FUNCTIONAL OUTCOME AFTER THE FONTAN OPERATION: FACTORS INFLUENCING LATE MORBIDITY

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Objectives: **The purpose of this study was to describe the functional outcome of a large number of patients after modifications of the Fontan operation and to investigate perioperative risk factors that might influence late functional state.** *Methods:* **A comprehensive cross-sectional review of the first 500 patients undergoing a Fontan operation at our institution was undertaken. Those surviving with an intact Fontan circulation were reviewed by questionnaire to assess functional status and medication history. Medical records, chest roentgenograms, echocardiograms, cardiac catheterizations, and laboratory investigations were also reviewed to assess postoperative status.** *Results:* **Three hundred sixty-three long-term survivors with an intact Fontan circulation were identified during cross-sectional follow-up. Median age at operation was 5.0 years (range 0.4 to 31 years), and median follow-up was 5.4 years (range 1.7 to 20 years). Most patients (91.1%) were in New York Heart Association class I or II. In a multivariate model, poor (class III or IV) functional state was associated with longer duration of follow-up ($p < 0.001$), a prior atrial septectomy ($p = 0.03$), and a prior main pulmonary artery–ascending aorta anastomosis ($p = 0.05$).** *Conclusions:* **A poor functional outcome is uncommon after the Fontan operation but becomes more frequent with increasing duration of follow-up. (J Thorac Cardiovasc Surg 1997;114:392-403)**

Over the past 20 years the early operative outcome after the Fontan operation has improved markedly.[1-5] As more patients survive the operation, attention is being drawn to the late sequelae of the Fontan circulation. Recent reports have emphasized a continuing risk of late failure[5-7] and a poor functional outcome in some long-term survivors.[6, 7] Exercise capacity is reduced,[8] atrial arrhythmias are common,[9, 10] some patients may have neurologic or cognitive deficits,[11] and protein-losing enteropathy can be debilitating.[12] Increasing numbers of these patients with poor functional outcome are being referred for cardiac transplantation.[5]

The purpose of this study was to describe the functional outcome of a large number of patients after various modifications of the Fontan operation and to assess perioperative risk factors affecting outcome in this patient population.

Methods

Subjects. The first 500 patients who underwent various modifications of the Fontan procedure at Children's Hospital, Boston, were identified. The date of the operation ranged from April 1973 to July 1991, and cross-sectional follow-up of survivors was undertaken between September 1992 and July 1994. Patients who had died or had undergone cardiac transplantation or takedown of their Fontan circulation to a bidirectional cavopulmonary shunt or an aortopulmonary shunt before the cross-sectional study period were excluded from this analysis. An analysis of patient- and procedure-related risk factors influencing early and late failure is the subject of a separate report.[5]

Patient contact. Records of the Departments of Cardiology and Cardiac Surgery of Children's Hospital, Boston,

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were reviewed and referring centers were contacted. Each patient's current status (alive with a Fontan circulation or otherwise) was thus verified and his or her most recent known address obtained. A questionnaire addressing medication use, medical history, functional state, employment, and insurance status was sent to each surviving patient. If the questionnaire was not returned within 30 days, a second questionnaire was sent, and if this was not returned attempts were made to contact the patient by telephone. If the patient could not be contacted by these means, attempts were made to verify the address and, when necessary, the process was repeated. The study was approved by our institutional review board on August 18, 1992.

Perioperative variables. Medical records, preoperative echocardiographic and cardiac catheterization data, and operation notes were reviewed to obtain the perioperative data outlined in Appendix A.

Outcome measurements. The following outcome indices were obtained.

Subjective data. Age-specific functional data were obtained from the questionnaire and the referring physician, and a New York Heart Association (NYHA) classification of functional status was derived by consensus of three of the authors (T.L.G., S.B.F., and G.W.). The presence of protein-losing enteropathy or liver disease was confirmed by review of the medical records or by contact with the referring physician.

Objective tests. Records were reviewed for the results of the following assessments obtained during the cross-sectional follow-up period: physical examination, chest roentgenogram, and serum liver function tests.

Results of all echocardiograms or cardiac catheterizations after the Fontan operation were recorded (Appendixes B and C). Twelve-lead and ambulatory electrocardiograms and neurologic and psychologic examinations were also undertaken and are the subjects of separate reports.[10, 13] In patients who were not evaluated at our institution, the aforementioned information was obtained from the referring physician.

Statistical analysis. Some outcome measures were not available for all patients. Thus, to determine the extent to which selection bias might have influenced the results, we used the Wilcoxon rank sum test, two-sample t test, or χ^2 test, as appropriate, to compare perioperative data for the subset of patients who had the outcome measure with data for those who did not. The primary outcome of interest, NYHA classification of functional status, was assigned from questionnaire data or physician correspondence, or both. This outcome was then collapsed to form two groups, "good" functional status (class I or II) and "poor" functional status (class III or IV). Relationships with perioperative variables were evaluated by means of contingency table methods and logistic regression analysis. When multivariate models were being constructed, a p value of 0.05 was required for retention in the model. Potential interactions among variables included in the model were examined.

