FACTORS AFFECTING BIVENTRICULAR FUNCTION FOLLOWING SURGICAL REPAIR OF TETRALOGY OF FALLOT

AKIO SUNAKAWA, M.D.*; HITOSHI SHIROTANI, M.D.; TATSUO YOKOYAMA, M.D.* AND HIDETAKA OKU, M.D.

Right and left ventricular functions were assessed in children following surgical repair of tetralogy of Fallot. The results were analyzed with regard to the relative contribution of preoperative, perioperative and postoperative factors to postoperative functional abnormalities. Pulmonary regurgitation of our Grade 3 or more depressed right and left ventricular ejection fractions and enlarged right ventricular end-diastolic volume. Right and left ventricular ejection fractions in patients with residual right ventricular outflow pressure gradients over 30 mmHg were significantly lower than those in patients with pressure gradients of 30 mmHg or less. The majority of those pressure gradients were at the pulmonary annulus or central pulmonary artery. Right and left ventricular ejection fractions were significantly lower in patients with a preoperative aortic oxygen saturation of less than 80% than in patients with one of 80% or more. The 3 variables of pulmonary regurgitation, residual pulmonary stenosis, preoperative aortic oxygen saturation were statistically independent. Left ventricular ejection fraction and end-diastolic volume correlated with the right ventricular ejection fraction and end-diastolic volume, respectively (r = 0.63, r = 0.68). These results show that severe pulmonary regurgitation, significant annular or central pulmonary stenosis and preoperative hypoxia are major contributing factors to right ventricular dysfunction after surgical repair of tetralogy of Fallot. The postoperative left ventricular dysfunction can be largely attributed to dysfunction of the right ventricle.

TOTAL repair of tetralogy of Fallot (TOF) can now be accomplished with a low operative mortality and excellent long-term symptomatic benefits. However, cardiovascular performance at rest or during exercise is often below normal. There may be multiple associated factors, including severity of the preoperative anatomy and hypoxia, the surgical procedure itself, residual right ventricular (RV) outflow tract obstruction, pulmonary regurgitation (PR), and a noncontractile patch. The relative contribution of these factors to the postoperative functional abnormalities remains uncertain. The purpose of the present study was to determine:

1) The influence of preoperative hemodynamics and perioperative factors on postoperative right and left ventricular (LV) functions.
2) The influence of RV outflow tract recon-
TABLE I METHODS USED FOR RELIEF OF RIGHT VENTRICULAR OUTFLOW TRACT OBSTRUCTION

<table>
<thead>
<tr>
<th>Group</th>
<th>Method</th>
<th>Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Transannular patch (+)</td>
<td>9 (18%)</td>
</tr>
<tr>
<td></td>
<td>CSAI &gt; 2.5 cm²/m²</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Transannular patch (+)</td>
<td>8 (16%)</td>
</tr>
<tr>
<td></td>
<td>CSAI ≤ 2.5 cm²/m²</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Valvotomy (+)</td>
<td>25 (50%)</td>
</tr>
<tr>
<td></td>
<td>outflow patch (−)</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>patch on RV only</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>Valvotomy (−) or PVR</td>
<td>8 (16%)</td>
</tr>
<tr>
<td></td>
<td>Infundibulectomy only</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>PVR</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>50 (100%)</td>
</tr>
</tbody>
</table>

CSAI = cross-sectional area index ie.; the degree of relief of right ventricular outflow tract obstruction; RV = right ventricle; PVR = pulmonary valve replacement.

...struction on RV function.

3) The influence of RV function on LV function.

MATERIALS

TOF in this study was defined as a combination of a large ventricular septal defect (VSD) with an "overriding" aorta, allowing equalization of right and left ventricular pressures and RV outflow tract obstruction, causing a bidirectional interventricular shunt with a net right-to-left shunt. The study population consisted of 50 Japanese children undergoing surgical repair for TOF and with no significant residual VSD. Eight had associated cardiac anomalies: patent ductus arteriosus in 2 and atrial septal defect in 6.

