Survival status and functional outcome of children who required prolonged intensive care after cardiac surgery

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ABSTRACT

Background: Children who require prolonged intensive care after cardiac surgery are at risk of high mortality. The long-term survival and functional outcome of these children have not been studied in detail.

Methods: Children who stayed in intensive care for >28 days after cardiac surgery from 1997 to 2012 were studied in a single institution. A total of 116 patients were identified; 107 (92%) were <1 year of age and 63 (54%) had univentricular physiology.

Results: The incidence of children requiring prolonged intensive care increased from 1.01/100 undergoing cardiac surgery in 1997 to 2000 to 2.66/100 in 2009 to 2012 (P trend = .002). This increase coincided with an increase in the number of children with hypoplastic left heart syndrome having prolonged intensive care during the same period (0.13/100 in 1997-2000 to 1.0/100 in 2009-2012; P trend = .001). Survival to pediatric intensive care unit (PICU) discharge was 74% (95% confidence interval [CI], 65-82) and 51% (95% CI, 41-59) at 3 years. Factors associated with mortality were univentricular repair (hazard ratio [HR], 2.12; 95% CI, 1.21-3.70; P = .008) and acute renal failure (HR, 3.01; 95% CI, 1.77-5.12; P < .001), but era did not influence mortality (1997-2005 vs 2006-2012; log-rank P = .66). Among PICU survivors, 3-year survival in those who did not need early reoperation was 81% (95% CI, 66-90), compared with 58% (95% CI, 42-71) in those who required early reoperation (log-rank P = .01). Among survivors, 36% had either moderate or severe disability and 13% had poor quality of life.

Conclusions: The incidence of children requiring prolonged intensive care after cardiac surgery has increased in our institution. Our data suggest that the long-term outcome for most of these children is poor, especially after univentricular repair. (J Thorac Cardiovasc Surg 2016;152:1104-12)

Kaplan-Meier survival analysis for biventricular and univentricular group.

Central Message

The incidence of children requiring prolonged intensive care after cardiac surgery has increased, and outcomes in this group are poor.

Perspective

Overall mortality after pediatric cardiac surgery is low and declining. However, outcomes among children who required prolonged intensive care after cardiac surgery are poor and have not improved in recent decades. More knowledge about these children will help us establish research priorities and formulate guidelines involving various aspects of the care process with the goal to improve outcomes.

See Editorial Commentary page 1113.

Overall mortality after pediatric cardiac surgery is low and declining,¹⁻³ and this progress has been achieved despite an increase in case complexity.⁴ However, in certain high-risk

groups, such as children who have required prolonged intensive care after cardiac surgery, there is very limited information on long-term survival and functional outcome. The limited literature in this area reports risk factors for prolonged intensive care after surgery and only reports early survival.⁵⁻⁸ An understanding of long-term outcomes in this complex group is particularly important in the current era of low postoperative mortality.

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Scanning this QR code will take you to the supplemental tables for this article.

Abbreviations and Acronyms

CPB	= cardiopulmonary bypass
ECMO	= extracorporeal membrane oxygenation
HLHS	= hypoplastic left heart syndrome
HR	= hazard ratio
HSUV	= health state utility value
IQR	= interquartile range
LOS	= length of stay
MGOS	= modified Glasgow outcome score
PICU	= pediatric intensive care unit

A recent review of pediatric intensive care units (PICUs) across Australia and New Zealand showed that children with a primary cardiac diagnosis account for the majority of those requiring prolonged intensive care, and that this proportion has increased in recent years.⁹ There are likely to be several factors contributing to this increase, including increasing numbers of children with complex circulations undergoing surgery^{4,10} and the widespread use of extracorporeal membrane oxygenation (ECMO) during cardiopulmonary resuscitation in children with cardiac disease.^{11,12}

Evaluation of long-term outcomes in these children is fundamental in evaluating the effectiveness of care beyond simple measurement of mortality. Knowledge of factors associated with poor long-term outcome might assist in care planning for this difficult group. Information on outcomes could also be valuable to health care staff counseling families during prolonged and complicated postoperative PICU stays. In this study, we review our experience over a 16-year period with infants and children who required prolonged intensive care (defined as >28 days in intensive care) after cardiac surgery.

More specifically, the aims of this review are (1) to analyze trends in admission rates of children who needed prolonged PICU stay after cardiac surgery between 1 January 1997 and 31 December 2012, (2) to identify risk factors for short- and long-term mortality, and (3) to report long-term survival patterns, functional outcome, and quality of life among survivors.

