Pediatric Cardiology (2018) 39:1389–1396
https://doi.org/10.1007/s00246-018-1908-6

ORIGINAL ARTICLE

Survival and Associated Risk Factors for Mortality Among Infants with Critical Congenital Heart Disease in a Developing Country

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Received: 29 January 2018 / Accepted: 8 May 2018 / Published online: 14 May 2018
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Abstract

Critical congenital heart disease (CCHD) is associated with significant morbidity and mortality. However, data on survival of CCHD and the risk factors associated with its mortality are limited. This study examined CCHD survival and the risk factors for CCHD mortality. Using a retrospective cohort study of infants born with CCHD from 2006 to 2015, survival over 10 years was estimated using Kaplan–Meier analysis, and the risk factors for mortality were analyzed using multivariate Cox proportional hazards regression. A total of 491 CCHD cases were included in the study, with an overall mortality rate of 34.8% (95% confidence interval [CI] 30.6–39.2). The intervention/surgical mortality rate was 9.8% ≤ 30 days and 11.5% > 30 days after surgery, and 17% died before surgery or intervention. The median age at death was 2.7 months [first quartile: 1 month, third quartile: 7.3 months]. The CCHD survival rate was 90.4% (95% CI 89–91.8%) at 1 month, 69.3% (95% CI 67.2–71.4%) at 1 year, 63.4% (95% CI 61.1–65.7%) at 5 years, and 61.4% (95% CI 58.9–63.9%) at 10 years. Weight of < 2 kg at diagnosis, associated syndromes, poor pre-operative condition, and non-duct-dependent CCHD were independent risk factors for poor survival, with hazard ratios of 2.61, 2.10, 2.22, and 1.70, respectively. CCHD is associated with a high mortality rate. Low weight, poor pre-operative condition, associated syndromes, and non-duct-dependent CCHD are significant risk factors affecting the survival of infants with CCHD.

Keywords Critical congenital heart disease · Survival rate · Mortality rate · Surgery · Intervention

Introduction

Congenital heart disease (CHD) is the most common major birth defect. The majority of CHD cases are mild lesions and require no intervention. However, 20–25% of CHD cases are critical and require early intervention or surgery during the first year of life [1].

Critical CHD (CCHD) in infants may have subtle signs that do not present until after hospital discharge [2, 3]. Delay in the diagnosis of CCHD is associated with significant morbidity and mortality. Factors potentially contributing to a late diagnosis include the absence of murmur, mild hypoxemia, and early postnatal hospital discharge. Screening for CHD, and especially CCHD, aims to avoid late diagnosis, because the timing of diagnosis affects the outcome.

In developed countries, the overall mortality rate for CCHD ranges from 15 to 25% and varies by the type of cardiac defect [4] and the timing of diagnosis [5–8]. With advancements in medical and surgical management, CCHD outcomes have improved [9–11]. However, there are insufficient studies on the survival of CCHD in developing countries, where human resources and expertise are limited [12–17].

This study aimed to estimate the short- and medium-term survival of CCHD and to identify the factors affecting CCHD survival in a developing country.

Materials and Methods

This research used data from a cohort study of infants born in Johor, a southern state of Malaysia, from January 2006 to December 2015, with echocardiographically confirmed

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CCHD. The state of Johor is one of the most developed states in Malaysia, with a population of 3.6 million and 55,000 live births (LB) per year. Hospital Sultanah Aminah Johor Bahru is a tertiary government hospital in Johor. The hospital's pediatric cardiology unit was established in 2006 and receives all cases of suspected CCHD from the government hospitals in eight districts, as well as from private hospitals, for confirmatory diagnosis and stabilization. However, because of the lack of a dedicated pediatric cardiac surgeon in this unit, almost all CCHD cases are referred to a major cardiac center in Kuala Lumpur for surgical intervention.

Patient data were retrieved from the Pediatric Cardiology Clinical Information System, a clinical registry of all children with heart disease in the state of Johor. The retrieved data include demographic, clinical, intervention, surgical, follow-up, and mortality data for all CHD cases during the study period in Johor. The data were regularly updated. For the purposes of this study, mortality data were verified with the National Registration Office.

