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Predictors of Survival After Single-Ventricle Palliation

The Impact of Right Ventricular Dominance

Yves d'Udekem, MD, PhD,* Mary Y. Xu, BMedSci,* John C. Galati, BSc, PhD,† Siming Lu, BMedSci,* Ajay J. Iyengar, MBBS, BMedSci,* Igor E. Konstantinov, MD, PhD,* Gavin R. Wheaton, MD,‖ James M. Ramsay, MD,¶ Leeanne E. Grigg, MBBS,# Johnny Millar, MB, ChB, PhD,‡ Michael M. Cheung, MD,§ Christian P. Brizard, MD*

Melbourne, Adelaide, and Perth, Australia

Objectives This study examined survival after surgical palliation in children with single-ventricle physiology.

Background Contemporary surgical outcomes for the entire population of newborns undergoing single-ventricle palliation are unclear.

Methods In a single-center review of 499 consecutive patients undergoing univentricular palliation from 1990 to 2008, predictors of mortality were determined using multivariate risk analysis, stratified for each post-operative stay and interim states.

Results After 2000, the population comprised more patients with dominant right ventricle (66% vs. 36%) and hypoplastic left heart syndrome (HLHS) (47% vs. 13%). Median age at bidirectional cavopulmonary shunt (BCPS) decreased from 15 months (10 to 22 months) before 2000 to 4 months (3.3 to 9 months) thereafter. Survival rates at 1, 5, and 10 years were, respectively, 82% (95% confidence interval [CI]: 79% to 85%), 74% (95% CI: 70% to 78%), and 71% (95% CI: 67% to 75%). Throughout the study, atrioventricular valve regurgitation (hazard ratio [HR]: 1.8; p = 0.008), not having transposition (HR: 2.0; p = 0.013), and heterotaxia (HR: 2.0; p = 0.026) were predictors of mortality. The most potent risk factor was right ventricular (RV) dominance (HR: 2.2; p = 0.001) because of its impact before BCPS. HR for death in patients with RV dominance went from 2.8 (95% CI: 1.4 to 5.7; p = 0.005) before BCPS to 1.0 (95% CI: 0.5 to 2.1; p = 0.98) thereafter. Survival of patients with RV dominance, adjusted for the risk factors noted here, improved over the study period (p = 0.001).

Conclusions Considerable mortality is still observed during the first years of life among patients with single ventricle. RV dominance is the most important risk factor for death but only before BCPS. (J Am Coll Cardiol 2012;59:1178–85)

Exact expectations of survival into adulthood for patients born with a univentricular heart remain to be specified. There have been a large number of publications detailing outcomes after specific surgical procedures (1–4) and linear reports for specific conditions (5–7), but they tend to give a fragmented perspective on this whole population. Currently, there are only 2 reports examining survival in a longitudinal cohort of patients born with single ventricle. Among these, 1 study was not a surgical series and included patients

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who had not undergone surgical palliation (8). The second study was a historical one in which contemporary measures of

From the *Department of Cardiac Surgery, Royal Children's Hospital, Murdoch Children's Research Institute, and the Department of Pediatrics, University of Melbourne, Melbourne, Australia; †The Clinical Epidemiology and Biostatistics Unit, Murdoch Children's Research Institute, Melbourne, Australia; ‡The Intensive Care Unit, Royal Children's Hospital, Melbourne, Australia; §Department of Cardiology, Royal Children's Hospital, Melbourne, Australia; ‖Department of Cardiology, Women's & Children's Hospital, Adelaide, Australia; ¶Department of Cardiology, Princess Margaret Hospital for Children, Perth, Australia; and the #Department of Cardiology, Royal Melbourne Hospital, Melbourne, Australia. Dr. d'Udekem is a Career Development Fellow of the National Heart Foundation of Australia (CR 10M 5339). This research project was supported by the Victorian Government's Operational Infrastructure Support Program. The authors have reported that they have no relationships relevant to the contents of this paper to disclose.

