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Right and left ventricular ejection patterns in D-transposition of the great arteries assessed by pulsed Doppler echocardiography

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Summary

Pulsed Doppler echocardiography (PDE) was performed to evaluate the flow velocity patterns of the right (RVOT) and left ventricular outflow tracts (LVOT) in 10 patients with transposition of the great arteries (D-TGA). Twenty normal children served as controls.

Systolic time intervals (STIs) and acceleration times (AcT) of the right and left ventricles were measured using PDE. The following results were obtained.

1. In normal controls, the right ventricular pre-ejection period (RPEP) was shorter than the left ventricular pre-ejection period (LPEP), and the right ventricular ejection time (RVET) was longer than the left ventricular ejection time (LVET). The mean RPEP/RVET was 0.33 (range 0.25–0.42) and the mean LPEP/LVET was 0.38 (range 0.28–0.55).
2. In normal controls, the flow velocity pattern of the RVOT had a dome-like contour with a peak velocity in mid-systole, and the mean AcT/RVET ratio was 0.50 (range 0.41–0.62); that of the LVOT had a triangular shape with a mean AcT/LVET ratio of 0.31 (range 0.24–0.38).
3. In patients with D-TGA, the RPEP was longer than the LPEP and the RVET was shorter than the LVET. The mean RPEP/RVET was 0.53 (range 0.39–0.76) in patients with intact ventricular septum and 0.52 (range 0.54–0.60) in patients with ventricular septal defect (VSD). The RPEP/RVET was significantly greater in patients with D-TGA than in normal controls. The mean LPEP/LVET was 0.27 (range 0.16–0.42) in patients with intact ventricular septum, and 0.34 (range 0.23–0.40) in patients with VSD. The LPEP/LVET was significantly less in patients with intact ventricular septum than in normal controls.

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4. The flow velocity patterns of the RVOT and LVOT were the same as those for normal controls. The mean AcT/RVET ratio was 0.51 (range 0.49–0.55) in patients with intact ventricular septum and 0.49 (range 0.39–0.67) in patients with VSD. The mean AcT/LVET was 0.32 (range 0.27–0.38) in patients with intact ventricular septum and 0.28 (range 0.20–0.45) in patients with VSD.

The flow patterns did not change after intraatrial baffle repair.

Our studies indicate that the flow velocity patterns of the RVOT and LVOT in patients with D-TGA were not reversed, in spite of inverted afterloads.

Key words

Doppler echocardiography Transposition of the great arteries Blood flow velocity Systolic time intervals

Introduction

Pulsed Doppler echocardiography (PDE) is a valuable non-invasive means of evaluating blood flow in the heart and great vessels with a variety of clinical applications, including the detection of valvular stenosis and insufficiency, and shunt lesions[1~3].

The flow velocity patterns of the right and left ventricular outflow tracts were studied by PDE. In hearts with normally positioned great arteries, the flow pattern in the left ventricular outflow tract (LVOT) is triangular with a peak velocity in early systole. The flow pattern in the right ventricular outflow tract (RVOT) has a dome-like contour with a peak velocity in mid-systole, but in patients with pulmonary hypertension it is triangular with a peak velocity in early systole[4]. This phenomenon has been ascribed to the altered afterload of each ventricle[5].

We analyzed flow patterns of the RVOT and LVOT in patients with transposition of the great arteries (D-TGA), in which the afterload of each ventricle was inverted.

This study assessed the flow velocity patterns of the RVOT and LVOT in patients with D-TGA and evaluated the clinical usefulness of PDE in patients with D-TGA.

Materials and Methods

Seven males and three females with D-TGA, three of whom had VSD, were examined between the ages of one week and $2^1/_2$ years (**Table 1**). Three patients were evaluated before and after Mustard's operation was performed. Ten age-matched normal neonates and 10 normal infants served as controls.

PDE was performed using an Aloka SSD-910 compound ultrasound diagnostic apparatus and a pulsed Doppler transducer combined with a mechanical sector scanner, having a carrier frequency of 3.5 MHz and a pulse repetition frequency of 4.4 KHz. The transducer was placed in the intercostal space at the left lower sternal border or at the apex to obtain a clear two-dimensional (2-D) echocardiogram. Then the sample volumes at each ventricular outflow tract were placed just beneath the semilunar valves (**Fig. 1**).

