Transposition of the Great Arteries

Changes in the Circulation after Birth

By Michael Tynan, M.D.

SUMMARY
Sequential cardiac catheterizations were performed on 19 infants with complete transposition of the great arteries (TGA). None had any additional cardiac abnormalities other than an atrial septal defect. All were under 3 months of age at the time of the initial study. The pulmonary artery pressures and pulmonary-to-systemic vascular resistance ratios were significantly higher under the age of 9 weeks than over this age. The major fall in pulmonary vascular resistance appeared to occur in the first 4 weeks of life. A systolic pressure gradient from the left ventricle to the pulmonary artery of more than 5 mm Hg (median 13) was found at all the investigations performed in patients over the age of 2 weeks. This suggests that such a pressure gradient is usual in TGA, and not a sign of pulmonary stenosis. No systematic distribution of pulmonary-to-systemic flow ratios or age-related changes in these ratios was demonstrated, but pulmonary flow was rarely the same as systemic flow. In TGA the pulmonary vasculature undergoes a maturation process with the transition from intra- to extraterine life. This process is similar in magnitude and time scale to that seen in the normal human infant.

Additional Indexing Words:
Pulmonary artery pressure
Left ventricle-to-pulmonary artery pressure gradient
Pulmonary vascular resistance

The changes which take place in the circulation as a consequence of the transition from intra- to extraterine life have been extensively studied in the normal mammal. However, little information is available concerning such changes in infants with transposition of the great arteries (TGA). In order to understand the circulation in TGA it is necessary to discover what changes, if any, occur as a result of this transition. To establish the usual pattern of these changes we first have to study TGA in its simplest form, uninfluenced by the effects of high-pressure communications between the pulmonary and systemic circuits. This paper presents the hemodynamic changes observed in a group of infants with uncomplicated TGA modified only by balloon atrial septostomy.1

Methods
Nineteen infants with TGA and intact ventricular septum and no evidence of persistent ductus arteriosus were studied sequentially by cardiac catheterization. All were under 3 months of age at the initial investigation. The pulmonary artery was entered in all cases either directly with a Goodale-Lubin catheter or by the coaxial flow-guided technic2 (the initial investigations of cases 2, 3, 9, 13, 15, and 17 were by the latter technic). Pressures and oxygen saturations were measured in all four cardiac chambers and in the systemic and pulmonary arteries and veins. Oxygen saturations were measured using the Kipp hemorefractor MO I, an individual calibration line being plotted at each investigation. Pressures were measured in expiration with the zero reference at the midthoracic level. Either
### Table 1

**Sequential Hemodynamic Findings in Simple TGA**

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THE GREAT ARTERIES

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were made on an

an Elema-Schonander EMT 34 pressure transducer or a Statham P23Gb strain gauge was used. Recordings were made on an Elema-Schonander Mingograph EM 81 direct-writing recorder.

Oxygen consumption was not measured. Flows are therefore expressed as a ratio of pulmonary-to-systemic flow (Qp:Qs) using the measured arteriovenous oxygen saturation differences in the two circuits. The systemic arteriovenous difference was calculated as the aortic saturation minus the mean of the superior and inferior vena cava saturations. When no inferior vena caval sample was obtained the superior caval sample was used as mixed venous. Although this method is potentially inaccurate, when compared with thermodilution estimation of Qp:Qs ratio good correlation was observed. In 10 cases of simple TGA with an interatrial communication only thermodilution estimation of Qp:Qs ratio was made by introducing a thermistor into the pulmonary artery and injecting saline into the left ventricle, and repeating the process with the thermistor in the aorta, injecting it into the right ventricle. The saline was at room temperature, and the Qp:Qs ratio was estimated by comparing the means of three areas under the curves for both circulations. The results for thermodilution and oxygen saturation were compared by bivariate rectilinear regression analysis. The equation was as follows: Qp:Qs thermodilution = 1.06 Qp:Qs oxymetry + 0.07; r = 0.962; se 0.19.

Pulmonary vascular resistance (Rp) and systemic vascular resistance (Rs) are also expressed as the ratio Rp:Rs.