In this study, CHD was categorized as mild, moderate, or severe, as suggested by Hoffman and Kaplan [18]. CCHD was defined as any infant with a ductal dependent lesion that required intervention or resulted in death before 3 months of age [1]. CCHD was further categorized into four groups [19]: (1) duct-dependent pulmonary circulation for pulmonary atresia or critical pulmonary stenosis (PS); (2) duct-dependent systemic circulation for severe left ventricular outflow tract (LVOT) obstruction (aortic stenosis, coarctation of the aorta, interrupted aortic arch); (3) parallel circulation for d-transposition of the great arteries (D-TGA); and (4) critical but non-duct-dependent lesion, such as total anomalous pulmonary venous drainage, truncus arteriosus, or complex lesion associated with total anomalous pulmonary venous drainage.

All patients were reviewed by a pediatric cardiologist, and the decision for further intervention or surgical management was based on the complexity of the lesion and the availability of treatment. Conservative management and comfort care were offered to all infants with severe medical conditions associated with CCHD, including grade IV interventricular hemorrhage, severe prematurity, extremely low birth weight, and lethal syndromes such as Patau syndrome or Edwards syndrome. Comfort care was also offered in cases of complex single ventricle lesions associated with a poor prognosis, including hypoplastic left heart syndrome and heterotaxy syndrome with obstructed pulmonary venous drainage. However, for complex lesions amenable to biventricular repair, such as truncus arteriosus, surgical intervention was offered. Patients who were treated conservatively were excluded from the risk factor analysis for mortality.

For outcome measures, the analyzed factors included baseline demographic data, the timing of diagnosis, and the presence of poor pre-operative condition before the intervention or surgery. Poor pre-operative condition among the infants was defined as presenting with cardiovascular compromise requiring resuscitation or with severe metabolic acidosis requiring respiratory support [6, 20].

This study was approved by the Malaysian Research and Ethics Committee.

Statistical Analysis

All analyses were performed using SPSS version 16. Means or medians were used to describe continuous variables, and frequencies and percentages were used for categorical variables. We used Kaplan–Meier survival analysis and the log-rank test to study the outcomes of CCHD. Univariate Cox proportional hazards regression was used to identify the unadjusted effect of each variable on mortality. Variables with p values < 0.05 in the univariate analyses were entered into the Cox proportional hazards regression to identify the independent risk factors associated with death. A hazard ratio was considered significant if the 95% confidence interval (CI) excluded one.

Results

There were 531,904 live births during the study period, including 3557 with CHD. Of these, 78 were born to foreigners and were excluded from this study. Of the 3479 remaining infants with CHD, 1636 (47%) were mild cases; 516 (15%) were moderate; 678 (19.4%) were severe non-critical, and 649 (18.6%) were CCHD. Of the 649 cases with CCHD, 158 (24%) received comfort care and were excluded from the study. The reasons for comfort care are as follows: 120 (76%) were because of the complexity of the lesion (44 with hypoplastic left heart syndrome, 40 with heterotaxy syndrome, and 36 with complex lesions); 18 (12%) were because of lethal congenital malformation (9 with Patau syndrome, 6 with Edwards syndrome, and 3 others), and 20 were because of severe associated medical conditions.

A total of 491 patients with CCHD were included in this study. Of these 491 patients with CCHD with the intention to treat, 429 (87.4%) were cases of isolated CHD; 44 (8.9%) had other associated syndromes, and 18 (3.7%) had associated non-cardiac malformations. The overall mortality rate was 34.8% (95% CI 30.6–39.2), with a median age at death of 2.7 months (first quartile: 1 month, third quartile: 7.3 months). Further analysis showed that 84 (17%) patients died before any surgery or other intervention (44% cardiac-related), 40 (9.8%) died within 30 days of surgery (70% cardiac-related), and 47 (11.5%) died > 30 days after surgery (51% cardiac-related).

