Isolated Valvular Pulmonic Stenosis
Clinical and Physiologic Response to Open Valvuloplasty

By S. Gilbert Blount, Jr., M.D., Malcolm C. Mc Cord, M.D., Helmut Mueller, M.D., and Henry Swan, M.D.

The preoperative and postoperative clinical and physiologic data are presented in 10 patients with isolated valvular pulmonic stenosis. The valvulotomy was performed in five patients by the generally accepted blind ventricular approach, while in the remaining five patients the valvular surgery was accomplished by a direct pulmonary arterial approach. The physiologic data revealed uniform obliteration of the systolic pressure gradient from the right ventricle to the pulmonic artery in the patients operated by the direct technic in striking contrast to the inadequate and variable relief of stenosis by the transventricular approach.

Isolated valvular pulmonic stenosis has been recognized in recent years to be a relatively common congenital anomaly. It has also become evident during this period that it is not the benign lesion that the asymptomatic clinical picture might suggest. Whenever the clinical diagnosis of valvular pulmonic stenosis with intact ventricular septum is entertained, complete physiologic evaluation is advisable and operative intervention should be considered in every instance. Sellors2 initiated operative correction of this lesion in 1948, employing a transventricular approach. This approach has subsequently been developed by Brock3 and others4,5 and employed in a large number of patients. While subjective clinical improvement has been reported, studies comparing the preoperative and postoperative physiologic status of such patients have been infrequent. The few reported studies of postoperative physiologic changes have demonstrated inadequate relief of the pulmonic valve obstruction in most instances and have been characterized by a striking lack of uniformity6-11 (table 1).

A transarterial approach to the pulmonic valve has been previously reported,12 but has been largely abandoned because of technical problems relating to the blind approach existing with closed heart surgery. Thus at the present time the transventricular approach to the stenotic valve is almost universally employed.

The recent application of hypothermia to this problem13 has allowed open heart surgery, and under these conditions the stenotic valve may be viewed with deliberation and valvuloplasty performed. This present communication deals with the clinical and physiologic response to transarterial pulmonic valvuloplasty and compares the results obtained by this method with those obtained following the transventricular approach.

Material and Methods
A diagnosis of isolated valvular pulmonic stenosis has been established in 51 patients during the past three years at this institution. Surgical therapy has been recommended in all patients demonstrating right ventricular systolic pressures exceeding 75 mm. Hg. Operative therapy was accepted and car-
TABLE 1.—Summary of Published Data of Postoperative Hemodynamic Changes Following Transventricular Pulmonic Valvuloplasty

<table>
<thead>
<tr>
<th>Source</th>
<th>Number of Cases</th>
<th>Pre-op. Average Rt. Vent. Pressure</th>
<th>Post-op. Average Rt. Vent. Pressure</th>
<th>Decrease Rt. Vent. Pressure (mm Hg)</th>
<th>Decrease Rt. Vent. Pressure in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lurie and Schumaker</td>
<td>7</td>
<td>99/1</td>
<td>78/2</td>
<td>21</td>
<td>30</td>
</tr>
<tr>
<td>Bing, et al.</td>
<td>8</td>
<td>127/29</td>
<td>92/16</td>
<td>35</td>
<td>36</td>
</tr>
<tr>
<td>Kirklin, et al.</td>
<td>2</td>
<td>125/5</td>
<td>52/6</td>
<td>73</td>
<td>77</td>
</tr>
<tr>
<td>Galligan, et al.</td>
<td>2</td>
<td>179/5</td>
<td>59/3</td>
<td>120</td>
<td>81</td>
</tr>
<tr>
<td>Soulie, et al.</td>
<td>9</td>
<td>171/7</td>
<td>108/6</td>
<td>63</td>
<td>45</td>
</tr>
<tr>
<td>Humphreys, et al.</td>
<td>3</td>
<td>193/12</td>
<td>75/10</td>
<td>118</td>
<td>72</td>
</tr>
<tr>
<td>Blount, et al. (Present communications)</td>
<td>5 168/2</td>
<td>65/1</td>
<td>103</td>
<td>75</td>
<td></td>
</tr>
</tbody>
</table>

ried out in 15 patients. Prior to 1953 the valvulotomy was performed by the ventricular approach, the Brock technique. This method consisted of incision of the right ventricular wall in the outflow area, and blind valvulotomy, using a valvulotome followed by dilatation of the sectioned pulmonic valve. Pulmonary valvulotomy was performed by this method in eight patients with an operative fatality in two patients. Postoperative catheterization data were obtained a year or more following surgery in five of these patients. For convenience this group will be designated as group A in the following presentation.

