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Outcome of Patients With Double-Inlet Left Ventricle or Tricuspid Atresia With Transposed Great Arteries

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OBJECTIVES We sought to determine the long-term outcomes and risk factors for mortality in patients with double-inlet left ventricle (DILV) or tricuspid atresia with transposed great arteries (TA-TGA).

BACKGROUND Patients with DILV or TA-TGA are at risk of systemic outflow obstruction and a poor outcome. The impact of various management strategies on the long-term outcomes of these patients remains unknown.

METHODS We reviewed the outcomes of 164 consecutive pediatric patients with DILV or TA-TGA who underwent surgical palliation between 1983 and 2002. Patients with a Holmes heart or heterotaxy syndrome or who were lost to follow-up (n = 24) were excluded. Risk factors for mortality or the need for orthotopic heart transplantation (OHT) were assessed by multivariate analysis.

RESULTS There were 105 patients with DILV and 35 patients with TA-TGA. The overall mortality rate, including OHT, was 29%. Patients with DILV had a lower mortality rate than patients with TA-TGA (23% vs. 49%, p = 0.007). Multivariate analysis showed the presence of arrhythmia and pacemaker requirement as independent risk factors for mortality, whereas pulmonary atresia or stenosis and pulmonary artery banding were associated with decreased mortality. Gender, era of birth, aortic arch anomaly, and systemic outflow obstruction were not risk factors. The perioperative and overall mortality were similar between patients who underwent the Damus-Kaye-Stansel procedure beyond the neonatal period and those had subaortic resection.

CONCLUSIONS The mortality of patients with DILV or TA-TGA remains high. The outcomes of these patients are influenced by restriction of pulmonary blood flow, arrhythmia, and pacemaker requirement. Surgical palliation to relieve systemic outflow obstruction is not associated with a poor outcome. (J Am Coll Cardiol 2004;43:113–9) © 2004 by the American College of Cardiology Foundation

Double-inlet left ventricle (DILV) and tricuspid atresia with transposed great arteries (TA-TGA) are two forms of a single left ventricle (LV) at risk of developing systemic outflow obstruction and poor outcomes (1–11). Patients with these types of congenital heart disease frequently have an associated aortic arch anomaly and may develop pulmonary vascular disease due to excessive pulmonary blood flow (5,6). Survival without surgical palliation in this group of patients is poor. Franklin et al. (12) reported a 10-year predicted survival of 11% for patients with systemic outflow obstruction in addition to unobstructed pulmonary blood flow and 79% for patients with pulmonary stenosis and no systemic outflow obstruction.

Systemic outflow obstruction in patients with DILV or TA-TGA can be relieved by the Damus-Kaye-Stansel (DKS) procedure or by resection of the bulboventricular foramen (BVF) and/or the subaortic muscle bundles. It has been speculated that the DKS procedure may provide better outcomes than BVF/subaortic resection, because BVF/subaortic resection carries an increased risk of complete heart block (13,14). In addition, many believe that pulmonary artery banding (PAB) can reduce LV end-diastolic volume, change LV geometry, and thereby lead to acceleration of systemic outflow obstruction (3,6,8,9,15–17). Although the surgical mortalities of these patients have decreased in the current era, it remains unclear whether the different surgical approaches and anatomic variables impact the long-term outcomes (18,19).

The goals of this study were to examine our single-institution experience with surgical palliation of these types of single LV heart defect over 20 years and to determine the effects of anatomic characteristics and surgical management on the long-term outcomes of these children.

METHODS

Patient selection. From 1983 through 2002, there were 164 consecutive pediatric patients (<18 years old) with DILV or TA-TGA who were referred for surgical palliation at our institution. We excluded patients with a Holmes heart (DILV with normally related great arteries) or heterotaxy syndrome, as well as patients lost to follow-up (n =

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Abbreviations and Acronyms

BVF = bulboventricular foramen
DILV = double-inlet left ventricle
DKS = Damus-Kaye-Stansel
LV = left ventricle/ventricular
OHT = orthotopic heart transplantation
OR = odds ratio
PAB = pulmonary artery band/banding
Qp/Qs = pulmonary blood flow to systemic blood flow ratio
TA-TGA = tricuspid atresia with transposed great arteries

24). A total of 140 patients entered into the study, including 105 patients with DILV and 35 with TA-TGA.