Results

Patient population. Of the 500 patients, 416 (83.2%) survived the early postoperative period with their Fontan circulation intact. During the cross-sectional follow-up period, 398 patients (95.7%) were accounted for; six were lost to follow-up after hospital discharge and a further 12 patients, known to be alive with a Fontan circulation 1.7 to 9.7 years after the Fontan operation, could not be traced.

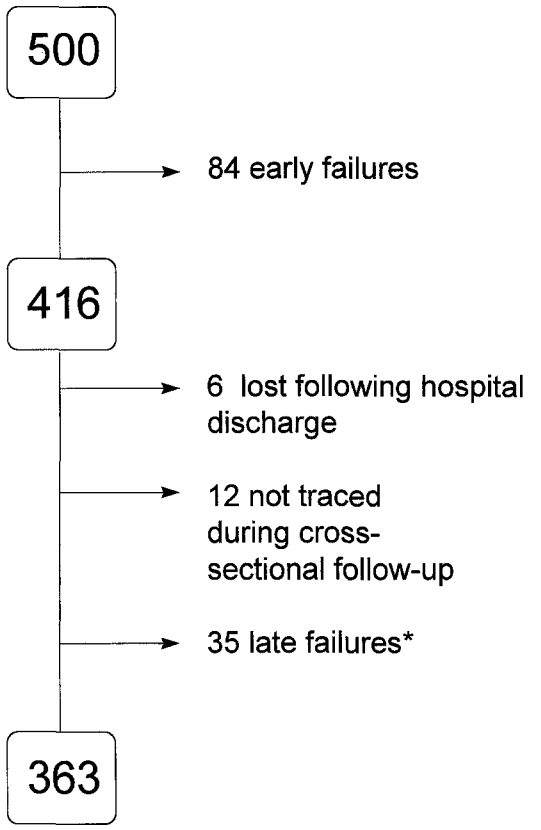

Fig. 1. Outcome in the 500 study patients. *An additional late failure occurred late in the cross-sectional follow-up period. Inasmuch as data collection for this individual had been completed before the failure, this patient has been included in the study group (see text for details).

A total of 35 late failures occurred (defined as death, takedown of the Fontan circulation to an aortopulmonary or cavopulmonary shunt, or cardiac transplantation) in a total of 2464 patient-years of follow-up (1.42 per 100 patient-years). One additional failure occurred late in the cross-sectional follow-up period; inasmuch as data collection for this individual had been completed before the failure, the information obtained has been included in the following analyses. Hence 363 of 381 potential long-term survivors (95.3%) with an intact Fontan circulation were identified during the cross-sectional review period (Fig. 1). No significant differences were noted between these 363 patients and the 18

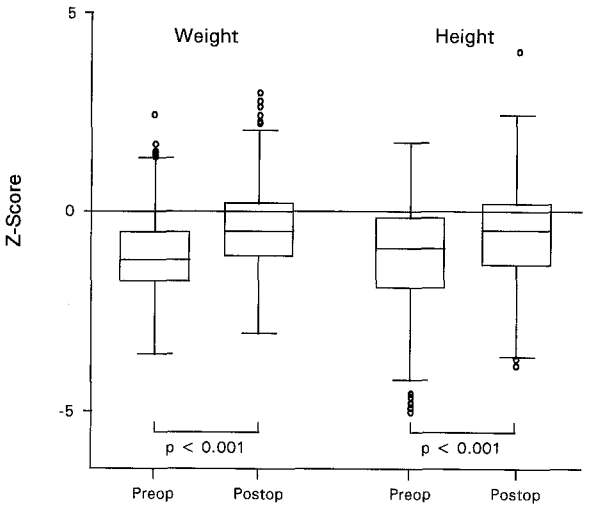

Fig. 2. Box plots of preoperative and postoperative weight and height Z-scores. The *central box* extends from the 25th percentile to the 75th percentile; the *center line* marks the 50th percentile (median). The lines projecting from the box encompass the range of the data, excepting outlying values, which are represented by *circles.*

patients lost to follow-up, except that those lost to follow-up were less likely to have had a baffle fenestration (1/18 [5.6%] vs 125/363 [34.4%], $p = 0.01$).