In 38 of these patients, preoperative cardiac catheterization data were available. Twenty-five patients underwent cardiac catheterization 1 to 2 months after surgery (early postoperative study), and 43 patients in the late postoperative periods (0.8 to 12 (4.9 ± 3.5) years after surgery) (late postoperative study). Eighteen underwent cardiac catheterization in both the periods with a time lapse of 5.2 ± 1.8 years. Although all the patients were initially maintained on digoxin in the early postoperative period, no patient was symptomatic nor on digoxin at the time of the late follow-up study.

Ages at the time of operation ranged from 0.5 to 8.8 (2.6 ± 1.4) years. Forty-five (90%) were 3 years of age or younger at the time of surgery. Repair was performed utilizing total cardiopulmonary bypass. Intermittent aortic cross-clamping was used for 24 patients. For the last 26 patients, we used cold blood cardioplegia combined with a topical application of ice slush. Various methods used to relieve the RV outflow tract obstruction are summarized in Table I. The patients were grouped into 4 according to the methods and degree of relief of the RV outflow tract obstruction. Infundibular muscle resection was carried out to various degrees in all patients. The degree of relief of the RV outflow tract obstruction was expressed as the cross-sectional area index (CSAI) of the pulmonary annulus after enlargement. The CSAI was obtained using the following equation: CSAI = π(d/2)²/BSA (in cm²/m²), where d is the diameter of the pulmonary annulus after enlargement at operation and BSA is the body surface area (m²). On the basis of our early experiences, the RV outflow tract was enlarged so as to obtain a CSAI greater than 1.75 cm²/m². A transannular patch (TAP) with a monocusp was used whenever the pulmonary annulus was judged at operation to be too small to obtain a CSAI greater than 1.75 cm²/m², by muscular resection and pulmonary valvotomy alone.

METHODS

Cardiac catheterization was performed under

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light sedation using pethidine (2 mg/kg) and promethazine (1 mg/kg) given 30 min before the procedure. Left and right heart pressures were obtained using a Millar micro-tip transducer catheter. Oxygen saturation in the blood was determined using reflectance oxymetry. The X-ray equipment consisted of a Bipane Gigantos RS 100G, Sirecon-2-duplex 25/15 high resolution (Siemens) and a Arritechno 35 cinecama (R-150) (Arnold-Richter).

The variables measured and analyzed in relation to the postoperative cardiac function are shown in Table II. Pulmonary artery index (PA index) means the sum of the maximum diameters of the left and right pulmonary arteries just before take-off of the first branch, normalized to the diameter of the descending aorta at the level of the diaphragm. These diameters were measured from anterior-posterior views of the cineangiograms. Cardiac volumes were obtained from biplane cineangiograms (70 frames/sec) filmed after injecting 1–1.5 ml/kg of body weight of Conratin-H into the RV, LV, main pulmonary artery or left atrium. Ectopic and postectopic beats were excluded from analysis. LV volumes were calculated, using the area-length method. RV volumes were calculated according to the Simpson’s rule method. These volumes were expressed as a percent of the normal predicted values, using the body surface area. Residual pulmonary stenosis (PS) was evaluated as pressure gradients between RV and pulmonary artery. The degree of PR was assessed by judging the extent and density of opacification of the RV in the lateral view of the pulmonary arteriogram and was graded from Grade 0 to 4. The details of this method have been given in a previous report.

Statistical analyses were performed using F test or Fisher’s exact probability test with a P value of <0.05 considered statistically significant.

RESULTS

Data on preoperative and postoperative measurements are shown in Tables III and IV.

1. Early postoperative study

Right and left ventricular end-diastolic vol-

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**TABLE III** PREOPERATIVE CARDIAC VOLUME VARIABLES AND OTHER MEASUREMENTS

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Mean ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>SaO₂ (%)</td>
<td>36</td>
<td>81 ± 8</td>
<td>63–92</td>
</tr>
<tr>
<td>PA index</td>
<td>34</td>
<td>1.98 ± 0.37**</td>
<td>1.59–3.18</td>
</tr>
<tr>
<td>LVEDV (% of normal)</td>
<td>33</td>
<td>89 ± 19**</td>
<td>57–138</td>
</tr>
<tr>
<td>RVEDV (% of normal)</td>
<td>29</td>
<td>99 ± 16</td>
<td>67–131</td>
</tr>
</tbody>
</table>

See Table II for abbreviations. **p < 0.01 compared with normal.

