Right Ventricular Volume Characteristics Before and After Palliative and Reparative Operation in Tetralogy of Fallot

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SUMMARY Right heart volume data were obtained in 63 patients with tetralogy of Fallot. The patients were divided into three groups: 1) preoperative tetralogy (N=34); 2) post shunt procedure (N=14); 3A) post repair without outflow patch (N=10); 3B) post repair with an outflow patch (N=8). In Group 1 right ventricular end-diastolic volume (RVEDV), RV ejection fraction (EF), and RV systolic output (SO) were all mildly depressed. In post shunt patients, RVEDV was normal but RVEF remained depressed. RVEDV and RVSO increased following a shunt procedure, and these variables were larger in patients with a large versus a small shunt. In Group 3A, RVEDV, RVEF, and RVSO were normal. In contrast in patients in Group 3B, RVEDV was increased averaging 177 ± 15% of normal, RVEF was depressed averaging 0.45 ± 0.04, and RVSO was normal. RV size and pump function are abnormal in patients whose operation requires an outflow tract patch and the factors which may contribute to these abnormalities include a higher RV peak pressure, pulmonary incompetence, and a larger noncontractile outflow tract. Longitudinal studies relating these variables to clinical performance and exercise testing will be important in assessment of the importance of these abnormalities.

ALTHOUGH TREATMENT for suspected right ventricular (RV) failure is common after tetralogy of Fallot repair, very little information is available on the direct measurement of RV performance in these patients. Such measurements may become increasingly important in the evaluation of current methods of treatment for both the infant and the older child with tetralogy of Fallot. The purpose of this investigation, therefore, was to analyze biplane cineangiograms in patients before and after surgery for tetralogy of Fallot to determine right ventricular end-diastolic and end-systolic volumes, ejection fraction, systolic output, and maximum right atrial volume and to attempt to correlate these findings with clinical course and other pertinent hemodynamic data.

Methods

All patients studied at Vanderbilt Hospital from July 1971 to October 1975 with the diagnosis of tetralogy of Fallot and adequate biplane cineangiograms for analysis were included. Tetralogy of Fallot was defined as the condition in which there is a large ventricular septal defect with equal right and left ventricular peak systolic pressures associated with right ventricular outflow tract obstruction, and bidirectional shunting. There were three basic patient groups.

Group 1 consisted of patients prior to any surgical procedure. There were 34 studies performed on 32 patients in this group whose ages ranged from 3 days to 12 years with an average age of 2.1 ± 0.4 yr (mean ± SEM). Sixteen patients were less than one year of age and 24 were less than two years. Arterial oxygen saturation (O2 SAT) ranged from 67-98% at rest and averaged 80 ± 2%. Only four patients had arterial O2 SATs at rest ≥ 90%, and all four had a decrease in O2 SAT with crying. Hematocrits ranged from 36-73% with an average of 47 ± 2%, table 1.

Group 2 included 14 studies in 13 patients who were studied at varying intervals following a shunt procedure to increase pulmonary blood flow. Seven patients had Waterston shunts, five patients had Blalock-Taussig shunts, and one patient had both shunts. The shunts were performed at ages ranging from 3-18 months and recatheterization was performed from 0.7 to 12 years later (mean 3.9 yr). Ages at restudy ranged from 1.3-14 years and averaged 4.5 ± 0.8 years. Arterial oxygen saturation ranged from 62-91% (mean 83 ± 2%) and hematocrit ranged from 40-78% (mean 50 ± 3%).

Group 3 consisted of 18 patients studied following a reparative operation. Ten patients were repaired without an outflow tract patch and constitute Group 3A. Eight patients required an outflow tract patch of either pericardium or dacron to be placed across the anulus in seven instances and up to the anulus in one patient with an anomalous coronary artery and these patients constitute Group 3B. Three patients in Group 3A and six patients in 3B had a prior shunt procedure.