The median age at operation in the 363 patients identified was 5.0 years (range 0.4 to 31 years). Median follow-up was 5.4 years (range 1.7 to 20 years) and median age at follow-up was 11.1 years (range 3.1 to 42 years). Preoperative diagnoses are detailed in Table I. The Fontan operation involved a conduit between the systemic venous atrium and ventricle or pulmonary artery in 43 patients (11.8%), a direct atriopulmonary connection in 120 (33.1%), and a total cavopulmonary anastomosis with an intracardiac lateral tunnel in 200 (55.1%). A residual connection between the systemic venous pathway and pulmonary venous pathway (baffle fenestration) was created in 125 patients (one with a conduit, 15 with a direct anastomosis, and the remainder with a total cavopulmonary anastomosis).[14] The baffle fenestration was closed with a transcatheter device in 73 patients (30 patients early, 43 patients late), closed spontaneously in 29,[5] and remained open in 23.

Reintervention. Of the 363 patients, 75 (20.1%) underwent 113 late reoperations (>30 days after the modified Fontan operation) and 88 patients (24.2%) underwent 128 transcatheter procedures, with an overall reintervention rate of 10.1 per 100 patient-years (Appendix D). Thirty-four patients (9.4%) had pacemakers implanted, four before the Fontan operation and 30 after.

Table I. *Anatomic subtypes*

Diagnostic group	*No.*	*%*
LV-NRGA	119	32.8
LV-TGA	141	38.8
RV/indeterminate V	43	11.8
Heterotaxy syndrome	26	7.2
Hypoplastic left heart syndrome	14	3.9
Other	20	5.5

LV-NRGA, Left ventricle with normally related great arteries; *LV-TGA,* left ventricle with transposed or malposed great arteries; *RV/indeterminate V,* right ventricle or ventricle of unknown morphology (excluding hypoplastic left heart syndrome and heterotaxy syndrome).

Examination characteristics. Height and weight measurements were available in 219 patients. No significant differences were noted in patient- or procedure-related risk factors or in postoperative functional status between those for whom these data were available and those for whom they were not available. Measurements were standardized with respect to age by subtracting the age-specific mean for the normal population and dividing by the standard deviation to create Z-scores. Height was more than two standard deviations below the normal population mean in 30 patients (13.7%) and weight in 13 patients (5.9%). Overall, the mean height and weight Z-scores were significantly lower than those of a normal population (-0.6 ± 1.3 and -0.3 ± 1.2, respectively; $p < 0.001$ for both). However, when compared with preoperative values, a significant increase was observed in both height and weight at follow-up ($p < 0.001$ for both), indicating catch-up growth had occurred after the Fontan operation (Fig. 2). Transcutaneous oximetry was available in 127 patients. The mean oximetry saturation was $93.1\% \pm 4.1\%$ and ranged from 80%, in a patient with pulmonary vein stenosis and a baffle fenestration, to 100%. A significant difference was noted between oximetry saturations in patients with an open baffle fenestration ($85.1\% \pm 2.3\%$) and those with no baffle fenestration ($93.6\% \pm 3.4\%$) or with a baffle fenestration that had been closed ($94.7\% \pm 2.7\%$, $p < 0.001$). Other examination findings and chest roentgenographic findings are summarized in Tables II and III.

Questionnaire. A questionnaire was completed by 313 of the 363 patients (86.2%). No major differences in patient- or procedure-related risk

Table II. *Additional examination findings (n = 280)*

Examination finding	*No.*	*%*
Systolic murmur	175	62.5
Systolic thrill	4*	1.4
Early diastolic murmur	24	8.6
Middiastolic murmur	4†	1.4
Ascites	1	0.4
Pitting edema	7	2.5

*All four patients with a systolic thrill had systemic ventricular outflow tract obstruction.

†All four patients with a middiastolic murmur had a systemic venous conduit with a residual resting gradient.

Table III. *Chest roentgenograms (n = 154)*

Chest roentogram finding	*No.*	*%*
Cardiomegaly		
None	84	54.5
Mild	37	24.0
Moderate	25	16.2
Severe	2	1.3
Not known	6	3.9
Elevated hemidiaphragm	12	7.8
Pleural effusion	3	1.9

factors were observed between those who returned the questionnaire and those who did not. The median duration of follow-up in these 313 patients was 5.4 years (range 1.7 to 20.2 years), and the median age was 10.3 years (range 2.4 to 41.9 years). Some respondents did not answer each question.

Functional state. Current health was reported as excellent or good by 283 of 310 respondents (91.3%), fair by 26 (8.4%), and poor by one (0.3%). The questionnaire responses to an age-specific assessment of functional state are summarized in Table IV.

Of the 53 questionnaire respondents aged more than 21 years, 50 (94.3%) have completed high school, 16 (30.2%) have completed college, 39 (73.6%) were employed or were students, and 14 (26.4%) were not employed. Eight of these 14 patients attributed their lack of employment to their heart condition. Compared with the other 45 patients aged more than 21 years, these eight were in a lower NYHA functional class (50.0% class III or IV vs 4.4%, $p < 0.001$) and rated their health less favorably (62.5% fair or poor vs 15.6%, $p = 0.003$). Health insurance coverage in this adult population was similar to that in the younger age group (89.6% vs 92.2%, p = not significant; analysis restricted to U.S. residents).