MATERIALS AND METHODS

All infants and children admitted to intensive care at the Royal Children's Hospital, Melbourne, after cardiac surgery between 1 January 1997 and 31 December 2012 (16 years) with a PICU length of stay (LOS) >28 days are included. Eligible patients were identified from the PICU database and all information was collected from this resource and from medical records. Information concerning the total number of children undergoing cardiac surgery and total number of cardiac surgeries during each year of study was obtained from the perfusion department database. Children with medical cardiac disease (cardiomyopathy, myocarditis, etc.) and those admitted to PICU following commencement of long-term ventricular assist device support were excluded.

The PICU at the Royal Children's Hospital is a 22-bed multidisciplinary unit. All major cardiac surgeries are performed here for infants and children

from 4 Australian states (Victoria, Tasmania, South Australia, Northern Territory) covering a population of around 8 million. Cardiac surgeries for all major congenital heart lesions, including heart transplantation, are performed at this center. The Human Research and Ethics Committee at the Royal Children's Hospital approved the study.

Data Collection

The following variables were collected. Demographic variables included age at admission, weight, gestation at birth, preoperative intubation, presence of comorbid condition, noncardiac congenital abnormalities and genetic defects, PICU and hospital LOS, duration of mechanical ventilation, cardiopulmonary bypass (CPB), and cross clamp time. Clinical variables included open sternum after surgery, major airways disease (malacia, stenosis, or external compression), pulmonary hypertension, arrhythmia, chylothorax, diaphragm palsy, necrotizing enterocolitis,¹³ renal failure,¹⁴ nosocomial bacteremia, cardiac arrest, requirement for ECMO, and need for early reoperation. Study variables and definitions are shown in [Table E1](#).

Long-term functional outcome and quality of life among survivors was assessed at least 6 months after discharge using the modified Glasgow outcome score (MGOS). The MGOS is a global assessment tool of independent living and social integration. A standardized questionnaire ([Table E2](#)) for the MGOS is used by research assistants trained in outcome evaluation during outcome calls. The functional outcome obtained by the MGOS divides children into the following categories: normal, functionally normal (physically and intellectually normal) but requiring medication or medical supervision; mild disability but likely to lead an independent existence; moderate disability and dependent on care; severe disability and totally dependent on care (including persistent vegetative state); and death. Quality of life was assessed using the Health Utilities Index Mark 1.¹⁵ Four attributes in the Health Utilities Index Mark 1 were defined as follows: (1) mobility/physical activity; (2) self-care/role activity; (3) social/emotional function; and (4) health problems. The different levels within each category were assigned a numerical value, and an overall health state utility value (HSUV) was calculated. The HSUV for all possible health states lies between 1.00 and -0.21, where 1.00 is healthy, 0.00 is dead, and negative values reflect a state "worse than dead." Four outcome categories were assigned: good (HSUV, 1-0.7); moderate (HSUV, 0.69-0.3); poor (HSUV, 0.29-0); and very poor (HSUV, <0). Children <2 years of age at the time of follow-up were not assigned an HSUV score. The questionnaire used for assessment of functional status is shown in [Table E2](#).

Statistics

Continuous variables are presented as medians with interquartile range (IQR) and categorical variables as number (%). Continuous variables were compared using the Mann-Whitney rank-sum test, and categorical variables were compared using the χ^2 test. If a patient had more than one prolonged admission after cardiac surgery, only the first admission was used in the analysis. Significance of trends in the number of children needing prolonged intensive care admission was assessed using Poisson regression. Children were categorized according to the year of admission, and the incidence rate ratios used for assessing the trend were calculated for each 4-year period of study.

Comparisons were made for 2 groups of children: the entire cohort of children who required prolonged admission after cardiac surgery, and the cohort of children who survived the prolonged PICU admission. The outcome of interest was 3-year survival and a multivariable Cox proportional-hazards model was used for the 2 groups of children to identify risk factors associated with mortality. For group 1 (the entire cohort), survival was evaluated from day 29 of PICU admission, with day 1 defined as the day after day 28, to 3 years. For group 2 (the cohort who survived PICU prolonged admission), survival was evaluated from date of PICU discharge to 3 years. Data were censored on the date of death. Children who were alive were censored from the analysis on the date when

they were last seen in clinic or admitted to hospital and were known to be alive. The following variables were considered for inclusion in the model: age at surgery, sex, prematurity, univentricular or biventricular repair, acute renal failure, requirement for ECMO, and early reoperation. Factors identified in a univariable model with a P value less than .2 were included in the final multivariable model, using a stepwise forward inclusion. The proportional-hazards assumption was assessed using Schoenfeld residuals. Analyses were evaluated with the null hypothesis at a two-sided significance level of .05, and 95% confidence intervals (CIs) were calculated where appropriate. Kaplan-Meier curves were constructed to determine unadjusted rates of 3-year survival and the log-rank test was used to investigate differences in survival patterns between groups.

