ORIGINAL ARTICLE

Risk factors for low cardiac output syndrome after congenital heart surgery

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Background. *Congenital Heart Disease (CHD) is the most frequent malformation at birth. Although Mexico does not have accurate statistics, the prevalence is estimated at 8 per 1,000 live births. Additionally, 5 to 20% of the patients will present heart failure, increasing even more after a surgical procedure.* ***Objective.*** *Identify risk factors for heart failure after congenital heart disease surgery in which Del Nido cardioplegia was used.* ***Material.*** *Longitudinal and observational study. Patients admitted to the intensive pediatric cardiovascular unit after cardiac surgery from January to August 2021 were included. Low cardiac output syndrome was diagnosed by clinical, echocardiographic and blood gas parameters.* ***Results.*** *Sixty-nine patients were included; the median age was 9 months, 60.9% were male, and the most frequent surgical risk was RACHS 2 and 3 (50.8 and 27%, respectively); 92% of the patient had biventricular physiology. The most frequent diagnoses were ventricular septal defect (VSD) (30.4%) and Tetralogy of Fallot (TOF) (13%). Cardiopulmonary bypass (CPB) and aortic cross-clamping times were 111.58 minutes ± 53.74 minutes and 64.87 minutes ± 34.99 minutes, respectively. The identify risk factors were preoperative characteristics, age, weight, and height (p <0.05); intraoperative risk factors, CBP, aortic cross-clamping, selective cerebral perfusion, minimum temperature, and maximum lactate (p< 0.05); postoperative factor, arrhythmias (OR 13.6; 95%CI 3.741 - 49.801; p=0.000). Low cardiac output syndrome (LCOS) increased mortality (OR 2.3; 95%CI 1.270 - 2.304; p=0.005).* ***Conclusions.*** *LCOS was present in 49.3% of the patients with a 2.3-fold increase in mortality. We identified several risk factors and documented a 14.3% mortality rate.*

Key words: *Cardiac surgery; Congenital heart disease, Low cardiac output syndrome.*

Antecedentes. *Las cardiopatías congénitas son las malformaciones más frecuentes al nacimiento. Aunque en México no se cuenta con una estadística exacta, 8 de cada 1,000 recién nacidos vivos presentará falla cardiaca, y si se someten a un procedimiento quirúrgico, este porcentaje se incrementa.* ***Objetivo.*** *Determinar factores de riesgo para síndrome de bajo gasto cardiaco postbomba en el postquirúrgico de cardiopatía congénita, utilizando cardioplegia Del Nido.* ***Material.*** *Estudio observacional, longitudinal, analítico y prospectivo. Se incluyeron pacientes ingresados a la terapia intensiva posterior a cirugía cardiaca, en la cual se haya administrado cardioplejia en el periodo de enero a agosto de 2021. El síndrome de bajo gasto cardiaco postbomba se definió por parámetros clínicos, ecocardiográficos y gasométricos.* ***Resultados.*** *Se incluyeron 63 pacientes con una mediana de edad de 9 meses. El 60.9% eran varones, y el riesgo quirúrgico más frecuente fue el RACHS 2 y 3 (50.8% y 27%, respectivamente). El 92% de los pacientes tenían fisiología biventricular. Los diagnósticos más frecuentes fueron comunicación interventricular (30.4%) y Tetralogía de Fallot (13%). Las características reportadas como factor de riesgo fueron: prequirúrgicos, edad, peso y talla (p <0.05); transoperatorios, circulación extracorpórea, pinzamiento aórtico, perfusión cerebral selectiva, temperatura mínima y lactato máximo (p <0.05); factores postquirúrgicos, arritmias (OR 13.6; IC 95% 3.741 - 49.801; p=0.000). La prevalencia de síndrome de bajo gasto cardiaco postbomba se reportó en el 49.2%, incrementando la probabilidad de defunción (OR 2.3; IC95% 1.270 – 2.304; p=0.005).* ***Conclusiones.*** *El síndrome de bajo gasto cardiaco postbomba estuvo presente en el 49.3% de los pacientes con un aumento de la mortalidad de 2.3 veces. Identificamos varios factores de riesgo y documentamos una tasa de mortalidad del 14.3%.*