Doppler signals were analyzed by fast Fourier transform, displayed in the form of frequency spectrum, and were recorded on a strip chart at a paper speed of 100 mm/sec with electrocardiogram, phonocardiogram and M-mode echocardiogram on which depth of the sample volume was marked. The flow away from the transducer was displayed below the baseline; toward the transducer, above the baseline.

On the spectral records of PDE, the time from the Q wave to the onset of ejection (pre-ejection period; PEP), the time from onset to the peak of ejection (acceleration time; AcT), and the time from onset to the end of ejection (ejection time; ET) were measured (**Fig. 2**). Five sequential complexes were measured and averaged to obtain the final STI and AcT.

Cardiac catheterization was performed for

Table 1. **Summary of data of cardiac catheterization and pulsed Doppler echocardiographic** (PDE) **data of 10 patients**

No.		Age	Sex	Diagnosis	Catheterization data				PDE data				
					LVSP (mmHg)	mean PAP (mmHg)	RVSP (mmHg)	mean AoP (mmHg)	HR	RPEP/ RVET	AcT/ RVET	LPEP/ LVET	AcT/ LVET
1.	T.R.	2y0m	F	TGA (I)	35	13	99	77	84	0.39	0.50	0.20	0.29
2.	T.M.	1y0m	M	TGA (I)	40	—	83	67	96	0.54	0.47	0.16	0.31
3.	K.Y.	7m	F	TGA (I)	43	—	94	—	130	0.48	0.55	0.28	0.38
4.	T.K.	1y5m	M	TGA (I)	48	10	110	87	126	0.76	0.48	0.29	0.31
5.	S.M.	10m	M	TGA (I)	56	23	93	79	127	0.52	0.49	0.25	0.32
6.	T.M.	2w	F	TGA (I)	82	—	58	—	160	0.39	0.53	0.26	0.27
7.	I.K.	1w	M	TGA (I)	64	—	75	—	160	0.60	0.54	0.42	0.34
8.	O.K.	1y1m	M	TGA (II)	92	56	80	—	84	0.60	0.42	0.23	0.45
9.	Y.M.	2y6m	M	TGA (II)	96	—	100	75	93	0.51	0.67	0.40	0.20
10.	K.H.	4w	M	TGA (II), & PDA	—	—	92	—	115	0.45	0.39	0.38	0.20

LVSP=left ventricular systolic pressure: mean PAP=mean pulmonary artery pressure; RVSP=right ventricular systolic pressure; mean AoP=mean aortic pressure; HR=heart rate; RPEP=right pre-ejection period; RVET=right ventricular ejection time; AcT=acceleration time; LPEP=left pre-ejection period; LVET=left ventricular ejection time.