Long-term functional outcome and quality of life measures are presented in a descriptive manner for the 2 main groups of study patients (univentricular and biventricular repair). Analysis was performed using Stata version 13 (StataCorp, LP, College Station, Tex).

RESULTS

Trends in Admissions Rates

In total, 5546 patients had 6807 cardiac surgical procedures in the 16 years between 1997 and 2012; 116 (2.1%) required prolonged intensive care (>28 days) after surgery. There were 63 of 116 patients (54%) who had a univentricular circulation and 44 (38%) who had a diagnosis of hypoplastic left heart syndrome (HLHS). The incidence of children requiring prolonged stay increased from 1.01/100 patients undergoing cardiac surgery in the 4-year period 1997 to 2000 to 2.66/100 in 2009 to 2012 (P for trend = .002). This increase corresponded with the increase in numbers of patients with HLHS requiring prolonged intensive care after surgery (0.13/100 patients in 1997 to 2000 to 1.0/100 patients in 2009 to 2012, P for trend = .001). There was no significant change over time in the numbers of children with biventricular repair requiring prolonged stay (0.74/100 patients in 1997-2000 to 1.39/100 patients in 2009-2012, P for trend = .25).

Demographics and Clinical Profile

Table 1 shows demographic, operative, complication, and outcome data for the study cohort, by postoperative physiology (biventricular vs univentricular). The underlying diagnoses in the 2 major groups of patients is shown in the flow chart (Figure 1). Whereas the median age (IQR) at surgery for the whole cohort was 7 (4-45) days, those with a univentricular circulation were younger than the biventricular group (median 4 vs 16 days, P < .001). A higher proportion of children in the biventricular group were born prematurely (21% vs 8%) and had a chromosomal/genetic abnormality (43% vs 21%). There was no difference in the PICU or hospital LOS between the groups.

Children in the univentricular group had a longer CPB time (median [IQR], 199 [159-248] minutes vs 155 [125-230] minutes, P = .02) and a higher proportion received ECMO support (49% vs 31%, P = .06). Forty-three percent of children in the biventricular group had pulmonary hypertension (compared with 13% in the

univentricular group, P < .001). Major airways disease (at least moderate-to-severe airway malacia, stenosis, or external compression by cardiac structures) was more common in the biventricular group (49% vs 17%, P for comparison < .001), and the rate of tracheostomy was higher in this group (21% vs 5%, P = .008).

Fifty-nine of 116 patients (51%) had an early reoperation. The cumulative incidence (95% CI) for first reoperation by days 7, 14, and 28 after admission to PICU was 13.2% (5.4%-25.3%), 24.5% (13.7%-38.2%), and 33.9% (21.5%-48.2%) for the biventricular group and 14.2% (6.7%-25.3%), 30.1% (19.2%-43%), and 44.4% (31.9%-57.5%) for the univentricular group, respectively. The nature of the first reoperation in study patients is shown in Table E3. Overall PICU mortality for the entire cohort was 26% (30 of 116 patients).

Long-Term Survival for the Entire Cohort (n = 116)

Survival for the entire cohort was 74% (95% CI, 65-82) to PICU discharge, 54% (95% CI, 45-63) at 1 year, and 51% (95% CI, 41-59) at 3 years. There was no difference in 3-year survival by era of study (1997-2005 compared with 2006-2012, log-rank P = .66). There was, however, a significant difference in survival between the biventricular and univentricular groups (Figure 2): 3-year survival was 62% (95% CI, 48-74) for biventricular repair and 41% (95% CI, 29-53) for the univentricular group (log-rank P = .03). There were no deaths in the biventricular group after 1 year. On multivariable analysis, the risk factors associated with mortality (Table 2) were univentricular repair (hazard ratio [HR], 2.12; 95% CI, 1.21-3.70, P = .008) and development of acute renal failure (HR, 3.01; 95% CI, 1.77-5.12, P < .001). The 1- and 3-year survival rates for HLHS were 50% (95% CI, 35-66) and 43% (95% CI, 28-57), respectively.