Table 1 shows the characteristics of the survivors and non-survivors of CCHD. There were significant differences between survivors and non-survivors in weight at diagnosis, the presence of an associated medical condition, clinical

Table 1 Comparison of demographic characteristics, clinical data, and type of critical congenital heart disease among non-survivors and survivors

Variable	Total CCHD *N* (%)	Non-survivors *N* (%)	Survivors *N* (%)	*p* value
Gestation				
Premature	46 (9.4)	18 (10.5)	28 (8.8)	0.52
Term	445 (90.6)	153 (89.5)	292 (91.3)	
Sex				
Female	212 (43.2)	75 (43.9)	137 (42.8)	0.82
Male	279 (56.8)	96 (56.1)	183 (57.2)	
Race				
Malay	335 (68.2)	118 (69.0)	217 (67.8)	0.74
Chinese	111 (22.6)	36 (21.1)	75 (23.4)	
Indian	31 (6.3)	13 (7.6)	18 (5.6)	
Other	14 (2.9)	4 (2.3)	10 (3.1)	
Birth year				
2006–2010	235 (47.9)	84 (49.1)	151 (47.2)	0.68
2011–2015	256 (52.1)	87 (50.9)	169 (52.8)	
Weight at diagnosis (kg)				**0.01**
< 2.0	42 (8.6)	22 (12.9)	20 (6.3)	
2.0–3.0	200 (40.7)	73 (42.7)	127 (39.7)	
> 3	247 (50.3)	74 (43.3)	173 (54.1)	
Associated condition				
Isolated CHD	429 (87.4)	137 (80.1)	292 (91.3)	**< 0.001**
Syndrome	44 (9.0)	26 (15.2)	18 (5.6)	**< 0.001**
Non-cardiac malformation	18 (3.7)	8 (4.7)	10 (3.1)	0.42
Maternal diabetes	84 (17.1)	26 (15.2)	58 (18.1)	0.48
Type of critical CHD				
DDPC	267 (54.4)	82 (48.0)	185 (57.8)	**0.04**
DDSC	78 (15.9)	32 (18.7)	46 (14.4)	0.24
CNDD	65 (13.2)	30 (17.5)	35 (10.9)	0.05
PC	81 (16.5)	27 (15.8)	54 (16.9)	0.80
Timing of diagnosis				
< 3 days	217 (44.2)	80 (46.8)	137 (42.8)	0.19
4–7 days	48 (9.8)	21 (12.3)	27 (8.4)	
8–28 days	86 (17.5)	23 (13.5)	63 (19.7)	
> 28 days	140 (28.5)	47 (27.5)	93 (29.1)	
Late diagnosis, > 3 days	274 (55.8)	91 (53.2)	183 (57.2)	0.39
Prenatal diagnosis	23 (4.7)	9 (5.3)	14 (4.4)	0.65
Poor pre-operative condition[a]	58 (11.8)	31 (18.1)	27 (8.4)	**0.002**
Other clinical presentation				
Heart failure	160 (32.6)	70 (40.9)	90 (28.1)	**0.004**
Cyanosis	372 (75.8)	137 (80.1)	235 (73.4)	0.10
Respiratory distress	169 (34.4)	65 (38.0)	104 (32.5)	0.22
Total	491 (100)	171 (100)	320 (100)	

Bold values indicate significance at $p < 0.05$

CCHD critical congenital heart disease, *CHD* congenital heart disease, *DDPC* duct-dependent pulmonary circulation, *DDSC* duct-dependent systemic circulation, *CNDD* critical, non-duct-dependent, *PC* parallel circulation

[a]Presented with shock or severe acidosis requiring ventilator support

presentation at diagnosis, and type of cardiac defect. However, there was no significant difference in the outcome of an early or late diagnosis of CCHD.

Table 2 shows diagnosis-specific mortality and timing of death. The lowest diagnosis-specific mortality rate was seen for severe or critical PS (15%), and the highest was for complex lesion with left-sided obstruction (64.7%). Almost 50% of patients with truncus arteriosus died before surgery, and the majority of infants who died within 30 days of surgery were D-TGA 12 (30%).