A pulmonary arterial approach was adopted in 1953 for the surgical correction of valvular pulmonic stenosis. Briefly this method consists of the use of hypothermia with occlusion of circulation. The pulmonary artery is incised and the pulmonic valve is exposed to direct vision. The stenosis is relieved by incision or partial excision as indicated in each instance. This operative procedure has been carried out in seven patients with no operative fatalities. Preoperative and postoperative physiologic studies were obtained in five consecutive patients. These five patients compose group B in the following presentation.

RESULTS

Clinical Observations

Three of the five patients operated by the Brock technique, group A, were symptomatic, describing varying degrees of limitation of exercise tolerance. Each of these patients was cyanotic. All three patients described an improvement in symptoms following surgery, and there was an apparent decrease in the degree of cyanosis. One patient in the group operated by the pulmonary arterial approach, group B, was limited in exercise tolerance and was slightly cyanotic. This patient showed an improvement in exercise tolerance postoperatively. The remaining patients in both groups were asymptomatic.

The pertinent findings on physical examination involved cardiac murmurs. The intensity of the systolic murmur in the second left intercostal space was grade IV or more in all patients in both groups preoperatively, and a thrill was palpable in the left second intercostal space in all patients. In group A the intensity of the systolic murmur decreased following surgery in all instances but one, C. T., where the intensity remained grade V. The magnitude of this decrease was only moderate, the murmur being at least grade III in intensity in the remaining patients, and a thrill persisting in three patients. In group B the murmur decreased to grade II in all instances and the thrill disappeared in all patients.

One of the patients in group A developed a diastolic murmur along the left sternal border following surgery. A diastolic murmur appeared in this location postoperatively in four of the five patients in group B. This murmur was medium to low in pitch and somewhat rough in quality, and was of maximum intensity in the third left intercostal space. The intensity

TABLE 2.—Magnitude of Decrease in Amplitude of R Wave in Precordial Lead V1. The First Five Patients Comprise Group A While the Second Five Represent Group B

<table>
<thead>
<tr>
<th>Patient</th>
<th>Pre-op. R-V1</th>
<th>Post-op. R-V1</th>
<th>Time after surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. T.</td>
<td>31</td>
<td>12</td>
<td>2½ yrs.</td>
</tr>
<tr>
<td>R. M.</td>
<td>36</td>
<td>24</td>
<td>1 yr.</td>
</tr>
<tr>
<td>D. N.</td>
<td>24</td>
<td>7</td>
<td>11 mos.</td>
</tr>
<tr>
<td>D. L.</td>
<td>20</td>
<td>9</td>
<td>6 mos.</td>
</tr>
<tr>
<td>A. N.</td>
<td>2</td>
<td>3</td>
<td>1 yr.</td>
</tr>
<tr>
<td>R. H.</td>
<td>10</td>
<td>16</td>
<td>8 mos.</td>
</tr>
<tr>
<td>J. K.</td>
<td>30</td>
<td>10</td>
<td>9 mos.</td>
</tr>
<tr>
<td>G. S.</td>
<td>25</td>
<td>9</td>
<td>10 mos.</td>
</tr>
<tr>
<td>M. G.</td>
<td>13</td>
<td>5</td>
<td>5 mos.</td>
</tr>
<tr>
<td>D. M.</td>
<td>19</td>
<td>16</td>
<td>9 mos.</td>
</tr>
</tbody>
</table>
of this murmur varied from grade I to grade III.