Systemic outflow obstruction. Systemic outflow obstruction was defined as obstruction at the BVF or subaortic area, as assessed by echocardiography and cardiac catheterization. Continuous-wave Doppler imaging was used to interrogate the flow velocity at the BVF and subaortic region to calculate the peak instantaneous gradient. During cardiac catheterization, catheter pullback or a simultaneous measurement technique was used to assess the pressure gradient between the LV and ascending aorta. For the purpose of this study, we defined systemic outflow obstruction as a resting peak instantaneous gradient ≥20 mm Hg by echocardiography or a resting peak-to-peak gradient ≥5 mm Hg by cardiac catheterization. Systemic outflow obstruction was considered clinically significant if the patient had findings of LV hypertrophy. In our institution, surgical procedures to relieve systemic outflow obstruction include the DKS procedure and resection of the BVF and/or subaortic muscle bundles. Details of the DKS technique have been reported by our group (20,21) and by others (22).

Clinical outcomes. Clinical outcomes were examined by reviewing the medical records and most recent outpatient follow-up at our institution and by contacting the referring cardiologists. In this study, we defined a subject as having tachyarrhythmia if the subject was treated for recurrent tachyarrhythmia beyond the immediate postoperative period for any surgical procedure. We used "failure of palliation" as the definition for mortality. This definition included patients who died during the study period and patients who underwent orthotopic heart transplantation (OHT) who might be alive with a transplanted heart at the time of follow-up.

Statistical analysis. All data are expressed as the mean value ± SD, unless otherwise stated. The Student *t* test was used for comparing continuous variables between groups. Categorical data were compared using the chi-square test. A p value <0.05 was considered statistically significant. All statistical analyses were performed using SPSS version 8.0 for Windows (SPSS Inc., Chicago, Illinois).

Multiple regression analysis was conducted to evaluate the predictors for mortality or the need for OHT. Kaplan-Meier survival analyses were conducted for all study subjects and for DILV and TA-TGA subgroups separately to compare the survival of these patients up to 25 years of age.

Table 1. Causes of 41 Deaths, Including Heart Transplantation, in the Study Population

	n	% of All Mortality
Perioperative mortality	19	46
Neonatal DKS	9	22
Arrhythmia or sudden death after Fontan operation or Fontan conversion	5	12
BVF resection or DKS procedure	2	5
Pacemaker placement	1	2
BVF resection	1	2
Clotted mechanical valve	1	2
Late mortality	22	54
Tachyarrhythmia	5	12
Sudden death	2	5
Dilated cardiomyopathy	12*	29
HIV infection	1	2
Sepsis	2	5

*Including eight patients who underwent orthotopic heart transplantation.
BVF = bulboventricular foramen; DKS = Damus-Kaye-Stansel; HIV = human immunodeficiency virus.

RESULTS

Patient characteristics. There were 140 patients in the study, with male predominance: 103 males (74%) and 37 females (26%). Of the patients, 78 (56%) were born before 1990 and 62 patients (44%) were born after 1990. There were 105 patients (75%) with DILV and 35 patients (25%) with TA-TGA. The mean age of the patients at the last follow-up was 11.8 ± 8.0 years (median 11.9 years, range 0.02 to 33 years). The median follow-up period was 7.7 years (range 0.01 to 28 years). The mean follow-up periods for patients with DILV and TA-TGA were 9.2 ± 5.8 years and 6.3 ± 6.0 years, respectively ($p = 0.01$).

Mortality. The overall actuarial mortality rate, including patients who underwent OHT, was 29% (n = 41, 8 patients underwent OHT) for the entire cohort of 140 patients. There were 19 perioperative deaths (14% perioperative mortality rate) and 22 late deaths (Table 1). The majority of the perioperative deaths occurred in neonates who underwent the DKS procedure (n = 9). Five patients died of postoperative arrhythmia. The majority of the late deaths were related to dilated cardiomyopathy or tachyarrhythmia. Figure 1 shows the Kaplan-Meier survival curve for all patients. The predicted survival rates for all study patients at 5, 10, 15, and 25 years were 83%, 80%, 75%, and 52%, respectively.