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**TABLE IV** EARLY AND LATE POSTOPERATIVE CARDIAC VOLUME VARIABLES, PULMONARY REGURGITATION AND PULMONARY STENOSIS

**Early**

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Mean ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at examination</td>
<td>25</td>
<td>2.9 ± 1.6</td>
<td>0.6–8.8 y</td>
</tr>
<tr>
<td>Time after operation</td>
<td>25</td>
<td>within 2 months</td>
<td></td>
</tr>
<tr>
<td>Body surface area (m²)</td>
<td>25</td>
<td>0.54 ± 0.13</td>
<td>0.34–0.95</td>
</tr>
<tr>
<td>LVEDV (% of normal)</td>
<td>25</td>
<td>113 ± 19*</td>
<td>83–149</td>
</tr>
<tr>
<td>LSVV (% of normal)</td>
<td>25</td>
<td>99 ± 17</td>
<td>67–128</td>
</tr>
<tr>
<td>LVEF</td>
<td>25</td>
<td>0.59 ± 0.06**</td>
<td>0.49–0.69</td>
</tr>
<tr>
<td>RVEDV (% of normal)</td>
<td>22</td>
<td>112 ± 16**</td>
<td>76–147</td>
</tr>
<tr>
<td>RVSV (% of normal)</td>
<td>22</td>
<td>100 ± 16</td>
<td>75–128</td>
</tr>
<tr>
<td>RVEF</td>
<td>22</td>
<td>0.53 ± 0.05**</td>
<td>0.43–0.63</td>
</tr>
<tr>
<td>The grade of PR</td>
<td>25</td>
<td>1.60 ± 0.96</td>
<td>0–3</td>
</tr>
<tr>
<td>PS (mmHg)</td>
<td>24</td>
<td>13 ± 6</td>
<td>5–26</td>
</tr>
</tbody>
</table>

**Late**

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Mean ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVEDV (% of normal)</td>
<td>43</td>
<td>121 ± 23**</td>
<td>84–181</td>
</tr>
<tr>
<td>LSVV (% of normal)</td>
<td>42</td>
<td>107 ± 18</td>
<td>80–155</td>
</tr>
<tr>
<td>LVEF</td>
<td>42</td>
<td>0.57 ± 0.05**</td>
<td>0.42–0.66</td>
</tr>
<tr>
<td>RVEDV (% of normal)</td>
<td>43</td>
<td>147 ± 43**</td>
<td>77–248</td>
</tr>
<tr>
<td>RVSV (% of normal)</td>
<td>43</td>
<td>115 ± 28**</td>
<td>69–191</td>
</tr>
<tr>
<td>RVEF</td>
<td>43</td>
<td>0.48 ± 0.07**</td>
<td>0.26–0.64</td>
</tr>
<tr>
<td>The grade of PR</td>
<td>42</td>
<td>2.43 ± 1.13</td>
<td>0–4</td>
</tr>
<tr>
<td>PS (mmHg)</td>
<td>41</td>
<td>17 ± 16</td>
<td>0–65</td>
</tr>
</tbody>
</table>

y = years; LSVV = left ventricular stroke volume; RVSV = right ventricular stroke volume.

See Table II for other abbreviations. *p < 0.05, **p < 0.01 compared with normal.

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Fig. 1. Correlation between right ventricular end-diastolic volume (RVEDV) and left ventricular end-diastolic volume (LVEDV) in the late postoperative period (n = 42).

Fig. 2. Correlation between right ventricular ejection fraction (RVEF) and left ventricular ejection fraction (LVEF) in the late postoperative period (n = 42).

