Clinical, Angiographic, and Hemodynamic Assessment of Late Results After Mustard Operation

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SUMMARY Since 1974, late results of the Mustard procedure for correcting complete transposition of the great arteries have been evaluated by cardiac catheterization, electrocardiography, roentgenography, history, and physical examination of 48 Mayo Clinic patients. Of these, 15 were studied 1 month to 2 years postoperatively because of clinical deterioration. The other 33 had been asymptomatic but were asked to return for hemodynamic reevaluation one-half to 11 years postoperatively. Of the asymptomatic group, 19 underwent exercise electrocardiography prior to catheterization and eight performed supine exercise during catheterization. Cardiac catheterization proved the most effective mode of study.

Significant cardiovascular abnormalities (caval obstruction, residual pulmonary stenosis, etc.) were found in 35 of the 47 patients—including 20 of the 33 who were asymptomatic. Eight of the symptomatic group and three of the others have died since this restudy. These poor results warrant renewed effort to devise better methods for correcting complete transposition.

SEVERAL PREVIOUS REPORTS have documented various hemodynamic and electrocardiographic conduction abnormalities following the Mustard operation. Cardiac obstruction, pulmonary venous obstruction, right ventricular dysfunction, tricuspid insufficiency, and residual left ventricular outflow tract obstruction have been well-recognized hemodynamic complications.1-10 Atrial fibrillation, slow junctional rhythm, sick sinus syndrome, and sudden death have been reported.11,12 The incidence rate and seriousness of these complications have varied. Some authors have hoped to avoid the problems by alterations in surgical methods, but the effects of the alterations have had to await comparison of long-term results. Also correlation of clinical and hemodynamic late results and comparison between symptomatic and asymptomatic patients have not previously been undertaken.

The purpose of this report is to provide hemodynamic documentation of the long-term results of the Mustard operation by right and left heart catheterization in a large number of patients and to provide clinical correlation between symptomatic and asymptomatic groups. The hemodynamic results of supine exercise obtained during catheterization in a small group of patients to allow better assessment of pump function are also included.

Material and Methods

We reviewed 48 cases in which cardiac catheterization had been performed recently at this clinic to assess results of the Mustard procedure for complete transposition of the great arteries. The operations had been performed in the years 1964 through 1975, from which period there were approximately 150 late survivors. Among these 150, 15 who were symptomatic were examined 1 month to 11 years postoperatively because of signs of clinical deterioration. Of the rest—who were considered asymptomatic by their primary physicians—some were excluded because of previous postoperative examination elsewhere and a number of those remaining were selected randomly for invitation to examination. Those able to return when invited totaled 33, and they made up the asymptomatic group in this study.

Both groups are described in table 1. All patients in the study were evaluated by history, physical examination, chest roentgenogram, electrocardiogram, vectorcardiogram, cardiac catheterization, and angiography.

The details of surgical correction were reviewed. Pulmonary and systemic venous blood flows had been transposed by Mustard's technique13 and modifications described by Stafford and McGoon.14 A dumbbell-shaped intra-atrial baffle was used in 18 of 33 asymptomatic and 9 of 15 symptomatic patients. Dacron material was employed in 24 of 33 asymptomatic and 8 of 15 symptomatic patients, and pericardium was utilized in the rest. In two of the asymptomatic patients the coronary sinus drained to the mitral valve and in the others the coronary sinus drained to the tricuspid valve. In more recent cases specific attempts had been made to avoid the sinoatrial node and its blood supply.