Patients with DILV had better overall survival than patients with TA-TGA (Fig. 2). The predicted survival rates at 5, 15, and 25 years were 89%, 80%, and 63%, respectively, for patients with DILV, and 68%, 63%, and 26%, respectively, for patients with TA-TGA. The differences in the survival rates were most evident in the first five years of life and during the late teen years. Table 2 compares the demographic, anatomic, and surgical variables between

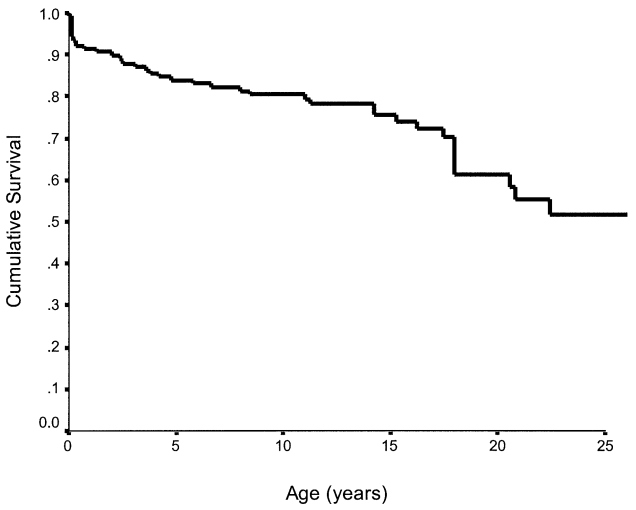

Figure 1. Kaplan-Meier survival curve for all-cause mortality in the entire cohort (n = 140) up to 25 years of age.

DILV and TA-TGA patients. The overall mortality rate for patients with TA-TGA (49%) was significantly higher than that for patients with DILV (24%) (p = 0.007). A higher proportion of patients with TA-TGA (n = 10; 29%) required neonatal DKS, compared with nine patients (9%) with DILV-TGA (p = 0.007). Eight of the 12 patients (67%) with TA-TGA who were >15 years old developed tachyarrhythmia between age 15 and 20 years, compared with 39% of patients with DILV (p = 0.16).

Systemic outflow obstruction and surgical management. Ninety-two patients (66%) developed systemic outflow obstruction and underwent the DKS procedure (n = 51) and/or BVF/subaortic resection (n = 44) to relieve the obstruction. There were 30 deaths (32% mortality rate) in this group of patients, including three perioperative deaths. This mortality rate was not statistically different from the 24% overall mortality rate in patients who did not require surgical relief of obstruction (p = 0.5). The perioperative mortality for BVF/subaortic resection was similar to the perioperative mortality for the DKS procedure performed beyond the neonatal period (2% vs. 3%, p = 0.6). In addition, patients who had the DKS procedure had a cumulative mortality rate similar to that of patients who had BVF/subaortic resection (33% vs. 32%, p = 0.95). Among the 44 patients who underwent BVF/subaortic resection, 15 patients (34%) developed complete heart block requiring pacemaker placement.

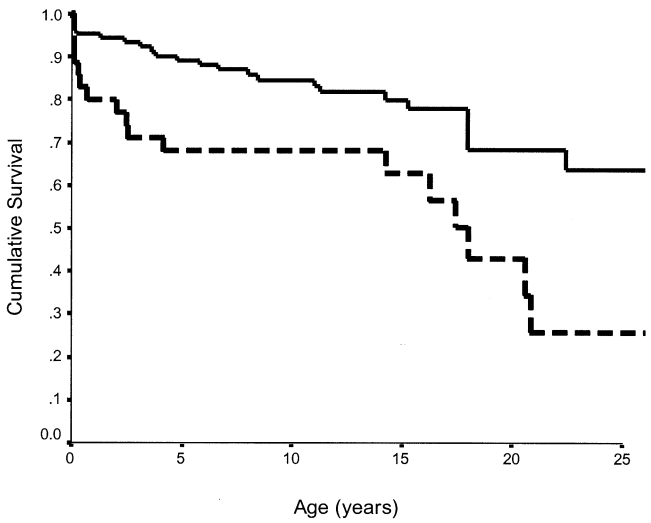

Figure 2. Kaplan-Meier survival curve for all-cause mortality of patients with double-inlet left ventricle up to 25 years of age (n = 105; **solid line**) and patients with tricuspid atresia with transposed great arteries (n = 35; **broken line**).