In table 2 age at operation, time from operation to restudy, right ventricular pressures (RVP) and resting gradients are compared for Group 3A versus 3B. Post-operatively Group 3B patients had a higher peak RVP and a higher gradient from RV to pulmonary artery than Group 3A. Three patients in each group had small residual shunts which were undetectable by oximetry and/or indicator dilution in all but one instance and were detected by cineangiography. The one patient with larger shunt had a small VSD with a 17% left-to-right shunt calculated from a dye curve. Seven of eight patients in Group 3B had pulmonary incompetence by clinical exam, and one patient had mild tricuspid incompetence by clinical exam and by RV cineangiography. None of the patients in 3A had either pulmonary or tricuspid incompetence by clinical exam or at catheterization.

All data were obtained during routine diagnostic cardiac catheterization. Premedication in infants < two years of age was with meperidine 1 mg/kg and hydroxyzine 1 mg/kg in-
TABLE 1. **Patient Groups**

<table>
<thead>
<tr>
<th>Group 1 Preoperative (N = 34 studies in 32 pt)</th>
<th>Group 2 Postshunt (N = 14 studies in 13 pt)</th>
<th>Group 3 Postrepair (N = 18 studies in 18 pt)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age at catheterization</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 days - 12 yr*</td>
<td>1.3 - 14 yr</td>
<td>1.6 - 10.8 yr</td>
</tr>
<tr>
<td>2.1 ± 0.4 yr</td>
<td>4.5 ± 0.8 yr</td>
<td>6.1 ± 0.7 yr</td>
</tr>
<tr>
<td><strong>Systemic O₂ sat</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>67 - 98%</td>
<td>62 - 91%</td>
<td>91 - 97%</td>
</tr>
<tr>
<td>80 ± 2%</td>
<td>83 ± 2%</td>
<td>94 ± 2%</td>
</tr>
<tr>
<td><strong>Hematocrit</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>36 - 73%</td>
<td>40 - 78%</td>
<td>34 - 45%</td>
</tr>
<tr>
<td>47 ± 2%</td>
<td>50 ± 3%</td>
<td>38 ± 2%</td>
</tr>
</tbody>
</table>

*Top line is range, second line is x ± SEM.

Results

Preoperative Patients

Right ventricular end-diastolic volume (RVEDV) averaged 88 ± 3% of normal for the entire preoperative group and was significantly different from normal, P < 0.01. The preoperative tetralogy group was also compared with normal by relating RVEDV to BSA for both groups. For the normal group, RVEDV (ml) = 69.9 (BSA)³7 and for the tetralogy group RVEDV (ml) = 65.9 (BSA)²¹. Both the coefficients (P < 0.05) and the exponents (P < 0.05) were significantly different by the likelihood ratio test. In nine of 34 studies, RVEDV was < 75% of predicted normal, and none of the 34 studies showed an RVEDV > 125% of normal (fig. 1). Of the nine patients with a low RVEDV, five had a low ejection fraction. There was no significant correlation of RVEDV with age, Hct, arterial O₂ saturation, or LVEDV in this group.

Right ventricular ejection fraction (RVEF) averaged 0.58 ± 0.02 versus a normal value of 0.65 ± 0.01 and was significantly decreased (P < 0.001). The lower limit of normal for our laboratory for RVEF (mean - 2 sd) is 0.49 and eight patients had values < 0.49 (fig. 2). Of the eight patients with an ejection fraction < 0.49, three had a low RVEDV. There was no significant correlation of RVEF with RVEDV, Hct, or arterial O₂ saturation in this group.

Right ventricular systolic output (RVSO) averaged 81 ± 6% and was also mildly depressed (P < 0.001). Fourteen patients had values < 75% of normal. The ratios RVEDV/LVEDV, RVEF/LVEF, and RVSO/LVSO averaged 0.98, 0.98, and 0.89 and were not significantly different from normal. Right atrial maximal volume (RaMax) could be calculated in 25 patients and averaged 135 ± 8% of normal (P < 0.001). Fourteen patients had RaMax values > 125% of normal (fig. 3).