### TABLE V THE RELATION OF PREOPERATIVE SaO₂ TO LATE POSTOPERATIVE CARDIAC VOLUME VARIABLES

<table>
<thead>
<tr>
<th>Preoperative SaO₂</th>
<th>RVEDV (%)</th>
<th>RVSV (%)</th>
<th>RVEF</th>
<th>LVEDV (%)</th>
<th>LVSV (%)</th>
<th>LVEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>SaO₂ &lt; 80%</td>
<td>163 ± 42</td>
<td>120 ± 29</td>
<td>0.44 ± 0.06</td>
<td>130 ± 20</td>
<td>109 ± 20</td>
<td>0.55 ± 0.06</td>
</tr>
<tr>
<td>SaO₂ ≥ 80%</td>
<td>142 ± 34</td>
<td>117 ± 25</td>
<td>0.50 ± 0.05</td>
<td>120 ± 22</td>
<td>109 ± 17</td>
<td>0.58 ± 0.04</td>
</tr>
<tr>
<td>[21]</td>
<td>[21]</td>
<td>[21]</td>
<td>[21]</td>
<td>[20]</td>
<td>[20]</td>
<td>[20]</td>
</tr>
</tbody>
</table>

F test ns ns p < 0.01 ns ns p < 0.05

ns = not significant. See Tables II and IV for other abbreviations.
[ ] = number of patients. Values are mean ± SD.

Volumes (EDV) were increased slightly over the normal, while right and left ventricular ejection fractions (EF) were significantly depressed (Table IV).

Preoperative variables were available for 20 patients. None of the preoperative variables correlated significantly with the postoperative RVEF or LVEF.

Cardiopulmonary bypass time (CBT) ranged from 73 to 310 (145 ± 60) min for 13 patients for whom cardioplegic solution was used. Six of those patients required an outflow patch and the CBT exceeded 150 min. In seven without an outflow patch, the CBT was under 150 min. The postoperative LVEF averaged 0.54 ± 0.04 (range 0.49 to 0.58) for patients with a CBT over 150 min and 0.63 ± 0.03 (range 0.56 to 0.66) for patients with a CBT under 150 min. The difference between the groups was statistically significant (p < 0.01). The postoperative RVEF averaged 0.51 ± 0.05 (range 0.43 to 0.57) in patients with a CBT over 150 min, compared with 0.55 ± 0.04 (range 0.51 to 0.62) in patients with a CBT under 150 min. This difference did not reach statistical significance.

The degree of PR was Grade 0 in 4 patients, Grade 1 in 6, Grade 2 in 11 and Grade 3 in 4. No patient had a residual RV outflow pressure gradient over 30 mmHg (Table IV). The degree of PR and PS did not correlate significantly with the postoperative volume variables or with the operative methods used for RV outflow tract reconstruction.

2. Late postoperative study

RVEDV, RVSV and LVEDV were signifi-
cantly increased over the normal. RVEF and LVEF were significantly depressed (Table IV). There was a significant correlation of \( r = 0.68, p < 0.01 \) between RVEDV and LVEDV, and also of \( r = 0.63, p < 0.01 \) between RVEF and LVEF (Fig. 1, 2).

### Table VI: The Relation of Operative Methods to Pulmonary Regurgitation in the Late Postoperative Period

<table>
<thead>
<tr>
<th>PR (Grade)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Total</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td>4</td>
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<tr>
<td>1</td>
<td>5</td>
<td>1</td>
<td></td>
<td></td>
<td>6</td>
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<tr>
<td>2</td>
<td>2</td>
<td>4</td>
<td>8</td>
<td>1</td>
<td>15</td>
</tr>
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<td>3</td>
<td>4</td>
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<td>5</td>
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<td>10</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Total</td>
<td>9</td>
<td>7</td>
<td>22</td>
<td>4</td>
<td>42</td>
</tr>
</tbody>
</table>

PR = pulmonary regurgitation. Values indicate the number of patients.

### Table VII: The Relation of Pulmonary Regurgitation to Late Postoperative Cardiac Volume Variables

<table>
<thead>
<tr>
<th>PR (Grade)</th>
<th>RVEDV (%)</th>
<th>RVSV (%)</th>
<th>RVEF</th>
<th>LVEDV (%)</th>
<th>LVSV (%)</th>
<th>LVEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–2</td>
<td>119 ± 27</td>
<td>98 ± 18</td>
<td>0.50 ± 0.06</td>
<td>111 ± 16</td>
<td>101 ± 13</td>
<td>0.58 ± 0.05</td>
</tr>
<tr>
<td>[23]</td>
<td>[23]</td>
<td>[23]</td>
<td>[23]</td>
<td>[23]</td>
<td>[23]</td>
<td>[23]</td>
</tr>
<tr>
<td>3–4</td>
<td>177 ± 33</td>
<td>132 ± 26</td>
<td>0.45 ± 0.06</td>
<td>130 ± 20</td>
<td>110 ± 19</td>
<td>0.54 ± 0.05</td>
</tr>
<tr>
<td>[19]</td>
<td>[19]</td>
<td>[19]</td>
<td>[19]</td>
<td>[18]</td>
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<td>[18]</td>
</tr>
<tr>
<td>F test</td>
<td>p &lt; 0.01</td>
<td>p &lt; 0.01</td>
<td>p &lt; 0.01</td>
<td>p &lt; 0.01</td>
<td>ns</td>
<td>p &lt; 0.05</td>
</tr>
</tbody>
</table>