When possible (in 19 cases), asymptomatic patients also underwent electrocardiographic stress testing with bicycle ergometry. For cardiac catheterization, patients were sedated with meperidine (Demerol), promethazine (Phenergan), and chlorpromazine (Thorazine). Some patients required additional sedation during catheterization, usually with halothane anesthesia (≤ 0.5%). Right heart catheterization was performed in all cases. Left heart catheterization was accomplished in all but one of the 33 asymptomatic patients and in seven of the 15 symptomatic patients. Eight of the asymptomatic patients performed supine leg exercise during cardiac catheterization. During left heart catheterization an attempt was made to enter the new left atrium and pulmonary veins retrogradely via the tricuspid valve. Withdrawal recordings were obtained across the pulmonary venous and systemic venous sides of the intra-atrial baffle to evaluate possible obstruction. In patients with significant gradients, superior vena caval and inferior vena caval angiograms were obtained for better assessment of the severity of obstruction. Right and left ventricular angiograms were obtained for comparison of anatomic details with ventricular function.

Findings

Clinical and General

Asymptomatic Group

No history of significant debilitation could be elicited in
TABLE 1. Patient Groups Studied for Late Results of Mustard Operation

<table>
<thead>
<tr>
<th></th>
<th>Asymptomatic (15 pts)</th>
<th>Symptomatic (15 pts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at operation:</td>
<td>range: 6 mo–16 yr</td>
<td>4 mo–16 yr</td>
</tr>
<tr>
<td></td>
<td>mean: 4.5</td>
<td>3.1</td>
</tr>
<tr>
<td>Postop interval:</td>
<td>range: 6 mo–11 yr</td>
<td>1 mo–11 yr</td>
</tr>
<tr>
<td></td>
<td>mean: 4.7</td>
<td>1.7</td>
</tr>
<tr>
<td>Age at postop study:</td>
<td>range: 1–24 yr</td>
<td>5 mo–27 yr</td>
</tr>
</tbody>
</table>

Intra-atrial baffle

- Dacon: 24
- Pericardium: 9
- Dumbell shape: 18
- Dumbell Dacron: 18

*Additional to transposition.
†Gradient >30 mm Hg.

this group, although one patient had some exercise limitation and required digoxin (Lanoxin) and diuretics. Five other asymptomatic patients had a history of supraventricular tachycardia and took digoxin or digoxin and propranolol because of it. Two of these five subsequently had electronic pacemakers inserted because of sick sinus syndrome. Standard electrocardiography showed that 11 of the asymptomatic patients had a junctional pacemaker. The remainder were considered to have a sinus mechanism, although some had low-voltage, bizarre biphasic or unusual axis P waves. In two patients attempts were specifically made to avoid the sinoatrial node during corrective surgery. However, postoperatively, both had junctional rhythm. Eight patients with ventricular septal defect had a right bundle branch block pattern (QRS > 0.12 second) which had been noted in the immediate postoperative period and was persisting. Right ventricular hypertrophy or right bundle branch block pattern was noted in all cases. Additionally, among the asymptomatic group, evidence of left ventricular hypertrophy was present in the two patients with severe pulmonary vascular obstructive disease and one other with residual subvalvular pulmonary stenosis.

Chest roentgenograms showed cardiomegaly (cardiothoracic ratio > 0.50) in eight of 14 patients who had had intact ventricular septum preoperatively, two of three with intact ventricular septum and pulmonary stenosis, seven of seven with ventricular septal defect, and two of nine with ventricular septal defect and pulmonary stenosis. Most patients had a nonspecific systolic murmur, but 14 had systolic and diastolic murmur at the lower left sternal border. Seven patients had hepatomegaly.

Exercise stress testing was done in 19 of the asymptomatic cases. During bicycle ergometry, 12 patients had relative endurance indices that were below normal by the criteria of Goldberg et al., and four of them fell below the second percentile for maximal endurance. Occasional premature ventricular contractions or junctional premature beats were observed in three patients, but they disappeared with exercise. Only one patient was noted to have ventricular or junctional extrasystoles in couplets during exercise; these progressed to ventricular or accelerated junctional tachycardia at 160 beats/min. After exercise, reversion to slow junctional rhythm occurred spontaneously. Three other patients with junctional rhythm had limited exercise response, with maximum heart rates of only 110 to 135.