Long-Term Survival of Children Who Survived the Prolonged PICU Stay (n = 86)

Of 116 children, 86 (74%) survived the index prolonged intensive care admission. In this cohort the 3-year survival rate from the time of PICU discharge was 70% (95% CI, 59-78). Requirement for early reoperation during the index intensive care admission (HR, 2.65; 95% CI, 1.15-6.11, P = .02) was associated with mortality in this cohort. The 3-year survival (Figure 3) in this cohort was 58% (95% CI, 42-71) in those with early reoperation, and 81% (95% CI, 66-90) in those without (log-rank P = .01). On further analysis of the cohort by number of reoperations required, the following results for the hazards for 3-year mortality were obtained: 1 reoperation (HR, 2.11, 95% CI, 0.85-5.27, P = .1) compared with no reoperation; >1 reoperation (HR, 4.44, 95% CI, 1.60-12.20, P = .004) compared with no reoperation. Of 43 children, 8 (19%) who did not require an early reoperation died during the

TABLE 1. Demographic and clinical characteristics compared between biventricular and univentricular repair

Variable	All patients (N = 116)	Biventricular repair (N = 53)	Univentricular repair (N = 63)	P value*
Age at surgery (d), median (IQR)	7 (4-45)	16 (5-105)	4 (2-10)	<.001
Weight (kg), median (IQR)	3.3 (2.8-4.1)	3.6 (2.9-5)	3.2 (2.7-3.7)	.11
Male sex, n/N (%)	61/116 (52)	23/53 (43)	38/63 (60)	.07
Prematurity (<37 wk), n/N (%)	16/113 (14)	11/51 (21)	5/62 (8)	.04
RACHS-1 score, n/N (%)				<.001
1-4	68/116 (59)	50/53 (94)	18/63 (29)	
5 or 6	48/116 (41)	3/53 (6)	45/63 (71)	
Noncardiac congenital abnormalities and genetic defects, n/N (%)	36/116 (31)	23/53 (43)	13/63 (21)	.008
Preoperative mechanical ventilation, n/N (%)	59/116 (51)	31/53 (58)	28/63 (44)	.13
PICU LOS (d), median (IQR)	38 (32-55)	40 (32-64)	37 (33-46)	.43
Hospital LOS (d), median (IQR)	69 (50-105)	68 (51-95)	72 (47-116)	.82
MV duration (d), median (IQR)	36 (30-52)	36 (31-61)	36 (29-43)	.22
CPB duration (min), median (IQR)	171 (137-247)	155 (125-230)	199 (159-248)	.02
Cross clamp duration (min), median (IQR)	73 (50-100)	83 (51-118)	66 (49-88)	.09
ECMO during admission, n/N (%)	48/116 (41)	17/53 (31)	31/63 (49)	.06
Delayed sternal closure, n/N (%)	84/115 (73)	27/52 (52)	57/63 (90)	<.001
Cardiac arrest, n/N (%)	49/116 (42)	23/53 (43)	26/63 (41)	.80
Postoperative arrhythmia, n/N (%)	41/115 (36)	15/52 (29)	26/63 (41)	.16
Chylothorax, n/N (%)	37/114 (32)	16/52 (31)	21/62 (34)	.72
Necrotizing enterocolitis, n/N (%)	25/114 (22)	8/52 (15)	17/62 (27)	.12
Diaphragm paralysis, n/N (%)	20/114 (17)	11/52 (21)	9/62 (14)	.35
Pulmonary hypertension, n/N (%)	31/116 (27)	23/53 (43)	8/63 (13)	<.001
Major airways disease, n/N (%)	37/116 (32)	26/53 (49)	11/63 (17)	<.001
Tracheostomy, n/N (%)	14/116 (12)	11/53 (21)	3/63 (5)	.008
Acute renal failure, n/N (%)	39/114 (34)	18/52 (35)	21/62 (34)	.93
Early reoperation, n/N (%)	59/116 (51)	25/53 (47)	34/63 (54)	.46
PICU mortality, n/N (%)	30/116 (26)	11/53 (21)	19/63 (30)	.25

IQR, Interquartile range; RACHS-1, Risk Adjustment for Congenital Heart Surgery¹⁶; PICU, pediatric intensive care unit; LOS, length of stay; MV, mechanical ventilation; CPB, cardiopulmonary bypass; ECMO, extracorporeal membrane oxygenation. *P values calculated using rank-sum test or χ^2 analyses.

3-year period. This compared with 11 of 32 (34%) who had one early reoperation and 7 of 11 (64%) who had more than 1 reoperation. Of the 43 children (of 86 in this cohort) who required an early reoperation, the median time to reoperation (from the time of primary surgery) was 10 days (IQR, 6-23) and there was no difference in this time between those who survived and those who died (median [IQR] 13 [6-25] days for survivors vs 9 [6-18] days for non-survivors, $P = .57$).

Functional Outcome and Quality of Life for Surviving Children

Of 55 children available for follow-up assessment, the MGOS assessing functional outcome was available for 50, and Health Utility Index (Mark 1) assessing quality of life was available for 38 children. The median (IQR) age was 48 months (35-89 months) at the time of outcome assessment, and outcome was evaluated at a median (IQR) of 36 months (23-69 months) after intensive care discharge. There was no difference in the timing of assessment between the biventricular and univentricular groups (Table 3).