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Table 1 Patient Characteristics According to Era

	Overall (N = 499)	Born Before 2000 (n = 265)	Born After 2000 (n = 234)
Demographics			
Male/female	309/190	164/101	145/89
Extracardiac defects	87 (17)	37 (14)	50 (21)
Dominant diagnosis			
Tricuspid atresia	75 (15)	52 (20)	23 (10)
Double-inlet left ventricle	62 (12)	43 (16)	19 (8)
Double-outlet right ventricle	40 (8)	26 (10)	14 (6)
Complete atrioventricular canal	29 (6)	12 (5)	17 (7)
Pulmonary atresia with intact ventricular septum	36 (7)	27 (10)	9 (4)
Hypoplastic left heart syndrome	143 (29)	34 (13)	109 (47)
Ebstein's anomaly of the tricuspid valve	5 (1)	5 (2)	0 (0)
Complex	103 (21)	66 (25)	37 (16)
Other	6 (1)	0 (0)	6 (3)
Predominant ventricular morphology			
Left	210 (42)	142 (54)	68 (29)
Right	250 (50)	96 (36)	154 (66)
Biventricular	30 (6)	19 (7)	11 (5)
Indeterminate	9 (2)	8 (3)	1 (0.5)
Other morphological characteristics			
Atrial isomerism	62 (12)	39 (15)	23 (10)
Left	20	13	7
Right	42	26	16
Bilateral superior vena cavae	84 (17)	45 (17)	39 (17)
Common atrioventricular valve	72 (14)	38 (14)	34 (15)
Atrioventricular valve regurgitation*	66 (13)	30 (11)	36 (15)
Transposition of the great arteries	112 (22)	64 (24)	48 (21)
Hypoplastic aortic arch	209 (42)	65 (25)	144 (62)
Interrupted aortic arch	15 (3)	9 (3)	6 (3)
Coarctation of the aorta	78 (16)	47 (18)	31 (13)
Aortic stenosis	39 (8)	30 (11)	9 (4)
Aortic atresia	85 (17)	19 (7)	66 (28)
Pulmonary stenosis	111 (22)	96 (36)	15 (6)
Pulmonary atresia	83 (17)	50 (19)	33 (14)

Values are n (%) or n. *Moderate or severe atrioventricular valve regurgitation, as defined by echocardiogram at birth.

treatment were not applied (9). Considerable improvement in the surgical management of hypoplastic left heart syndrome (HLHS) has been repeatedly reported (5,6,10–12), but it is unclear whether progress has been limited to this specific condition. We retrospectively reviewed our experience to evaluate the contemporary outcomes of patients undergoing surgery for single-ventricle physiology.

Methods

This study was approved by our institutional human research ethics committee. The records of all children born with a functionally single ventricle between 1990 and 2008 at the Royal Children's Hospital Melbourne were reviewed. Follow-up data were gathered from our database and reports from referring cardiologists. Patients were included if their anatomy precluded a biventricular repair. Overseas patients were excluded.

A total of 543 patients were identified. Of these, 44 patients were excluded because they had died before surgical palliation (n = 38), proceeded directly to heart transplantation (n = 2), or had not undergone an operation at last follow-up (n = 4). The remaining 499 patients all underwent surgical palliation and constitute the core of this study. Patients' characteristics are given in Table 1. The definition of HLHS was strictly limited to those with aortic and mitral hypoplasia or atresia and a small ascending aorta. Complex cardiac morphology was defined as the presence of ≥2 major cardiac malformations that could not be grouped into a single diagnosis.

We defined neonatal palliation as one of the following procedures: Norwood operation, systemic–pulmonary shunt, pulmonary artery banding procedure, Damus-Kaye-Stansel connection, attempted biventricular repair, total anomalous pulmonary venous drainage repair, or arterial

Abbreviations and Acronyms

BCPS = bidirectional cavopulmonary shunt
CI = confidence interval
HLHS = hypoplastic left heart syndrome
HR = hazards ratio