Table 3 shows the non-adjusted and adjusted hazard ratios for mortality. The multivariate Cox regression analysis revealed the independent risk factors for mortality to be weighing < 2 kg at diagnosis, having an associated syndrome, the presence of poor pre-operative condition, and having a critical but non-duct-dependent lesion. Figure 1 shows the effect of these variables on the survival of patients with CCHD in this study.

Figure 2 shows the Kaplan–Meier survival estimates for all CHD cases according to the severity of the lesion. Of the 3479 infants with CHD, 548 (15.7%) died during the study period, with an estimated survival rate of 95.3% (95% CI 94.9–95.7%) at 1 month, 86.7% (95% CI 86.1–87.3%) at 1 year, 83.3% (95% CI 82.6–84.0%) at 5 years, and 81.7% (95% CI 80.9–82.5%) at 10 years. The survival rate varied significantly by CHD severity, with CCHD having the lowest survival rates at 1, 5, and 10 years.

Table 4 shows the Kaplan–Meier survival estimates for diagnosis-specific CCHD with the intention to treat. Survival rates under 50% at 1 year of age were found for infants with complex lesions with LVOT obstruction, those with truncus arteriosus, and those with interrupted aortic arch. However, the survival rate remained stable at 5 and 10 years. In contrast, infants with pulmonary atresia with ventricular septal defect (PAVSD) had a 95% survival rate during the neonatal period, which declined to 65% at 1 year and 45% at 5 years.

Discussion

The survival rate of all infants born with CHD in this study was 86.7% at 1 year, 83.3% at 5 years, and 81.7% at 10 years. In a developing country with many limitations in human resources and expertise, our findings for the survival rate for patients with CHD were similar to the findings reported in

Table 2 Diagnosis-specific mortality rate and timing of death among infants with critical congenital heart disease with intention to treat

Type of critical CHD	Total (*n*)	Death (*n*)	Mortality rate (95% CI)	Timing of death in relation to surgery or intervention, *n* (%)		
				Prior[a]	Within 30 days[b]	After 30 days[b]
Duct-dependent pulmonary circulation	267	82	30.7 (25.3, 36.7)	38 (14.2)	13(5.7)	31 (13.5)
TOF with PA or severe PS	60	15	25.0 (15.1, 38.1)	5 (8.3)	2 (3.6)	8 (14.5)
Complex lesion with PA or severe PS	56	16	28.6 (17.7,42.4)	6 (10.7)	1 (2.0)	9 (18.0)
PAVSD	42	19	45.2 (30.2, 61.2)	8 (19.0)	1 (2.9)	8 (23.5)
PAIVS	40	15	37.5 (23.2, 54.2)	9 (22.5)	5 (16.1)	1(3.2)
Tricuspid atresia	37	12	32.4 (18.5, 49.9)	6 (16.2)	2 (6.4)	4 (12.9)
Critical or severe PS	32	5	15.6 (5.9, 33.5)	2 (6.3)	2 (6.7)	1 (3.3)
Duct-dependent systemic circulation	78	32	41.0 (30.2, 52.7)	17 (21.7)	9 (14.7)	6 (9.8)
Critical or severe CoA	46	13	28.3 (16.5, 43.6)	5 (10.8)	4 (9.7)	4 (9.7)
IAA	15	8	53.3 (27.4, 77.7)	5 (33.3)	2 (20.0)	1 (10.0)
Complex lesion with severe CoA or IAA	17	11	64.7 (38.6, 84.7)	7 (41.2)	3 (30.0)	1 (10.0)
Critical, non-duct-dependent	65	30	46.1 (33.9, 58.9)	18 (27.7)	6 (12.8)	6 (10.6)
TAPVD	32	13	40.6 (24.2, 59.2)	5 (15.6)	3 (11.1)	5 (18.5)
Truncus arteriosus	23	13	56.5 (34.8, 76.1)	11 (47.8)	1 (8.3)	1 (8.3)
Other	10	4	40.0 (13.7, 72.6)	2 (20.0)	2 (25.0)	–
Parallel circulation						
D-TGA	81	27	33.3 (23.5, 44.8)	11 (13.6)	12 (17.1)	4 (5.7)
Total	491	171	34.8 (30.6, 39.2)	84 (17.1)	40 (9.8)	47 (11.5)