Of 50 children who had functional assessment, 18 (36%) had an unfavorable outcome (moderate or severe disability). Of the 18 children who had unfavorable outcome, 11 experienced a cardiac arrest during their long-stay intensive care admission (compared with 7 of 32 who had a favorable outcome). Also, 9 of 18 children who had unfavorable outcome had an associated noncardiac congenital abnormality or genetic defect (compared with 6 of 32 who had a favorable outcome). Overall, 70% of children in the biventricular group and 53% in the univentricular group for whom functional outcome assessment was made had a favorable outcome (normal, functionally normal, or mild disability).

The Health State Utilities Index was used to assess quality of life in children ≥ 2 years of age at the time of outcome assessment. According to this measure, 71% had a good quality of life (HSUV, 1.00-0.7), 16% had moderate quality (HSUV, 0.69-0.3), and 13% of children had a poor quality (HSUV, 0.29-0). 26 of 27 children who had a good quality of life assessment also had a favorable functional outcome (normal, functionally normal, or mild disability). Of the 5 children who had

FIGURE 1. Flow chart of study patients with underlying diagnoses. AA, Aortic arch; IAA, interrupted aortic arch; VSD, ventricular septal defect; ASD, atrial septal defect; MAPCAs, major aortopulmonary collaterals; TAPVD, total anomalous pulmonary venous drainage; HLHS, hypoplastic left heart syndrome; DORV, double outlet right ventricle; AV, atrioventricular.

poor quality of life, 3 had severe disability and 2 had moderate disability.

DISCUSSION

Major Findings

Among pediatric patients who required prolonged intensive care after cardiac surgery, around 50% had died within 3 years. Most deaths occurred during the first year, but with further deaths in children in the univentricular group. In surviving children, 36% had moderate or severe disability and 13% had poor quality of life. These findings are particularly relevant in the current era of pediatric cardiac surgery, when mortality in congenital heart disease is low and has been steadily decreasing during the last 2 decades.² Furthermore, the number of children requiring prolonged intensive care after cardiac surgery has been increasing during this time. A major contributor to this trend in our institution has been the increase in children with HLHS requiring prolonged stay, consequent to greater numbers of these infants being offered surgical palliation.¹⁰ This increase in HLHS patients requiring prolonged stay has occurred despite the overall improvement in survival of these children in our institution.¹⁰

The first large-scale description of long-stay after pediatric cardiac surgery was reported by Brown and colleagues in 2003.⁵ The authors, using >95% centile for LOS as long-stay (equating to >14 days after surgery),

reported a 12% incidence and a hospital mortality of 17%. Their report did not include long-term survival or functional outcome of survivors; however, it highlighted this important problem and reported risk factors for these patients. Other investigators, using shorter lengths of stay in their definitions, have reported intensive care mortality rates of 6.6% and 17%.^{6,17} Whatever definitions are used, a small proportion of children in every unit have a protracted intensive care course after cardiac surgery, and it is likely that this proportion is increasing in most major pediatric cardiac surgical programs.

The Norwood procedure was first described in 1983¹⁸; before that HLHS was a universally fatal condition. Considerable progress in the intervening period has improved survival rates¹⁹ for stage 1 single-ventricle reconstruction surgery. The 1-year survival following single-ventricle palliation in our institution is around 82% (95% CI, 79%-85%),¹⁰ but many challenges still remain. Thirty-eight percent of our study patients had HLHS, the major diagnostic group. Although risk factors for mortality have been reported by several investigators²⁰⁻²² for this condition, the usefulness of this information in making early important management decisions, such as limiting or withdrawing treatment, is limited when dealing postoperatively with an infant in the intensive care unit.

The 2 risk factors for mortality for the entire cohort of patients in our study were univentricular repair and acute

FIGURE 2. Kaplan-Meier estimates showing survival patterns for biventricular and univentricular repair. Zero in the x axis represents day 29 of intensive care admission. The number of patients at risk at each time point is shown below the graph.

