Wall thickness, cavity dimensions, and myocardial contractility of the left ventricle in patients with simple transposition of the great arteries

A multicenter study of patients from 10 to 20 years of age

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ABSTRACT Fifty-one patients with uncomplicated transposition of the great arteries (TGA) and normal pulmonary pressure who were 10 to 20 years old and 69 normal subjects matched for age were studied by M mode echocardiography. Left ventricular internal dimensions and posterior wall thickness showed positive correlation with the body surface area in the TGA as well as in the control groups. Values for these parameters in the TGA group were generally smaller than those in the normal population. Septal thickness of patients with TGA (5.9 ± 1 mm) was also smaller than that in the control group (6.6 ± 1 mm) (p < .01). Septal motion was normal in 11 patients with TGA and paradoxical in 19 patients in this group. In the other 21 patients the septum was flat. The following systolic time intervals of the left ventricle were found for patients with TGA: pre-ejection period (PEP) 64 ± 11 msec, ejection time (ET) 310 ± 37 msec, and PEP/ET 0.21 ± 0.04. These values were significantly different from those of the right ventricle for the normal population: PEP 77 ± 12 (p < .01), ET 327 ± 25 (p < .05), and PEP/ET 0.24 ± 0.03 (p < .01). Shortening fraction and mean velocity of circumferential fiber shortening (49 ± 7% and 1.6 ± 0.3 circum/sec, respectively) were also significantly higher (p < .01) in patients with TGA than in the control group (33 ± 4% and 1.1 ± 0.2 circum/sec). These data should help achieve reliable quantitative and qualitative interpretations of echocardiograms of patients with TGA.

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IN THE GREAT MAJORITY of patients with simple transposition of the great arteries (TGA) and normal pressure in the pulmonary circulation the disorder is corrected by surgical rerouting of the venous returns. One of the consequences of this approach is that the left ventricle maintains, throughout life, its anatomic relationship with the pulmonary circulation. This should influence not only the muscular growth but also the general dynamics of the ventricular walls. Indeed, in a previous report it has been shown that wall thickness and cavity dimensions of the left ventricles of patients with uncomplicated TGA are different from those of normal children when they are as young as 7 to 10 months of age.1 The population of this study was from 1 day to 10 years old. Data on the influence of the aging process on the same echocardiographic parameters later on in life are, to our knowledge, not available, even though the number of patients with TGA who are older than 10 is constantly increasing. Studies of anatomic specimens have all been carried out in younger subjects.2-5 To be able to achieve a reliable quantitative assessment of left ventricular function in patients with TGA older than 10 years of age, a reference table of values in patients with uncomplicated disease is indispensable. This collaborative study was planned to fulfill this need.

Materials and methods

Subjects. The study population consisted of 51 patients treated at two Canadian centers (Hôpital Sainte-Justine, Montréal, and The Hospital for Sick Children, Toronto) and at the Hôpital...
d’Enfants, Nancy, France. In all cases, the following criteria were met as conditions for inclusion in the study: uncomplicated and asymptomatic TGA, age from 10 to 20 years, and normal pressure in the pulmonary circulatory system verified by postoperative hemodynamic investigation and defined as a left ventricular systolic pressure less than 40 mm Hg. When cardiac catheterization was performed more than 1 year before the present echocardiographic study, noninvasive criteria for normal pulmonary pressures had to be satisfied.\(^6\)\(^7\) Patients with a gradient of 20 mm Hg or less in the left ventricular outflow tract were included in the study. All 51 patients had undergone surgical correction by either Mustard or Senning procedure. Their mean age was 14 years at the time of the echocardiographic study. In this group, the anatomic left and right ventricles refer to the venous and systemic ventricles, respectively. Another group of 69 normal subjects, matched for age, served as the control group.

Echocardiographic technique. Each subject was represented by one echocardiographic study to avoid undue influence of individual cases on the data for the group. Echocardiograms were recorded and interpreted according to the technique previously described.\(^1\) The following left ventricular parameters were measured: posterior wall (LVPW) and septal thickness (IVS), cavity dimensions at end-systole (LVIDd) and end-diastole (LVIDs), prejection period (PEP), ejection time (ET), shortening fraction, and mean velocity of circumferential fiber shortening (mean Vcf). Septal motion was classified as normal, flat, or paradoxical. Because of technical difficulties in complete identication of the pulmonary valve, systolic time intervals could not be measured in 10 subjects. No attempt was made to calculate the shortening fraction or mean Vcf of patients in whom septal motion was abnormal.