Table 2. Characteristics of Patients With a DILV and Patients With TA-TGA

	DILV Group (n = 105)	TA-TGA Group (n = 35)	p Value
Gender (M/F)	77/28	26/9	0.91
Mortality	24 (23)	17 (49)	0.007
Tachyarrhythmia	21 (20)	13 (37)	0.069
Complete heart block	21 (20)	3 (9)	0.20
Pacemaker placement	31 (30)	7 (20)	0.38
Arch anomaly	30 (29)	11 (31)	0.91
Pulmonary atresia/stenosis	44 (42)	11 (31)	0.37
Pulmonary artery banding	72 (69)	17 (49)	0.054
DKS procedure	38 (36)	13 (37)	0.92
BVF/subaortic resection	36 (34)	8 (23)	0.29

Data are presented as the number (%) of patients.

DILV = double-inlet left ventricle; TA-TGA = tricuspid atresia with transposed great arteries; other abbreviations as in Table 1.

Pulmonary or subpulmonary stenosis and PAB. By univariate analysis, the mortality rate of patients without pulmonary or subpulmonary stenosis was not statistically different from that of patients with pulmonary or subpulmonary stenosis (36% vs. 19%, p = 0.055) (Table 3), nor was there a statistically significant difference in the mortality rates between patients who underwent PAB and those who did not (23% vs. 39%, p = 0.078) (Table 3). However, by multivariate analysis, the odds ratio (OR) for mortality was

Table 3. Univariate Analysis of Baseline and Surgical Variables Associated With Mortality

	Relative Risk*	p Value
Baseline variables		
TA-TGA vs. DILV	2.13	0.007
Tachyarrhythmia (yes vs. no)	2.69	0.0002
PA/PS (present vs. absent)	0.53	0.055
Coarctation of aorta (present vs. absent)	1.55	0.15
Gender (male vs. female)	0.77	0.48
L-loop vs. D-loop ventricle	0.81	0.54
Surgical variables		
Neonatal DKS procedure	2.79	0.0004
Pacemaker placement	2.56	0.0004
Pulmonary artery banding	0.60	0.078
BVF/subaortic resection	1.13	0.81
DKS procedure beyond neonatal period	1.24	0.55

*Relative risks for mortality were calculated using the underlined groups as the reference (relative risk = 1.0).

PA/PS = pulmonary atresia/pulmonary stenosis; other abbreviations as in Tables 1 and 2.

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Table 4. Multivariate Analysis for Mortality Risk Factors

Independent Variables	Odds Ratio*	95% CI	p Value
Demographic variables			
Male gender (female)	0.59	0.21–1.58	0.29
Born after 1990 (before 1990)	1.11	0.37–3.27	0.86
Anatomic variables			
TA-TGA (DILV)	1.54	0.39–6.09	0.53
Presence of PA/PS (no PA/PS)	0.11	0.02–0.73	0.02
Coarctation of aorta (no coarctation)	3.02	0.80–11.4	0.10
AV valve atresia (no AV valve atresia)	2.05	0.56–7.46	0.28
Surgical variables			
BVF/subaortic resection	1.61	0.47–5.49	0.45
Pulmonary artery banding	0.15	0.03–0.61	0.01
DKS procedure	0.61	0.15–2.51	0.49
Pacemaker placement	4.53	1.56–13.14	0.006
Tachyarrhythmia	4.52	1.40–14.64	0.01

*Odds ratios for mortality were calculated using the groups in parenthesis as the reference (odds ratio = 1.0).

AV = atrioventricular; CI = confidence interval; other abbreviations as in Tables 1 and 2.

significantly lower in patients who had pulmonary or subpulmonary stenosis or PAB (OR 0.11 and 0.15, respectively) than in those who did not have pulmonary or subpulmonary stenosis or PAB (Table 4).

In the comparison of pre-Fontan hemodynamic data, patients who had undergone PAB had higher saturation than patients who had undergone aortopulmonary shunt procedures (85 ± 6% vs. 79 ± 10%, p = 0.002). However, there was no statistically significant difference between the two groups in pulmonary artery pressure (14 ± 4 mm Hg vs. 15 ± 6 mm Hg, p = 0.44), transpulmonary gradient (6 ± 3 mm Hg vs. 6 ± 3 mm Hg, p = 0.85), and LV end-diastolic pressure (9 ± 3 mm Hg vs. 8 ± 3 mm Hg, p = 0.77).