Post Shunt Patients

RVEDV was normal in this group, averaging 114 ± 6%, and only one of the patients had a small RVEDV (< 75% of normal). RVEDV in shunted patients was significantly greater than that found for preoperative patients (P < 0.002).

Four patients with large shunts as judged by clinical course, physical exam, chest film, cardiac catheterization data, and LV volume overload (LVEDV 160–262% of normal) had both pre and post shunt RVEDV data as shown in figure 4. Here RVEDV in ml is plotted as a function of body

TABLE 2. **Comparative Values for Postcorrection Patients with and without an Outflow Patch**

<table>
<thead>
<tr>
<th>Group 3A (No outflow patch) N = 10</th>
<th>Group 3B (Outflow patch) N = 8</th>
<th>P value (3A vs 3B)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age at operation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 mos - 8 yr*</td>
<td>1.7 - 9.8 yr</td>
<td>NS</td>
</tr>
<tr>
<td>4.1 ± 0.8 yr</td>
<td>5.9 ± 1.0 yr</td>
<td></td>
</tr>
<tr>
<td><strong>Time from operation to restudy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 mos - 5.2 yr</td>
<td>0.8 - 2.8 yr</td>
<td>NS</td>
</tr>
<tr>
<td>1.4 ± 0.2 yr</td>
<td>1.2 ± 0.2 yr</td>
<td></td>
</tr>
<tr>
<td><strong>Right ventricular peak pressure</strong></td>
<td></td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>30 - 58 mm Hg</td>
<td>31 - 100 mm Hg</td>
<td></td>
</tr>
<tr>
<td>46 ± 3 mm Hg</td>
<td>65 ± 8 mm Hg</td>
<td></td>
</tr>
<tr>
<td><strong>Right ventricular end-diastolic pressure</strong></td>
<td></td>
<td>NS</td>
</tr>
<tr>
<td>2 - 12 mm Hg</td>
<td>4 - 12 mm Hg</td>
<td></td>
</tr>
<tr>
<td>8 ± 1.1 mm Hg</td>
<td>8 ± 1.0 mm Hg</td>
<td></td>
</tr>
<tr>
<td><strong>Resting gradient (RV - PA)</strong></td>
<td></td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>0 - 26 mm Hg</td>
<td>0 - 50 mm Hg</td>
<td></td>
</tr>
<tr>
<td>18 ± 4 mm Hg</td>
<td>29 ± 7 mm Hg</td>
<td></td>
</tr>
</tbody>
</table>

*Top line is range, second line is x ± SEM.
surface area. RVEDV clearly increases following a successful shunt procedure with preoperative values being normal or less than normal and postoperative RVEDV being greater than the normal upper limit for RVEDV. There was in this group a negative association of RVEDV with Hct (r = 0.671) as well as a positive correlation with arterial O₂ saturation (r = 0.689) and LVEDV (r = 0.848).

RVEF was mildly depressed in this group also, averaging 0.52 ± 0.02 (P < 0.001). This variable was not significantly different from that found for the preoperative group. In regard to individual values, five patients had RVEF < 0.49. Of these five patients, two had increased RVEDV and three had normal values.

RVSO also was mildly depressed averaging 91% of normal (P < 0.01). The value was not significantly different from the preoperative value. Only two patients in the shunt group showed RVSO values < 75% of normal and both had small shunts at the time of the study as reflected by elevated Hct (55 and 59%) and normal LVEDV (96 and 78% of normal).

In the 14 studies, seven showed large shunts and seven relatively small shunts as judged by clinical exam, chest film, Hct, systemic O₂ saturation, LVEDV, and LVSO (table 3, fig. 5). RVEDV and RVSO were significantly larger in the large shunt group as shown in figure 5. The ratios RVEDV/LVEDV and RVSO/LVSO were decreased from normal in the large shunt group but not different from normal in the small shunt group.