Palabras clave: *Cirugía Cardiaca; Cardiopatía congénita; Síndrome de bajo gasto cardiaco.*

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Congenital Heart Disease (CHD) is the most frequent malformation at birth. Although Mexico does not have accurate statistics, the prevalence is estimated at 8 per 1,000 live births. CHD is an important cause of in-

fant mortality ranking as the sixth cause of mortality in children under 1 year of age, and as the third cause of mortality in children between 1 to 4 years of age [1].

Most of these infants must undergo one or more cardiac surgical procedures to correct the CHD. An important complication in the postoperative period is the low cardiac output syndrome (LCOS). This syndrome was first described in 1975 by Parret as a patient in a postoperative state with a cardiac index lower than 2.0 liters/min/m2. The incidence was estimated in approximately 25% in patients following cardiopulmonary bypass (CPB) for correction of CHD. It has been reported that this phenomenon usually occurs within 6 - 18 hours after the procedure. Furthermore, this low cardiac output syndrome (LCOS) is associated with longer periods of in-hospital stay and a high mortality rate (6.8% to 8%) [2,3].

The causes of heart failure in the pediatric population are vast and can be classified into two main groups: secondary to cardiac surgery, and due to acquired heart disease. There are four fundamental mechanisms for the development of heart failure: 1) systolic dysfunction, 2) diastolic dysfunction, 3) Pulmonary over-circulation with poor systemic perfusion, and 4) inadequate blood mixing [4].

Systolic and diastolic dysfunction can be observed during the postoperative period because of a poor myocardial protection strategy [5]. Myocardial protection is essential in cardiac surgery, a series of measures aimed to avoid myocardial injury induced by the production of harmful metabolites to the heart during CPB, as well as those produced by the ischemia of aortic cross-clamping [6-8]. Myocardial protection involves preoperative measures for cardiac conditioning and intraoperative measures such as administration of a cardioplegia solution, controlled hypothermia, preventing both myocardial overdistension and retraction injury during the procedure, regulation of acid-base balance, avoiding excessive hemodilution and myocardial reperfusion injury following the aortic clamp removal. All these actions are important in myocardial protection protocols. However, the use of cardioplegia solutions and controlled hypothermia are especially important [9-11].

The most noteworthy problem faced by the surgical team concerning myocardial protection is the myocardial maturity. The transition between neonatal to mature myocardium, which occurs around 4 months of age, is an important feature to consider in the myocardial protection strategy due to the differences between mature and immature myocardium, as the latter obtains ATP through fatty acid metabolism, ketones, and amino acids; it shows a decreased insulin sensitivity; it has an increased ability to carry out anaerobic metabolism; it shows a greater sensitivity to extracellular calcium levels; its enzyme systems are less active as are its free radical scavengers, resulting in a greater sensitivity to ischemia-reperfusion injury; and, it is more tolerant to ischemia but less susceptible to catecholamines [12-15].

Within the population at our institution, a significant number of patients have CHD. In our experience, an increase in incidence of LCOS in the postoperative period has been observed, which has become a relevant cause for morbidity and mortality. The purpose of the study is to provide valuable information in order to establish a standardized protocol for myocardial protection, aiming to reduce the incidence of LCOS, time in mechanical ventilation, intensive care unit length of stay, and length of in-hospital stay. In this way, better results can be theoretically achieved in short- and intermediate-term.

MATERIAL

This is a longitudinal and observational study performed in the operating room and pediatric cardiovascular intensive care unit (CICU) at our institution. Sixty-nine patients were included. The variables of interest were collected preoperatively, intraoperatively and postoperatively (48 hours after operation). A descriptive analysis of all variables was performed. Inferential statistical analysis was performed.

RESULTS

Sixty-three patients who met the selection criteria for the period between January and August 2021 were included. Median age was 9 months (range, 0.2 to 156 months). Sixty-one percent was male, with a median weight and height of 7.5 kg (range, 2.5 to 55 kg), and 72 cm (range, 48 to 167 cm), respectively.