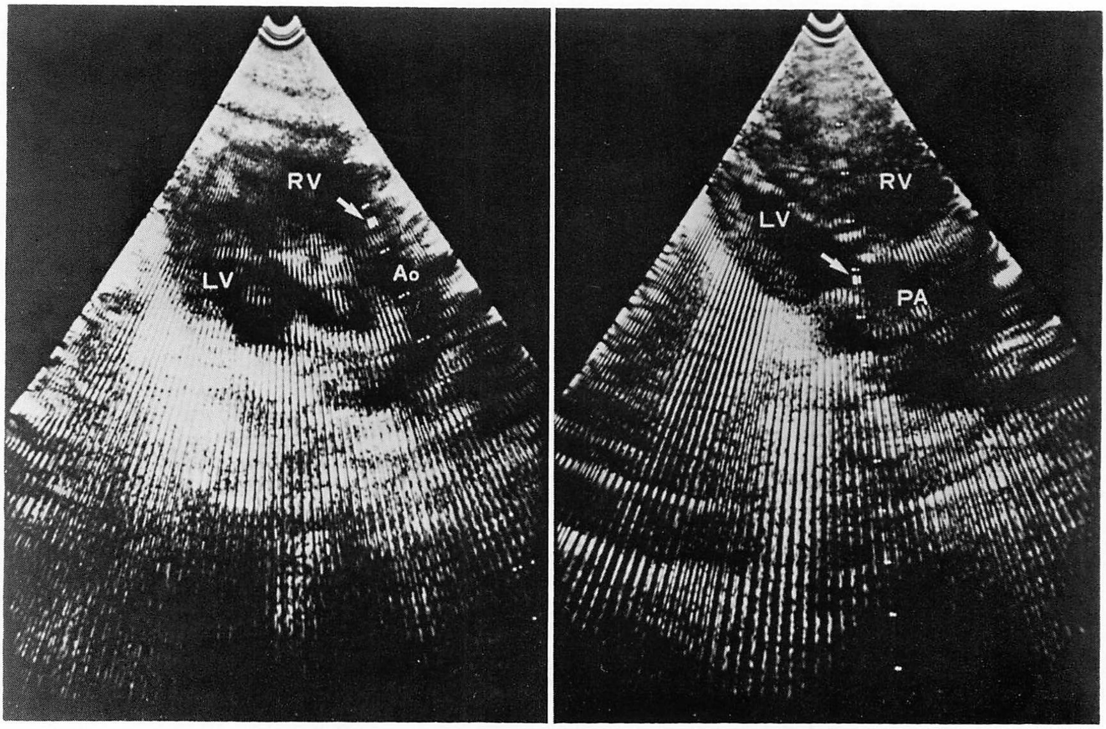

Fig. 1. Two-dimensional echocardiograms illustrating the direction of ultrasonic Doppler beam (white dotted line) **and the sample volume** (white arrow) **in a patient with D-TGA.**
Left: sample volume at the right ventricular outflow tract beneath the aortic cusp.
Right: sample volume at the left ventricular outflow tract beneath the pulmonic valve.
RV=right ventricle; LV=left ventricle; PA=pulmonary artery; Ao=aorta.

patients with D-TGA several days before echocardiography using a standard technique.

Data were expressed as means±standard deviations. Groups' data were compared using the Student's paired or unpaired *t* test. With the two tail test, a probability value of <0.05 was considered significant.

Results

1. Normal controls (Fig. 2)

1) Right and left ventricular systolic time intervals (RVSTI and LVSTI) of normal controls (**Table 2**)

LPEP was longer than RPEP in 16 of 20 controls and the mean LPEP/RPEP ratio was 1.10 (range 0.85–1.49). Left ventricular ejection time (LVET) was shorter than the RVET in 15 of 20 controls and the mean LVET/RVET ratio was 0.95 (range 0.82–1.05). The mean RPEP/RVET ratio was 0.33 (range 0.25–0.42); the mean LPEP/LVET ratio was 0.38 (range 0.28–0.55).

Table 2. The average ratio of left and right ventricular STIs in the normal controls and patients with D-TGA

	Controls	D-TGA (I)	D-TGA (II)
LPEP/RPEP	1.10	0.63	0.78
LVET/RVET	0.95	1.25	1.18
RPEP/RVET	0.33	0.53	0.52
LPEP/LVET	0.38	0.27	0.34

Abbreviations: see Table 1.
D-TGA=D-transposition of the great arteries.