TOF tetralogy of Fallot, *PA* pulmonary atresia, *PS* pulmonary stenosis, *PAVSD* pulmonary atresia with ventricular septal defect, *PAIVS* pulmonary atresia with intact septum, *AS* aortic stenosis, *TAPVD* total anomalous pulmonary venous drainage, *D-TGA* d-transposition of the great arteries, *IAA* interrupted aortic arch, *CoA* coarctation of the aorta

[a]% of total

[b]% of surgery or intervention

Table 3 Factors associated with all-cause mortality in infants with critical congenital heart disease

Variable	Hazard ratio (95% CI)[a]	
	Crude	Adjusted
Weight at diagnosis		
> 3 kg	Reference	Reference
< 2 kg	2.4 (1.49–3.89)	2.61 (1.59–4.27)
2–3 kg	1.3 (0.94–1.79)	1.21 (0.86–1.68)
Associated syndrome	2.11 (1.39–3.21)	2.10 (1.35–3.28)
Poor pre-operative condition	2.12 (1.44–3.13)	2.22 (1.40–3.52)
Heart failure	1.57 (1.14–2.11)	1.16 (0.79–1.72)
Defect type		
Duct-dependent pulmonary circulation	Reference	Reference
Parallel circulation	1.28 (0.79–1.89)	1.17 (0.73–1.86)
Duct-dependent systemic circulation	1.54 (1.02–2.31)	1.21 (0.75–1.94)
Critical, non-duct-dependent	1.76 (1.16–2.68)	1.70 (1.07–2.70)

Hazard ratios are considered to statistically significantly differ from the reference category if their 95% confidence intervals exclude one

[a]Analyzed with Cox proportional regression

a recent systematic meta-analysis of 16 population studies with pooled 1-, 5-, and 10-year survival rates of 87, 85.4, and 81.4%, respectively [10]. The similarity of the rates found in the present study may be because of the high percentage of mild and moderate CHD cases in our study, which may have led to higher survival rates.

As expected, the mortality and survival rates varied with the severity of CHD, and survival was lower among patients with CCHD. The mortality rate of CCHD with intention to treat in our study cohort was 34%, with a median age at death of 3 months. This rate is higher than those reported in other studies in developed countries, which range from 16 to 25% [4, 8, 21–23]. Our study has also revealed a rather low survival rate of 69% at 1 year of age, in contrast to a previous study's estimate of 82% from Atlanta, in the United States [21]. These findings are not unexpected, given the lack of resources, infrastructure, and expertise in Malaysia. This is also seen in the high percentage (17%) of infants who died before any intervention or surgery, 56% of whom died because of non-cardiac causes such as pneumonia or infection. Furthermore, of those undergoing surgery or other intervention, the post-operative or post-intervention mortality rate was still high, compared with a previous study [24].

The management of infants with CCHD requires a good congenital heart surgery program with the involvement of a highly skilled, multidisciplinary team and the support of the health authorities [14, 15, 26]. Currently, only four major cardiac centers and only five dedicated congenital cardiac surgeons (one in a government hospital and four in private hospitals) cover 31.7 million people living in Malaysia. Furthermore, of the 500,000 annual live births in Malaysia, an estimated of 500–1000 are born with critical lesions requiring urgent intervention. With the lack of intensive care beds, insufficient operation theatres, and long waiting times for congenital cardiac surgery in the current setting, we believe that complex single ventricle lesions should be treated with comfort care. These aspects of the setting explain our finding of a high rate of patients who received comfort care, who accounted for almost one in four (25%) of patients with CCHD. Almost no patients with hypoplastic left heart syndrome or heterotaxy were offered surgical treatment. These two types of cardiac lesions and other complex single ventricle lesions require a multiple-stage procedure and are associated with significant medium- and long-term morbidity [25]. Previous attempts to correct these lesions have to longer intensive care unit and hospital stays and eventually death.