There was a predominance of RACH 2 surgical risk with 50.8% (n = 32) of the sample, followed by RACH 3 and 4 with 27% and 12.7%, respectively. Biventricular physiology was reported in 92.8%, and the most frequent diagnosis was ventricular septal defect (VSD) with 30.4% (n = 21), followed by Tetralogy of Fallot (TOF) in 13% (n = 9), and aortic arch hypoplasia in 10.1% (n = 7).

The intraoperative characteristics of the patients with Del Nido cardioplegia: a median of 108 min of CPB (range, 24 to 285 min), with 34.9% of patients with prolonged CPB (>140 min) and a mean of 65.17 ± 36.15 min of aortic cross-clamping time; out of them, 52.4% was considered as prolonged aortic cross-clamping time (> 55 minutes). Only 1 patient underwent circulatory arrest, and 8 patients had selective cerebral perfusion (**Table 1**).

Hypotension was reported in 34.9%; oliguria, in 41.3%; and elevated lactate, in 39.7% with metabolic acidosis in 25.4%. The median Vasoactive Inotropic Score was 16.15 (range, 0 to 133), which was considered elevated in 50.8% of the patients. The median length of stay in the CICU was 5 days (range, 0 to 124 days) with a median length of hospital stay of 20.5 days (minimum 5; maximum 141 days).

In the postoperative laboratory results, hyponatremia and hemodilution were reported in 55.6% and 50.8%, respectively. Hyperglycemia was reported in only 27% of patients. Overall,

Table 1. Intraoperative features (n = 63)

Features	Median (SD) / n (%)
Cardiopulmonary Bypass Time (minutes)*	108 (24 – 285)
Prolonged Cardiopulmonary Bypass Time	22 (34.9)
Aortic Cross-clamp Time (minutes)	65.17 (36.15)
Prolonged Aortic Cross-clamp Time	33 (52.4)
Circulatory Arrest*	1 (1.6)
Circulatory Arrest (minutes)*	0 (0 – 30)
Selective Cerebral Perfusion	8 (12.7)
Selective Cerebral Perfusion (minutes)*	0 (0 – 48)
Minimal Temperature*	31 (18 – 37)
Minimal Hematocrit*	25 (18 – 39)
Maximal Lactate*	2.2 (0.7 – 8.5)
Modified Ultrafiltration*	6 150 (0 – 1,100)
Electric or Mechanical Activity in Ischemia	2 (3.2)

**Nonparametric distribution: median, minimum, and maximum are reported*

there were statistically significant elevations of CPK, CPK-MB and Troponin T at 48 hours after surgery with CPB ($p < 0.05$). Elevated Pro-BNP at 24 hours after surgery was recorded in 7.9% of patients (**Table 2**) (**Table 3**). Heart failure was oresent in 49.2% (n = 31), and the mortality rate was 14.3%.

Patients diagnosed with LCOS were compared with those who did not present heart failure to identify associated factors. Concerning preoperative features, statistically significant differences were found in the variables of age, weight, and height, indicating that younger patients are at higher risk (**Table 4**).

In relation to surgical risk factors, statistically significant differences were found in the variables of CPV, aortic cross-clamp, selective cerebral perfusion, minimum temperature, and maximum lactate ($p < 0.05$), as well with prolonged CPB (OR of 12.462; 95% CI 3.104 - 50.024; p = 0.000) (**Table 5**).

The postoperative risk factors with a significant association were the presence of arrhythmias with an OR of 13.6 for heart failure (95% CI 3.741 - 49.801; p = 0.000) and hemodilution 48 hours after surgery as a protective factor for heart failure with an OR of 0.3 (95% CI 0.111 - 0.901; p = 0.029). LCOS was present in 49.3% of the patients with a 2.3-fold increase in mortality (CI 1.270 - 2.304; p = 0.005) (**Table 6**).