Medications. A medication history was obtained in 327 patients (90.1%). One hundred twenty-four (37.9%) were receiving no cardiac medications, and 31 (9.5%) were receiving four or more cardiac medications. Antiarrhythmic medication (other than digoxin) was taken by 36 (11.0%) (Fig. 3).

NYHA functional class. NYHA class could be assigned from questionnaire data or physician correspondence, or both, in 359 patients (98.9%). No major differences were observed between perioperative variables in the groups with and without a known NYHA class, except that patients who had a fenestration were more likely to have had an NYHA class assigned ($p = 0.01$). Of the 359 patients, 327 (91.1%) were in class I or II ("good" outcome) whereas 32 (8.9%) were in class III or IV ("poor" outcome) (Table V). Relationships between functional outcome and perioperative variables were evaluated. Results of univariate and multivariate analyses are detailed in Table VI. A multivariate logistic regression model suggested that longer follow-up time (odds ratio 1.3, $p < 0.001$), a prior atrial septectomy (odds ratio 3.0, $p = 0.03$), and a prior main pulmonary artery–ascending aorta anastomosis or ventricular septal defect enlargement (odds ratio 3.4, $p = 0.05$) were associated with an increased probability of poor NYHA classification. Immediate postoperative variables such as right atrial pressure, duration of hospital stay, and prolonged pleural or pericardial effusions were not independent predictors of functional outcome in the multivariate model. Furthermore, neither the presence or absence of a baffle fenestration at the time of operation, nor its status (open or closed) at the time of follow-up, was associated with functional outcome.

Laboratory investigations

Synthetic liver function. Serum albumin was below the normal range (< 3.4 gm/L) in four of 92 patients (4.3%) for whom data were available: all four had symptomatic protein-losing enteropathy. The prothrombin time was available in 67 patients (excluding those receiving warfarin). It was normal (<12.5 seconds) in 28 patients (41.8%), mildly elevated (12.5 to 13.5 seconds) in 36 patients (53.7%), and markedly elevated (≥14 seconds) in three patients (4.5%), one of whom had protein-losing enteropathy. The international normalized ratio was not systematically recorded.

Enzymatic liver function. Measurements of serum transaminases (aspartate transaminase or alanine

Table IV. *Response to questionnaire—Age-specific functional status*

Age at follow-up		*No.*	*%*
<6 years	Median follow-up duration 2.9 years (range 1.8-5.9 years)		
(n = 52)	Physical limitation:		
	No limitation	36	69.2
	Slight limitation (stops playing earlier than peers)	13	25.0
	Severe limitation (unable to partake in "usual" activities)	3	5.8
6-17 years	Median follow-up duration 5.4 years (range 1.7-15.3 years)		
(A: n = 187)	Physical limitation:		
	No limitation	65	34.8
	Slight limitation	93	49.7
	Significant limitation	27	14.4
	Severe limitation	2	1.1
(B: n = 184)	Maximal amount of activity:		
	Takes part in gym class, keeps up with peers	82	44.6
	Takes part in gym class, does not keep up	78	42.4
	Cannot take part in gym class, tires walking one block	18	9.8
	Unable to judge	6	3.3
≥18 years	Median follow-up duration 9.9 years (range 2.2-20.2 years)		
(A: n = 69)	Physical limitation:		
	No limitation	13	18.8
	Slight limitation	43	62.3
	Significant limitation	11	15.9
	Unable to perform daily living tasks without discomfort	2	2.9
(B: n = 70)	Maximal amount of activity:		
	Participate in strenuous activity	15	21.4
	Climb three flights of stairs	20	28.6
	Perform heavy housework	8	11.4
	Participate in light sports	12	17.1
	Climb one flight of stairs	10	14.3
	Perform light housework	5	7.1

Note: Not all patients responded to all questions.

transaminase) were available in 97 patients and were within normal limits in four (4.1%), mildly elevated (less than twice the upper limit of normal) in 86 (88.7%), moderately elevated (two to three times the upper limit of normal) in five (5.2%), and severely elevated (more than three times the upper limit of normal) in two patients (2.1%). No patient is known to have cirrhosis, but one individual with serologic evidence of previous hepatitis C infection has chronic active hepatitis.

Protein-losing enteropathy. Protein-losing enteropathy, defined as persistent hypoalbuminemia (<3.0 mg/dl) in the absence of liver or renal disease, with accompanying clinical features including abdominal pain, diarrhea, edema, and ascites, was present in nine of the 363 patients (2.5%) traced during the cross-sectional follow-up period. An additional two patients whose Fontan circulations failed before the cross-sectional follow-up period were known to have protein-losing enteropathy. Hence protein-losing enteropathy developed in 11 of the 416 early survivors (2.6%) with an intact Fontan circulation, a rate of 0.45 cases per 100 patient-years.