**Figure 1.** Right ventricular end-diastolic volume as a function of body surface area for all preoperative tetralogy patients. The shaded area indicates the normal range.

**Figure 2.** Right ventricular ejection fraction as a function of body surface area for all preoperative tetralogy patients. The shaded area indicates the mean ± two standard deviations for normal.

RaMax was determined in eight patients and was increased in seven and at the upper limit of normal in one instance from that for the preoperative group (fig. 3).

**Post Repair**

RVEDV averaged 108 ± 6% and was not different from normal in Group 3A patients with no outflow patch. This variable, however, was increased from the preoperative value of 88 ± 3% (P < 0.05). One of the ten patients had a slightly increased RVEDV of 138% of normal while all other patients were well within the normal range (fig. 6).

In contrast RVESV was increased in seven of eight patients with an outflow patch (Group 3B) and averaged 177 ± 15% of normal (P < 0.001) (fig. 6).

RVEF was normal in nine of ten patients in Group 3A and averaged 0.60 ± 0.02 (NS) (fig. 7). This value was not different from the preoperative value of 0.58 ± 0.02. RVEF in Group 3B, however, was decreased in six of eight patients and averaged 0.45 ± 0.04 (P < 0.01) (fig. 7). This variable was also significantly decreased from the preoperative value (P < 0.002). For the entire post repair group, there was a

**Table 3.** Postshunt Tetralogy Patients — Large and Small Shunt Groups (X ± SEM)

<table>
<thead>
<tr>
<th></th>
<th>2A. Small shunt</th>
<th>2B. Large shunt</th>
<th>P value (2A vs 2B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hct (%)</td>
<td>54 ± 1</td>
<td>45 ± 1</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Systemic O₂ sat (%)</td>
<td>79 ± 4</td>
<td>87 ± 2</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>LVEDV (%)</td>
<td>97 ± 7</td>
<td>187 ± 28</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>LVSO (%)</td>
<td>73 ± 9</td>
<td>184 ± 14</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>RVEDV (%)</td>
<td>97 ± 4</td>
<td>130 ± 5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>RVEF</td>
<td>0.53 ± 0.02</td>
<td>0.52 ± 0.03</td>
<td>NS</td>
</tr>
<tr>
<td>RVSO (%)</td>
<td>77 ± 0</td>
<td>106 ± 5</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>RVEDV/LVEDV</td>
<td>0.87 ± 0.04</td>
<td>0.65 ± 0.07</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>RVEF/LVEF</td>
<td>1.17 ± 0.14</td>
<td>0.84 ± 0.07</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>RVSO/LVSO</td>
<td>1.04 ± 0.13</td>
<td>0.55 ± 0.04</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

**Figure 3.** Right atrial maximum volume for preoperative, post shunt, and postcorrection tetralogy patients. The shaded area indicates the normal range.
weak negative association of RVEF with RVEDV ($r = 0.572$).

RVSO was normal in eight of ten patients without a patch, averaging $95 \pm 8\%$. This variable was increased in three of eight patients with a patch and averaged $120 \pm 16\%$, a value which was not different from normal but was increased over the preoperative value of $81 \pm 6$ ($P < 0.001$) (fig. 8).

$Ra_{\text{max}}$ was measured in ten patients and increased in two of six patients in Group 3A and in three of four patients in Group 3B (fig. 3).

The ratios RVEDV/LVEDV and RVEF/LVEF were not different from normal in Group 3A, but were significantly abnormal in Group 3B averaging $1.26 \pm 0.11$ ($P < 0.001$) and $0.73 \pm 0.05$ ($P < 0.001$). RVSO/LVSO was not different from normal for either group.

An initial attempt was made to separate the post repair patients into two groups according to age at operation. There were only five patients, however, with correction at $\leq 2.0$ yr of age and four of these had no patch used in the operation. Such a comparison, therefore, did not seem valid.