Table 2. Postsurgical Features: Laboratory Assays (n = 63)

Features	Median (SD) / n (%)
Hyponatremia (Sodium < 135 mmoL/L)	39 (56.5)
Hyperkalemia (Potassium > 5.0 mmoL/L)	22 (31.9)
Hyperglycemia (Glucose > 200 mg/dL)	18 (26.1)
Hypocalcemia (Ionic Calcium < 0.9 mmoL/L)	5 (7.2)
Hypercalcemia (Ionic Calcium > 1.35 mmoL/L)	5 (7.2)
Hemodilution (Hematocrit < 30%)	3 (47.8)
Previous CPB CPK (U/L)º	84.52 (30.65)
Intraoperative CPK (In CPB) (U/L)º*	307 (120 – 1,115)
Post-Surgical CPK (Postsurgical 48 hours) (U/L)º*	648 (136 – 3,405)
Previous CPB CPK (U/L)º	28.79 (11.14)
Intraoperative CPK MB (In CPB) (U/L)º	91.52 (59.16)
Post-surgical CPK MB (Postsurgical 48 hours) (U/L)º*	66.7 (14.8 – 555.4)
Previous CPB Troponin T (pg/mL)º*	20.9 (3.10 – 281.8)
Intraoperative Troponin T (In CPB) (pg/mL)º*	457.9 (82.3 – 5,622)
Postsurgical Troponin T (Postsurgical 48 hours) (pg/mL)º*	1,009 (122.8 – 14,701.2)
Pro-BNP (Postsurgical 24 hours) (pg/mL)º*	4,841 (65.5 – 39,070)
High level Pro-BNP (> 12,000 pg/mL)	5 (7.2)

**Non-parametric Distribution: median, minimum, and maximum are reported; ºMissing cases are reported; CPB: Cardiopulmonary bypass.*

Table 3. Postsurgical Features: Laboratory Results (n = 63)

Feature	Previous CPB	Post-surgical 48 hours	p value
CPK (U/L)	89 (36 – 276)	537 (131 – 4,739)	0.000
CPK MB (U/L)	25.5 (9.1 – 53.1)	57.1 (14.8 – 555.4)	0.000
Troponin T (pg/mL)	28 (3.1 – 2,201)	1,009 (65.9 – 14,701)	0.823

**Non-parametric Distribution: Median, minimum, and maximum are reported. Sign test and Wilcoxon ranges.*

DISCUSSION

The surgical risk is similar to that reported in the literature, as we recorded RACHS 2 (50.8%) and 3 (27%) in most of our patients, with a lower report of RACHS 1 (1.6%), 4 (12.7%) and 6 (1.6%) [16,17]. The most frequent acyanotic CHD in our center is VSD (30.4%) and the cyanotic one is TOF (13%).

The demographic characteristics are comparable with patients in other centers, as well the CPB and aortic cross-clamping times are comparable to those presented in the global literature [18,19].

The incidence of LCOS in cardiac surgery in our center is much higher with 49.2% compared to 9.98% in a study conducted at Shanghai Children's Medical Center, and 25% reported in a study conducted at Baylor College of Medicine [20].

In our study, we found different risk factors for heart failure grouped into preoperative risk factors: age, weight and height, younger patients presenting heart failure more often; intraoperative risk factors: CPB, aortic cross-clamp, selective cerebral perfusion, minimum temperature, and maximum lactate [20]; and postoperative risk factors: arrhythmias, high

Table 4. LCOS Postsurgical Risks Factors (n = 63)

Risk Factor	LCOS 31(49.2)	No LCOS 30 (47.6)	p value	OR	95% CI
Age (months)	6 (0.2 – 144)	13.5 (3 – 132)	0.028		
Gender					
Male	17 (54.8)	20 (66.7)	0.344	0.607	0.215 – 1.714
Female	14 (45.2)	10 (33.3)	0.344	1.647	0.584 – 4.649
Weight (kilograms)	5.9 (2.5 – 50.7)	9.2 (3.75 – 55)	0.021		
Height (centimeters)	64 (48 – 160)	77.5 (52 – 160)	0.022		
Physiology					
Univentricular	2 (6.5)	2 (6.7)	0.973	0.966	0.127 – 7.334
Biventricular	29 (93.5)	28 (93.3)	0.973	1.036	0.136 – 7.867

*LCOS: Low cardiac output syndrome; *Non-parametric Distribution: Median, minimum, and maximum are reported; *Mann-Whitney U Test.*

vasoactive-inotropic score, elevated myocardial injury enzymes, high pro-BNP [21-25]. Hemodilution was found as a preoperative protective factor.