Our results have shown a low survival rate (< 50%) at 1 year among infants with truncus arteriosus or critical lesions with left-sided obstructions. This highlights the challenges in managing such lesions and the limitations of our congenital cardiac surgery program. Despite active interventions for these lesions, our results showed that almost 50% of patients with truncus arteriosus and 20% of those with left-sided lesions died of various causes while waiting for intervention.

Interestingly, despite a reasonably high survival rate at 1 month and 1 year of age, fewer than 50% of patients with PAVSD survived to the age of 5 years. This can be explained by staged palliative surgery in PAVSD (i.e., palliative shunt at an early age and subsequent corrective surgery at a later age), because each stage of the procedure carries its own risk of mortality. Furthermore, in PAVSD, the main pulmonary artery and its branches vary among patients, which may affect the outcome.

The identification of the risk factors that may affect the long-term survival of CCHD is very important, so that

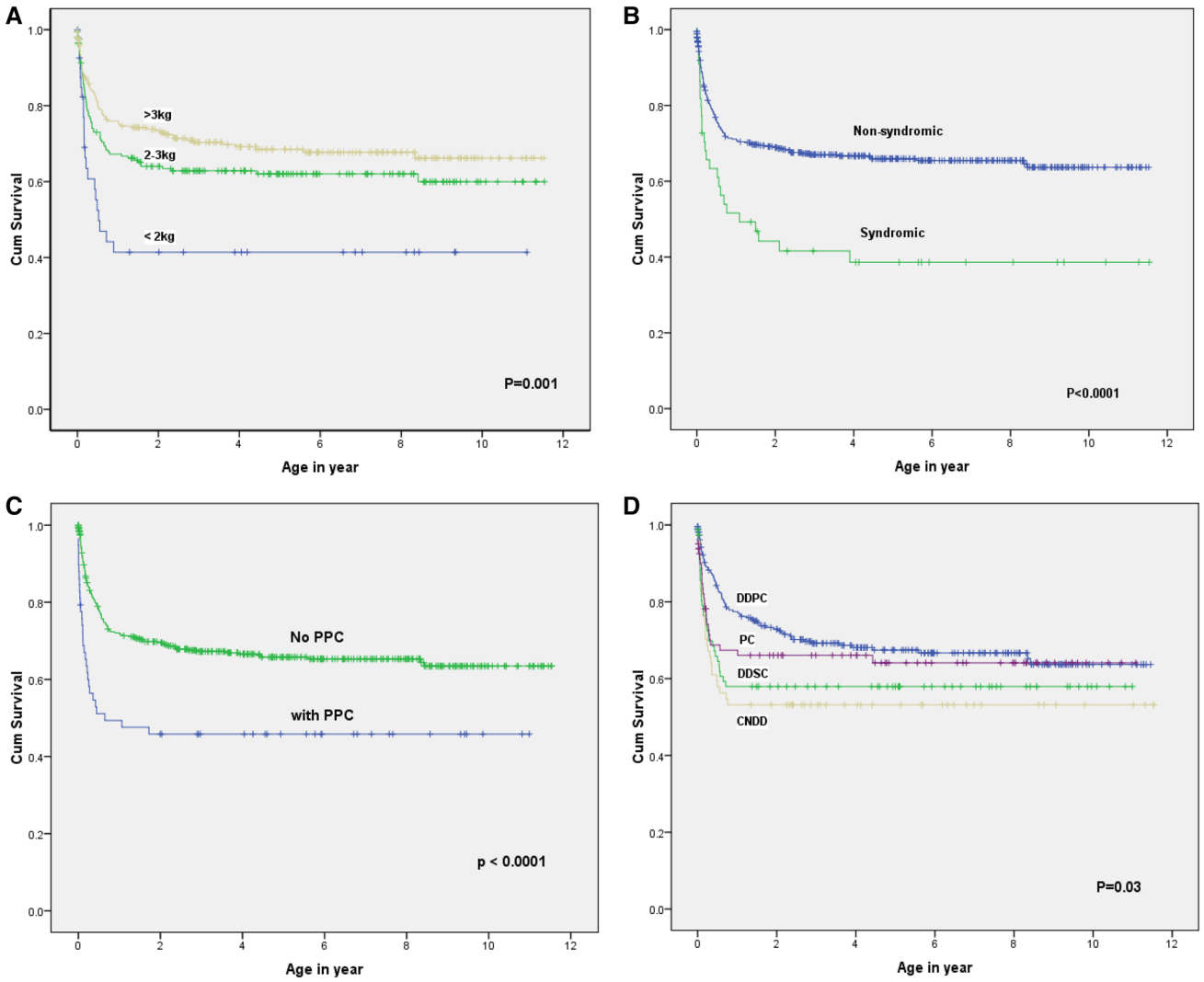

Fig. 1 Kaplan–Meier survival analysis showing the effects of weight at diagnosis (**a**), associated syndromes (**b**), poor pre-operative condition (**c**), and defect type (**d**) on the survival of infants with critical congenital heart disease in Johor, Malaysia, 2006–2015. *PPC* poor pre-operative condition, *DDPC* duct-dependent pulmonary circulation, *DDSC* duct-dependent systemic circulation, *PC* parallel circulation, *CNDD* critical, non-duct-dependent lesion

clinicians and health authorities can focus on these factors and take steps to improve the outcome. Early diagnosis is one of the widely studied factors affecting CCHD outcomes, and many studies have shown early diagnosis to be associated with good outcomes [7, 8, 22]. However, in this study, patients who were diagnosed within 3 days of birth had a similar mortality rate as did those who were diagnosed later. This finding is in contrast to the study by Oster et al., which showed an association between early diagnosis and poor outcomes [21]. The timing of diagnosis could be a reflection of the severity of the lesion (i.e., the more severe the lesion, the earlier its presentation). Another possible reason for poor outcomes is a delay in intervention or surgery because of the limitations of congenital cardiac surgery programs in Malaysia.