The possible influence of a previous shunt procedure on the post repair RV volume variables also was considered. Three of the ten patients in Group 3A had a prior shunt. These patients' RVEDVs were $93, 118$, and $115\%$ of normal following correction, and their RVEFs were $0.61, 0.60, \text{and } 0.69$. Six of eight patients in Group 3B had a prior shunt procedure. Although the numbers are small, there was no obvious difference within each post repair group in RVEDV and RVEF values for patients with or without a previous shunt.

The possible influence of peak RV pressure on RV function following operation also was considered. In Group 3A none of the patients had a resting value for peak RVP $> 58 \text{ mm Hg}$. In Group 3B peak RVP was $> 60 \text{ mm Hg}$. In the four patients with high RVP (mean $84 \text{ mm Hg}$), RVEDV averaged $210\%$ of normal versus $144\%$ of normal for the four patients with low RVP which averaged $46 \text{ mm Hg}$. RVEF averaged $0.45$ in both the high and low RVP subgroups. Thus in these small subgroups, RVEDV is larger but the ejection fraction is unchanged in the presence of more severe residual RV outflow obstruction.

Finally, the possible influence of pulmonary valvular inflow.
competence on RV size and function was considered. None of the patients in Group 3A had a significant diastolic mur-
mur (I/VI) or evidence of filling of the body of the RV with
pulmonary artery injections of contrast media. In Group 3B,
six of eight patients had a pulmonary incompetence (PI)
murmur of grade II–III/VI. All six patients had at least
moderate RV body filling with pulmonary artery injection.
Because of these small numbers and our inability to quan-
titate PI further, no conclusions could be made concerning
this hemodynamic abnormality and RV size and function.

Discussion

In this investigation preoperative patients with tetralogy
of Fallot were found to have mild depressions of RV end-
diastolic volume, ejection fraction, and systolic output.
Similar findings have been reported previously for both the
left ventricle4 and the right ventricle5 in tetralogy patients.
In the presence of a low end-diastolic volume, a subnormal
ejection fraction does not necessarily indicate abnormal ven-
tricular function since initial load (preload) is an important
determinant of ejection fraction at least in acute experi-
mental conditions.

In patients studied following a successful shunt pro-
cedure, RVEDV increases commensurate with the increase
in pulmonary blood flow. This finding is in agreement with
data we have obtained in patients with an isolated ventric-
ular septal defect (VSD) in whom RVEDV was increased
when pulmonary blood flow was increased. This increase in
RVEDV, which is less than the corresponding increase in
LVEDV, is explicable in terms of the significant amount of
diastolic and isovolumic LV to RV shunting which has been
demonstrated in patients with both an isolated VSD6 and
tetralogy of Fallot. These findings, together with the low
end-diastolic volumes in preoperative patients, indicate the
importance of pulmonary blood flow as a determinant of
both right and left ventricular volumes in patients with a
VSD.

The RV ejection fraction in the shunted patients remained
abnormally low despite a normal value for RVEDV. A low
ejection fraction usually indicates a depression of RV func-
tion if the afterload for the RV is either normal or
decreased. Quantitation of afterload for the RV is not pos-
ible by current methodology. Patients with isolated pul-
monary stenosis have a normal or even increased RV ejection
fraction,3 and thus a chronic pressure overload per se does
not cause a depression of RVEF. Patients with trans-
position of the great arteries, however, usually have a
depressed RVEF;2,11 suggesting that the combination of cy-
nosis and RV pressure overload can result in abnormal RV
function. The possibility of a disturbance in the normal rela-
tionship between RV oxygen demands and oxygen supply
being associated with such an abnormality in RV function13
seems worthy of further investigation.

The increased right atrial volume seen in preoperative
patients probably reflects the right ventricular pressure over-
load with resultant altered filling pressures for the RV.
Although the RA size was in general lower following repair,
some of this decrease in size may be related to the excision
of RA tissue during bypass.