Mortality was much higher in our study than that reported in the literature, 12.6% vs. 0 – 5% with similar diagnoses and surgical risk classification. In addition, the presence of heart failure in the postoperative period increased by 2.3-fold the risk of mortality. However, surgical risk stratification in the literature generally uses the STAT score, meanwhile we used RACHS-1, a method that is well known for underestimating surgical risk. In some cases, we use the Aristotle score. According to the RACHS-1 risk classification mortality in our center is twice as high as expected according to the world literature [26-28].

This study may serve as a precedent for establishing multiple lines of investigation, both in our center and in any other hospital where cardiac surgery is performed, since no study was found in the literature making a correlation between the use of a specific cardioplegia solution and the incidence of LCOS, as well as its possible relationship to myocardial injury markers.

This study identified several areas of improvement in our center such as complementing the diagnostic approach with various imaging studies, since the surgical findings differed from the preoperative diagnosis, standardizing the preparation of cardioplegia solutions, homogenizing dosage, administration time, pressure and purging of the solution among the different surgical teams, following recommendations described in international guidelines. In addition, we suggest an improvement in the invasive monitoring in the immediate postoperative period with cardiac output surveillance with thermodilution, regional saturation (NIRS), capnography, as well as establishing postoperative treatment protocols, promoting continuous medical education, and implementing collegiate morbimortality sessions.

As limitations of our study, we can mention that we only had one cardioplegia solution (del Nido, Plasmalyte ®); in some patients we did not obtain biomarkers of myocardial injury and BNP because of scarce of resources, nor did we have a catheter to calculate cardiac output by thermodilution or to perform a transthoracic echocardiography at 48 hours after surgery.

Table 5. Intraoperative risk factors for Low Cardiac Output Syndrome (n = 63)

Risk Factor	LCOS 31(49.2)	No LCOS 30 (47.6)	p value	OR	95% CI
CPB (minutes)	138.39 (48.47)	80.3 (35.99)	0.000		
CPB prolonged (minutes)	18 (58.1)	3 (10)	0.000	12.462	3.104 – 50.024
Aortic cross-clamping (minutes)	76.13 (35.56)	47.5 (28.59)	0.000	0.004	
Aortic cross-clamping prolonged (minutes)	18 (58.1)	14 (46.7)	0.373	1.582	0.575 – 4.352
Selective cerebral perfusion	7 (22.6)	1 (3.3)	0.053	8.458	0.972 – 73.635
Selective cerebral perfusion (minutes)*	0 (0 – 48)	0 (0 – 22)	0.014		
Minimum Temperature*	30 (18 – 35)	32 (27 – 37)	0.001		
Minimum Hematocrit*	25 (19 – 39)	24.5 (18 – 32)	0.971		
Maximum Lactate*	3.1 (0.7 – 8.5)	1.9 (0.8 – 3.5)	0.006		
Modified Ultrafiltration*	150 (0 – 1,100)	160 (0 – 300)	0.823		

*CPB: Cardiopulmonary Bypass ; T test for independient examples; *Non-parametric distribution: median, minimum and maximum are reported; * Mann–Whitney U test.*

Table 6. Postoperative Risk factors for Low Cardiac Output Syndrome (n = 63)