ns = not significant. See Tables II and IV for other abbreviations. [ ] = number of patients. Values are mean ± SD.

### Table VIII: The Relation of Presence of RV Patch to Late Postoperative Cardiac Volume Variables

<table>
<thead>
<tr>
<th>RV patch</th>
<th>RVEDV (%)</th>
<th>RVSV (%)</th>
<th>RVEF</th>
<th>LVEDV (%)</th>
<th>LVSV (%)</th>
<th>LVEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>(−)</td>
<td>146 ± 41</td>
<td>114 ± 27</td>
<td>0.48 ± 0.08</td>
<td>115 ± 18</td>
<td>104 ± 17</td>
<td>0.57 ± 0.05</td>
</tr>
<tr>
<td>[23]</td>
<td>[23]</td>
<td>[23]</td>
<td>[23]</td>
<td>[23]</td>
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<td>[23]</td>
</tr>
<tr>
<td>(+)</td>
<td>148 ± 44</td>
<td>116 ± 29</td>
<td>0.47 ± 0.04</td>
<td>127 ± 25</td>
<td>109 ± 20</td>
<td>0.56 ± 0.05</td>
</tr>
<tr>
<td>[20]</td>
<td>[20]</td>
<td>[20]</td>
<td>[20]</td>
<td>[19]</td>
<td>[19]</td>
<td>[19]</td>
</tr>
<tr>
<td>F test</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
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</tbody>
</table>

ns = not significant. See Tables II and IV for other abbreviations. [ ] = number of patients. Values are mean ± SD.

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TABLE IX  THE RELATION OF F PULMONARY STENOSIS TO LATE POSTOPERATIVE CARDIAC VOLUME VARIABLES

<table>
<thead>
<tr>
<th>PS (mmHg)</th>
<th>RVEDV (%)</th>
<th>RVSV (%)</th>
<th>RVEF</th>
<th>LVEDV (%)</th>
<th>LVSV (%)</th>
<th>LVEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS ≥ 30 mmHg</td>
<td>149 ± 36</td>
<td>102 ± 18</td>
<td>0.42 ± 0.07</td>
<td>124 ± 13</td>
<td>101 ± 10</td>
<td>0.51 ± 0.05</td>
</tr>
<tr>
<td>[8]</td>
<td>[8]</td>
<td>[8]</td>
<td>[8]</td>
<td>[7]</td>
<td>[7]</td>
<td>[7]</td>
</tr>
<tr>
<td>PS &lt; 30 mmHg</td>
<td>146 ± 36</td>
<td>118 ± 28</td>
<td>0.49 ± 0.06</td>
<td>119 ± 22</td>
<td>106 ± 18</td>
<td>0.58 ± 0.05</td>
</tr>
<tr>
<td>[33]</td>
<td>[33]</td>
<td>[33]</td>
<td>[33]</td>
<td>[33]</td>
<td>[33]</td>
<td>[33]</td>
</tr>
<tr>
<td>F test</td>
<td>ns</td>
<td>ns</td>
<td>p &lt; 0.01</td>
<td>ns</td>
<td>ns</td>
<td>p &lt; 0.01</td>
</tr>
</tbody>
</table>

ns = not significant. See Tables II and IV for other abbreviations. [ ] = number of patients. Values are mean ± SD.