2) Flow velocity patterns in the RVOT and

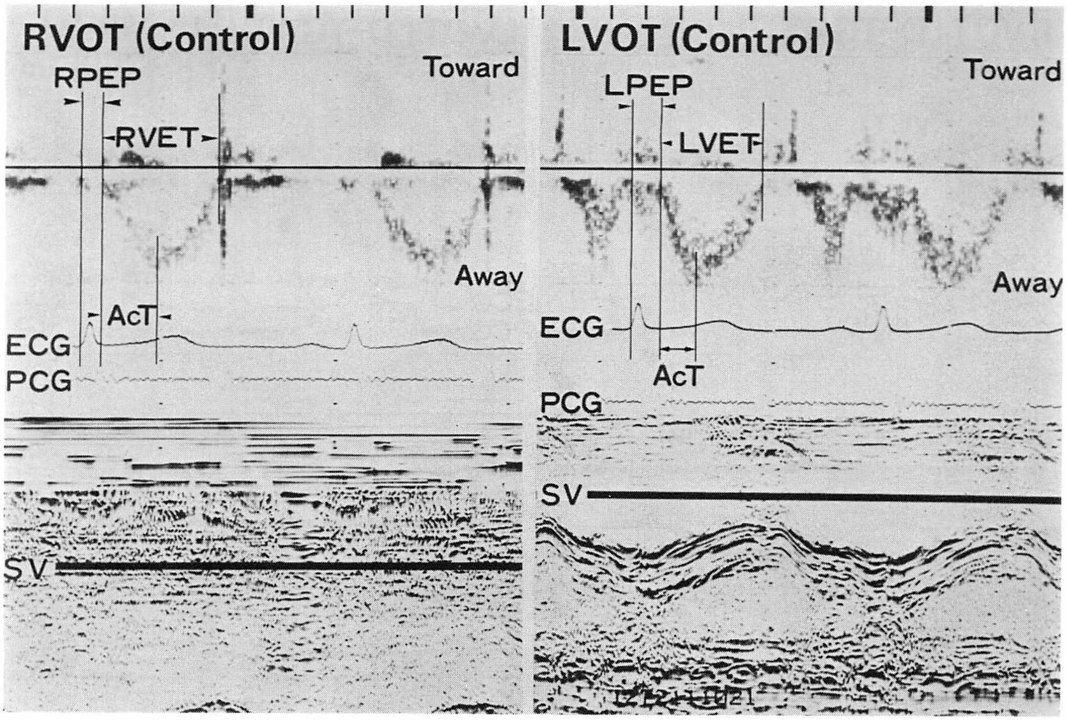

Fig. 2. Flow velocity patterns in the RVOT and LVOT and the method of analysis in a normal control subject.

Flow pattern in the RVOT is dome-like with a peak velocity in mid-systole. Flow pattern in the LVOT is triangular with a peak velocity in early systole.

RVOT=right ventricular outflow tract; RPEP=right pre-ejection period; RVET=right ventricular ejection time; AcT=acceleration time; LVOT=left ventricular outflow tract; LPEP=left pre-ejection period; LVET=left ventricular ejection time; SV=sample volume in M-mode echocardiogram; ECG=electrocardiogram; PCG=phonocardiogram.

LVOT of normal controls (**Table 3**)

The flow velocity pattern of the RVOT was dome-like with a peak velocity in mid-systole and a mean AcT/RVET ratio of 0.50 (range 0.41–0.62). That of the LVOT was triangular and the mean AcT/LVET ratio was 0.31 (range 0.24–0.38).

2. Patients with D-TGA (Fig. 3)

1) RVSTI and LVSTI of patients with D-TGA (**Table 2**)

LPEP was shorter than RPEP in all patients, and the mean LPEP/RPEP ratio was 0.63 (range 0.38–0.88) in patients without ventricular septal defect (VSD), and 0.78 (range 0.50–0.96) in patients with VSD. LVET was longer than RVET in all patients. The mean LVET/RVET ratio was 1.25 (range 1.10–1.46) in patients without VSD, and 1.18 (range 1.09–1.33) in patients with VSD. RVSTI of patients with D-TGA showed prolonged RPEP and shortened

Table 3. The mean AcT/ET ratio in the RVOT and LVOT in the normal controls and in patients with D-TGA

	Controls	D-TGA (I)	D-TGA (II)
AcT/RVET	0.50	0.51	0.49
AcT/LVET	0.31	0.32	0.28

Abbreviations: see Table 1 & 2.