Statistical analysis. Covariance analysis was performed to compare the data from the three centers. The analysis was carried out on all parameter values obtained, with age as the covariate. The effects of biological variables (age, height, weight, and body surface area) on the echocardiographic data from the normal group were then studied by regression techniques. For those variables with a high correlation coefficient ($r > .5$) the analysis was pursued further and the best regressor was sought among the biological variables previously mentioned and some of their transformations. The correlation studies showed that when a parameter was influenced by biological variables, body surface area always had the strongest index of correlation. Therefore, results of data analysis were always expressed in relation to body surface area. Tolerance limits about the regression lines for TGA and control groups were established by $\pm 2$ residual SDs. For clinical application, a table was constructed from these regressions giving the mean and the upper tolerance limit.

The results for parameters not influenced by the set of biological variables are given as mean $\pm$ SD. Their values in the TGA group were compared with those in the control group by Student’s $t$ test.

Results

The results from the covariance analysis showed sufficient homogeneity to warrant pooling of the data from the three centers.

LVID. The LVIDd and LVIDs showed a positive correlation with the body surface area for both normal and TGA groups (figure 1). However, in the TGA group, 30 LVIDd values and 32 LVIDs values were below the lower tolerance limits for the normal group. The expected values for these diameters in relation to body surface area in patients with uncomplicated transposition are given in table 1.

LVPW. A positive correlation was also found between LVPW and the body surface. The slope of the regression line was quite similar to that for the normal population (figure 2). In diastole 19 patients and in systole only four had values within the tolerance limits for the normal population. All the others were below these limits. The expected values for these parameters in patients with TGA are shown in table 1.

IVSd, IVSs for the TGA group (5.9 $\pm$ 1 mm) was smaller than normal (6.6 $\pm$ 1 mm) ($p < .01$). This value did not change with variation in the body surface area (table 1). The septum was consistently thicker than the left ventricular posterior wall in the TGA group. The IVSd/LVPWd ratio was always greater than 1.3, thus creating an asymmetric septal hypertrophy. Septal motion was normal in 11 patients and paradoxical in 19. The septum was flat in the remaining 21.

Systolic time intervals. The systolic time intervals calculated from the pulmonary valve in the TGA group were as follows: PEP 64 $\pm$ 11 msec, ET 310 $\pm$ 37 msec, and PEP/ET 0.21 $\pm$ 0.04. These values were significantly different from those taken from the pulmonary valve in the control group: PEP 77 $\pm$ 12 msec ($p < .01$), ET 327 $\pm$ 25 msec ($p < .05$), and PEP/ET 0.24 $\pm$ 0.03 ($p < .01$). Heart rate was significantly lower in the TGA group (76 $\pm$ 13 beats/min) compared with the control value (81 $\pm$ 12 beats/min) ($p < \ldots$

### TABLE 1

Mean values and upper tolerance limits for left ventricular parameters in patients with simple d-TGA

<table>
<thead>
<tr>
<th>Body surface area (m²)</th>
<th>LVIDd (mm)</th>
<th>LVIDs (mm)</th>
<th>LVPWd (mm)</th>
<th>LVPWs (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>30.0 (40.7)</td>
<td>17.4 (28.8)</td>
<td>3.3 (5.0)</td>
<td>6.0 (8.5)</td>
</tr>
<tr>
<td>1.1</td>
<td>30.8 (41.4)</td>
<td>17.9 (29.3)</td>
<td>3.5 (5.1)</td>
<td>6.3 (8.9)</td>
</tr>
<tr>
<td>1.2</td>
<td>31.6 (42.2)</td>
<td>18.4 (29.8)</td>
<td>3.6 (5.3)</td>
<td>6.6 (9.2)</td>
</tr>
<tr>
<td>1.3</td>
<td>32.3 (43.0)</td>
<td>18.9 (30.4)</td>
<td>3.8 (5.4)</td>
<td>7.0 (9.5)</td>
</tr>
<tr>
<td>1.4</td>
<td>33.1 (43.8)</td>
<td>19.4 (30.9)</td>
<td>3.9 (5.4)</td>
<td>7.3 (9.8)</td>
</tr>
<tr>
<td>1.5</td>
<td>33.9 (44.6)</td>
<td>20.0 (31.4)</td>
<td>4.0 (5.7)</td>
<td>7.6 (10.1)</td>
</tr>
<tr>
<td>1.6</td>
<td>34.7 (45.3)</td>
<td>20.5 (31.9)</td>
<td>4.2 (5.8)</td>
<td>7.9 (10.5)</td>
</tr>
<tr>
<td>1.7</td>
<td>35.5 (46.1)</td>
<td>21.0 (32.4)</td>
<td>4.3 (6.0)</td>
<td>8.2 (10.8)</td>
</tr>
<tr>
<td>1.8</td>
<td>36.2 (46.9)</td>
<td>21.5 (33.0)</td>
<td>4.5 (6.1)</td>
<td>8.6 (11.1)</td>
</tr>
<tr>
<td>1.9</td>
<td>37.0 (47.7)</td>
<td>22.0 (33.5)</td>
<td>4.6 (6.3)</td>
<td>8.9 (11.4)</td>
</tr>
<tr>
<td>2.0</td>
<td>37.8 (48.5)</td>
<td>22.6 (34.0)</td>
<td>4.7 (6.4)</td>
<td>9.2 (11.7)</td>
</tr>
</tbody>
</table>

