Predicted clinical factors associated with the intensive care unit length of stay after total cavopulmonary connection

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ABSTRACT

Objectives: A longer length of stay (LOS) in the intensive care unit (ICU) after the total cavopulmonary connection (TCPC) is thought to be a predictive sign of late Fontan failure. This study was performed to determine the clinical risk factors for ICU LOS.

Methods: In total, 483 patients who underwent a TCPC between May 1994 and December 2016 were included the study. Patients' main diagnosis, morphologic characteristics, palliative procedures, hemodynamic parameters, and perioperative variables, were analyzed to identify risk factors influencing ICU stay based on Cox regression. Causes of longer ICU LOS and the impact of ICU LOS on late outcomes were evaluated.

Results: Age at TCPC, type of TCPC, and fenestration at TCPC did not affect the ICU LOS. With multivariable model, hypoplastic left heart syndrome ($P = .001$) and anomalous systemic venous drainage ($P < .001$) were identified as independent morphologic risk factors for prolonged ICU LOS. Of hemodynamic variables, preoperative high transpulmonary gradient ($P = .037$), and low aortic oxygen saturation ($P = .031$) were risks for longer ICU LOS. Of postoperative variables, pleural effusion ($P < .001$), chylothorax ($P = .001$), ascites ($P < .001$), and infection ($P = .028$) were risks for longer ICU LOS. The ICU LOS was found to be significantly associated with late mortality ($P < .001$) and late cardiac reoperation ($P = .007$).

Conclusions: Patients with hypoplastic left heart syndrome and anomalous systemic venous drainage had longer ICU LOS. Extended cyanosis and elevated pulmonary artery pressure affect the ICU LOS. Special care should be provided during the initial postoperative phase in patients with such risk factors. (J Thorac Cardiovasc Surg 2019;157:2005-13)

Preoperative risk factors for longer ICU stay after TCPC.

Central Message

HLHS and anomalous SVD were morphologic risks for longer ICU stay. Extended cyanosis, elevated pulmonary artery pressure, and presence of aortopulmonary collaterals affected the length of ICU stay.

Perspective

Certain morphologic and hemodynamic features were associated with longer ICU LOS after TCPC. Similar to previous reports, prolonged longer ICU LOS stay is a significant risk factor for late outcomes. Special attention is needed for postoperative care in patients with HLHS and anomalous SVD. The presence of APCs might cause postoperative complications.

See Commentaries on pages 2014 and 2016.

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Recently, Downing and colleagues¹ demonstrated in their large single-center study that long post-Fontan intensive care unit (ICU) stay is a strong risk factor for worse early and late outcomes. Our previous study also showed that longer length of stay (LOS) in the ICU after total

Scanning this QR code will take you to the article title page to access supplementary information.

Abbreviations and Acronyms

APCs	= aortopulmonary collaterals
AVV	= atrioventricular valve
BCPS	= bidirectional cavopulmonary shunt
CPB	= cardiopulmonary bypass
HLHS	= hypoplastic left heart syndrome
ICU	= intensive care unit
LOS	= length of stay
PA	= pulmonary artery
PAP	= pulmonary artery pressure
RV	= right ventricle
SO ₂	= aortic oxygen saturation
SVD	= systemic venous drainage
TCPC	= total cavopulmonary connection
TPG	= transpulmonary gradient

cavopulmonary connection (TCPC) was associated with late mortality, reoperation, and catheter intervention.² In clinical practice, we cannot accurately predict longer ICU LOS after TCPC. We observed that certain patients needed longer ICU LOS, both with and without high preoperative risk. Postoperative ICU stay can be prolonged by pleural effusion, chylothorax, ascites, arrhythmia, and infections. Previous studies demonstrated that postoperative ICU LOS was influenced by the following factors: systemic right ventricle (RV),³ hypoplastic left heart syndrome (HLHS),⁴ longer hospital stay at stage II and pre-Fontan complications,⁵ lower preoperative aortic oxygen saturation (SO₂),⁶ high volume expansion,⁷ and viral season (November to March),⁸ as well as fenestration at TCPC.⁹

In the present study, we analyzed our large cohort of functional single-ventricle patients who underwent TCPC and intended to identify the risk factors predicting longer ICU LOS. We also evaluated the causes of longer ICU LOS and the impact of ICU LOS on late outcomes.