Table 2 Risk Factors for Mortality for Entire Cohort

	HR	p Value	95% CI
Univariate analyses			
Atrial isomerism	2.82	0.000	1.87–4.25
Dominant right ventricle	2.26	0.000	1.54–3.32
Atrioventricular valve regurgitation*	2.34	0.000	1.55–3.54
Common atrioventricular valve	2.23	0.000	1.50–3.33
No transposition of great arteries	2.57	0.001	1.49–4.42
Hypoplastic arch	1.58	0.019	1.08–2.33
Aortic atresia	1.56	0.042	1.02–2.41
Bilateral superior vena cavae	1.50	0.059	0.98–2.27
Atrioventricular discordance	0.38	0.060	0.14–1.04
Pulmonary atresia	0.62	0.064	0.38–1.03
Hypoplastic left heart syndrome	1.41	0.089	0.95–2.10
Interrupted inferior vena cava	1.75	0.115	0.87–3.53
Biventricular morphology	1.49	0.169	0.85–2.62
Dextrocardia	1.36	0.300	0.76–2.44
Interrupted aortic arch	1.45	0.378	0.63–3.32
Coarctation of aorta	1.15	0.521	0.75–1.76
Aortic stenosis	1.18	0.581	0.66–2.09
Mesocardia	1.46	0.603	0.35–6.09
Pulmonary stenosis	0.95	0.827	0.59–1.52
Multivariate analysis			
Biventricular morphology	1.86	0.086	0.92–3.75
Dominant right ventricle	2.17	0.001	1.39–3.41
Atrioventricular valve regurgitation	1.79	0.008	1.16–2.77
No transposition of great arteries	2.03	0.013	1.16–3.54
Atrial isomerism	1.95	0.026	1.08–3.50
Common atrioventricular valve	1.11	0.717	0.62–1.98

Stratified cox regression analysis was performed. Univariate factors with $p < 0.05$ and HR >2.0 or HR <0.5 were selected for inclusion in the multivariate analysis. *Moderate or severe atrioventricular valve regurgitation, as defined by echocardiogram at birth.
HR = hazard ratio.

switch. The surgical techniques used in these patients have been described previously (1,2).

Statistical analysis. Survival was estimated by using Kaplan-Meier curves. Patients were considered at-risk from birth, and risk factors for mortality were investigated by using Cox regression. The list of variables analyzed to estimate their effect on mortality is given in Table 2. Because the patients' experiences were characterized by undergoing various step procedures, conventional Cox regression analysis did not seem appropriate. Our study was characterized by successions of hospital stays to perform intermediate step operations, during which a peak of mortality could be expected, and intermediate periods between surgeries during which a more constant rate of death was expected. To allow for this anticipated difference in instantaneous risk of death during and after each of the surgical procedures, a stratified Cox model was used. In the stratified model, each patient record was divided into the following time segments: hospital stay (or up to 30 days) after the neonatal surgery, interval between neonatal surgery and bidirectional cavopulmonary shunt (BCPS), hospital stay (or up to 30 days) after BCPS, and interval between BCPS and Fontan completion. The lack of mortality during and after Fontan precluded analysis of risk factors for these time periods.

The stratified Cox model allows for different instantaneous risk of death during and after each surgical procedure but assumes that the effect of each risk factor remains constant across stages. To assess differences in relative hazards at different stages, Cox regressions were performed separately for each of the 4 stages described here. The results suggested that effects of risk factors were similar across the initial hospital stay and survivors of initial surgery stages, and also across the BCPS hospital stay and survivors of BCPS stages but differed before and after BCPS. Therefore, to increase statistical power in these analyses, we pooled initial hospital stay and survivors of neonatal surgery into a single stratified Cox model; we did the same for BCPS hospital stay and survivors of BCPS surgery.

To assess whether survival had improved over time, Cox regression was used, with calendar time included as an explicit covariate in the model. One unit of time was set to the entire 18-year study period, so that the hazard ratio (HR) for the time covariate refers to the relative hazard of