Arrhythmia and pacemaker placement. Of the patients, 34 (24%) developed recurrent late tachyarrhythmia during the study period. The tachyarrhythmia included atrial flutter/atrial fibrillation (n = 26), supraventricular tachycardia (n = 3), and ventricular tachycardia (n = 5); 38 patients (27%) underwent pacemaker placement. Complete heart block was the most common indication for a pacemaker, accounting for two-thirds of all pacemaker placements (Table 5). By univariate analysis, both tachyarrhythmia and pacemaker requirement were strongly associated with increased mortality (Table 3). The mortality rate was 56% for patients who developed tachyarrhythmia, compared with 21% for those who did not (p = 0.0002), and 53% for patients who required pacemaker placement compared with 21% for those who did not (p = 0.0004). By multivariate analysis, both pacemaker requirement and the presence of tachyarrhythmia were significant independent risk factors for mortality (OR 4.5 and 4.5, respectively) (Table 4).

Table 5. Indications for Pacemaker Placement

Reason for Pacemaker	DILV Group (n = 31 [30%])	TA-TGA Group (n = 7 [20%])
Sick sinus syndrome	10	4
Complete heart block secondary to		
BVF resection	13	2
Spontaneous	3	0
Cardiac catheterization	3	1
DKS procedure	1	0

Abbreviations as in Tables 1 and 2.

Table 6. Comparisons of Pre-Fontan Hemodynamic Data by Cardiac Catheterization Between Survivors and Nonsurvivors

	Nonsurvivors (n = 15)	Survivors (n = 63)	p Value
Pulmonary artery pressure (mm Hg)	17 ± 7	13 ± 4	0.03
Transpulmonary gradient (mm Hg)	7 ± 2	6 ± 3	0.17
LVEDP (mm Hg)	8 ± 3	8 ± 3	0.84
BVF gradient (mm Hg)	14 ± 22	9 ± 14	0.28
Pulse oximetry (%)	85 ± 6	83 ± 7	0.37
Qp/Qs ratio	1.8 ± 1.0	1.3 ± 0.7	0.15

Data are presented as the mean value ± SD.

BVF = bulboventricular foramen; LVEDP = left ventricular end-diastolic pressure; Qp/Qs = pulmonary blood flow to systemic blood flow ratio.

Other variables. Variables such as gender, era of birth (before vs. after 1990), atrioventricular valve atresia, coarctation or arch anomaly, and systemic outflow obstruction were not independent predictors of mortality by multiple regression analysis (Table 4).

Fontan palliation. Of the 140 study patients, 95 (68%) underwent the Fontan operation; 11 patients were awaiting the Fontan operation. Thus, 76% of the study patients were considered as candidates for the Fontan operation. Of the patients, 34 (24%) in our series were not candidates for the Fontan operation because of high pulmonary vascular resistance (n = 14), poor ventricular function (n = 5), and death before the Fontan operation (n = 15). Of the 95 patients, 42 (44%) who had undergone the Fontan operation were staged with a Glenn shunt before the operation. The overall mortality rate for patients who completed the Fontan sequence was 22%, including five perioperative deaths (5% mortality) and 16 late deaths. Nonsurvivors had higher pulmonary artery pressure on the pre-Fontan catheterization than survivors (17 ± 7 mm Hg vs. 13 ± 3 mm Hg, p = 0.03) (Table 6). The ages at the Fontan operation for survivors and nonsurvivors were similar (5.0 ± 2.9 years [median 4.3] vs. 5.6 ± 3.6 years [median 4.8], p = 0.53).

Among 42 patients who were staged with a Glenn shunt before the Fontan operation, there were 5 deaths (12% mortality rate), including 2 perioperative deaths and three late deaths. In comparison, there were 16 deaths (30% mortality rate), including 3 perioperative and 13 late deaths, among 53 patients who were not staged before the Fontan operation (p = 0.06). For the nonsurvivors, the mean age at the time of the Fontan operation was not statistically different between patients staged with a Glenn shunt and those nonstaged (3.4 ± 1.1 years [median 3.8] vs. 5.5 ± 3.1 years [median 4.8], p = 0.16). However, patients who were not staged with a Glenn shunt were older at the time of death. The mean age at the time of death for patients with

the Fontan operation without staging was 15.0 ± 7.5 years (median 16.9), compared with 8.1 ± 4.9 years (median 8.4, p = 0.07) for the patients who were staged with a Glenn shunt. The pre-Fontan hemodynamics, with the exception of the pulmonary blood flow to systemic blood flow (Qp/Qs) ratio, were not significantly different between the patients staged with a Glenn shunt and those without staging. Patients not staged with a Glenn shunt had a higher Qp/Qs ratio (1.61 ± 0.81 vs. 1.03 ± 0.41, p = 0.01).