Symptomatic Group

All 15 symptomatic patients were significantly debilitated. All but two required digitalis or diuretics; and most presented with signs of caval obstruction (facial edema, chylothorax, neck vein distention, hepatomegaly, protein-losing enteropathy, and ascites) or with signs of pulmonary venous obstruction (whheezing, cough, and respiratory distress), or with both. Others who had tricuspid insufficiency, residual shunt, or pulmonary vascular obstructive disease presented with signs of congestive heart failure (pulmonary congestion, hepatomegaly).

Cardiomegaly was evidenced roentgenographically in three of eight patients who had had intact ventricular septum preoperatively, two of two with intact ventricular septum and pulmonary stenosis, three of three with ventricular septal defect, and two of two with ventricular septal defect and pulmonary stenosis. Six patients had electrocardiographic evidence of junctional rhythm, and three had a history of supraventricular tachycardia, which was the primary complaint of one. One patient with ventricular septal defect developed a right bundle branch block pattern after surgical correction. Both right and left ventricular hypertrophy were noted in one patient with pulmonary venous obstruction, in one patient with severe tricuspid insufficiency, and in two patients with pulmonary vascular obstructive disease.

Hemodynamic and Angiographic

Asymptomatic Group

Table 2 summarizes hemodynamic abnormalities found at catheterization in the 33 asymptomatic patients. Pressure recordings in all 33 showed a characteristic deep Y descent in the atrial tracing, as described by Venables et al. In 11 cases mild (4–5 mm Hg mean gradients) or moderate angiographic obstruction indicated obstruction of the vena cava — superior in 4, inferior in 2, and both in 5. Four patients had evidence of mild to moderate pulmonary venous obstruction, the gradients between pulmonary wedge or pulmonary venous and left atrial mean pressures being 3, 6, 9, and 10 mm Hg. However, only the patients with the 9 and 10 mm gradients had angiographic evidence of obstruction. All of these patients with caval or pulmonary venous obstruction had Dacron intra-atrial baffles.

Tricuspid insufficiency, by hemodynamic and angiographic evidence, was moderate in seven patients and mild in seven. Right ventricular angiography showed posterior prolapse or bulging of the tricuspid leaflets during systole (fig. 1) in 22 (67%) of the asymptomatic patients. This dyskinetic bulging into the new left atrium seemed to decrease the effectiveness of right ventricular ejection, even in the absence of significant valve incompetence. Also, prominent V waves (> 18 mm Hg) were recorded from the surgically created left atrium in 21 cases (64%), and the mean left atrial pressure was increased to 15 mm Hg or more in 10 (30%). With moderate tricuspid insufficiency, the V waves were > 30 mm Hg in five patients (15%).
One patient had severe right ventricular dysfunction associated with tricuspid valve insufficiency. The right ventricular end-diastolic pressure was markedly elevated, and poor right ventricular contraction was seen by right ventricular cineangiography. Two patients had evidence of pulmonary vascular obstructive disease, with pulmonary arteriolar resistance calculated as > 8 units m⁻².

Four patients had mild to moderate mitral valve insufficiency, and nine had small atrial right-to-left and left-to-right shunts. Residual pulmonary stenosis was indicated in 15 cases: moderate (gradient > 50 mm Hg) in 3 (valvular in 1, subvalvular in 2) and mild in 12 (subvalvular in all).

Supine exercise by eight asymptomatic patients (table 3) produced evidence of consistent hemodynamic abnormalities in four who preoperatively had had ventricular septal defect with pulmonary stenosis: an abnormal rise in pulmonary artery pressure (fig. 2) and a drop in stroke volume index which was disproportionate to the increase in cardiac index (fig. 3). One of the four had a cardiac index disproportionately low for his pulmonary artery saturation; and in the other three, though the actual rise in cardiac index was within normal limits, the slope of the drop in pulmonary artery saturation was distinctly less than in the remaining four patients observed during exercise (fig. 4). One subsequent death. Three of the four patients with the abnormal responses described had also an abnormal rise in right ventricular end-diastolic pressure during exercise; and the left ventricular-to-pulmonary artery gradient increased in three—mildly in one, moderately in two. Among the four patients with otherwise normal response, one had a slightly abnormal rise.