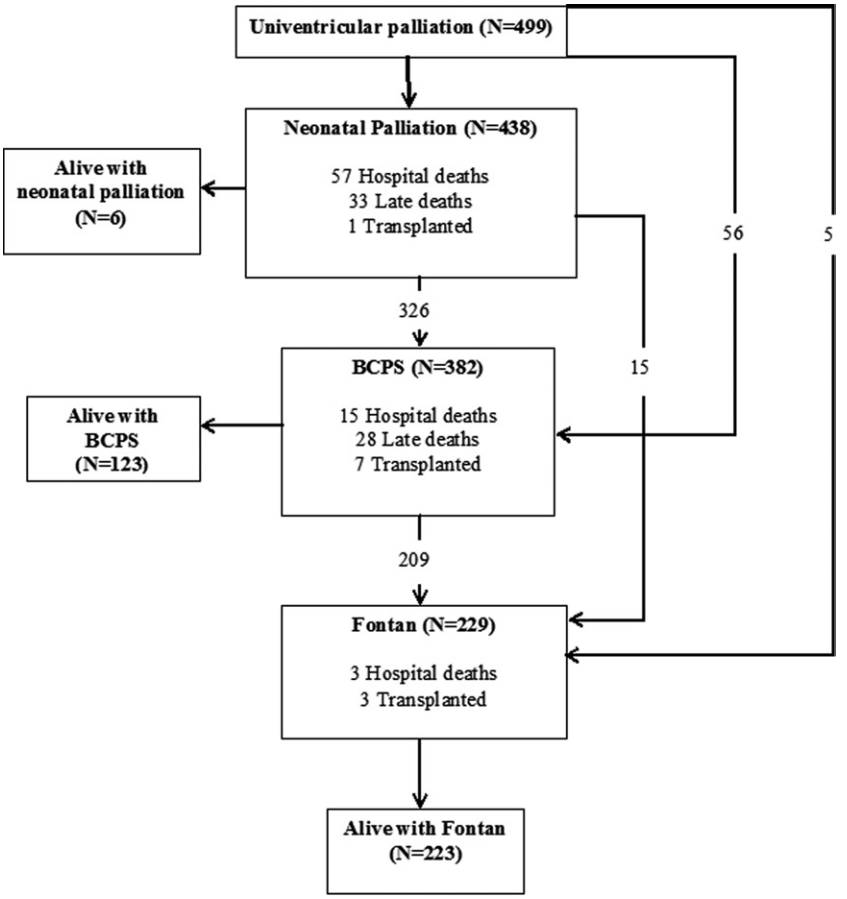

Figure 1 Patient Outcomes

The final status of all 499 patients enrolled in the study.

patients at the end of the study period (2008) compared with patients at the start of the study period (1990). To account for changes in the prevalence of risk factors in the study population over time, these analyses were adjusted for the dominant mortality risk factors in Table 2. To provide a consistency check on these continuous time results, analyses were also undertaken with period of birth as a covariate, where period of birth refers to birth either before or after 2000.

All statistical analyses were performed by using Stata version 11 (Stata Corp., College Station, Texas).

Results

Outcomes. Complete follow-up was obtained for 98% of patients, with a mean follow-up duration of 6.6 ± 5.3 years. The surgical procedures performed and patient outcomes are described in Figure 1 and Table 3. Of the 499 patients who were offered surgery, 438 underwent a first operation in the neonatal period at a median age of 7 days (1 to 855 days). There were 57 hospital deaths (hospital mortality 13%).Thirty-three of the 381 hospital survivors of this neonatal operation died before BCPS at a median age of 5.8 months (1.4 to 90 days). Thirty-two patients underwent an additional 35 cardiac procedures between hospital discharge and BCPS.

Of the 499 patients, 382 underwent a BCPS. The characteristics of these patients are listed in Table 4. The age at which the BCPS was performed gradually decreased over the study period, from a median age of 14.8 months for patients undergoing BCPS during 1990 to 1991 to 3.4 months for patients undergoing BCPS during 2007 to 2008. Two patients required BCPS takedown. Fifteen patients died during the hospital stay after BCPS (3.9%).

After hospital discharge following BCPS, an additional 28 deaths occurred before Fontan completion. The interim mortality between BCPS and Fontan completion did not appreciably improve between the first decade and the second decade of the study. It was 8.9% (16 of 180 patients) between 1990 and 1999, and 6.6% (12 of 182 patients) between 2000 and 2008 (HR = 0.8; p = 0.55). Sixteen patients underwent an additional 17 cardiac procedures before proceeding to Fontan completion.

At last follow-up, 229 of the 499 patients had undergone Fontan procedure at a median age of 5 years (1.3 to 16.0 years). Operative mortality was 1.3% (3 of 229 patients). There were no late deaths after Fontan completion during the study period.

Eleven patients underwent heart transplantation after univentricular palliation: 1 between neonatal palliation and BCPS, 7 between BCPS and Fontan, and 3 after the Fontan procedure. Two patients died after heart transplantation. Three patients were listed for heart transplantation at the time of the study; all 3 had previously undergone Fontan surgery.