The second heart sound in the second left intercostal space was decreased in intensity or absent prior to surgery in all patients. Postoperatively there was an increase in intensity or appearance of this sound in four of the patients in group A and in all of the patients in group B.

Electrocardiography

A tall R wave with a delayed intrinsicoid deflection time exceeding 0.03 second was present in precordial lead V₁ in 9 of the 10 patients preoperatively. Postoperatively there was a decrease in the amplitude of this R wave in lead V₁ in all nine patients (table 2). The average decrease in group A was 36 per cent whereas the average drop in the amplitude in group B was 42 per cent thus showing no significant difference. A significant change in the configuration of the QRS complex in lead V₁ was noted in three patients in group B. The high-amplitude R wave present preoperatively, indicating right ventricular hypertrophy, evolved to a lower amplitude rSR'.
pattern interpreted as incomplete or partial right bundle-branch block (fig. 1).

Roentgenography

The three patients in group A who were cyanotic showed a decreased vascularity of the peripheral lung fields prior to surgery. The vascularity was normal in the remaining patients in both groups. Following surgery there was no significant change in the peripheral vascularity of the lung fields in any patient.

The right and left pulmonary arteries showed a decreased amplitude of pulsation in all patients in both groups prior to surgery. In three patients in group A, those who were cyanotic, the low amplitude pulsations persisted after surgery. There was an increase in the pulsations in the remaining two patients. The amplitude of pulsations in the right pulmonary artery increased after surgery in all patients in group B.

There was no significant change in the prominence of the main pulmonary artery in any patient. The heart size increased following surgery in three patients in group A and in all patients in group B, the increase ranging from 0.5 to 1.5 cm. in transverse diameter (fig. 2). This increase in heart size occurred immediately following surgery, and there was no further significant change during the follow-up period (fig. 3).

Hemodynamics

The pressure phenomena observed in the right ventricle and pulmonary arteries in these patients is summarized in tables 3 and 4. In the five patients operated by the ventricular approach the right ventricular systolic pressure ranged from 110 to 221 mm. Hg with an average of 168 mm. Hg. The right ventricular systolic pressure was reduced following surgery in all patients in this group, the average postoperative pressure being 65 mm. Hg. This decrease ranged from 29 to 96 per cent with

Fig. 2. Increase in transverse cardiac diameter and straightening of left cardiac border following transarterial pulmonic valvuloplasty. (M. G. group B.)
FIG. 3. Increase in heart size in immediate postoperative period with no progression during subsequent eight months. (G. S. group B.)

### TABLE 3.—Pressure Changes in the Right Ventricle and Pulmonary Artery Following Transventricular Pulmonic Valvuloplasty, Group A

<table>
<thead>
<tr>
<th></th>
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<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>C. T.</td>
<td>200/5</td>
<td>151/1</td>
<td>122/13</td>
<td>29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R. M.</td>
<td>165/14</td>
<td>38/2</td>
<td>128</td>
<td>94</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D. N.</td>
<td>221/10</td>
<td>60/6</td>
<td>161</td>
<td>84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D. L.</td>
<td>142/1</td>
<td>34/5</td>
<td>108</td>
<td>96</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. N.</td>
<td>110/3</td>
<td>40/2</td>
<td>70</td>
<td>87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avg.</td>
<td>168/2</td>
<td>65/3</td>
<td>103</td>
<td>75</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 4.—Pressure Changes in the Right Ventricle and Pulmonary Artery Following Transarterial Pulmonic Valvuloplasty, Group B