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**TABLE 2.** *Hemodynamic Abnormalities at Catheterization in 33 Patients Asymptomatic Late after Mustard Operation*

<table>
<thead>
<tr>
<th>Findings at late postop cath</th>
<th>Preoperative diagnosis</th>
<th>Intact VS</th>
<th>VSD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No PS* (N = 14)</td>
<td>With PS (N = 3)</td>
<td>No PS (N = 7)</td>
</tr>
<tr>
<td>Caval obstruction Mild (4-5 mm Hg gradient)</td>
<td>-</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>Moderate (&gt;5 mm Hg gradient or angio)</td>
<td>4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Pulmonary venous obstruction</td>
<td>2</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Tricuspid insufficiency</td>
<td>3</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Moderate</td>
<td>3</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Pulmonary vascular obstructive disease, pulmonary arteriolar resistance &gt;8 units-m²</td>
<td>1</td>
<td>-</td>
<td>1†</td>
</tr>
<tr>
<td>Ventricular septal defect</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Right ventricular dysfunction</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Mitral insufficiency Mild to moderate</td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Atrial septal defect</td>
<td>4†</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Pulmonary stenosis, residual gradient &lt;50 mm Hg</td>
<td>5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>≥50 mm Hg</td>
<td>-</td>
<td>2</td>
<td>-</td>
</tr>
</tbody>
</table>

*PS = pulmonary stenosis with gradient > 30 mm Hg prior to operation.
**10 dumbbell shaped, 3 rectangular shaped.
†One subsequent death.
‡Due with subsequent increase of cardiomegaly, with congestive heart failure.

Abbreviations: VS = ventricular septum; VSD = ventricular septal defect.
in mean pulmonary artery pressure at peak exercise, one
developed a mild left ventricular-to-pulmonary artery
gradient, and another developed a moderate gradient in the
area in which a pulmonary artery band had been before the
operation.

Symptomatic Group

Table 4 summarizes the hemodynamic abnormalities in
the 15 symptomatic patients. Five patients had caval
obstruction only, two had pulmonary venous obstruction
only, and three had both. This subgroup of ten patients with
obstruction was composed of six with Dacron intra-atrial
baffles and four with pericardial baffles. The baffle was
dumbbell shaped in seven and rectangular in three. In five
patients the baffle was of Dacron material and dumbbell
shaped. Right ventricular dysfunction was evidenced in one

patient by increased right ventricular end-diastolic pressure
and poor right ventricular contractility.

Subsequent Course

Of the 33 asymptomatic patients, one subsequently
developed severe pulmonary venous obstruction (not
recognized at previous study) and died at reoperation.
Another with severe pulmonary vascular obstructive disease
and right ventricular dysfunction died. A sudden unexpected
death occurred in one patient with a history of supraven-
tricular tachycardia and sick sinus syndrome despite treat-
ment with a permanent pacemaker, digitalis, and Inderal.

Of the 15 symptomatic patients, 11 underwent a second
operation and four of them required a third operation
because of recurrent caval obstruction. Five patients with
caval obstruction continue to require diuretics because of

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**Table 3. Hemodynamic Data at Peak Supine Exercise during Catheterization of Eight Patients Asymptomatic Late after Mustard Operation**