Survival analysis. The risk of death of the overall population was the highest the first 5 years, and after that time, mortality remained minimal (Fig. 2). Survival rates at 1, 5, and 10 years were 82% (95% confidence interval [CI]: 79% to 85%), 74% (95% CI: 70% to 78%), and 71% (95% CI: 67% to 75%), respectively. Survival remained stable thereafter, with 15-year survival holding at 71%.

Results of Cox regression analyses for the whole period are displayed in Table 2. According to multivariate

Table 3 Surgical Procedures and Mortalities

	n	No. of Hospital Deaths	Hospital Mortality (%)	No. of Interstage Deaths	Interstage Mortality (%)
Neonatal palliation					
Norwood procedure	137	28	20.4	12	11.0
Systemic-pulmonary shunt	179	10	5.6	14	8.3
Pulmonary artery banding	100	8	8.0	4	4.3
Damus-Kaye-Stansel connection	15	7	46.7	3	37.5
Other	7	4	57.1	0	0.0
Total	438	57	13.0	33	8.7
BCPS					
BCPS	298	9	3.0	17	5.9
Bilateral BCPS	60	5	8.3	8	14.5
Kawashima operation	12	0	0.0	2	16.7
Classic Glenn	10	1	10.0	1	11.1
Other	2	0	0.0	0	0.0
Total	382	15	3.9	28	7.6
Fontan surgery					
Atriopulmonary connection	4	0	0	0	0
Lateral tunnel	41	0	0	0	0
Extracardiac conduit	184	3	1.6	0	0
Total	229	3	1.3	0	0

BCPS = bidirectional cavopulmonary shunt.

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Table 4 Characteristics of Patients Who Underwent Bidirectional Cavopulmonary Shunt (N = 382)

Demographics	
Male/female	232/150
Median age at surgery (months)	9.6 (4–16)
Dominant diagnosis	
Tricuspid atresia	62 (16)
Double-inlet left ventricle	57 (15)
Double-outlet right ventricle	26 (7)
Complete atrioventricular canal	21 (6)
Pulmonary atresia with intact ventricular septum	27 (7)
Hypoplastic left heart syndrome	101 (26)
Ebstein's anomaly of the tricuspid valve	5 (1)
Complex	79 (21)
Other	4 (1)
Predominant ventricular morphology	
Left	178 (46)
Right	179 (47)
Biventricular	18 (5)
Indeterminate	7 (2)
Other morphological characteristics	
Atrial isomerism	39 (10)
Left	15
Right	24
Bilateral superior vena cavae	67 (18)
Interrupted inferior vena cava	15 (4)
Transposition of the great arteries	97 (25)
Atrioventricular valve regurgitation*	43 (11)
Prior staging with neonatal palliation	326 (85)
Neonatal palliation	
Norwood procedure	95 (29)
Modified Blalock-Taussig shunt	101 (31)
Pulmonary artery banding	80 (25)
Damus-Kaye-Stansel connection	10 (3)
Central shunt	33 (10)
Other	7 (2)

Values are n or n (%). *Indicates moderate or severe atrioventricular valve regurgitation determined on echocardiogram at birth.

analysis, independent predictors of mortality were right ventricular dominance (HR: 2.2; p = 0.001), atrioventricular valve regurgitation (HR: 1.8; p = 0.008), absence of transposition of the great arteries (HR: 2.0; p = 0.013), and atrial isomerism (HR: 2.0; p = 0.026). The 1-, 5-, 10-, and 15-year survival rates for patients born with single left ventricle were, respectively, 94% (95% CI: 90% to 96%), 87% (95% CI: 82% to 91%), 85% (95% CI: 79% to 89%), and 85% (95% CI: 79% to 89%) compared with 74% (95% CI: 67% to 79%), 64% (95% CI: 57% to 70%), 60% (95% CI: 53% to 67%), and 60% (95% CI: 53% to 67%) for patients born with single right ventricle.

Results of Cox regression analyses restricted to initial hospital stay and survivors of neonatal palliation are displayed in Table 5. Of the 7 factors identified by using univariate analysis as potential predictors of mortality, only right ventricular dominance (HR: 2.8; p = 0.005) and atrial isomerism (HR: 2.8; p = 0.002) clearly remained independent predictors in the subsequent multivariate analysis. There was moderate evidence for atrioventricular valve regurgitation (HR: 1.9; p = 0.013) being an independent risk factor, whereas the results for having a hypoplastic arch (HR: 1.95; p = 0.066) and absence of transposition of the great arteries (HR: 2.0; p = 0.074) were inconclusive. There was no evidence that aortic atresia (HR: 1.2; p = 0.53) was an independent predictor of mortality. In addition, a test of equality of HRs for dominant right ventricle patients with and without HLHS revealed no evidence that those with HLHS fared worse than those without (difference in HR: −0.31; p = 0.76).