<table>
<thead>
<tr>
<th>Patient</th>
<th>Pre-op. R. V.</th>
<th>Pre-op. P. A.</th>
<th>Post-op. R. V.</th>
<th>Post-op. P. A.</th>
<th>Decrease R. V. Pressure (mm. Hg)</th>
<th>Decrease R. V. Pressure in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>R. H.</td>
<td>93/3</td>
<td>23/12</td>
<td>23/8</td>
<td>64</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>J. K.</td>
<td>142/1</td>
<td>17/7</td>
<td>15/3</td>
<td>123</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>G. S.</td>
<td>110/3</td>
<td>18/12</td>
<td>32/9</td>
<td>78</td>
<td>98</td>
<td></td>
</tr>
<tr>
<td>M. G.</td>
<td>119/15</td>
<td>18/9</td>
<td>25/9</td>
<td>89</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>D. M.</td>
<td>115/64</td>
<td>29/7</td>
<td>15/9</td>
<td>88</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Avg.</td>
<td>116/11</td>
<td>19/10</td>
<td>23/7</td>
<td>88</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>
an average reduction of 75 per cent. This value was derived by a comparison of the preoperative right ventricular systolic pressure with a theoretic normal of 30 mm. Hg and calculated as follows:

\[
\text{Decrease in RV systolic pressure} \times 100 \\
\text{Preoperative RV systolic pressure} - 30 \text{ mm. Hg}
\]

The pulmonary arterial pressures in group A were uniformly low preoperatively, averaging 16/10 mm. Hg. A normal pulmonary artery pulse pressure was approximated following surgery in only two of the five patients in group A (fig. 4) while in the remaining three patients a narrow pulse pressure persisted (fig. 5). The average postoperative pulmonary artery pressure in this group was 22/10 mm. Hg. In all patients a pressure gradient between the right ventricle and the pulmonary artery during systole persisted following surgery, averaging 43 mm. Hg. There was thus evidence of residual stenosis at the pulmonic valve level in every patient in group A.

The right ventricular systolic pressure in the patients operated by the pulmonary arterial route ranged from 93 to 142 mm. Hg, with an average of 116 mm. Hg. Following operation the right ventricular pressure was reduced to normal levels in every instance with an average pressure of 28 mm. Hg.

The pulmonary arterial pressure was low, and there was a narrow pulse pressure in every patient preoperatively with an average pulmonary artery pressure of 19/10 mm. Hg. Following surgery the pulse pressure increased in all patients, and a normal pulmonary

Fig. 4. Reduction of right ventricular pressure and return to normal of pulmonary arterial pressure and pulse contour following transventricular valvulotomy. (D. N. group A.)
arterial pulse contour was established (figs. 6 and 7).

The most striking physiologic change was the almost complete obliteration of the systolic pressure gradient between the right ventricle and pulmonary artery in every instance with an average gradient of only 5 mm. Hg.

The gradient between the pulmonary artery and the right ventricle during diastole was significantly decreased in two patients in whom the pulmonary valve was widely excised. The pulmonary arterial diastolic pressure in these patients was 3 and 5 mm. Hg, respectively (fig. 8).

**DISCUSSION**

The clinical evaluation of these patients following surgery was not considered to be significant in a critical evaluation of the success of the operative procedure. There were four patients who were cyanotic prior to operation and each presented some degree of dyspnea and fatigue with exertion. Definite improvement in exercise tolerance was described following surgery in these patients. Relief of symptoms bore no relationship to degree of improvement of the hemodynamic pattern following surgery. No definite or significant symptomatology was described by the remaining six patients. Thus, it is not considered that the evaluation of symptomatology prior to and following operation is of any significant value in determining the extent to which the valvular pulmonic stenosis has been relieved. Definite conclusions regarding the degree of improvement following surgery

**Fig. 5.** Reduction in right ventricular pressure to near normal levels and persistence of low-pressure pulmonary arterial pulse wave following transventricular valvulotomy. (A. N. group A.)
can only be based on objective physiologic data rather than subjective impressions.

Similarly, the physical examination is not considered to offer criteria for precise evaluation of operative results; however, certain trends were noted. While the intensity of the systolic murmur tended to decrease in all patients, a more pronounced and uniform decrease was present in the patients in whom transarterial direct valvuloplasty was performed. This uniform decrease in intensity of the systolic murmur in the latter group tended to parallel the more complete obliteration of the pressure gradient between the right ventricle and the pulmonary artery as determined by right heart catheterization.