In patients studied following repair, two distinct groups
were apparent. The presence of a noncontractile patch in the
RV outflow tract with resultant significant pulmonary in-
competence is associated with an abnormally large RV with
a low ejection fraction. In contrast, patients who did not re-
quire an outflow patch had normal values for RVEDV and
RVEF. There are multiple factors which may be associated
with these findings including severity of RV outflow obstruc-
tion and cyanosis prior to operation, operative procedure it-
self, residual RV outflow obstruction, pulmonary incom-
tence, and the presence of the noncontractile patch itself.

There is no simple way to quantify the severity of the pre-
operative anatomy in these patients. The patients with
severe RV outflow obstruction who required a patch usually
had a shunt operation early in life and thus did not have a
long period of extreme cyanosis when compared with the no-patch group. In addition the operative procedure did not differ considerably between the two groups except for the need for the outflow tract patch in Group 3B.

We believe that the differences in RV function between the two groups are related to the combination of the presence of a noncontractile patch, pulmonary incompetence, and the slight difference in residual outflow tract obstruction between the two groups. The relative contribution of these three factors to the functional abnormalities remains difficult to determine.

Experimental animal studies of the effect of pulmonary incompetence on RV function have yielded conflicting results with some investigators showing normal RV function and output while others have shown evidence for depressed function.15-17 Burnell and co-workers18 studied seven dogs 4-5 months following pulmonary valvectomy. When compared with a group of five normal dogs, there were no differences in RV pressure, but there was a 50% increase in RV weight/body weight (2.1 g/kg vs 1.4 g/kg), an increase in RVEDV as measured by thermodilution (4.1 ml/kg vs 3.3 ml/kg), and a decrease in RVEF (0.31 vs 0.45). There were no obvious clinical signs of right heart failure in these animals and cardiac output was not different between the two groups. These investigators concluded that overall cardiac performance was relatively well maintained despite these laboratory measurements of abnormal RV size and pump function.

Burnell and co-workers19 also have studied patients with thermodilution volume determinations 1-3 years following reparative operation for tetralogy. RVEDV in eight patients averaged 153 ml/m² versus a normal value of 103 ml/m² and RVEF was 0.33 versus a normal value for their lab of 0.47. The thermodilution method generally overestimates volume, but these directional differences in normal versus tetralogy patients undoubtedly are significant. Three of the eight postoperative patients with abnormal RV size and EF had neither clinical nor angiographic evidence for pulmonary incompetence. Residual gradients did not exceed 32 mm Hg in their patients and peak RV pressure ranged from 28-55 mm Hg. No data were given regarding the use of outflow tract patches in these patients.

The deleterious effect of RV a pressure overload in combination with a RV volume overload is well known. In our patients peak RVP was higher in the group with an outflow patch, and within this small group RV size was larger but RVEF the same in the high versus the low pressure group.

The possible relationship between abnormalities of RV size and ejection fraction and overall cardiovascular performance remains unclear. Most patients have a remarkable clinical improvement following tetralogy repair and usually show a normal response to mild exercise.20-26 Bristow et al.,27 however, studied ten patients at 13 months and again at seven years following tetralogy repair using supine exercise with a bicycle ergometer. Seven of the ten patients had an outflow patch. RV end-diastolic pressure was mildly elevated at both studies, and the exercise factor was mildly depressed in five of the ten patients. Epstein et al.28 studied ten postrepair tetralogy patients, aged 12-36 yr, whose operation was performed 6 months - 4 yr prior to study. Five of the ten patients had clinical signs of significant pulmonary incompetence. Peak RVP at rest ranged from 22-43 mm Hg. The cardiac output response to intense exercise fell below the normal range in nine of the ten patients. Peak RVP increased from a mean of 35 mm Hg at rest to 80 mm Hg with intense exercise in six of the ten patients. The RV to pulmonary artery gradient increased from 17 mm Hg at rest to 43 mm Hg with intense exercise. Thus, these authors found significant impairment of the cardiovascular response to intense upright exercise despite lack of symptoms, near normal hemodynamics at rest, absence of dysrhythmias, absence of residual shunts, and absence of pulmonary hypertension.