Discussion

This study details the functional status of a large number of patients who underwent the Fontan operation over a period that encompassed many changes in preoperative management and operative technique. The majority of patients (more than 90%) perceived their state of health to be good or excellent and were able to partake in most of the activities of daily living. Most adults were either employed or continuing tertiary education, a finding similar to that reported by Mair, Puga, and Danielson.[15] Nevertheless, cardiac medication use was common, and reintervention was frequent. Furthermore, a small group of patients were more severely limited and, disturbingly, the incidence of limitation appeared to be related to length of follow-up. Because duration of follow-up in this cohort is closely related to age at follow-up, date of operation, age at operation, and type of operation, it is not

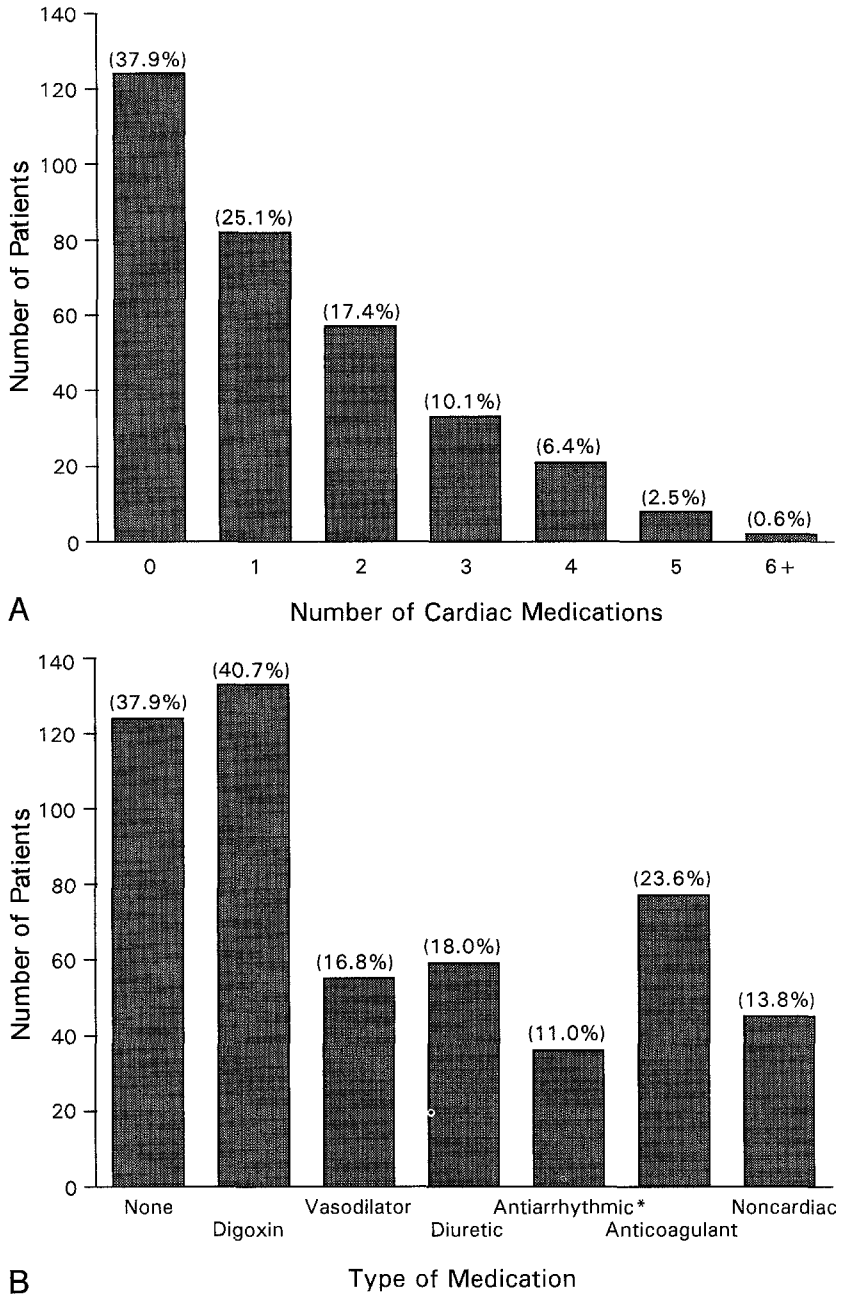

Fig. 3. A, Number of medications per patient. **B,** Type of medications (many patients were receiving more than one type of medication). *Antiarrhythmic medication other than digoxin.

possible to be certain as to the cause of the poorer functional state of patients followed up for longer periods. In addition, the perception of limitation and expectations alter with age; limitations are less apparent to the parents and family of young children than they are to adolescents and adults. Nir and coworkers[16] found no deterioration in serial exercise tests in a small group of patients after the Fontan operation, suggesting that changing expectations may be an important factor.