Corresponding results for BCPS hospital stay and survivors of BCPS are displayed in Table 6. Univariate analysis identified common atrioventricular valve (HR: 3.6; p < 0.001), bilateral superior vena cavae (HR: 3.1; p = 0.001), and atrial isomerism (HR: 3.0; p = 0.004) as potential risk factors for mortality post-BCPS. However, due to the smaller number of deaths after BCPS (Table 3), subsequent multivariate analysis was inconclusive, with no factors being clearly identified as predictive of mortality. Most notably, there was no evidence that dominant right ventricle remained a predictor of mortality after BCPS (HR: 1.0; p = 0.98).

Predictors of mortality remained similar when the analysis was performed separately on the first or the second decade of the study (1990 to 1999 vs. 2000 to 2008). HLHS morphology registered as a univariate predictor of mortality before 2000 (HR: 2.2; p = 0.01) but not thereafter (HR: 1.2; p = 0.47). From 2000 onward, there was no difference in survival between patients diagnosed with HLHS and patients with a dominant right ventricle of a different morphology (Fig. 2). The 1-, 5-, and 10-year survival rates for HLHS versus non-HLHS right ventricle were 75% (95% CI: 67% to 83%) versus 69% (95% CI: 53% to 80%), 70% (95% CI: 61% to 78%) versus 65% (95% CI: 48% to 76%), and 65% (95% CI: 53% to 75%) versus 60% (95% CI: 43% to 73%), respectively.

The era of birth did not influence survival of patients with dominant left ventricle (HR: 0.7; p = 0.55), whereas patients with dominant right ventricle showed clear improvement in survival over time (HR: 0.3; p = 0.001). Results from analyses using decade of birth were consistent with the continuous time results.

Discussion

The assumption that, in the past 2 decades, there has been a dramatic improvement in the survival of infants born with a single ventricle is based on a scarcity of data. Numerous reports have demonstrated improvements in outcomes after the Norwood procedure (5,6,13), yet it is unclear whether these improvements can be extrapolated to all patients born with a univentricular heart. Similarly, the low mortality rates after Fontan surgery, reported in contemporary series, may not accurately reflect mortality

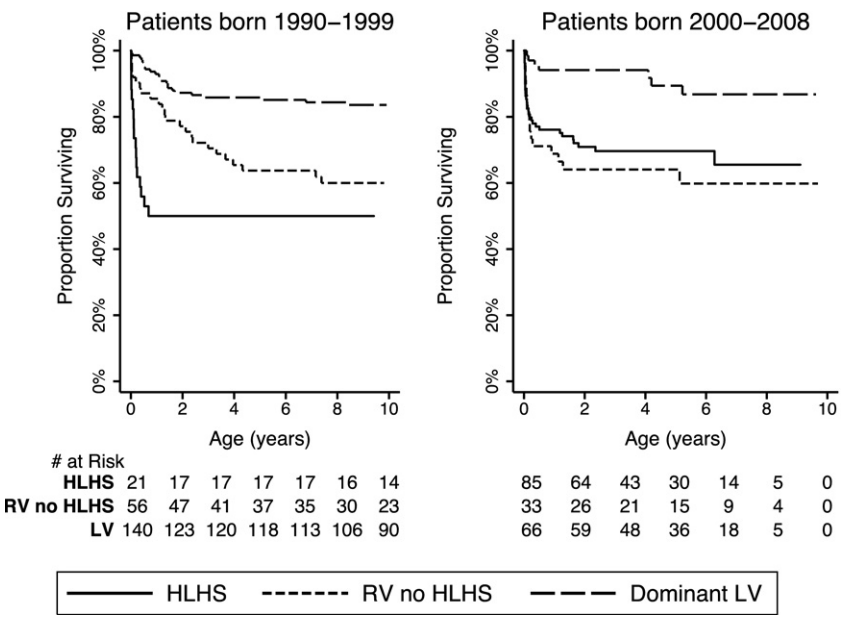

Figure 2 **Kaplan-Meier Survival Curves**

Patients were separated into 2 groups according to era of birth. Era 1 consisted of patients born from 1990 to 1999; era 2 consisted of patients born from 2000 to 2008. HLHS = patients with hypoplastic left heart syndrome; LV = patients with a dominant left ventricle; RV no HLHS = patients with a dominant right ventricle but not a diagnosis of HLHS.