The increase in intensity of the second heart sound in the left second intercostal space following surgery is a finding that is not well understood. It has generally been considered that the diastolic pressure in the pulmonary artery is the major factor governing the relative intensity of the second heart sound in this area. Certainly the increased intensity does not reflect an increased pulmonary arterial diastolic pressure in these patients, since this pressure level was lower post-operatively than prior to surgery in all patients.

**Fig. 6.** Reduction of right ventricular pressure to normal and restoration of normal pulmonary arterial pressure and pulse contour following transarterial valvulotomy. The pressure gradient between the right ventricle and pulmonary artery has been abolished. (R. H. group B.)
in group B. It is postulated that the increased intensity of this sound following surgery might be due to an increased mobility of the incised pulmonic valve.

The appearance of a diastolic murmur in all patients operated by the transarterial approach, and considered to indicate organic pulmonic insufficiency, is of considerable interest. This murmur was of a different quality than that characteristically associated with functional pulmonic insufficiency. The murmur encountered in these patients was rougher in quality and lower in pitch than the classic Graham Steell murmur.

Definite regressive changes were noted in serial postoperative electrocardiograms of all patients. The decrease in R-wave amplitude reflected the decrease in right ventricular pressure; however, no quantitative relationship was apparent. It has been demonstrated that there is a poor relationship between the degree of right ventricular hypertrophy and the level of pressure within the right ventricle. Therefore, a quantitative evaluation of the postoperative results cannot be determined from a study of the electrocardiographic changes. Transition of the QRS complex in precordial lead V1 from a right ventricular hypertrophy pattern to one suggesting an incomplete right bundle-branch block represents an interesting alteration. This phenomenon may reflect a stage in the regression of a right ventricular hypertrophy pattern or may reflect the dilatation of the right ventricle with an alteration in the type of ventricular stress, as proposed by Cabrera.

The roentgenographic changes consisted principally in an increase in over-all heart size and an increase in the amplitude of pulsations within the right and left main pulmonary arteries. The increase in heart size that occurred following valvuloplasty was more pronounced in the patients treated by wide excision of the pulmonic valve, and the murmur
of pulmonic insufficiency was of greater intensity in these patients. This suggests dilatation of the right ventricle occurring as a result of an increased residual diastolic chamber volume due to the pulmonic insufficiency. An increase in heart size was also noted postoperatively in the patients not evidencing pulmonary insufficiency. In this case an increase in diastolic volume and, consequently, heart size may be a manifestation of increased stroke volume following the relief of pulmonic valve obstruction. The increase in heart size showed no progression beyond the immediate postoperative period.

There was an apparent correlation between the postoperative increase in the pulmonary artery pulse pressure and the increase in amplitude of the pulsations noted in these vessels on fluoroscopy. This relationship tends to emphasize the role of the pulmonary arterial pulse pressure in the production of pulsations in the pulmonary arteries in addition to the factor of pulmonary blood flow. Increase in pulmonary blood flow did not appear to be a factor in producing this increase in pulsations as the pulmonary artery blood flow was not significantly altered following surgery.

Pre- and postoperative hemodynamic studies form the basis for the most critical and conclusive evaluation of the efficacy of pulmonic valvular surgery. Using these criteria, the superiority of the direct transarterial valvuloplasty over the blind ventricular valvulotomy is apparent. The hemodynamic event of most significance in relief of stenosis is the obliteration of the systolic pressure gradient existing between the right ventricle and the pulmonary artery. This gradient was abolished in the patients undergoing direct valvuloplasty. The restitution of a normal pulmonary arterial pulse contour is also of importance. This dynamic change again was present uniformly in the patients treated by direct valvuloplasty. The degree of stenosis, as reflected by the level of the systolic pressure in the right ventricle was somewhat more severe in the patients in group A than in those patients in group B. However, it is not considered that this factor in any way obviates the superiority of the transarterial approach.