Procedural variables including a history of prior atrial septectomy, main pulmonary artery–ascending aorta anastomosis, or ventricular septal defect enlargement were also associated with a poor functional state. These procedures are common in patients with left-sided atrioventricular valve atresia or

Table V. *NYHA functional class at follow-up (n = 359)*

NYHA class	*No.*	*%*
I	190	52.9
II	137	38.2
III	32	8.9
IV	0	0.0

stenosis, left ventricular hypoplasia, and obstruction of the systemic outflow tract. We have also found these anatomic subgroups to be associated with a higher risk of early and late failure of the Fontan circulation.[5] Reasons for the poorer outcome in these subgroups are speculative and probably multiple. Ventricular hypertrophy exacerbated by outflow tract obstruction may impair diastolic function and thus increase central venous pressure.[17] Only three patients in this series had ventricular septal defect enlargement; thus it is unlikely that ventricular dysfunction resulting from myocardial resection is a contributing cause. However, many did have hypoplastic left heart syndrome, an anatomic subtype particularly at risk for ventricular dysfunction as a result of ventricular morphology, coronary artery anomalies, extensive palliative procedures in early infancy, or residual arch obstruction.

Neither the presence nor absence of a baffle fenestration was related to functional outcome. Although numbers are small—only 23 patients had an open fenestration at follow-up—these findings suggest that mild arterial desaturation is well tolerated. Fenestration closure frequently results in a fall in resting cardiac output and an increase in systemic venous pressure.[18] Furthermore, it is possible that the ability to increase cardiac output with exercise is enhanced when a patent fenestration is in place. A study of cardiorespiratory exercise capacity before and after fenestration closure would clarify this issue.

Driscoll and colleagues[7] have identified heterotaxy as a risk factor for death and for a poor functional outcome in survivors. Although heterotaxy syndrome was not a risk factor for poor functional outcome in the current series, we[5] have found it to be a predictor of late failure of the Fontan circulation; many patients with heterotaxy syndrome had Fontan failure before the cross-sectional review and therefore could not be included in an analysis of late functional outcome.

Atrial arrhythmias, especially sinus node dysfunction and atrial flutter, are an important cause of morbidity after the Fontan operation. A significant minority of patients in the current series were receiving antiarrhythmic medication or had undergone pacemaker implantation. Using the same patient cohort, we[10] have previously demonstrated that atrial flutter was less likely to occur in patients in NYHA class I (10%) than in those with class II or class III symptoms (21% and 26%, respectively, $p = 0.02$). In addition, the atrial flutter became more prevalent with increasing duration of follow-up; the probability of freedom from atrial flutter was 94.6% at 2 years, 89.7% at 5 years, and 67.7% at 10 years. Atrial arrhythmias may well have contributed to the association between poor functional outcome and duration of follow-up in the current series.

Although height and weight were lower than those of the normal population, the group as a whole exhibited "catch-up" growth after the Fontan operation. This suggests that many patients had a more favorable hemodynamic state after the operation than before; chronic preoperative cyanosis and congestive heart failure may have a greater impact on growth than the elevated central venous pressure and low-normal cardiac output after the Fontan operation. Neurologic, psychologic, and developmental abnormalities are another important cause of morbidity in this patient group. A detailed investigation in a subgroup of this cohort is the subject of a separate report.[19]

Laboratory investigations. Minor abnormalities in serum liver function tests were common. Others have reported a small but important incidence of cirrhosis after the Fontan operation.[7] Our study population included no patients with cirrhosis, but a number, who have not had definitive investigations, had at least moderately elevated transaminase levels. In addition to hepatic congestion, transfusion-related hepatitis, particularly hepatitis C, should be considered as a cause of elevated transaminase levels. Abnormal coagulation factors, particularly the procoagulation factor protein C, have been reported after the Fontan operation.[20] To our knowledge, a high prevalence of abnormal prothrombin times has not been reported. This finding may be related to hepatic dysfunction resulting from chronic congestion and carries important clinical implications; care should be taken when administering medication that requires hepatic metabolism and especially when titrating warfarin for anticoagulation.