<table>
<thead>
<tr>
<th>Case</th>
<th>Diagnosis</th>
<th>SAP</th>
<th>RV</th>
<th>PAP</th>
<th>LV</th>
<th>CI</th>
<th>HR</th>
<th>PAo2</th>
<th>SAo2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>IVS, PA band</td>
<td>148/85 (105)</td>
<td>128/8</td>
<td>37/16 (23)</td>
<td>74/8</td>
<td>5.9</td>
<td>135</td>
<td>49</td>
<td>90</td>
</tr>
<tr>
<td>9</td>
<td>IVS</td>
<td>123/78 (93)</td>
<td>105/8</td>
<td>25/10 (15)</td>
<td>53/8</td>
<td>4.7</td>
<td>144</td>
<td>44</td>
<td>93</td>
</tr>
<tr>
<td>10</td>
<td>IVS</td>
<td>120/65 (83)</td>
<td>113/13</td>
<td>45/17 (26)</td>
<td>52/5</td>
<td>5.4</td>
<td>77</td>
<td>48</td>
<td>94</td>
</tr>
<tr>
<td>23</td>
<td>VSD</td>
<td>163/90 (112)</td>
<td>155/13</td>
<td>31/13 (19)</td>
<td>38/11</td>
<td>4.5</td>
<td>80</td>
<td>67</td>
<td>97</td>
</tr>
<tr>
<td>26</td>
<td>VSD with PS</td>
<td>148/84 (105)</td>
<td>132/27</td>
<td>58/46 (50)</td>
<td>105/30</td>
<td>4.5</td>
<td>174</td>
<td>37</td>
<td>92</td>
</tr>
<tr>
<td>27</td>
<td>VSD with PS</td>
<td>169/90 (116)</td>
<td>164/22</td>
<td>44/23 (30)</td>
<td>67/11</td>
<td>3.9</td>
<td>108</td>
<td>52</td>
<td>96</td>
</tr>
<tr>
<td>30</td>
<td>VSD with PS</td>
<td>134/80 (98)</td>
<td>116/20</td>
<td>41/25 (30)</td>
<td>54/9</td>
<td>5.2</td>
<td>96</td>
<td>59</td>
<td>97</td>
</tr>
<tr>
<td>31</td>
<td>VSD with PS</td>
<td>118/80 (79)</td>
<td>126/12</td>
<td>39/27 (31)</td>
<td>70/14</td>
<td>4.1</td>
<td>120</td>
<td>48</td>
<td>95</td>
</tr>
</tbody>
</table>

Summary of abnormal findings: Abnormal increase of m PAP (4); SVI inadequate for CI during exercise (4); Abnormal increase of RV end-diastolic pressure (3); Increased LV-PA gradient (2); Developed mild LV-PA gradient (2); Developed moderate gradient at site (1) of previous PA band; CI increase inadequate for PAo2 decrease (1).

Abbreviations: CI = cardiac index; HR = heart rate; IVS = intact ventricular septum; LV = left ventricle; PA = pulmonary artery; PS = pulmonary stenosis; PAo2 = pulmonary artery O2 saturation; PAP = pulmonary artery pressure; RV = right ventricle; SAo2 = systemic arterial O2 saturation; SAP = systemic artery pressure; VSD = ventricular septal defect.

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**Figure 2.** Shaded area represents predicted normal rise in PA pressure with increase of cardiac index during exercise, as reported by Epstein et al.16 Five subjects had abnormal rise of mean PA pressure in response to exercise.

**Figure 3.** Shaded area represents predicted normal change in stroke volume index, as reported by Epstein et al.16 In four subjects markedly abnormal exercise response was observed.
fluid retention. Eight of the symptomatic patients have died since the examination reported herein.

**Discussion**

**Specific Observations**

**Junctional Rhythm Despite Surgical Caution**

Among all 49 patients, 17 had junctional rhythm and 8 had a history of documented supraventricular tachycardia. Thus far attempts to avoid the sinoatrial node at surgery did not prevent the occurrence of junctional rhythm or supraventricular tachycardia postoperatively. These observations seem consistent with the recent surgical observation of Wittig et al. that in the Mustard procedure junctional rhythm most often develops during atrial septal resection and insertion of the intra-atrial baffle.