Cardiac catheterization was performed on the conscious patient breathing air on all except two occasions (case 6, second investigation and case 19, first investigation) when general anesthesia was necessary to maintain a steady state. The anesthetic mixture used contained approximately 30% oxygen. Under 6 months of age local anesthesia alone was used, and the infants remained content sucking a pacifier dipped in a brandy and syrup mixture. Over the age of 6 months a sedative mixture was given: meperidine 50 mg, promethazine 12.5 mg, and chlorpromazine 12.5 mg in 2 ml, the dose of the mixture being 1 ml per 9 kg (20 lb) body weight.

There was no evidence of pulmonary venous hypoxemia during any of the investigations. Adequacy of ventilation was confirmed at 40 of 42 investigations by estimating the systemic arterial pCO2 by the Astrup method. In all instances the arterial pCO2 was less than 45 mm Hg.

The diagnosis of TGA was confirmed by both cardiac catheterization and angiocardiology in

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all patients. Associated abnormalities were excluded by biventricular biplane angiocardiography during at least one of the investigations.

The effect of age on the hemodynamic findings was tested using analysis of variance. The results were analyzed in three groups, namely, under 2 weeks, 2–9 weeks, and over 9 weeks of age. The null hypothesis was retained when its probability exceeded 0.05.

Results

Forty-two investigations were performed on the 19 patients, and the results are presented in table 1. Seven patients had their initial study while under 1 week of age and a total of 11 studies were performed during the first 2 weeks of life. A further nine studies were performed between the ages of 2 and 9 weeks, and the remaining 22 were performed between 9 weeks and 2 years 9 weeks of age.

Changes in Pulmonary Artery Pressure

The pulmonary artery systolic pressure (fig. 1) was highest in the youngest patients. There were significant differences between those observations made in patients under 9 weeks and those made over 9 weeks of age \((P < 0.01)\). Thirteen cases showed an overall fall in pressure, one showed an overall rise, and five showed no change. A change was arbitrarily judged to have occurred when the difference between the initial and final observations exceeded 9 mm Hg.

The pulmonary artery mean pressure was also highest in the youngest patients, but in these cases significant differences were demonstrated between those pressures measured in patients under 2 weeks and those measured over 2 weeks of age \((P < 0.01)\).

Similar changes were seen in the \(R_p:R_s\) ratio which was highest in the early weeks of life. There was a significant difference between those patients under 9 weeks of age and those over 9 weeks \((P < 0.01)\). After 9 weeks of age only one case revealed an \(R_p:R_s\) ratio greater than 0.2.

Changes in the Pulmonary-to-Systemic Flow Ratio

The changes in \(Q_p:Q_s\) ratio showed no clear-cut pattern (fig. 2). In 11 cases there was an overall rise, in four an overall fall, and four showed no overall change. The impression that the \(Q_p:Q_s\) increased with age was not borne out statistically \((P > 0.05)\).

Left Ventricle-to-Pulmonary Artery Pressure Gradient

A systolic pressure gradient of 5 mm Hg or more between the left ventricle and the pulmonary artery was found in 35 of the investigations (fig. 3). The seven investigations in which a pressure difference of less than 5 mm Hg was found were all performed during the first 2 weeks of life. After the age of 14 days the range of pressure gradient was from 8 to 35 mm Hg with a median of 13 mm Hg. All seven patients who had no pressure gradient during the first 2 weeks of life had

![Figure 1](image1.png)

**Figure 1**

Changes in pulmonary artery systolic pressure, in mm Hg, with age: serial observations in 19 cases of simple TGA. See text for discussion.

![Figure 2](image2.png)

**Figure 2**

Changes in pulmonary-to-systemic flow ratio with age: serial observations in 19 cases of simple TGA. See text for discussion.
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Figure 3

LV-PA systolic pressure gradient in simple TGA. 42 observations. See text for discussion.

developed one by their subsequent investigation. On regression analysis no correlation was found between the pressure gradients and $Q_p:Q_s$ ratios ($r = < 0.01; P > 0.1$).