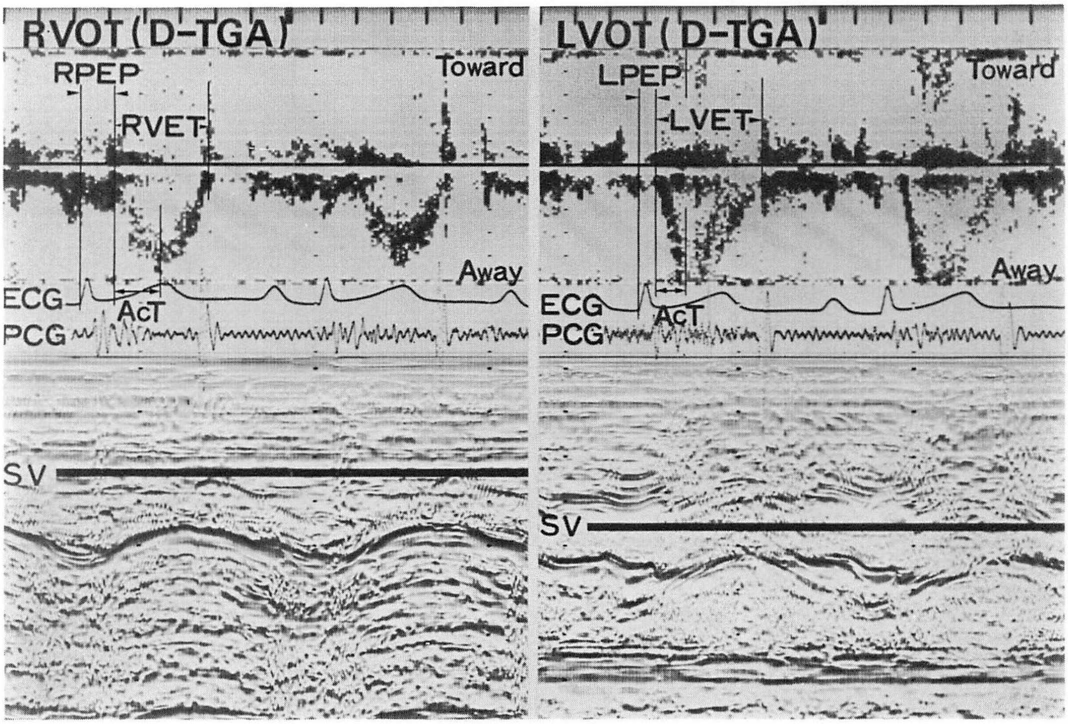

Fig. 3. Flow velocity patterns of the RVOT and LVOT in a patient with D-TGA.

RVSTI shows prolongation of RPEP and shortening of RVET. Flow velocity pattern in the RVOT is dome-like with a peak velocity in mid-systole. LVSTI shows shortening of LPEP and prolongation of LVET. Flow velocity pattern in the LVOT is triangular with a peak velocity in early systole.

Abbreviations: see Fig. 2.

RVET, while their LVSTI showed a shorter LPEP and prolonged LVET.

The mean RPEP/RVET was 0.53 (range 0.39–0.76) in patients without VSD; it was 0.52 (range 0.45–0.60) in patients with VSD. RPEP/RVET was significantly greater in patients with D-TGA than in normal controls ($p<0.001$). The mean LPEP/LVET was 0.27 (range 0.16–0.42) in patients without VSD, and 0.34 (range 0.23–0.40) in patients with VSD. LPEP/LVET was significantly less in patients with intact ventricular septum than in normal controls ($p<0.01$) (**Fig. 4**). Thus, the relationship between RPEP/RVET and LPEP/LVET was reversed in patients with D-TGA. These ratios were not changed after intraatrial baffle repair (**Fig. 5**).

2) Flow velocity patterns in the RVOT and LVOT in patients with D-TGA (**Table 3**)

The flow velocity pattern of RVOT was dome-like with a peak velocity in mid-systole in nine of 10 patients with D-TGA. The mean AcT/RVET ratio was 0.51 (range 0.47–0.54) in patients without VSD and 0.49 (range 0.39–0.67) in patients with VSD. The flow pattern in the LVOT was triangular shape in 9/10 patients. The mean AcT/LVET ratio was 0.32 (range 0.27–0.38) in patients without VSD, and 0.28 (range 0.20–0.45) in patients with VSD. Thus, the ratios AcT/ET both in RVOT and LVOT, were nearly the same as those of normal controls (**Fig. 6**).

The flow patterns were not changed after intraatrial baffle repair (**Fig. 7**).