Limitations. This cross-sectional review documents the functional state of a large number of

Table VI. *Perioperative variables associated with a poor functional outcome (n = 359)*

	Univariate analysis		*Multivariate analysis*		
	Good vs poor outcome (n = 327 vs n = 32)	*p Value*	*Odds ratio*	*95% Confidence interval*	*p Value*
Diagnosis (hypoplastic left heart syndrome)	3.1% vs 12.5%	0.02			
Prior coarctation repair	9.8% vs 21.9%	0.04			
Prior atrial septectomy	12.5% vs 28.1%	0.02	3.0	1.1-8.3	0.03
Prior PA-Ao anastomosis or VSD enlargement	8.3% vs 18.8%	0.06	3.4	1.0-11.1	0.05
Prior Glenn shunt (unidirectional cavopulmonary shunt)	7.6% vs 18.8%	0.04			
Type of Fontan procedure (conduit)*	9.8% vs 34.4%	<0.001			
Valve in systemic venous pathway	5.8% vs 28.1%	<0.001			
Earlier year of operation (1973-1984)	18.0% vs 53.1%	<0.001			
Longer hospital stay after Fontan operation	15.7 ± 13.8 vs 22.3 ± 24.4 days	0.03			
Longer duration of follow-up	6.0 ± 3.4 vs 9.5 ± 4.4 years	<0.001	1.3	1.2-1.4	<0.001

Analyses compare functional outcome (good = NYHA class I or II, poor = NYHA class III or IV) for perioperative variables. Variables associated with functional outcome at a level $p < 0.1$ by univariate analysis were entered into a multivariate logistic regression model (see text for details). *PA-Ao,* Main pulmonary artery–ascending aorta; *VSD,* ventricular septal defect.

*Poor outcome was more commonly associated with a modification of the Fontan operation using a conduit and least commonly associated with a total cavopulmonary anastomosis.

patients who underwent the Fontan operation between 1973 and 1991 and survived with an intact circulation. Those in whom the Fontan repair failed before the cross-sectional review are not included in the current analysis but are the subject of a separate report.[5] It is possible that outcomes in this study may not reflect the expected long-term results in those operated on more recently at our institution. Patients now tend to be younger at the time of the Fontan operation and are more likely to have an intermediate bidirectional cavopulmonary shunt. They are therefore less likely to be exposed to long-standing ventricular volume overload. Perhaps most important, the duration of "late" postoperative follow-up remains relatively short. Information gathered over the coming decades will further delineate the progress of this challenging group.

A large number of variables were analyzed with respect to functional outcome. However, operations were performed over several decades, and it was not possible to gather sufficient data relative to factors such as preoperative ventricular hypertrophy or pulmonary artery size that may well affect late outcome.[17, 21] In addition, catheterization and echocardiographic data available at the time of the cross-sectional review were unsuitable for analysis in that they had frequently been collected because of a specific clinical concern. It was therefore not possible to relate factors such as postoperative hemodynamics, ventricular function, or atrioventricular valve regurgitation to functional outcome.

Conclusions

At a mean follow-up of 5.4 years after the Fontan operation, more than 90% of patients are satisfied with their overall health and quality of life. Catch-up growth occurs after the Fontan operation, but height and weight are less than in the normal population. Furthermore, late reintervention, medication use, and liver function abnormalities are prevalent. Functional state may deteriorate with increasing duration of follow-up, but the cause of this phenomenon is not clear.

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Appendix A. *Perioperative variables*

Patient-related	
Demographics	Age at operation
	Year of operation
	Sex
Diagnosis	Left ventricle with normally related great arteries
	Left ventricle with transposed great arteries
	Right ventricle and ventricle with unknown morphology
	Hypoplastic left heart syndrome
	Heterotaxy syndrome
	Other
Atrioventricular valve anatomy	
Systemic ventricular morphology	
Anomalous pulmonary venous drainage	Yes, no
Anomalous systemic venous drainage	Yes, no
Atrioventricular valve regurgitation	None, mild, moderate, severe
Pulmonary artery distortion	Yes, no
Previous procedures	Aortopulmonary shunt
	Atrial septectomy
	Pulmonary artery band
	PA-Ao anastomosis or VSD enlargement
	Coarctation repair
	Unidirectional cavopulmonary shunt (Glenn)
	Bidirectional cavopulmonary shunt (bidirectional Glenn)
	Pulmonary artery reconstruction
	Pacemaker
Preoperative hemodynamics	Ao saturation, hemoglobin
	LAp, RAp, Aop, PAp
	Qp, Qs, Qp/Qs, Qp + Qs, PVR
	Ventricular work ((Qp + Qs) × Aop)
	Total resistance to pulmonary blood flow ([LAp/(Qp + Qs)] + PVR)
Procedure-related	
Type of atriopulmonary connection	Conduit
	Direct
	Total cavopulmonary anastomosis with lateral tunnel
Baffle fenestration	Yes, no
Coronary sinus position	Left, right
Origin of the atriopulmonary connection	
Distal connection points	
Valve in atriopulmonary connection	Yes, no
Valve anywhere on right side	Yes, no
Additional procedures	
Myocardial preservation technique	
Cardiopulmonary bypass time	
Aortic crossclamp time	
Postoperative—immediate	
Systemic atrioventricular valve	
Systemic ventricle	Left, right, both, indeterminant
Systemic atrioventricular valve/baffle relationship	
Postoperative pressures on day of surgery	Systemic venous atrium and pulmonary venous atrium
Postoperative—other	
Prolonged effusions (drainage ≥14 days)	Yes, no
Duration of hospital stay	
Reoperations	None, minor, major
Baffle fenestration	Never, open, closed