**Correlation of Abnormalities**

The clinical findings of systolic murmur seemed nonspecific and lacked specific correlation with hemodynamic abnormalities demonstrated by catheterization. Presence of systolic and diastolic murmur at the lower left sternal border correlated best with tricuspid valve insufficiency. Although Park et al. recently reported a continuous murmur in three patients with severe pulmonary venous obstruction, we did not observe a continuous murmur in any of our patients with pulmonary venous obstruction. Hepatomegaly was not unexpected in patients with inferior vena caval obstruction, but it was also observed in patients with cardiac failure secondary to pulmonary vascular obstructive disease and tricuspid valve insufficiency.

Twenty-three patients had vena caval and/or pulmonary venous obstruction. This occurred more frequently in patients with Dacron intra-atrial baffles (18 of 32 cases), but was found also in patients with pericardial baffles (5 of 16 cases). The frequency of obstruction within the group of patients with Dacron intra-atrial baffles, however, was not statistically significant using Chi-square test. The frequency of caval or pulmonary venous obstruction was also higher among patients with dumbbell-shaped baffles (17 of 27 cases). The proportion of obstruction versus nonobstruction was statistically significantly higher ($P$ value = 0.02; one degree of freedom). Also, obstruction was more frequent in patients with dumbbell-shaped Dacron baffles (15 of 24 cases). This difference was also statistically significant ($P$ value = 0.04; one degree of freedom). This data would support the conclusion that a dumbbell-shaped or Dacron intra-

**Table 4. Hemodynamic Abnormalities at Catheterization in 15 Patients Symptomatic Late after Mustard Operation**

<table>
<thead>
<tr>
<th>Finding at late postop cath</th>
<th>Preoperative diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inlet VSD</td>
</tr>
<tr>
<td></td>
<td>N = 8</td>
</tr>
<tr>
<td><strong>Caval obstruction</strong></td>
<td></td>
</tr>
<tr>
<td>Mild (4-5 mm Hg gradient)</td>
<td>—</td>
</tr>
<tr>
<td>Severe (angio)</td>
<td>5</td>
</tr>
<tr>
<td><strong>Pulmonary venous obstruction</strong></td>
<td></td>
</tr>
<tr>
<td>Mild</td>
<td>—</td>
</tr>
<tr>
<td>Severe</td>
<td>4</td>
</tr>
<tr>
<td><strong>Tricuspid insufficiency</strong></td>
<td></td>
</tr>
<tr>
<td>Mild to moderate</td>
<td>2</td>
</tr>
<tr>
<td>Severe</td>
<td>1</td>
</tr>
<tr>
<td><strong>Pulmonary vascular obstructive disease, pulmonary arteriolar resistance 8 units-m</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>—</td>
</tr>
<tr>
<td><strong>Ventricular septal defect (significant)</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>—</td>
</tr>
<tr>
<td><strong>Right ventricular dysfunction</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>—</td>
</tr>
<tr>
<td><strong>Mitr al insufficiency</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>—</td>
</tr>
<tr>
<td><strong>Atrial septal defect (small residual shunts)</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
</tr>
<tr>
<td><strong>Pulmonary stenosis, residual gradient &gt;50 mm Hg</strong></td>
<td></td>
</tr>
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<td></td>
<td>—</td>
</tr>
</tbody>
</table>

Eight patients have died since study:
1 with caval obstruction and severe subvalvular pulmonary stenosis; 2 with pulmonary venous obstruction; 1 with severe tricuspid insufficiency; 1 with tricuspid insufficiency and supraventricular tachycardia; 2 with pulmonary vascular obstructive disease; 1 with ventricular septal defect.

PS = pulmonary stenosis with gradient > 30 mm Hg.

Dumbell shaped, 3 rectangular shaped.