Discussion

M-mode and two-dimensional (2D) echo-

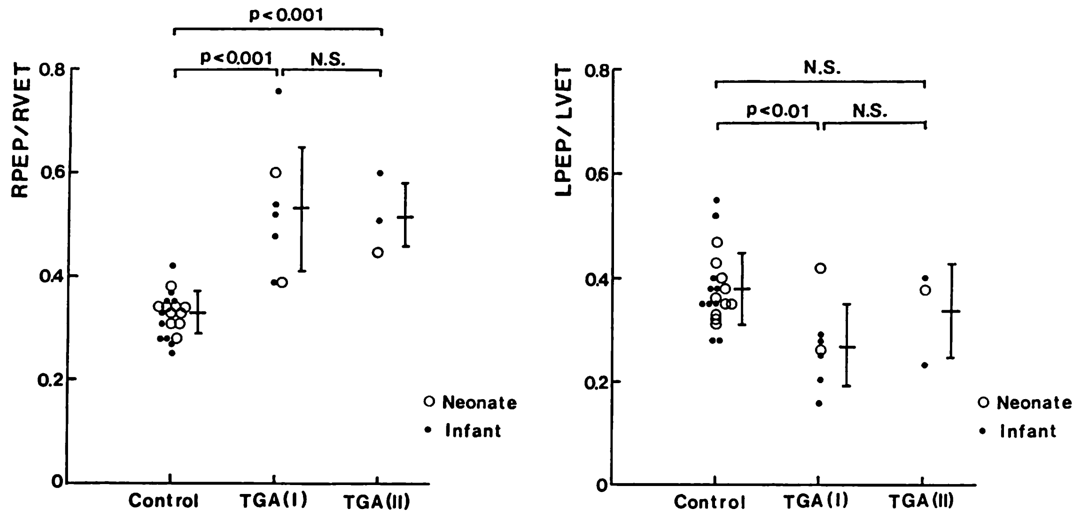

Fig. 4. The RPEP/RVET and LPEP/LVET ratios in normal controls and in patients with D-TGA.

The RPEP/RVET ratios in patients with D-TGA are significantly greater than those of the normal controls. The LPEP/LVET ratios in patients with D-TGA with the intact ventricular septum (TGA-I) are significantly less than those of the normal controls.

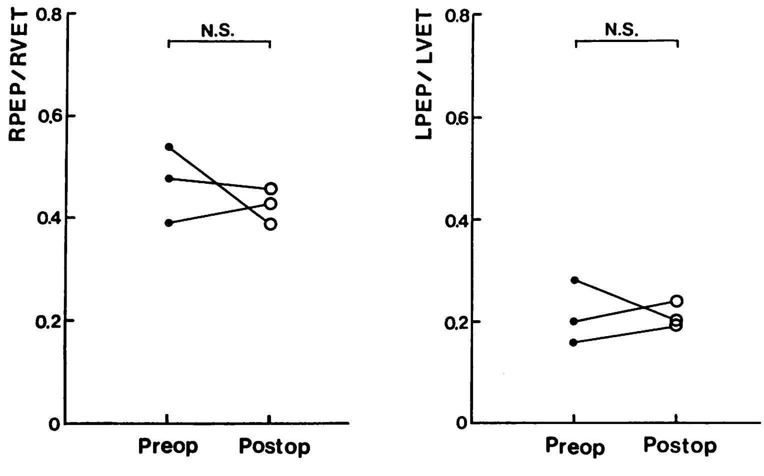

Fig. 5. The RPEP/RVET and LPEP/LVET ratios in patients with D-TGA before and after intraatrial baffle repair.

cardiograms have been used for diagnosing[6], and evaluating cardiac function[7~10] and assessing pulmonary vascular beds[11] in patients with D-TGA. However, few PDE studies have been reported[12,13].