The clinical significance of the findings of the present investigation remain unclear at present. Although many patients with tetralogy and markedly reduced pulmonary blood flow have a somewhat small right (and left) ventricle, the reduction in end-diastolic volume is usually only moderate in degree with both RVEDV and LVEDV being > 65% of predicted normal. We do not believe that such a reduction in ventricular size is a contraindication to repair. Rarely relatively severe hypoplasia of the right ventricle occurs which can be associated with an abnormality of the tricuspid valve (overriding tricuspid valve). If the RVEDV (and/or LVEDV) is < 55% of normal, we would present consider a shunt procedure as a preferable first operation. Obviously, other major considerations such as outflow tract and pulmonary artery size enter into this decision. The data are not available at present in sufficient numbers of patients with both ventricular volume determinations as well as careful postoperative monitoring of right and left atrial pressures with cardiac output to determine if our present considerations regarding ventricular size and operative procedure are correct.

In regard to the effect of an outflow tract patch and pulmonary incompetence on long-term right heart function, the findings of this as well as previous studies indicate significant abnormalities of RV size and pump function. In patients with low RV pressure, these abnormalities are well tolerated. The majority of these patients have such severe abnormalities of the RV outflow tract that the use of a patch as well as the residual pulmonary incompetence are unavoidable consequences. The only alternative procedure at present would be the use of a valved conduit or homograft to reconstruct the outflow tract. Because of the uncertainty regarding possible future complications of this procedure, it does not seem a reasonable alternative for the usual tetralogy patient.

The long-term follow-up of large numbers of post repair tetralogy patients with ventricular volume determinations, exercise studies, and evaluation of their clinical course will be required to determine the significance of residual abnormalities of right heart function as reported herein and elsewhere.6-19

Acknowledgment

The authors would like to express their appreciation to Miss Odessa Gatlin and Mrs. Sharon Johnson for their long and diligent work in preparation of this manuscript.

References

2. Graham TP Jr, Jannamani JM, Atwood GF, Canent RV Jr: Right ven-
Potential Role of QT Interval Prolongation in Sudden Infant Death Syndrome

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SUMMARY To investigate the possibility that a genetically transmitted cardiac abnormality is involved in the genesis of the sudden infant death syndrome (SIDS), 42 sets of parents who had at least one infant with SIDS were studied by electrocardiography. Prolongation of the QT interval was present in at least one member of 11 (26%) sets of parents. In families in which QT interval prolongation was found in a parent, prolonged QT interval was also present in 39% of the siblings of infants with SIDS, suggesting an autosomal dominant pattern of inheritance. In addition, an infant with "near-miss" SIDS showed marked prolongation of the QT interval. Thus, our data suggest that prolonged QT interval may play a role in a considerable proportion of sudden and unexpected infant deaths. However, definitive confirmation of the relation between QT interval prolongation and SIDS will require large prospective investigations.

SUDDEN INFANT DEATH SYNDROME (SIDS) is the largest single cause of death between one week and one year of age in the United States, accounting for the deaths of approximately 10,000 apparently well infants annually.1,2 Although numerous theories have been proposed,3-8 the primary mechanisms responsible for SIDS are still unknown. Recently, many investigators have incriminated respiratory and cardiac mechanisms such as chronic hypoxemia,9 prolonged apnea,9 dysfunction of central nervous system reflexes that are responsible for stabilization of cardiac rate,9 or cardiac arrhythmias10,11 as the cause of SIDS.

We have considered the possibility that prolonged QT interval syndrome,11-13 a genetically transmitted cardiac condition known to cause sudden death in children13-15 and in infants,14-21 is related to SIDS. The present study describes our investigation into the possible relation between prolonged QT interval syndrome and sudden, unexplained death in infancy.
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Circulation. 1976;54:417-423
doi: 10.1161/01.CIR.54.3.417

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

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