Blood flow pattern of the interatrial communication in patients with complete transposition of the great arteries: a pulsed Doppler echocardiographic study

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ABSTRACT We analyzed blood flow pattern in the interatrial communication in 24 patients with complete transposition of the great arteries (TGA). Eight had TGA with atrial septal defect (group 1), nine had TGA with patent ductus arteriosus or ventricular septal defect (group 2), and seven had pulmonary arterial banding and Blalock-Taussig shunt (group 3). The flow pattern was determined at the site of atrial septal defect by Doppler echo beam directed as perpendicular to the septum as possible. The flow pattern was composed of a left-to-right (L-R) flow and right-to-left (R-L) flow. The turning point (T1) from the R-L to L-R flow occurred immediately after the initiation of the QRS on the electrocardiogram and was common in all groups. The other turning point (T2) from L-R to R-L occurred after the second heart sound (S2). The S2-T2 interval decreased on inspiration, indicating prolongation of the period of R-L flow. The minimum S2-T2 interval ranged from 20 to 70 (mean ± SD 50 ± 18) msec in group 1, from 70 to 150 (114 ± 25) msec in group 2, and from 50 to 138 (75 ± 29) msec in group 3. The maximum S2-T2 interval ranged from 48 to 110 (88 ± 21) msec in group 1, from 140 to 235 (175 ± 36) msec in group 2, and from 80 to 170 (111 ± 30) msec in group 3. The minimum ratio of L-R flow duration to that in the whole cardiac cycle (T1-T2/RR) was 0.47 to 0.61 (mean ± SD 0.53 ± 0.04) in group 1, 0.66 to 0.88 (0.74 ± 0.10) in group 2, and 0.53 to 0.77 (0.65 ± 0.08) in group 3. The maximum T1-T2/RR ratio ranged from 0.57 to 0.74 (0.67 ± 0.06) in group 1, from 0.75 to 1.0 (0.87 ± 0.09) in group 2, and from 0.68 to 0.91 (0.79 ± 0.08) in group 3. We conclude that, in patients with TGA (1) an interatrial shunt occurs in a rather simple flow pattern, with L-R shunting mainly in systole and R-L shunting mainly in diastole, (2) the pattern is affected by respiration, and (3) the associated ventricular septal defect or patent ductus arteriosus causes the shunt, which directs flow toward the pulmonary artery and away from the systemic ventricle or artery.


It is well known that interatrial shunting is bidirectional in patients with complete transposition of the great arteries (TGA) with intact ventricular septum. Carr investigated flow dynamics of the shunt using the cineangiogram and pressure measurements and found that left-to-right (L-R) shunting was seen during ventricular systole and right-to-left (R-L) shunting occurred during diastole. Rudolph documented that the atrial L-R shunt was dominant when a ventricular septal defect coexisted with TGA. Although the blood flow through the interatrial communication in those with complete TGA has been fairly well described, a precise analysis of direct recordings of the blood flow has not been reported. Also, the interatrial shunt in patients with complete TGA associated with ventricular septal defect or patent ductus arteriosus has not been fully studied. The analysis of the blood flow through the interatrial shunt should contribute to the understanding of the hemodynamics of this anomaly. Therefore, we analyzed blood flow pattern at the interatrial communication using pulsed Doppler echocardiography and a catheter-tipped velocity sensor to clarify (1) flow dynamics at the site of interatrial communication, (2) the effect of ventricular or ductal shunting, (3) the effect of respiration, and (4) changes after palliative operations, including pulmonary arterial banding and the Blalock-Taussig (BT) shunt.
Material and methods

Study subjects. The study group consisted of 24 patients with complete TGA. Fifteen were boys and nine were girls. Their ages ranged from 1 to 18 months, with a mean of 10 months. They were classified into three groups as follows: Group 1 consisted of eight patients with intact ventricular septum and no ductal shunt. Group 2 included nine patients with a ventricular septal defect and/or patent ductus arteriosus. Group 3 consisted of seven patients who had undergone pulmonary arterial banding with or without BT anastomosis in preparation for the arterial switch operation or for reducing pulmonary blood flow.