TABLE X  THE RELATIONSHIPS OF PREOPERATIVE Sao2, LATE POSTOPERATIVE PS AND PR TO ONE ANOTHER

<table>
<thead>
<tr>
<th>Sao2</th>
<th>PS</th>
<th>PR</th>
<th>PS</th>
<th>Sao2</th>
<th>PR</th>
<th>PR</th>
<th>Sao2</th>
<th>PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sao2 &lt; 80%</td>
<td>15 ± 14</td>
<td>2.6 ± 1.2</td>
<td>PS &lt; 30 mmHg</td>
<td>81 ± 7</td>
<td>2.6 ± 1.0</td>
<td>PR 0–2</td>
<td>81 ± 7</td>
<td>19 ± 17</td>
</tr>
<tr>
<td>Sao2 ≥ 80%</td>
<td>18 ± 15</td>
<td>2.4 ± 1.0</td>
<td>PS ≥ 30 mmHg</td>
<td>82 ± 8</td>
<td>2.1 ± 1.2</td>
<td>PR 3–4</td>
<td>81 ± 8</td>
<td>15 ± 15</td>
</tr>
<tr>
<td>F test</td>
<td>ns</td>
<td>ns</td>
<td>F test</td>
<td>ns</td>
<td>ns</td>
<td>F test</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

ns = not significant. See Table II for other abbreviations. Values are mean ± SD.

TABLE XI  SERIAL CHANGES OF CARDIAC VOLUME VARIABLES AND OTHER MEASUREMENTS

<table>
<thead>
<tr>
<th>RVEDV (%)</th>
<th>RVSV (%)</th>
<th>RVEF</th>
<th>LVEDV (%)</th>
<th>LVSV (%)</th>
<th>LVEF</th>
<th>PR</th>
<th>PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>117 ± 22</td>
<td>104 ± 20</td>
<td>0.53 ± 0.05</td>
<td>116 ± 21</td>
<td>102 ± 17</td>
<td>0.59 ± 0.06</td>
<td>1.8 ± 0.7</td>
</tr>
<tr>
<td>2nd</td>
<td>147 ± 40</td>
<td>118 ± 28</td>
<td>0.49 ± 0.05</td>
<td>122 ± 24</td>
<td>109 ± 20</td>
<td>0.57 ± 0.04</td>
<td>2.7 ± 1.1</td>
</tr>
<tr>
<td>F test</td>
<td>p &lt; 0.01</td>
<td>ns</td>
<td>p &lt; 0.01</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>p &lt; 0.01</td>
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ns = not significant. See Tables II and IV other abbreviations. Values are mean ± SD.

methods are shown in Table VI. In the patient undergoing pulmonary valve replacement, the PR was considered absent on auscultation. In one patient, the PR could not be evaluated because the catheter could not be inserted into the pulmonary artery. The occurrence of PR of Grade 3 or more was more frequent in group 1 than in groups 2 to 4 (p < 0.05). The influence of PR on postoperative volume variables is shown in Table VII. RVEDV, RVSV and LVEDV were significantly larger, and both RVEF and LVEF were significantly lower in patients with PR of Grade 3 or more than in patients with PR of Grade 2 or less. There were no significant differences in postoperative volume variables between patients with an outflow patch and those without one (Table VIII).

Eight patients had RV outflow pressure gradients over 30 mmHg. A significant gradient existed at the distal end of an outflow patch or supravalvular level in 4 with a TAP, and at the annular or valvular level in 3 without an outflow patch. In the remaining one patient without an outflow patch, the major gradient was at the bifurcation of the main pulmonary artery. In 6 of those 8 patients, early postoperative pressure data were available and the gradients increased with time, from 22 ± 11 mmHg in the early postoperative period to 46 ± 13 mmHg in the late postoperative period (time lapse 34–147 (88 ± 41) months). Most of those patients had a slight to moderate aneurysmal dilatation of the RV outflow tract. RVEF and LVEF were lower in patients with residual RV outflow pressure.
gradients over 30 mmHg than in patients with
gradients of 30 mmHg or less (Table IX).

The 3 variables of preoperative \( \text{SaO}_2 \), PR
and residual PS were statistically independent
and did not correlate with the age of the patient
at the time of surgical repair (Table X).

3. Serial changes of the volume variables after
surgical correction (Table XI).

RVEDV increased and RVEF was further
depressed in the late postoperative period. The
degree of PR also increased further in the late
postoperative period.