renal failure. Infants with single-ventricle physiology have the highest risk of death after cardiac surgery, with 1-year survival rates around 70% in a recent single-ventricle reconstruction trial.¹⁹ Therefore, within this cohort of patients with prolonged intensive care stay, one would expect univentricular physiology to confer a high risk of mortality, and this is indeed the case.³ It has also recently been shown that longer post-Norwood LOS is also associated with longer LOS following stage 2 procedures in infants with single-ventricle reconstruction,²³ and this likely represents a surrogate for several other problems these infants may have such as decreased ventricular function, atrioventricular valve regurgitation, feeding difficulties, etc. Renal failure

has been associated with poor outcome in previous studies,^{24,25} and may be both a marker of the severe protracted course in PICU and a contributor to death. Many of the complications and postoperative events identified in our study are likely to have contributed to prolonged stay. The rates of these events were higher in this cohort than would be expected in the general postoperative cardiac surgical population. Around 42% of our cohort experienced a cardiac arrest, which is several-fold higher than the reported rate of <5% in pediatric cardiac intensive care patients.^{26,27} Similarly, complications such as chylothorax (32%), diaphragm palsy (17%), necrotizing enterocolitis (22%), and acute

TABLE 2. Factors associated with 3-year mortality, by univariate and multivariate analyses

Variable	Univariate analysis		Multivariate analysis	
	Hazard ratio (95% CI)	P value	Hazard ratio (95% CI)	P value
3-y mortality (entire cohort, n = 116)				
Univentricular repair	1.80 (1.05-3.11)	.033	2.12 (1.21-3.70)	.008
Acute renal failure	2.83 (1.67-4.80)	<.001	3.01 (1.77-5.12)	<.001
Requirement for ECMO	2.06 (1.22-3.47)	.007	NS	
3-y mortality (PICU discharge cohort, n = 86)				
Requirement for early reoperation				
No reoperation (reference)	1.0	—	1.0	—
1 reoperation	2.11 (0.85-5.27)	.10	2.11 (0.85-5.27)	.10
>1 reoperation	4.44 (1.60-12.20)	.004	4.44 (1.60-12.20)	.004

CI, Confidence interval; ECMO, extracorporeal membrane oxygenation; NS, not significant; PICU, pediatric intensive care unit.

FIGURE 3. Kaplan-Meier estimates showing survival patterns for children who were discharged from intensive care after their prolonged admission and who either had or did not have a reoperation. Zero in the x axis represents day of discharge from intensive care. The number of patients at risk at each time point is shown below the graph.

renal failure (34%) were frequent in this high-risk cohort. It is possible that the high proportion of complications seen in this cohort is likely because this was a high-risk cohort and the presence of these complications also meant the patients needed prolonged intensive care. Tools for analyzing morbidity, such as the recent STS Morbidity Score and Categories, which take into account the average risk of major complication with each cardiac surgical procedure and the postoperative LOS, may provide useful information when assessing outcomes for these groups of patients.²⁸

We are not aware of any reports detailing the proportion of children needing early reoperation during their prolonged intensive care after primary operation. However, it is well known that an early reoperation may be associated with high morbidity and mortality,²⁹ particularly the need for urgent operation. Recent experience from our institution has also shown a higher mortality in children with single-ventricle lesions needing reoperations on their atrioventricular valves.³⁰ Almost 50% of our study patients required an early reoperation, but given the

TABLE 3. Comparison of long-term outcome (among survivors) between biventricular and univentricular repair

Variable	Overall (N = 55)	Biventricular repair alive (N = 31)	Univentricular repair alive (N = 24)
Age at assessment (mo), median (IQR)	48 (35-89)	44 (35-81)	59 (26-97)
Timing of assessment (mo), median (IQR)*	36 (23-69)	36 (29-69)	34 (20-66)
Modified Glasgow outcome score†			
Normal, functionally normal, mild disability, n/N (%)	32/50 (64)	16/27 (70)	16/23 (53)
Moderate or severe disability, n/N (%)	18/50 (36)	11/27 (30)	7/23 (47)
HSUI‡			
Good quality of life (HSUV, 1.00-0.7), n/N (%)	27/38 (71)	14/20 (70)	13/18 (72)
Moderate quality (HSUV, 0.69-0.3), n/N (%)	6/38 (16)	3/20 (15)	3/18 (17)
Poor quality (HSUV, 0.29-0; excluding death), n/N (%)	5/38 (13)	3/20 (15)	2/18 (11)
HSUI, overall score among surviving children, median (IQR)	0.87 (0.55-0.87)	0.87 (0.48-0.88)	0.87 (0.55-0.87)

IQR, Interquartile range; HSUI, Health State Utility Index; HSUV, health state utility value. *From the time of intensive care discharge. †MGOS not known for 5 children (4 in the biventricular group and 1 in the univentricular group). ‡HSUI not assessed for 11 children in the biventricular group (6 were <2 years of age at the time of assessment and 5 could not be contacted) and 6 children in the univentricular group (5 were <2 years of age at the time of assessment and 1 could not be contacted); categories for HSUI: good quality of life (HSUV, 1.00-0.7), moderate quality (HSUV, 0.69-0.3), poor quality including death (HSUV, 0.29-0), very poor quality of life (HSUV, <0).

nature of our study and the heterogeneity of the cohort, it is not reasonable to comment on the reoperation characteristics for individual morphologic diagnoses. However, information about long-term survival of children who require reoperation may be useful in discussions about prognosis and outcomes with families of such children.