Discussion

These results show that the maturation of the pulmonary circulation after birth in simple TGA is similar to that demonstrated in the normal human infant 4-9 and other mammalian species.8, 10, 11 The time course of these changes has considerable species variation, but in the normal human infant the pulmonary artery pressure should be below 30 mm Hg by 20-30 days of extrauterine life. The fall of pulmonary artery pressure and of pulmonary vascular resistance appears to follow a similar time course in transposition, both being normal in most cases by the age of 9 weeks (63 days). From the sequential investigations it appears that the major fall occurs in the first 3 or 4 weeks of life. The similarity between transposition and the normal is neither unexpected nor unreasonable since the pulmonary circulation is subjected to similar changes in both, namely, expansion of the lungs with a rise of $pO_2$ in the pulmonary vessels. Furthermore, the hemodynamic evidence for normal maturation of the pulmonary vascular bed in simple transposition of the great arteries is in accord with recent histologic studies of the lung vessels in this condition.12, 13

After birth the circulation in TGA differs from the normal in one basic respect. In the normal circulation the left and right ventricles are connected in series so their outputs must, over a period of time, be equal. In TGA the ventricles are not connected in series and need not generate equal outputs. The only necessity is that the net flow from the pulmonary to systemic circuit must equal the net flow from the systemic to pulmonary circuit. Given this degree of independence, the outputs of the two ventricles should be determined by their individual filling pressures, ventricular compliances, and the resistances in their respective vascular beds. With the fall in pulmonary vascular resistance relative to systemic, which occurs after the first breath, one would expect the $Q_p:Q_s$ ratio to be greater than unity soon after birth, even if both ventricles have similar compliances and similar filling pressures. During the early months of life the right ventricle in the normal14, 15 and the left ventricle in transposition16 show a progressive diminution in muscle mass relative to the systemic arterial ventricle. This is probably accompanied by an increase in the compliance of the pulmonary arterial ventricle, the left ventricle in TGA. This increase in compliance of the left ventricle should lead to a progressive increase in $Q_p:Q_s$ ratio during the early months of life. In fact the pulmonary flow was less than systemic flow in the majority of instances, and no increase of $Q_p:Q_s$ with age was statistically shown. These findings were unexpected, but Graham and colleagues have reported a wide range of left ventricular systolic outputs in TGA with intact ventricular septum.17 At least 10 of their observations showed left ventricular outputs that were lower than normal; figure 4 in their paper is remarkably similar to figure 2 in this paper. Since little is known about ventricular mechanics in the fetus and infant, there is even doubt about the relative outputs of the two ventricles in utero.18-21 More information is needed before we can explain the wide

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scatter of $Q_p:Q_s$ ratios seen in TGA.

A systolic pressure gradient from the left ventricle to the pulmonary artery is a usual finding in uncomplicated TGA (Tynan M, Carr I: Unpublished data). The findings in this paper suggest that it develops during the first few weeks after birth and is not related to the $Q_p:Q_s$ ratio. In fact it is one of the maturation changes found in TGA and as such it is not meaningful, in the absence of evidence of fibrous narrowing, to call it subvalvar pulmonary stenosis.22, 23 Kirklin and colleagues24 have suggested that determinants other than increased outflow resistance may be responsible for the low $Q_p:Q_s$ ratios seen in some infants with TGA. The lack of correlation between the LV to PA pressure gradient and $Q_p:Q_s$ ratio in this series supports this view.

The maturation of the pulmonary vascular bed in infants with TGA is similar to the normal process and is accompanied by a comparable fall in pulmonary artery pressure. However, because of the unique mode of connection of the circulation in TGA there are differences from the normal. First, the pulmonary flow is usually different in magnitude from the systemic flow. Second, there is usually a pressure gradient from the left ventricle to the pulmonary artery which appears to develop over the first few weeks of life.

Acknowledgments
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References
17. Graham TP, Jarmakani JM, Canent RV, Jewett PH: Quantification of the left heart volume and systolic outputs in transposition of the great arteries. Circulation 44: 899, 1971
20. Assali NS, Morris JA, Beck R: Cardiovascular hemodynamics in the fetal lamb before and

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after lung expansion. Amer J Physiol 208: 122, 1965


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