**DISCUSSION**

**Influence of preoperative hemodynamics and
perioperative factors on postoperative right and
left ventricular functions**

Left or right ventricular volume is often small
in TOF before operation.\textsuperscript{15} Earlier, we reported
that a critically small LV or RV might increase
the potential risk of low cardiac output imme-
diately after repair.\textsuperscript{15} In the present study,
however, preoperative LVEDV or RVEDV did
not significantly correlate with the postoperative
LVEF or RVEF, which was measured more than
1 month after the repair. Thus, a small LV or
RV is not a significant contributing factor to
the postoperative LV or RV dysfunction more than
1 month after repair.

Several authors have shown that the preope-
ra tive long-standing pressure overload or hypoxia
in case of TOF induces structural changes in the
myocardium, the degree of which increases with
age.\textsuperscript{19–21} Kato et al\textsuperscript{21} did histological studies
and arrived at the conclusion that corrective
surgery for TOF should be performed at or
before the age of 3 years, in order to prevent an
irreversible alteration of the RV muscle fibers.
In relation to this finding, several clinical studies
have shown that early repair is associated with a
better result in terms of RV or LV function than
repair later in childhood.\textsuperscript{22–24} In the present
study, the vast majority of patients underwent
surgical repair at the age of 3 years or less.
Nevertheless, in the late postoperative period,
patients with a preoperative \( \text{SaO}_2 \) of less than
80% had a poor postoperative RV and LV
function, as compared with patients with a
preoperative \( \text{SaO}_2 \) of 80% or more. \( \text{SaO}_2 \) ref-
lects the severity of the preoperative anatomy.\textsuperscript{16}
Therefore, this result can be related to the severe
preoperative anatomy in patients with severe
preoperative hypoxia. However, we found no
significant relationship between the postope-
rateive LVEF and RVEF and the preoperative
variables, except for \( \text{SaO}_2 \). Further, \( \text{SaO}_2 \) did
not correlate significantly with CBT, PS, PR or
age at the time of operation. Although there was
a significant difference between the groups in the
use of an outflow patch, the presence of an
outflow patch had no apparent effect on the late
postoperative RVEF and LVEF. These findings
suggest that severe preoperative hypoxia affects
the postoperative RV and LV function, despite
surgical repair at an early age, although cumula-
tive effects of the hypoxia-related factors may
not be negligible in RV dysfunction. Surgery at
a much younger age may be needed to lessen the
influence of the preoperative hypoxia.

Open heart surgery with cardiopulmonary
bypass does produce some degree of myocardial
damage. We found a significant depression of the
early postoperative LVEF in patients with a long
CBT. None of the other variables correlated
significantly to the LVEF. These findings indi-
cate that myocardial damage during cardiopul-
monary bypass may well be a principal cause of
LV dysfunction in the early postoperative period.
It may also be linked to early postoperative RV
dysfunction, although differences in the RVEF
between the CBT groups did not reach statistical
significance. There is no doubt that the patients
requiring a long CBT had difficult anatomy to
correct, thus undergoing extensive surgical
procedures for the RV outflow tract. The added
effect of the surgical procedure itself is difficult
to quantify, but does contribute to RV dysfunc-
tion in the early postoperative period. On the
other hand, these factors were not significant in
the late postoperative period, presumably be-
cause preoperative hypoxia, PS or PR became
relatively more significant in the late postope-
rateive period.

**Influence of RV outflow tract reconstruction on
RV function**

Residual PS and PR are inevitable in the
majority of repairs of TOF, although they vary in
degree. Differences in opinion have centered
around the long-term relative importance of
residual PS versus PR and seem to stem mainly
from disagreements concerning the effects of
PR on the postoperative RV function. Wessel
and colleagues\textsuperscript{7} noted a decreased exercise tol-
erance in patients with PR. Lange et al\textsuperscript{2} showed
that the RVEDV increased and the RVEF
decreased with an increasing RV volume overload secondary to PR and/or residual VSD. Bove and associates found RV dysfunction to be worse in patients with PR. In the present study, PR of Grade 3 or more was found to impair the late postoperative RV function in terms of RVEDV and RVEF. In contrast, other workers concluded that PR appeared to be well tolerated if there was no significant distal residual obstruction.