for the entire surgical palliation process. We have previously demonstrated that interim mortality between BCPS and Fontan surgery may be higher than expected, with a disappointingly low Fontan completion rate (2). Staging with BCPS before Fontan surgery has become a selection process, and therefore objective survival of the entire group of patients born with single-ventricle physiology has been difficult to quantify. Objective survival data for single-ventricle patients, which are necessary to counsel affected families, seem to be missing from current literature. Two previous studies have shed limited light on the topic, both pointing to 5- to 10-year survival rates of close to 60%. The first study was population based and included all newborns born with single ventricle in Texas between 1996 and 2003 (8). Their overall results were worse than those presented in our study because their series had included patients who did not undergo surgical palliation. The majority of our patients, who were not operated on after birth, died because they were denied surgery. The second study, from South Korea, had a similar design to ours, but, for historical reasons, the majority of their patients did not undergo staging with BCPS before Fontan completion (9). Their results are therefore difficult to compare with contemporary practices.

Overall survival. The overall survival of the entire population of infants born with single-ventricle physiology is still disappointingly low. According to our data, 30% of infants born with a functional single ventricle, who undergo surgery, will not reach adulthood. These perspectives clearly differ depending on individual cardiac morphology. Up to 85% of those born with a dominant left ventricle may hope to reach adulthood, whereas this number is only 65% for those born with a dominant right ventricle. One should not be overconfident that these outcomes will ineluctably improve in the future. It is remarkable that, over a period spanning ~2 decades, no improvement in survival was noted in patients with single left ventricle. Similarly, interstage mortality between BCPS and Fontan completion did not improve during the course of the study. Despite the lack of obvious increase in survival of the entire population, improvement in the management of these patients cannot be denied, as we are now operating on a greater number of patients with more complex diseases and worse prognosis. Between the first and the second decade, the proportion of patients with a dominant right ventricle almost doubled, largely because the number of Norwood procedures for HLHS quadrupled. Our results confirm the improvement obtained in recent years with this condition. In our center, being born with HLHS no longer carries a worse prognosis than being born with a dominant right ventricle of a different morphology.

Risk factors for mortality. The most striking finding of the present study is the demonstration of worse survival among patients with a dominant right ventricle. It has been previously shown that having a single right ventricle was a risk factor for adverse outcome after Fontan surgery (4), but even this result has been disputed (3,14,15). Until now, no

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Table 5 Risk Factors for Mortality After Neonatal Surgery

	HR	p Value	95% CI
Univariate analyses			
Dominant right ventricle	3.47	0.000	2.09–5.76
Atrial isomerism	2.76	0.000	1.68–4.53
Atrioventricular valve regurgitation	2.70	0.000	1.66–4.39
No transposition of great arteries	3.43	0.001	1.65–7.13
Hypoplastic left heart syndrome	2.22	0.001	1.37–3.62
Aortic atresia	2.13	0.003	1.30–3.51
Hypoplastic arch	2.08	0.003	1.28–3.40
Common atrioventricular valve	1.81	0.023	1.08–3.01
Pulmonary atresia	0.73	0.275	0.42–1.28
Atrioventricular discordance	0.59	0.302	0.21–1.61
Pulmonary stenosis	0.72	0.353	0.37–1.43
Biventricular morphology	1.33	0.427	0.66–2.67
Interrupted inferior vena cava	1.43	0.439	0.58–3.56
Interrupted aortic arch	1.36	0.546	0.50–3.73
Coarctation of aorta	0.89	0.692	0.52–1.55
Aortic stenosis	0.93	0.856	0.43–2.03
Dextrocardia	1.07	0.864	0.48–2.37
Bilateral superior vena cavae	0.96	0.890	0.53–1.73
Mesocardia	1.05	0.962	0.15–7.55
Multivariate analysis			
Biventricular morphology	2.42	0.060	0.96–6.08
Dominant right ventricle	2.69	0.005	1.35–5.36
Atrial isomerism	2.76	0.002	1.44–5.32
Atrioventricular valve regurgitation	1.92	0.013	1.15–3.20
Hypoplastic arch	1.95	0.066	0.96–3.98
No transposition of great arteries	2.04	0.074	0.93–4.45
Aortic atresia	1.21	0.529	0.66–2.21

CI = confidence interval; HR = hazard ratio.

data have been available to clarify this suspicion for stages preceding Fontan procedure (16).