Methods. The pulsed Doppler echocardiography unit used for this study was a Toshiba SDS-10A combined with a two-dimensional echocardiograph (Toshiba SSH-11A) with a 2.4 MHz transducer. The pulsed Doppler echocardiogram, phonocardiogram, and electrocardiogram were recorded simultaneously with a strip-chart recorder at a paper speed of 10 cm/sec. The pulse repetition frequency was 6.0 kHz and the low cutoff filter was usually set at 100 or 200 Hz to avoid recording the Doppler signal resulting from cardiac wall motion. The subxiphoid four-chamber view was obtained with the sample volume set at the interatrial communication as perpendicular to the interatrial septum as possible (figure 1). The pulsed Doppler echocardiogram was displayed on a sound spectrograph with fast-Fourier transform analysis. Pulsed Doppler echocardiographic examinations were performed in subjects under mild sedation with chloral hydrate. The time interval measurements were obtained by pulsed Doppler echocardiography. A typical blood flow pattern obtained from a group 1 patient showed a biphasic and bidirectional pattern (figure 2). The sound spectrographic signals above the baseline indicate the interatrial L-R shunt and those below the baseline indicate the R-L shunt. The turning point from the R-L to the L-R shunt, which appeared immediately after the initiation of the QRS complex of the electrocardiogram, was designated as T1, and the turning point from the L-R to the R-L shunt as T2. The T1 and T2 determined by this method are illustrated in figure 3.

Because of the presence of the ambiguity zone produced by the use of low cutoff filter, when the descending limbs of the upside and downside waves appeared misaligned, the midpoint between t2’ and t2’’ was taken as T2. Determination of the T1 had to be made on occasion in the same way. The time interval between the second heart sound (S2) and the T2 (S2-T2 interval) was also measured. The ratio of the T1-T2 interval to the RR interval of electrocardiogram (T1-T2/RR) was calculated. The

FIGURE 1. The Doppler echo beam was set as perpendicular to the interatrial septum as possible. RA = right atrium; LA = left atrium.

FIGURE 2. A typical blood flow pattern in patients with complete TGA with intact ventricular septum (group 1) shows biphasic and bidirectional pattern. The L-R shunt is mainly in systole and the R-L shunt is mainly in diastole. PCG = phonocardiogram; ECG = electrocardiogram; P-DE = pulsed Doppler echocardiogram.

FIGURE 3. Schematic illustration of the method of time interval measurements. Because of the presence of the ambiguity zone produced by the use of low cutoff filter, when the descending limbs of the upside and downside waves appeared misaligned, the midpoint between t2’ and t2’’ was taken as T2. Determination of the T1 had to be made in the same way on occasion. PCG = phonocardiogram; ECG = electrocardiogram; P-DE = pulsed Doppler echocardiogram.
test was used for statistical analysis and \( p < 0.05 \) was considered indicative of significance. In eight patients (three in group 1, three in group 2, and two in group 3), a catheter-tipped flow velocity probe (Miller VPC-663A) was introduced to obtain the flow pattern at the interatrial communication during routine cardiac catheterization. Left atrial pressure was simultaneously obtained with a catheter-tipped pressure sensor.

**Results**

The L-R shunt signal was recorded mainly in ventricular systole, and the R-L shunt signal was noted mainly in ventricular diastole in all the groups. The minimum \( S_2-T_2 \) interval ranged from 20 to 70 (50 ± 18) msec in group 1, from 70 to 130 (114 ± 25) msec in group 2, and from 50 to 138 (75 ± 29) msec in group 3 (figure 4). The maximum \( S_2-T_2 \) interval ranged from 48 to 110 (88 ± 21) msec in group 1, from 140 to 235 (175 ± 36) msec in group 2, and from 80 to 170 (111 ± 30) msec in group 3 (figure 4, right). The minimum \( T_1-T_2/RR \) ratio ranged from 0.47 to 0.61 (0.53 ± 0.04) in group 1, from 0.66 to 0.88 (0.74 ± 0.10) in group 2, and from 0.53 to 0.77 (0.65 ± 0.08) in group 3 (figure 5, left). The maximum \( T_1-T_2/RR \) ratio ranged from 0.57 to 0.74 (0.67 ± 0.06) in group 1, from 0.75 to 1.0 (0.87 ± 0.09) in group 2, and from 0.68 to 0.91 (0.79 ± 0.08) in group 3 (figure 5, right). In two patients in group 2, L-R shunt flows were observed throughout a cardiac cycle during expiration, so that \( T_1-T_2/RR \) ratio was 1.0. The \( S_2-T_2 \) interval was significantly lower in group 1 than in group 2 (\( p < 0.01 \)), both with respect to the maximum and the minimum values. In group 3, these values were scattered between those in group 1 and group 2.