Good functional outcome and quality of life for children surviving prolonged intensive care are the clear goals upon which such care is based; survival with significant disability or poor quality of life comes at significant cost to patients, families, and society. Longer postoperative cardiac intensive care stay is associated with subsequent worse cognitive function,³¹ so it is expected that some of our patients would demonstrate below normal performance in measurements of IQ and cognitive function.

Study Limitations

Despite its inherent limitations, a single-center study can provide important and useful information in this cohort of children. However, good multicenter collaboration is essential to collect demographic, treatment, and outcome data, which will be useful in writing guidelines and establishing research priorities, with the ultimate aim of influencing outcomes. These priorities could be used to prevent progression to prolonged critical illness, plan specific aspects of management such as weaning from ventilation, specific nutritional recommendations, prevention of infections, rehabilitation, support and communication for families, and end-of-life care.

There may be aspects of the underlying disease and care provided that are unaccounted for in our study, and that may have influenced outcome in individual patients. So, it is difficult from our study to fully identify the factors associated with a specific outcome reported in an individual patient.

The impact of the child's illness on the family, both the index prolonged intensive care admission and the subsequent course, is not measured in our study. The levels of stress experienced by family members of children with complex congenital heart disease can be considerable,³² and there are significant demands and consequences of caring for a chronically disabled child that are pertinent to the families of children described in our study and should be the focus of future studies.³³

The tests that we have used in our study (MGOS for functional outcome and Health State Utility Index for quality of life) are general outcome measures, rather than cognitive assessments.²⁸ Differences have been reported between the outcomes reported in these 2 types of tests: for example, a good outcome on a MGOS can equate to a below average score on the mental development index of the Bayley Scales of Infant Development II test.³² However, the tests we have used provide a quick method with high

clinical relevance³³ in identifying someone's ability to live and function independently (functional outcome) while also measuring their quality of life. In a heterogeneous population, such as that reported here, a generic assessment tool provides for a reasonably complete overview of function and disability.³⁴

CONCLUSIONS

Current outcomes of children who have prolonged intensive care (>28 days) after cardiac surgery are poor, with approximately 50% 3-year mortality, and with one-third of survivors experiencing moderate-to-severe disability. As the numbers of children in each unit per year may not be big enough, large prospective multicenter studies with good data collection using standard definitions and reporting will be crucial to get important information about these groups of children. This information could be used in formulating guidelines and recommendations involving several aspects of the care process for these children.

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

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Key Words: survival status, functional outcome, prolonged intensive care, pediatric cardiac surgery

TABLE E1. Definition of study variables

Variables	Definition
Postoperative arrhythmia	Arrhythmia requiring infusion of antiarrhythmic drug or pacing
Cardiac arrest	Loss of circulation necessitating cardiopulmonary resuscitation
Requirement for ECLS	Need for ECLS in the peri-operative period
Pulmonary hypertension	Diagnosed from a pulmonary artery line or by echocardiography
Nosocomial bacteremia	Identification of positive blood culture or strong clinical suspicion of infection at least 48 hours after admission ^{3,4}
Chylothorax	Confirmation of chyle drainage in postoperative chest drain losses
Diaphragm paralysis	Confirmed by ultrasonography or fluoroscopy
Necrotizing enterocolitis	Diagnosis based on the modified Bell's Staging Criteria ¹³
Acute renal failure	Defined as increase in serum creatinine greater than 1.5 times upper limit of normal for age or twice the most recent value ¹⁴
Noncardiac congenital abnormalities and genetic defects	Defects specific to individual identified genes or recognized by a constellation of clinical features, eg, Noonan syndrome, 22Q11 deletion ²²
Noncardiac structural abnormality	Presence of abnormality in other systems, eg, cerebral infarction, trachea-oesophageal fistula, etc.
Major airways disease	Presence of at least moderate-to-severe degree of airway malacia or stenosis or external compression of airway by cardiac structures
Early reoperation	Unplanned reoperation during long-stay admission; not included: emergency chest opening, ECMO cannulation, chest exploration
Delayed sternal closure	Children discharged from theater with open sternum and subsequently had sternal closure in PICU
RACHS-1	A congenital cardiac surgical risk score stratifying procedural mortality across 6 categories ¹⁶

ECLS, Extracorporeal life support; ECMO, extracorporeal membrane oxygenation; PICU, pediatric intensive care unit; RACHS-1, The Risk Adjustment for Congenital Heart Surgery.