Interestingly, having a dominant right ventricle was only a risk factor for mortality up to the BCPS stage. One could use this finding as an argument to perform the BCPS at an earlier age. We initially decided to decrease the age at which the BCPS was performed to decrease interstage mortality between Norwood and BCPS in patients with HLHS. Before we could gather any clinical evidence, we arbitrarily set the timing of BCPS at 3 months of age because it seemed the youngest age at which this procedure could be performed safely. Because of the success of this policy, we have progressively extended it to patients with single ventricle of other morphologies.

The remaining risk factors for mortality have been identified previously. Heterotaxia seriously weakens the prognosis of these patients. The Toronto team demonstrated that up to 60% of the patients with right atrial isomerism and one-half of those with left atrial isomerism will die before reaching Fontan status (17–19). Meanwhile, studies have shown that atrioventricular valve regurgitation before the time of BCPS was associated with increased mortality, particularly among patients with HLHS (20,21). Finally, it was not surprising to note that the prognosis of our patients without transposition was better, as they clearly gathered a larger proportion of patients with dominant left ventricles.

Study limitations. This study was historical in nature. The study cohort was a heterogeneous population of patients undergoing a multistage surgical palliation process. As the study period spans 18 years, over time the patient population and surgical practices have changed. We are now operating on more patients with dominant right ventricle and HLHS. In the early 1990s, our patients underwent BCPS at a much later age because it was the first time that this procedure was used as a staging procedure before Fontan procedures in our center. Our initial patients were therefore older at the time of BCPS. For these reasons, the results reported have to be considered best estimates and may not reflect current practices.

Conclusions

Progress in the care of patients born with functional single ventricle has been achieved, especially in patients with HLHS. However, considerable mortality is still observed during the first few years of life. Right ventricular dominance is the most important risk factor for death but only before BCPS status is reached.

Table 6 Risk Factors for Mortality After BCPS

	HR	p Value	95% CI
Univariate analyses			
Common atrioventricular valve	3.61	0.000	1.84–7.09
Bilateral superior vena cavae	3.05	0.001	1.60–5.81
Atrial isomerism	3.00	0.004	1.42–6.31
Coarctation of aorta	1.94	0.060	0.97–3.88
Hypoplastic left heart syndrome	0.46	0.081	0.20–1.10
Pulmonary atresia	0.37	0.107	0.11–1.24
Aortic stenosis	1.92	0.141	0.81–4.56
Interrupted inferior vena cava	2.32	0.170	0.70–7.73
Dextrocardia	1.90	0.174	0.75–4.80
Atrioventricular valve regurgitation	1.64	0.242	0.72–3.74
No transposition of great arteries	1.57	0.280	0.69–3.58
Biventricular morphology	1.74	0.297	0.61–4.95
Aortic atresia	0.64	0.369	0.24–1.70
Mesocardia	2.65	0.388	0.29–24.05
Interrupted aortic arch	1.68	0.489	0.39–7.24
Pulmonary stenosis	1.23	0.559	0.61–2.50
Dominant right ventricle	1.18	0.612	0.62–2.26
Hypoplastic arch	0.98	0.949	0.49–1.96
Atrioventricular discordance	—	—	—
Multivariate analysis			
Biventricular morphology	1.02	0.976	0.31–3.30
Dominant right ventricle	1.01	0.982	0.49–2.09
Common atrioventricular valve	2.64	0.055	0.98–7.12
Bilateral superior vena cavae	2.05	0.084	0.91–4.61
Atrial isomerism	0.87	0.804	0.28–2.65

CI = confidence interval; HR = hazard ratio.

Reprint requests and correspondence to: Dr. Yves d'Udekem, Department of Cardiac Surgery, Royal Children's Hospital, Flemington Road, Parkville, Melbourne, Victoria 3052 Australia. E-mail: yves.dudekem@rch.org.au.

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