The flow velocity pattern of the right ventricular outflow tract by PDE allows the non-invasive evaluation of pulmonary vascular resistance, pulmonary artery pressure[4,5] and the severity of pulmonic valvular stenosis[14]. Kita-

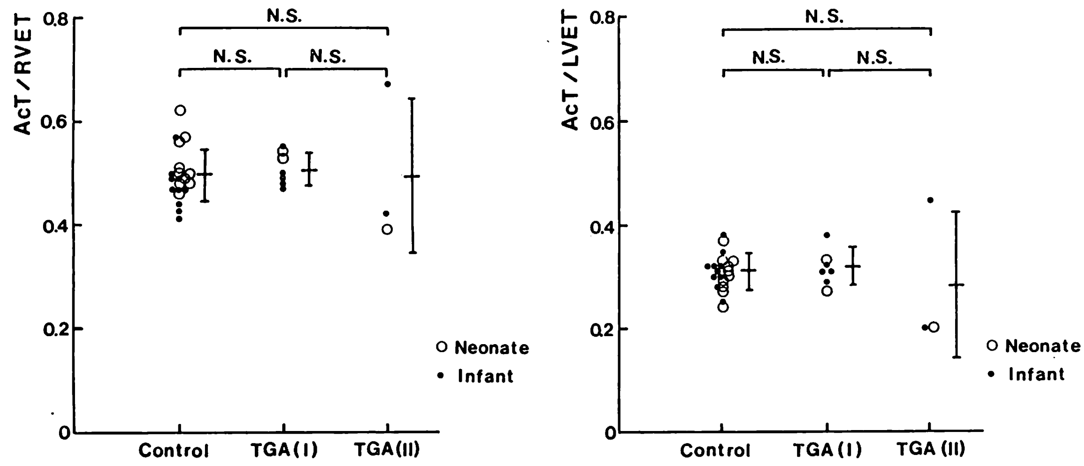

Fig. 6. The AcT/RVET and AcT/LVET ratios in the normal controls and in patients with D-TGA.

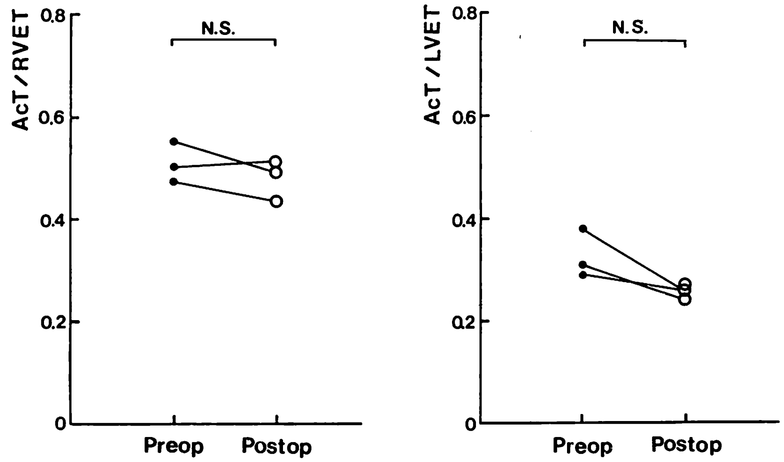

Fig. 7. The AcT/RVET and AcT/LVET ratios in patients with D-TGA before and after intra-atrial baffle repair.

batake et al.[5] reported that a decrease in the AcT/RVET ratio correlates with pulmonary artery pressure in adult patients. Assessment of the pulmonary vascular bed is essential for the management of patients with D-TGA, because of the early development of pulmonary vascular obstructive changes[15,16].

Hemodynamic problems associated with switching ventriculoarterial attachments alter the STI of each ventricle observed using M-mode[17] and the left ventricular geometry observed by 2D echocardiography[18].

Using M-mode echocardiography, Hirschfeld et al.[17] reported the natural reversal of right and left ventricular STIs in children with transposition of the great arteries, and they concluded that prolonged RPEP might have resulted from the increased afterload of systemic pressure or from myocardial dysfunction.

Gutgesell et al. reported that PEP and PEP/LVET correlate closely with pulmonary artery diastolic pressure in patients with D-TGA[11].

In this study, the RVSTI and LVSTI obtained by PDE in patients with D-TGA were nearly the same as those previously reported; i.e., prolongation of RPEP and shortening of RVET, and shortening of LPEP and prolongation of LVET[17]. However, the flow velocity patterns of patients with D-TGA, in whom systemic and pulmonary vascular circuits were inverted, have not been previously described.