TABLE E2. Outcome assessment questionnaire

1. Mobility/physical activity
 - a. Does your child have any limitations in regard to walking/running/jumping? Yes/No. If yes, please specify
 - b. Does your child experience any unexpected breathlessness/tiredness when playing with other children or exercising? Yes/No. If yes, please specify
 - c. Is help required from other people, or from mechanical aids (wheelchair, frame), for your child to move around? Yes/No. If yes, please specify
 - d. Parent's perceptions of child's physical abilities in relation to children of a similar age
2. Self-care/role activity. Please circle the most appropriate
 - a. How much help does your child need to eat/dress/bathe/toilet (as age appropriate)
 1. No help
 2. A small amount of help
 3. A moderate amount of help
 4. Totally dependent on help from another person
 - b. Which of the following does your child attend?
 1. Kindergarten
 2. School year
 3. None
 - c. Does your child need any of the following support?
 1. Integration aide
 2. Special needs school
 3. Rehabilitation (including physiotherapy, occupational therapy, speech therapy)
 4. None
 - d. If your child attends school, how much school is missed throughout the year?
 1. Less than 1 wk
 2. Between 1 and 2 wk
 3. Between 2 and 4 wk
 4. More than a month
 - e. Parent's perception of child's ability to cope with school level
3. Social/emotional function
 - a. During an average day is your child generally
 1. Happy
 2. Anxious
 3. Depressed
 4. Aggressive
 - b. Does your child have any problems in making and maintaining friendships? Yes/No
 - c. Parents concerns with respect to child's behavior. Please specify
4. Health problems
 - a. Has your child developed any new health problems since your admission to hospital? Yes/No. If yes, please specify
 - b. Has there been any change in the management, or the severity of those health problems that your child experienced prior to admission to hospital? Yes/No. If yes, please specify
 - c. Does your child require regular follow-up by a specialist doctor? Yes/No. If yes, how often?
 - d. Does your child require regular medication? Yes/No. If yes, please specify
 - e. Does your child experience any pain/discomfort on a regular basis? Yes/No. Specify location and frequency
 - f. Does your child have any vision problems? Yes/No. If yes, please specify
Does your child need to wear glasses? Yes/No
 - g. Does your child have any hearing difficulties or do you have any concerns regarding your child's hearing (exclude selective deafness)?
Does your child require a technical aide (hearing aide, cochlear implant, other) to hear?
Did your child have any hearing difficulties prior to admission to hospital?
 - h. Does your child have any scars that have healed poorly, or have any other physical problems that cause your child, or you, concern? If yes, please specify
 - i. Additional comments:

TABLE E3. Nature of the first reoperation performed in study patients

Type of reoperations*
Univentricular repair
BCPC revision (1), BCPC takedown (1), early BCPC surgery (1)
Septectomy
Shunt takedown
LV plication, VSD closure
Thoracic duct ligation, pleurodesis
Central shunt revision
TV valve repair (4)
MBT shunt revision (6)
MBT shunt banding (5)
Aortopexy (2)
PDA ligation (2)
Re-do Damus-Kaye-Stansel connection
PA band
Aortic arch repair
RV-PA conduit re-do (1), RV-PA conduit takedown (1)
Norwood or Norwood type procedure (3)
PA closure
Biventricular repair
Permanent pacemaker implantation (2)
Aortopexy (2)
Thoracic duct ligation
Aortic arch repair
Coronary artery repair
Mitral valve repair (4)
MBT shunt revision (2), MAPCA ligation
Shunt takedown
PA band tightening (1), PA band removal (1), PA band insertion (1)
VSD closure (2), subaortic resection
AVSD repair, myomectomy
PA enlargement (2)
Airway stabilisation
PDA ligation (2), bronchus reconstruction, RPA reconstruction
Pulmonary homograft reconstruction
Maze procedure
TV replacement
Pulmonary vein stenosis repair
ASD repair
Pulmonary autograft, RVOT resection

BCPC, Bidirectional cavopulmonary connection; LV, left ventricular; VSD, ventricular septal defect; MBT, modified Blalock Taussig; PDA, patent ductus arteriosus; PA, pulmonary artery; RV-PA, right ventricle to pulmonary artery; MAPCA, major aortopulmonary collateral artery; VSD, ventricular septal defect; AVSD, atrioventricular septal defect; RPA, right pulmonary artery; TV, tricuspid valve; ASD, atrial septal defect; RVOT, right ventricular outflow tract. *More than one reoperation may have been performed per patient.