DISCUSSION

Although the clinical outcomes of patients with DILV and TA-TGA have improved significantly from the studies published in the late 1980s (1,5), the overall mortality rate in these patients remains high, despite advancement in medical and surgical management. The cumulative actuarial mortality was 29% (including eight patients who underwent OHT) for our cohort of patients. Because our institution is one of the major referring centers for OHT, this high cumulative mortality may partly result from a selection bias. Nonetheless, this study supports that even with improved surgical palliation, the longevity of a single-ventricle heart remains guarded, with only 52% of the patients having a single LV expected to survive beyond 25 years of age.

Several studies have shown that systemic outflow obstruction results in ventricular hypertrophy and ischemia, leading to a poor outcome (1–11). The overall survival rate of 68% among our patients with systemic outflow obstruction was apparently higher than that reported by Franklin et al. (12) in 1990, where only 15% of patients with DILV and TGA with systemic outflow obstruction survived at 8.5 years of follow-up (5). Additionally, systemic outflow obstruction in the present study was not a significant risk factor for mortality. Although 66% of our patients required surgical intervention for systemic outflow obstruction, the mortality rate for this group of patients was not statistically different from that of patients who did not develop obstruction. We believe that this discrepancy is due to the early recognition and treatment of hemodynamically significant obstruction in our patients. Indeed, very few patients in our study had hemodynamically significant obstruction for a prolonged period. In fact, the survivors and nonsurvivors had a similar systemic outflow gradient on pre-Fontan catheterization.

We had previously proposed that neonates with moderate-size BVF and coarctation could be effectively managed with PAB and repair of the coarctation in the neonatal period, followed by a combined Glenn shunt and DKS at four to six months of age (23). In that study, short-term systemic outflow obstruction did not negatively impact the surgical outcomes of these patients. The present study suggests that short-term and hemodynamically insignificant obstruction (i.e., presence of a gradient without significant ventricular hypertrophy) does not have a significant impact on long-term outcome either. O'Leary et al. (7) showed that ventricular hypertrophy and LV end-diastolic pressure improved after relief of obstruction. This may partly explain why short-term obstruction did not impact the long-term outcomes of these patients. However, systemic outflow obstruction remains a potential threat to the long-term outcomes of patients with DILV or TA-TGA. It is well recognized that many patients who did not have obstruction at presentation develop obstruction over time and after volume-reducing surgeries, such as PAB or the Fontan operation (3,6,8,9,15–17). We have similarly seen a few patients who had "large and unobstructive" BVF as infants who eventually developed cardiomyopathy and required OHT secondary to significant obstruction years after the Fontan operation. This emphasizes the importance of vigilant follow-up for the development of systemic outflow obstruction in these patients.

Although PAB reduces ventricular volume load and can potentially facilitate development of systemic obstruction (3,5,6,15–17,24), PAB itself does not appear to be a risk factor for mortality. In fact, our study showed that protection of the pulmonary vascular bed, either by native pulmonary or subpulmonary stenosis or a surgically placed PAB, is beneficial to the survival of patients with these congenital heart defects. Although PAB could potentially cause pulmonary artery distortion or pulmonary insufficiency and thus make a future Fontan or DKS procedure more difficult, we and others (17,23,25–27) have found that a well-positioned short-term PAB is generally well tolerated in these patients and does not compromise subsequent surgical palliation or long-term survival.

Our data further support that pulmonary or subpulmonary stenosis is advantageous for an improved outcome (12). Some may argue that patients with pulmonary or subpulmonary stenosis have a better outcome because they tend to have a large BVF and are less likely to develop systemic outflow obstruction. However, our data suggest that the survival advantage for this group of patients is not due to the lack of obstruction. When we adjusted for systemic outflow obstruction as a variable, those patients with pulmonary or subpulmonary stenosis still had better survival. The protective effect of pulmonary and subpulmonary stenosis is most likely secondary to protection of the pulmonary vascular bed, which makes the patient a better candidate for Fontan palliation. This is further supported by the fact that among patients who had undergone the Fontan operation, nonsurvivors had higher pulmonary artery pressure on the pre-Fontan catheterization than survivors.