We had assumed that the flow velocity patterns of the RVOT of patients with D-TGA would be triangular in shape with peak velocities in early systole, since the right ventricle ejects blood into a relatively high pressure circuit as does the left ventricle in normal controls, and as the right ventricle does in patients with pulmonary hypertension[4,5]. However, it had a dome-like contour with a peak velocity in mid-systole, and the AcT/RVET ratio did not differ significantly from that of normal controls.

Increased right ventricular end-diastolic volumes and low ejection fractions in patients with D-TGA have been reported[10]. The increased AcT/RVET ratio in our patients with D-TGA may have been due to myocardial dysfunction; we could not evaluate the pulmonary vascular bed using this ratio in patients with D-TGA. Lack of change in this ratio after intraatrial repair raised a suspicion of whether the right ventricle can serve as a systemic ventricle.

The flow velocity pattern of the LVOT in patients with D-TGA should have a dome-like contour with a peak velocity in mid-systole, since the left ventricle ejects into a pulmonic circuit of low resistance like the right ventricle in normal controls. In this study it had a triangular shape with a peak velocity in early systole and the AcT/LVET ratio was like that of normal controls.

In patients with D-TGA the LV ejection fraction has been reported to remain normal despite arterial desaturation and some decrease in RV ejection[10]. Since there was some degree of pulmonary hypertension even in patients with intact interventricular septa, the increased afterload might have influenced the flow velocity pattern of the LVOT, and the AcT/LVET ratio showed a pattern identical to that of normal controls.

It is also noted that the STIs and AcT of each ventricle in patients with D-TGA did not change after intraatrial repair.

Conclusions

In patients with D-TGA, the RVSTI and LVSTI correlated inversely with those of normal controls; whereas, the flow velocity patterns obtained using PDE were not reversed, in spite of the inverted afterload.

超音波パルス・ドップラー法による完全大動血管転位における左・右心室流出路血流パターン評価

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要　　約

超音波パルス・ドップラー法 (PDE 法) を完全大血管転位 10 例と正常小児 20 例に施行し，左・右心室流出路駆出血流パターンの評価を行なった．左・右心室の systolic time intervals (STI) と acceleration time (AcT) について，PDE 法を用いて計測した．

1.　正常対照では，右室前駆出時間 (RPEP) は左室前駆出時間 (LPEP) より短く，右室駆出時間 (RVET) は左室駆出時間 (LVET) より長かった．平均 RPEP/RVET は 0.33 (0.25～0.42)，平均 LPEP/LVET は 0.38 (0.20～0.55) であった．

2.　正常対照での右室流出路駆出血流パターンはドーム型で，収縮中期に駆出血流速のピークを持ち，AcT/RVET 比は 0.50 (0.41～0.62) であった．また左室流出路駆出血流パターンは三角型で，収縮早期に駆出血流速のピークを持ち，AcT/

LVET比は0.31(0.24～0.38)であった．

3. 完全大血管転位の患児では，右室前駆出時間(RPEP)は左室前駆出時間(LPEP)より長く，右室駆出時間(RVET)は左室駆出時間(LVET)より短かかった．平均RPEP/RVETは心室中隔欠損を伴わない群で0.53(0.39～0.76)，心室中隔欠損を伴う群で0.52(0.52～0.60)であった．完全大血管転位の患児におけるRPEP/RVETは，正常対照に比べ有意に増大していた．平均LPEP/LVETは心室中隔欠損を伴わない群で0.27(0.16～0.42)，心室中隔欠損を伴う群で0.34(0.23～0.40)であった．心室中隔欠損を伴わない群におけるLPEP/LVETは，正常対照に比べ有意に低下していた．

4. 完全大血管転位における左右の心室流出路駆出血流パターンは，対照群より求めた値と同様であった．平均AcT/RVETは心室中隔欠損を伴わない群で0.51(0.49～0.55)，心室中隔欠損を伴う群で0.49(0.39～0.67)であった．平均AcT/LVET比は心室中隔欠損を伴わない群で0.32(0.27～0.38)，心室中隔欠損を伴う群で0.28(0.20～0.45)であった．

左右心室流出路駆出血流パターンは心房内血流置換術後も変らなかった．

完全大血管転位症例における左・右心室流出路駆出血流パターンは，心室における後負荷の逆転にもかかわらず，逆転がみられなかった．

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