The significance of the creation of pulmonary insufficiency in these patients is not established at this time. To our knowledge, there is no study available of the effect of pulmonary insufficiency upon the cardiovascular system in man. The creation of pulmonary insuf-
ficiency has been employed in an attempt to produce cardiac decompensation in the experimental animal, but it has been unsuccessful. The postoperative course of the patients with pulmonic insufficiency did not differ in any way from the course of patients with no evidence of pulmonary insufficiency. Since the pulmonary circulation is a low pressure system and the gradient during diastole between pulmonary artery and right ventricle is small, the creation of pulmonary insufficiency of this order should have little effect upon the dynamics of the right heart. The final answer cannot be stated at this time, and must await further evaluation. At the present time, however, it can be stated that there is no evidence of significant derangement in the hemodynamic pattern of these patients.

Summary and Conclusions

Surgical correction of isolated valvular pulmonic stenosis has been effected almost exclusively by the transventricular approach. The hemodynamic studies following this procedure reveal evidence of inadequate relief of the stenosis, and lack of uniformity of results. The advent of open heart surgery afforded by hypothermia has now permitted the direct vision of the stenotic pulmonic valve from the arterial side. This communication presents the pre- and postoperative clinical and physiologic evaluation of 10 patients with isolated valvular pulmonic stenosis. In five patients the approach to the valve was through the wall of the right ventricle, while in the remaining five patients the approach was through the pulmonary arterial wall.

Although subjective improvement was described in patients in both groups, such an evaluation of results of surgery is not considered to represent a critical analysis of the success of this operation. The physiologic studies obtained in the group in which the valve was approached through the ventricle were variable, and in no instance was there evidence of complete removal of the valvular obstruction. The physiologic data determined following the transarterial approach to the stenotic valve revealed uniformly good results.

The right ventricular systolic pressure was reduced to normal levels in all five patients, and the pulmonary arterial pulse contour assumed a normal form in each instance. There was obliteration of the preoperative systolic pressure gradient from the right ventricle to the pulmonary artery in every patient. Thus, in this group complete relief of valvular obstruction was demonstrated, in contrast to the variable and inadequate relief of obstruction when the valve was approached via the right ventricle. The transarterial approach therefore, is recommended as the method of choice in the surgical therapy of isolated valvular pulmonic stenosis.

Sumario Español

La corrección quirúrgica de la estenosis pulmonar valvular aislada se ha efectuado casi exclusivamente por el aproche transventricular. Los estudios hemodinámicos que prosiguen este procedimiento revelan evidencia de una inadecuada mejora de la estenosis y de una falta de uniformidad en los resultados. El advenimiento de la cirugía cardíaca abierta hecho posible mediante la hipotermia ha permitido la visualización directa de la válvula estenótica pulmonar desde el lado arterial. Esta comunicación presenta la evaluación clínica y fisiológica pre y postoperatoria de 10 pacientes con estenosis valvular pulmonar. En cinco pacientes el aproche a la válvula fue a través de la pared del ventrículo derecho, mientras que en los cinco restantes el aproche fue a través de la pared de la arteria pulmonar.

Aunque mejoría subjetiva fué descripta por pacientes en ambos grupos, tal evaluación de los resultados quirúrgicos no es considerada representar un análisis crítico del éxito de la operación. Los estudios fisiológicos obtenidos en el grupo en que la válvula fué aprochada a través del ventrículo fueron variables y en ningún instante hubo evidencia completa de desaparición de la obstrucción valvular. Los datos fisiológicos determinados luego del aproche transarterial a la válvula estenótica revelaron resultados buenos uniformemente. La presión sistólica ventricular derecha fué reducida a niveles normales en todos los cinco pacientes y el contorno del pulso arterial
Pulmonar se tornó en normal en cada caso. Hubo obliteración de la pendiente de presión sistólica preoperatoria del ventrículo derecho a la arteria pulmonar en cada paciente. Así es que en este grupo se demostró completa desaparición de la obstrucción valvular, en contraste a la mejoría inadecuada y variable de la obstrucción cuando la válvula fué aprochada vía ventrículo derecho. El aproche transarterial se recomienda como el método preferido en la terapia quirúrgica de la estenosis pulmonar aislada.

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