indices of regurgitation derived from indicator-dilution curves are also subject to error. Gross distortion of the curve occurs when the left atrial volume is large; conversely, a small left atrium may produce little distortion of the curve despite a relatively large regurgitant flow.\(^{29, 34}\) Distortion of the indicator-dilution curve was pronounced in cases 1 and 2, in which there was considerable left atrial enlargement. In the remaining cases there was no significant distortion of the indicator-dilution curves recorded at a peripheral arterial sampling site \((C_L/C_R \text{ ratio } < 0.65)\), despite significant regurgitation. The present cases demonstrate that, while abnormality in either the wedge-pressure pulse or the indicator-dilution curve may offer evidence for the presence of significant mitral regurgitation, there are some cases with hemodynamically significant regurgitation in which neither the pressure pulse nor the indicator-dilution curve may show abnormality of diagnostic significance. Quantitative estimates of regurgitant volume based on either of these methods,\(^8, 11\) therefore, are unlikely to give uniformly consistent results.

The technic described in this paper permits direct evaluation of regurgitation and appears to be a satisfactory method for recognition and approximate quantitation of mitral insufficiency. Moreover, a new dimension—volume and volume change—is added to the description of the hemodynamics of congenital mitral insufficiency.

**Summary**

Clinical, hemodynamic, and angiocardiographic findings are described in seven cases of congenital mitral insufficiency. The volumes and changes in volume of the left atrium and left ventricle were calculated from the angiocardiograms and were found to be increased above the range of normal. Left ventricular stroke volumes thus obtained were compared with forward flows calculated from indicator-dilution curves in order to quantitate regurgitant flow. Regurgitant flows varied between 19 and 94 per cent of the total left ventricular ejection volume, and forward flow was maintained as a result of a considerable increase in left ventricular volume. The left ventricular ejection volume was 50 to 64 per cent of the end-diastolic volume.

**References**

9. Miller, G. A. H., and Swan, H. J. C.: Normal left heart volumes determined angiocardo-
CONGENITAL MITRAL INSUFFICIENCY

graphically in subjects of differing body size. Unpublished data.


28. Rahimtoola, S. H.: Personal communication to the authors.


Isolated Congenital Mitral Insufficiency with Particular Reference to Left Heart Volumes

GRAHAM A. H. MILLER, RICHARD BROWN and H. J. C. SWAN

_Circulation_. 1964;29:356-365
doi: 10.1161/01.CIR.29.3.356

_Circulation_ is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1964 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/29/3/356

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in _Circulation_ can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to _Circulation_ is online at:
http://circ.ahajournals.org//subscriptions/