Another important factor that may affect survival is the presence of poor pre-operative condition. The prevalence of poor pre-operative condition in our study was 12%, which is comparable to the findings of a study by Schultz et al. [20]. Our study supports a previous finding that infants with poor pre-operative condition had a greater risk of mortality than did their counterparts [6]. Therefore, the optimization of pre-operative condition and improvements in resuscitation may help to improve the outcomes.

In line with previous studies, our results showed syndromic and small infants to have higher mortality [26–28]. This is not surprising, because syndromic and small infants are more likely to have multiple medical and surgical problems and to require more intensive care.

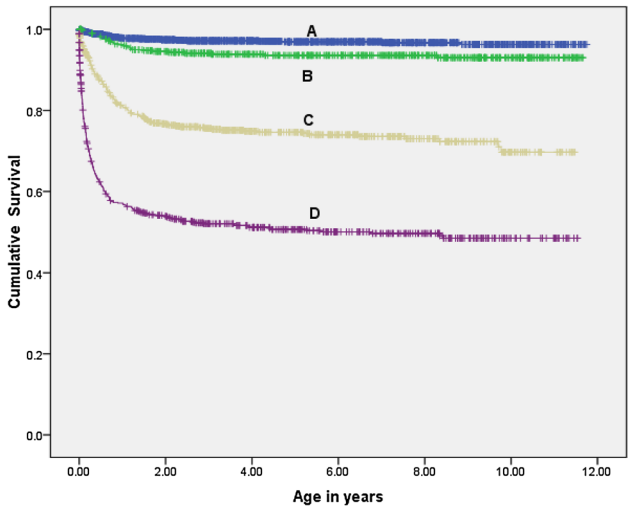

Fig. 2 Kaplan–Meier estimates of survival for all infants with (*A*) mild, (*B*) moderate, (*C*) severe non-critical, and (*D*) critical congenital heart disease in Johor, Malaysia, 2006–2015

Study Limitations

The limitations of this study include the possibility of underreporting. Some parents may have sought treatment at a cardiac center in Singapore or Kuala Lumpur, Malaysia, leading to a lower rate of CHD. However, we believe that these cases involved non-critical lesions, because the temporal trend of all CHD showed a significant increase, from 5.1 per 1000 LB in 2006 to 7.8 per 1000 LB in 2015 ($p < 0.001$), without a significant increase in the trend of CCHD (0.9 per 1000 LB in 2006 and 1.3 per 1000 LB in 2015, $p = 0.4$). A low rate of CCHD in 2006 could have resulted from undiagnosed cases of CCHD, where the patients died either at home or in other hospitals. For this study, we lacked postmortem data. However, we believe that the number of unreported CHD cases is small, because the overall prevalence of CCHD in our study is comparable with that reported for other studies (ranging from 1 to 2 cases per 1000 LB) [1, 8]. Another limitation is insufficient surgical data, which limits the analysis of the effect of surgical variables on CCHD outcomes.