PA-Ao, Pulmonary artery–ascending aorta; *VSD,* ventricular septal defect; *LAp,* mean left atrial pressure; *RAp,* mean right atrial pressure; *Aop,* mean aortic pressure; *PAp,* mean pulmonary artery pressure; *Qp,* indexed pulmonary blood flow; *Qs,* indexed systemic blood flow; *PVR,* indexed pulmonary vascular resistance (see text for details).

Appendix B. *Echocardiographic findings (n = 281) (5.3 ± 3.8 years after the Fontan operation)*

Atrioventricular valve regurgitation	
Mitral	
Absent or trivial	178 (75.4)
Mild	42 (17.8)
Moderate	3 (1.3)
Severe	0 (0.0)
Not known	13 (5.5)
Tricuspid	
Absent or trivial	109 (67.7)
Mild	39 (24.2)
Moderate	5 (3.1)
Severe	0 (0.0)
Not known	8 (5.0)
CAVV	
Absent or trivial	6 (24.0)
Mild	13 (52.0)
Moderate	4 (16.0)
Severe	0 (0.0)
Not known	2 (8.0)
Semilunar valve regurgitation	
Absent or trivial	218 (77.6)
Mild	35 (12.4)
Moderate	2 (0.7)
Severe	0 (0.0)
Not known	26 (9.3)
Systemic ventricular outflow tract obstruction (MIG >10 mm Hg)	
None	241 (85.8)
Sub AS	19 (6.8)
Not known	21 (7.5)
Ventricular function*	
Normal	192 (68.3)
Mildly impaired	38 (13.5)
Moderately impaired	25 (8.9)
Severely impaired	4 (1.4)
Not known	22 (7.8)

CAVV, Common atrioventricular valve; *MIG,* Doppler-derived maximal instantaneous gradient; *Sub AS,* subaortic stenosis.
*Subjective assessment of ventricular function.

Appendix C. *Postoperative catheterization hemodynamics (n = 177) (3.5 ± 3.8 years after the Fontan operation)*

Variable	*No.*	*Mean ± SD*	*Range*
Systemic venous atrial pressure (mm Hg)*	174	12.3 ± 3.6	5-24
Pulmonary artery pressure (mm Hg)	173	11.7 ± 3.4	4-22
Pulmonary artery wedge pressure (mm Hg)	143	7.2 ± 3.2	1-18
Aortic saturation (%)	172	92.8 ± 4.5	76-100
Cardiac index (L/min/m^2)	149	2.5 ± 0.8	1.1-4.8
Pulmonary vascular resistance (wu · m^2)	121	2.3 ± 1.3	0.7-9.0
Systemic vascular resistance (wu · m^2)	131	29.6 ± 10.8	12-74

SD, Standard deviation.
*There was a mean gradient >2 mm Hg between the systemic venous "atrium" and the pulmonary arteries in 36% of patients with a systemic venous conduit (many of whom were catheterized because of suspected conduit obstruction), in 6% of patients with a direct right atrium–pulmonary artery anastomosis, and in no patient with a total cavopulmonary anastomosis.

Appendix D. *Late reintervention*

Late reoperation (113 procedures in 75 patients)	
Pacemaker insertion/replacement	38
Conduit revision/replacement	13
Relief of subaortic obstruction	10
Closure of residual atrial right-to-left shunt	11
Pericardiotomy	10
Revision of right atrioventricular valve patch	3
Conversion to total cavopulmonary anastomosis	4
Baffle revision or cavopulmonary anastomosis for systemic venous obstruction	4
Atrioventricular valve replacement	3
Baffle revision for pulmonary venous obstruction	1
Closure of residual left-to-right shunt	1
Other	15
Interventional cardiac catheterization (128 procedures in 88 patients)	
Clamshell closure of fenestration	43
Coil embolization of aortopulmonary collaterals	25
Device or coil occlusion of residual defect in atrial baffle	10
Stent placement in systemic venous conduit	10
Branch pulmonary arterioplasty	16
Radiofrequency ablation	5
Stent placement for systemic ventricular outflow tract obstruction	4
Dilation of stenosed conduit or cavopulmonary anastomosis	4
Device closure of residual ventricular-cavopulmonary communication	2
Other	9