Risk Factor	LCOS 31(49.2)	No LCOS 30 (47.6)	p value	OR	95% CI
Hypotension	21 (67.7)	1 (3.3)	0.000	60.9	7.230 – 512.958
Oliguria (< 1 mL/kg/h)	23 (74.2)	3 (10)	0.000	25.8	6.138 – 109.073
High Lactate (> 3.5 mmoL/L)	22 (71)	10 (3)	0.000	22.0	5.303 – 91.267
Metabolic Acidosis (>3.5 mmoL/L)	15 (48.4)	1 (3.3)	0.000	27.1	3.282 – 225.207
Vasoactive inotrope score (<18mmoL/L)	28.79 (13.63)	10.29 (4.36)	0.000		
High vasoactive inotrope score (> 20)	28 (90.3)	3 (10)	0.000	84.0	15.572 – 453.130
Arrhythmia	21 (67.7)	4 (13.3)	0.000	13.6	3.741 – 49.801
Transfusion of blood products	16 (51.6)	12 (40)	0.363	1.6	0.580 – 4.414
Hyponatremia	16 (51.6)	17 (56.7)	0.692	0.8	0.297 – 2.237
Hyperkalemia	13 (41.9)	7 (23.3)	0.122	2.3	0.785-7.177
Hyperglycemia	11 (35.5)	6 (20)	0.178	2.2	0.691 – 7.006
Hypocalcemia	5 (16.1)	0.0	0.053	0.4	0.350 – 0.615
Hypercalcemia	0 (0)	4 (13.3)	0.053	0.4	0.344 - 0.606
Hemodilution	12 (38.7)	20 (66.7)	0.029	0.3	0.111 - 0.901
CPK before CPB*	67.5 (45 – 149)	95.5 (42-119)	0.426		
CPK intraoperative	409 (309.45)	497.2 (339.42)	0.496		
CPK postoperative	592.5 (193 – 3,405)	561.5 (136 – 807)	0.190		
CPK MB before CPB	28.93 (12.14)	28.07 (11.12)	0.316		
CPK MB intraoperative	90.51 (56.65)	94.80 (67.06)	0.393		
CPK MB postoperative*	63.5 (14.8 – 555.4)	61.5 (23.1 – 390.1)	0.413		
T Troponin before CPB*	34.3 (3.3 – 281.8)	15.3 (3.1 – 104.7)	0.190		
T Troponin intraoperative*	593.0 (82.3 – 2,629)	819.4 (114.7 – 5,622)	0.915		
T Troponin postoperative*	1,266.5 (122.8 – 14,701)	833.4 (220.7 – 9,207)	0.374		
Pro-BNP (postoperative 24 hr)*	3,899 (971.5 – 39,070)	5,644.5 (65.5 – 10,002)	0.194		
High Pro-BNP (> 12,000 pg/mL)	4 (25)	0 (0)	0.113	0.5	0.335 – 0.746
Deaths	8 (25.8)	0 (0)	0.005	2.3	1.270 - 2.304

*T test for independient examples; * Non-parametric distribution: median, minimum and maximum are reported; * Mann–Whitney U test.*

As a conclusion, we identified an incidence of low cardiac output at 48 hours after cardiac surgery in patients with CHD (49.2%) as well as its associated mortality, both of which were twice as high as those reported in the literature.

Heart failure and its risk factors are an important cause of morbidity and mortality, although if treated in a timely manner, the patient's prognosis can be modified and improve their survival.

Some actions that can be taken to reduce the high incidence of heart failure and mortality in our center were identified, such as: improving CPB times and aortic cross-clamp, standardization of the use of cardioplegia solutions, and myocardial protection measures, as well as the implementation of treatment protocols, together with continuous medical education to improve postoperative care.

The advantages and limitations of myocardial protection with del Nido cardioplegia in our population, comparing to other solutions, cannot be specifically established due to the limitations of the study. Therefore, we suggest initiating new lines of investigation with the aim of improving the results in our center, such as comparing myocardial protection results between cardioplegia solutions, comparing markers of myocardial injury between surgical procedures, evaluating the impact of the implementation of postoperative treatment protocols, among others. Another fact that should be considered as limitation is that some surgical procedures develop a greater degree of heart failure due to the inherent characteristics of the surgical technique, which could bias the results.

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