Conclusions

The mortality and survival of infants with CHD vary with the severity of the lesion, with CCHD having high mortality and low short- and medium-term survival rates. Poor pre-operative condition, low weight, associated syndromes, and severity of cardiac defect are risk factors affecting the survival of patients with CCHD.

Table 4 Kaplan–Meier estimates of survival for infants with critical congenital heart disease with intention to treat

Diagnosis	Total (*n*)	Death (*n*)	Survival rate (95% CI)		
			1 month	1 year	5 years
Duct-dependent pulmonary circulation	267	82	93.4 (91.9–94.9)	77.4 (74.8–90.0)	67.4 (64.3–70.5)
TOF with PA or severe PS	60	15	96.7 (94.4–99.0)	86.6 (82.2–91.0)	77.4 (71.8–83.0)
Complex lesion with PA or severe PS	56	16	96.4 (93.9–98.9)	81.2 (75.8–86.6)	69.3 (62.5–76.1)
PAVSD	42	19	94.6 (90.9–98.3)	64.9 (57.1–72.7)	44.7 (35.8–53.6)
PAIVS	40	15	83.8 (77.7–89.9)	62.0 (54.0–70.0)	59.2 (51.1–67.3)
Tricuspid atresia	37	12	94.6 (90.9–98.3)	78.4 (71.6–85.2)	67.0 (59.2–74.8)
Critical or severe PS	32	5	89.9 (84.4–95.4)	86.3 (79.9–92.7)	82.2 (74.9–89.5)
Duct-dependent systemic circulation	78	32	81.6 (77.2–86.0)	57.9 (52.2–63.6)	57.9 (52.2–63.6)
Critical or severe CoA	46	13	93.3 (89.5–97.1)	70.5 (63.6–77.4)	70.5 (63.6–77.4)
IAA	15	8	66.7 (54.5–78.9)	46.7 (33.8–59.6)	46.7 (33.8–59.6)
Complex lesion with CoA or IAA	17	11	64.7 (53.1–76.3)	35.3 (23.7–46.9)	35.3 (23.7–46.9)
Critical, non-duct-dependent	65	30	89.1 (85.2–93.0)	53.2 (47.0–59.4)	53.2 (47.0–59.4)
TAPVD	32	13	90.5 (85.3–95.7)	58.2 (49.3–67.1)	58.2 (49.3–67.1)
Truncus with no IAA or truncal stenosis	23	13	82.6 (74.7–90.5)	43.5 (33.2–53.8)	43.5 (33.2–53.8)
Other	10	4	90.0 (80.5–99.5)	60.0 (44.5–75.5)	60.0 (44.5–75.5)
Parallel circulation					
D-TGA	81	27	89.9 (86.5–93.3)	67.4 (62.0–72.8)	64.1 (58.5–69.7)
All	491	171	90.4 (89.0–91.8)	69.3 (67.2–71.4)	63.4 (61.1–65.7)

TOF tetralogy of Fallot, *PA* pulmonary atresia, *PS* pulmonary stenosis, *PAVSD* pulmonary atresia with ventricular septal defect, *PAIVS* pulmonary atresia with intact septum, *CoA* coarctation of the aorta, *IAA* interrupted aortic arch, *AS* aortic stenosis, *TAPVD* total anomalous pulmonary venous drainage, *D-TGA* d-transposition of the great arteries

Acknowledgements The authors would like to thank the Director General of Health Malaysia for permission to publish this paper. We thank Jennifer Barrett, PhD, from Edanz Group (http://www.edanzediting.com/ac) for editing a draft of this article.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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