Abbreviations: PS = pulmonary stenosis; VS = ventricular septum; VSD = ventricular septal defect.
atrial baffle should not be used. The difficulties of caval or pulmonary venous obstruction may be offset by modifications of the Mustard repair or by a return to an intra-atrial repair similar to that described by Senning.

Mild degrees of cardiomegaly and increased vascularity were frequent findings among both symptomatic and asymptomatic patients. Cardiomegaly was found most often in patients who preoperatively had had a ventricular septal defect, although this did not correlate postoperatively with the presence of residual cardiac shunt or significant hemodynamic abnormalities at catheterization.

**General Observations**

**Frequency of Complications**

Our findings demonstrate a high incidence of significant complications following the Mustard procedure (table 5). Moderate and severe degrees of caval obstruction, various degrees of tricuspid valve insufficiency and pulmonary stenosis, and small atrial shunts existed without being suspected in the patients who were considered asymptomatic. Although many hemodynamic abnormalities were mild, combinations of three or four in single patients compromised surgical results.

Table 5 compares the incidence of insignificant and significant hemodynamic abnormalities in the symptomatic and asymptomatic groups of patients. Significant abnormalities were found in all 15 of the symptomatic group and in 20 (61%) of the 33 asymptomatic patients. Only four of these 33 were nearly normal by both clinical and hemodynamic criteria (at most one minor hemodynamic abnormality). One patient (who preoperatively had had a large ventricular septal defect) had normal resting hemodynamics and no clinical history of rhythm disturbance and clinically was doing well; but her cardiothoracic ratio was abnormally large at 0.60. One other patient had only a mild to moderate gradient at the site of a preoperative pulmonary artery band. One had only minimal mitral valve insufficiency, and another had mild tricuspid insufficiency.

Among the symptomatic patients, the most frequent serious complications were caval obstruction and pulmonary venous obstruction. Their subsequent clinical course tended toward even less satisfactory results at reoperation and high mortality. Tricuspid insufficiency and progressive pulmonary vascular obstructive disease also were significant and lethal complications in the symptomatic patients.

**Methods of Examination**

Catheterization was the most effective of the methods used for assessment of late postoperative condition. In comparison, routine exercise stress testing provided little significant information—it produced significant dysrhythmia in only one of 19 patients. Whereas supine exercise during catheterization of eight patients revealed significant hemodynamic abnormalities in four, only one of the four had both an abnormal relative endurance index and low maximal work capacity in the precatheterization exercise studies. The relative endurance index alone was abnormal in one other patient with abnormal response to supine exercise. However, in seven of eight patients, supine exercise during cardiac catheterization provoked abnormalities not clearly demonstrated at rest.

**Conclusion**

We conclude that the poor long-term results of the Mustard operation warrant renewed attempts to find better methods for correction of complete transposition of the great arteries—particularly with intact ventricular septum, with or without pulmonary stenosis. Currently the Rastelli operation seems a successful alternative if there is a ventricular septal defect or ventricular septal defect with pulmonary stenosis. An arterial transplant procedure—aortopulmonary window and right ventricle-to-pulmonary artery conduit as described independently by Kaye, Stansel, and Damus (personal communication to D. C. McGoone, M.D., September, 1972)—has been used successfully at this institution in cases where the left ventricular pressure is at least three-fourths of the right ventricular pressure and the left ventricular outflow tract is not obstructed. After the Mustard operation, patients require at least yearly observation. Postoperative right and left heart catheterization, if possible with supine exercise stress, is essential for adequate assessment of long-term results of the Mustard operation.

**Acknowledgment**

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**References**

WT: Hemodynamic studies in children four to ten years after the Mustard operation for transposition of the great arteries. Circulation 53: 532, 1976
7. Clarkson PM, Neutze JM, Barratt-Boyes BG, Brandt PWT: Late postoperative hemodynamic results and cineangiocardio graphic findings after Mustard atrial baffle repair for transposition of the great arteries. Circulation 53: 525, 1976
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