Mean values for additional parameters are as follows: IVSd $5.9 \pm 1.0$ mm, shortening fraction 49 $\pm 7\%$, mean Vcf $1.6 \pm 0.3$ circ/sec, PEP 64 $\pm 11$ msec, PEP/ET $0.21 \pm 0.04$.

Values in parentheses represent the upper tolerance limits.
FIGURE 1. Individual values for LVIDd (A) and LVIDa (B) in patients with uncomplicated TGA in relation to body surface area. The dotted lines correspond to the regression line (middle) and 95% tolerance limits for the same parameters in a normal age-matched population (10 to 20 years old).
FIGURE 2. LVPW_s (A) and LVPW_d (B) in patients with TGA in relation to body surface area. The regression line (middle) and the 95% tolerance limits for the same parameters in a normal population of the same age (10 to 20 years) are presented as dotted lines.
.05). The equations correlating ET and heart rate were quite comparable for both groups.

**Shortening fraction and mean Vcf.** Shortening fraction and mean Vcf for the normal subjects and the 11 patients with TGA and normal septal motion were not influenced by age or body surface. The mean values for the TGA group (shortening fraction 49 ± 7%, mean Vcf 1.6 ± 0.3 circ/sec) (table 1) were significantly higher than those for the normal population (shortening fraction 33 ± 4%, mean Vcf 1.1 ± 0.2 circ/sec; p < .01).

**Discussion**

These results confirm that morphologic and dynamic assessment of the left ventricle of patients with TGA cannot be based on comparisons with data gathered from a normal population. Patients with TGA must be compared with others with the same malformation, providing that the reference group is free of any other complication. To obtain such a reference group, patients with TGA included in the present study were carefully selected as those who were asymptomatic and had normal pressures in the pulmonary circulation.

The great majority of patients with TGA had a LVID significantly smaller than that measured in the normal population both in systole and diastole. A previous study had demonstrated that this situation is already present in the first months of life. This is most likely related to the systemic pressure in the right ventricle causing a reversal of the septal curvature and flattening of the left ventricular cavity. For this reason no attempt was made to calculate ventricular outputs, since linear measurement of LVID does not allow any reliable conclusion concerning systolic and diastolic volumes. The posterior bulging of the septum into the left ventricular cavity changes ventricular geometry, and the usual equation based on the assumption that the left ventricular cavity is an ellipsoid can no longer be applied.

The LVPW in the TGA group was always thinner than the control value. This is likely related to the left ventricle being connected to the low-pressure pulmonary circulation. In our study, a progressive increase in the LVPW was observed as patients grew older. This increase, albeit modest, is nevertheless intriguing considering that the same parameter previously measured from birth to 10 years showed a constant diastolic mean value of 2.3 mm. The reasons for this difference between the two age groups cannot be inferred from the present data. The thicker septum creates a situation of asymmetric hypertrophy of the left ventricular wall and also alters normal septal dynamics. Indeed, septal motion was normal only in 11 of the 51 patients with TGA included in our study.

The lower heart rate among the patients with TGA is most likely related to the sinoatrial node dysfunction commonly observed after Mustard operation. On the other hand, the shorter PEP and lower PEP/ET in the same group as compared with the normal population could be related to the shorter electromechanical delay known to be present in the left ventricle compared with the right. The PEP could theoretically also be influenced by a difference in afterload. This possibility is unlikely since pulmonary pressures and resistances were found to be normal in all the patients selected for this study.

Finally, the indexes of myocardial contractility mean Vcf and shortening fraction were always found to be higher in the TGA group. The same observation has been made previously. Here again, the changes in left ventricular geometry could explain this difference. This point should always be kept in mind in echocardiographic evaluation of left ventricular contractility in patients with uncomplicated TGA.

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