Of our patients, 76% were considered as Fontan candidates; 68% of these patients had already undergone the Fontan operation. This is higher than the rate reported by Franklin et al. (12) in 1991, where only 57% of the patients were suitable candidates for the Fontan operation. Of the patients who were not candidates for the Fontan operation, a major determinant of whether the patient was a Fontan candidate was pulmonary vascular resistance. A comparison of patients who were evaluated for Fontan palliation showed that patients who had undergone PAB had higher satura-

tion than patients who had undergone an aortopulmonary shunt procedure; however, they had similar LV end-diastolic pressure. These data suggest that PAB is an effective procedure to control pulmonary blood flow and provide adequate saturation without a negative impact on ventricular compliance.

Of our patients who had the Fontan operation, 44% were staged with a Glenn shunt. We found that patients who were not staged with a Glenn shunt tended to have worse outcomes (mortality 30% vs. 12% for patients who were staged, $p = 0.06$). However, patients who were not staged with a Glenn shunt were older at the time of death; therefore, the difference in mortality between the two groups of patients may be due to difference in age rather than staging. Alternatively, patients who were not staged with a Glenn shunt had a higher Qp/Qs ratio than those staged, and their ventricles were under higher volume load and thus at greater risk of poor ventricular compliance.

We also found that a pacemaker requirement and the presence of tachyarrhythmia were significant risk factors for mortality. The perioperative mortality rates for BVF/subaortic resection and the DKS procedure performed beyond the neonatal period were similar. However, 15 (34%) of 44 subaortic resections were complicated by complete heart block. The reason for pacemaker requirement as a significant risk factor for mortality was largely due to late deaths, not perioperative deaths. We speculate that it might be some other variables associated with pacemaker and pacemaker requirement that accounted for the late deaths of patients, and the pacemaker itself might not have been the cause of deaths. Because the majority of patients who had pacemaker placement had a DDD pacemaker, it is unlikely that the poor outcome was due to a lack of atrioventricular synchrony. Whether or not pacemaker-induced cardiomyopathy due to asynchrony of the ventricular contraction occurs in patients with a single ventricle remains to be examined.

Atrial tachycardia is the most common type of arrhythmia seen in children after a Fontan operation and has been reported to range from 17% to 50% in follow-up periods of up to 15 years (28–33) and has been shown to be strongly associated with persistent hemodynamic abnormalities (31). Twenty-four percent of our study patients developed recurrent late tachyarrhythmia, the majority being atrial tachycardia, with 56% cumulative mortality. In this study, by both univariate and multivariate analyses, recurrent late tachyarrhythmia was a strong predictor of a poor outcome. Although Ghai et al. (33) and Gewillig et al. (28) showed no statistically significant association between late arrhythmia and mortality in adult patients with the Fontan operation, our study is in agreement with the study by Humes et al. (34), which reported a significant number of late deaths (26%) attributable to arrhythmia. Whether or not this discrepancy in the findings is due to a different study population (adults vs. children, types of single ventricles being studies) is unclear.

Although the subgroup of patients with TA-TGA was younger and had a shorter follow-up time than patients with DILV, our study showed a significantly higher mortality rate in the former group (49% vs. 23%). This difference in mortality was most evident in the first five years of life and during the late teen years. The early mortality in TA-TGA patients was largely due to perioperative deaths associated with the neonatal DKS procedure. The late mortality in these patients may be associated with a higher rate of tachyarrhythmia during the late teens for the TA-TGA subgroup. In this study, we did not compare the outcomes between patients with TA-TGA and patients with tricuspid atresia and normally related great arteries. More studies are needed to investigate the impact of the relation of great arteries on surgical treatment and long-term outcomes of patients with tricuspid atresia.

Conclusions. Although surgical mortality has been significantly reduced, the long-term outcomes of patients with DILV and TA-TGA, albeit improved compared with the last large series study, remain poor. Patients with DILV have better overall outcomes than those with TA-TGA. Late arrhythmia and pacemaker requirement are independent risk factors for mortality. Systemic outflow obstruction, as long as it is recognized and relieved early, has no significant impact on long-term survival. Protection of the pulmonary vascular bed by either naturally occurring pulmonary or subpulmonary stenosis or by PAB, is associated with better survival.

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