From catheterization data, pulmonary-to-systemic flow ratio ranged from 0.9 to 3.2 (2.1 ± 0.9) in group 1, from 1.1 to 5.2 (2.7 ± 1.4) in group 2, and from 1.1 to 3.6 (1.9 ± 1.2) in group 3.

The interatrial shunt flow was affected by respiration. The pulsed Doppler echocardiogram from group 1 during respiration is shown in figure 6. During inspiration, the \( S_2-T_2 \) interval decreased and the \( T_1-T_2/RR \) ratio also shortened. During expiration, the \( S_2-T_2 \) interval was lengthened and the \( T_1-T_2/RR \) ratio increased. The same finding was observed in the blood flow pattern obtained with a catheter-tipped velocity sensor. The duration of R-L shunt flow was prolonged during inspiration, which was indicated by a decrease in left atrial pressure. There was no relationship between \( S_2-T_2 \) or \( T_1-T_2/RR \) and arterial oxygen saturation.

**Discussion**

In the patient with an atrial septal defect with concordant ventriculoarterial connection, it seems generally accepted that there are two major peaks in L-R
shunt flow; one is during ventricular systole and early diastole and the other one is during atrial contraction. Trivial R-L shunting occurs at the onset of ventricular contraction.6-10

In contrast, the present study showed that the interatrial shunt was principally biphasic in patients with complete TGA, with R-L shunting in ventricular diastole and L-R shunting in systole. Our present findings are similar to the results reported by Carr6 and by Rudolph.7 Diastolic R-L shunting is considered to be due to the difference in distensibility of the ventricles, which is caused by low left ventricular pressure and high right ventricular pressure load. Systolic L-R shunting is thought to result from the differences in capacity of the pulmonary venous and systemic venous systems.

In group 1, the net volume of L-R flow must have been equal to that of R-L flow because it was the only communication between the pulmonary and systemic circulations. Actually, the T1-T2/RR ratio was nearer to 0.5 in group 1 than in the other two groups (figure 2). Although the minimum T1-T2/RR ratio in group 1 was around 0.5, the maximum ratio was larger than 0.5. These data indicate that the time interval of each R-L and L-R shunt was not of the exact same duration according to the time measurements made in our study. This inequality in the time intervals was considered to be compensated for by the difference of velocity. However, the Doppler recordings did not necessarily show higher velocity in the R-L shunt than in the L-R shunt. This is possibly explained by the fact that R-L and L-R shunting are not nearly parallel to the orifice of the atrial septal defect. Thus, the angle of the beam to flow would differ with changes in direction of the shunt.

The association of TGA with ventricular septal defect and/or patent ductus arteriosus increases pulmonary blood flow. The increase in pulmonary venous return leads to increased interatrial L-R shunting. Although our study was confined only to time interval measurements, in patients with TGA and associated ventricular septal defect and/or patent ductus arteriosus, the time duration of interatrial L-R shunting was prolonged to the extent that it covered a whole RR interval in some cases. From these results it appears that the interatrial L-R shunt is increased not only in time interval but also in the net volume. Cineangiographically, the pulmonary artery is well opacified by right ventriculography via the ventricular septal defect or by aortography via the ductus, although the systemic artery is opacified very little by left ventriculography or by pulmonary arteriography in these patients. Therefore, the ventricular septal defect or patent ductus arteriosus causes the shunt, which directs flow toward the pulmonary artery and away from the systemic ventricle or artery. This increases the interatrial L-R shunt, resulting in a further increase in systemic oxygenation.11

Minimum and maximum values for S2-T2 interval showed a change similar to that in the T1-T2/RR ratio, which was smaller in group 1 than in group 2; in group 3 values were scattered between those in group 1 and group 2. On real-time observations during recording, these minimum and maximum values varied in relation to the respiration. The S2-T2 interval became longer in inspiration and shorter in expiration (figure 6). This was proved by the simultaneous recording of blood flow at the interatrial septum and the left atrial pressure obtained by catheter-tipped transducer. In general, during inspiration systemic venous return increases and pulmonary venous return decreases, which is conventionally explained by the blood pooling in the lungs.12,13 This results in an increase in right atrial filling and a decrease in left atrial filling. This could be the reason that interatrial R-L shunt flow increases during inspiration.

In conclusion, in patients with complete TGA, an interatrial shunt occurs in a rather simple flow pattern. L-R shunting occurs mainly during ventricular systole and R-L shunting occurs during diastole. The flow pattern is affected by respiration and the presence of shunts elsewhere, such as ventricular septal defects, patent ductus arteriosus, and/or BT anastomoses.

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