There may be several contributing factors to this controversy. First, PR may very considerably in extent and there have been no accurate methods to estimate the degree. The cineangiographic technique used in this study gives only a semiquantitative approximation of PR. However, it is considered an acceptable method for evaluating the effects of PR on RV function because the grades of PR coincide with volumetric or hemodynamic data. Second, the majority of authors who found that PR did not impair RV function evaluated their patients largely based on symptomatic status. Symptomatic views give only limited information on the long-term effects of PR. In fact there were no apparent symptoms even in our patients with severe PR and resultant RV dysfunction. Third, factors other than PR may affect RV function after the repair of TOF. RV volume overload alone cannot account for RV dysfunction, in view of the finding that RVEF does not decrease in children with atrial septal defect. The cumulative effects of various factors may enhance the deleterious effect of PR, resulting in an earlier appearance of RV dysfunction.

In the light of all these findings, we conclude that moderate to severe PR impairs postoperative RV function.

Significant residual PS has been shown to result in an increased rate of hospital deaths and poor late results although there is no general agreement as to what degree of residual PS is an acceptable compromise. Apart from the degree, the other important influence is location of the PS. Nakazawa et al. found no significant correlation between the postoperative RV systolic pressure and RVEF. In their patients, the main cause of RV hypertension was a residual infundibular stenosis. In our study, significant PS depressed the RVEF. The major pressure gradients in such PS were at the central pulmonary artery or pulmonary valve annulus. These findings suggest that central or annular PS is more likely than infundibular stenosis to depress RVEF. This may be related partly to a paradoxical expansion of the RV outflow tract during systole, as observed in patients with a central or annular PS, and partly to the fact that EF varies inversely with afterload, at any level of myocardial contractility.

These adverse effects of PS and PR were not significant in the early postoperative period. Administration of digitalis and the lesser degree of PS and PR in the early postoperative period may be the cause. The degree of PS or PR in several patients increased with time to become significant in the late postoperative period.

The question arises as to whether patch graft reconstruction of the outflow tract is advisable in borderline situations in relation to the influence of PR or PS. The insertion of an outflow patch across the pulmonary valve always results in some degree of PR. However, use of a TAP does not always induce a severe PR. Too much enlargement using a TAP (CSAI > 2.5 cm²/m²) very likely induces a severe PR, while an adequate enlargement using a TAP with a monocusp (CSAI ≤ 2.5 cm²/m²) probably preserves pulmonary valve function to some extent. On the other hand, not using a TAP does not necessarily guarantee against a severe PR. In this study, some patients without a TAP had a severe PR postoperatively, which seems to be the result of extensive pulmonary valvotomy such as an enforced enlargement of the pulmonary annulus by a Hegar dilator. These were "borderline situations" where we hesitated to use a TAP to obtain a CSAI greater than 1.75 cm²/m². In addition, some borderline cases for whom a TAP was not used showed a significant central or annular PS in the late postoperative period.

From the viewpoint of the late postoperative results, it is important to avoid too much enlargement with a TAP (CSAI > 2.5 cm²/m²) and extensive pulmonary valvotomy. The insertion of a TAP is preferable to extensive pulmonary valvotomy, in a borderline situation.

Influence of RV function on LV function

The enlarged LVEDV and depressed LVEF corresponds to previous reports of LV dysfunction, evaluated by a variety of techniques. Prolonged hypoxia and an additional hemodynamic load from residual VSD have been suggested as causative factors for postoperative LV dysfunction. Little attention has been paid to the right to left ventricular interrelationship, especially the effect on LV function.

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of RV volume overload due to PR. Indeed, the LV performance is not independent of the RV functional status, as shown clinically and experimentally. In addition, biochemical and morphologic changes were found in the LV of animals with isolated RV failure, experimentally produced. In the present study, significant PS or PR was found to depress LVEF as well as RVEF. Further, there was a significant linear correlation between LVEF and RVEF. Bove and associates noted a depression in the LVEF, which occurred to a greater degree in patients with PR than in those without it. These findings indicate that postoperative LV dysfunction in TOF is largely due to RV dysfunction resulting from PR, residual PS, etc., although the direct effect of hypoxia on LV is an additional untoward factor. Efforts to preserve RV function will no doubt improve the LV function.

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