PATIENTS AND METHODS**Patients' Inclusion Criteria**

This single-center retrospective cohort study considered all patients who underwent a TCPC at the German Heart Center Munich between May 1994 and December 2016 for inclusion. TCPC included the intracardiac lateral tunnel and extracardiac conduit techniques. Patients who underwent Fontan conversion from "classic" atriopulmonary Fontan to extracardiac TCPC were excluded from this study. Patients were identified using our institutional database. Demographic, morphologic, clinical, operative, and hospital information were abstracted from the medical records. Approval of this study was obtained from the institutional review board of the Technical University Munich; the need for individual patient consent was waived for this retrospective, observational study.

Surgical Techniques and Postoperative Management

The surgical techniques for a TCPC were described in our previous report.¹⁰ Fenestration was not routinely performed and was only used for high-risk patients. Indications for fenestration¹¹ and for atrioventricular

valve (AVV) surgery¹² were described in our previous report. Stage II palliation was a bidirectional cavopulmonary shunt (BCPS), and antegrade pulmonary blood flow was terminated at this procedure.¹³ Since 2009, we adopted an early extubation strategy after TCPC.¹⁴

Follow-up

Postdischarge outcomes were determined from outpatient clinic documentation in the electronic patient chart of the German Heart Center Munich or from direct correspondence with referring pediatric cardiologists. Mortality was ascertained at each of the follow-up sites through direct contact with the families and attending physicians.

Identification of Factors Affecting Prolonged ICU Stay

To identify risk factors for longer ICU LOS, we evaluated the variables related to the patients' primary diagnosis, cardiac morphology, palliative surgeries, and other preoperative conditions (Table E1).

Statistical Analysis

Continuous variables are expressed as means $\pm$ standard deviations or medians with interquartile ranges, if appropriate. Kaplan-Meier curves were constructed to estimate probability of ICU discharges, overall survival, freedom from reoperation, and from catheter intervention. Time zero was defined as the date of TCPC, and failure was defined as heart transplantation or death within the study period. Patients alive without transplant were censored at the end of the study period. Risk factor analysis of preoperative and operative variables was performed using uni- and multivariable Cox-regression analysis. Risk factor analysis of postoperative variables was performed using Cox model with time varying covariates. Those variables with a $P < .1$ in univariable analysis were considered for entry into the multivariable models. $P < .05$ was considered significant. Analysis was conducted with Statistical Package for the Social Sciences (SPSS), version 22.0 for Windows (IBM Corp, Ehningen, Germany).

RESULTS**Preoperative Variables**

A total of 483 patients underwent TCPC at the German Heart Center Munich during the study period. Baseline characteristics of the study cohort are displayed in Table 1. In brief, the median age at TCPC was 2.3 years, and the most frequent primary diagnosis was HLHS ($n = 120$, 24.8%). Dominant RV was observed in 261 (54%), and anomalous systemic venous drainage (SVD) was observed in 53 (11.0%) patients. Patients with anomalous SVD had significant high association with dominant RV (81.1%, $P < .001$), heterotaxy (47.2%, $P < .001$), common atrioventricular valve (43.4%, $P < .001$), dextrocardia (32.1%, $P < .001$), and anomalous pulmonary venous drainage (28.3%, $P < .001$), as compared with patients with normal SVD. Staged Fontan completion after BCPS was performed in 434 (89.9%) patients. Preoperative cardiac catheterization and echocardiographic data are shown in Table E2. The mean pulmonary artery pressure (PAP) was 9.6 mm Hg and the mean transpulmonary gradient (TPG) was 3.9 mm Hg. Significant aortopulmonary collaterals (APCs) were present in 126 (26.7%) patients. Impaired ventricular function was observed in 44 (9.1%) patients, and moderate AVV regurgitation was observed in 56 (11.6%) patients and severe in 7 (1.4%).

TABLE 1. Baseline characteristics of patients

Variables	n (%) or median (IQR)
Number of patients	483
Age at TCPC, y	2.3 (1.8-3.8)
Weight at TCPC, kg	12.0 (10.6-14.5)
Genetic disorders	14 (2.9)
Association of extracardiac anomaly	50 (10.4)
Primary diagnosis	
HLHS	120 (24.8)
DILV	70 (14.5)
TA	73 (15.1)
PAIVS	24 (5.0)
ccTGA	24 (5.0)
Unbalanced AVSD	12 (2.5)
AVV morphology	
Single TV	167 (34.6)
Two AVV	160 (33.1)
Single MV	110 (22.8)
Common AVV	46 (9.5)
Associated cardiac anomaly	
TGA	189 (39.1)
DORV	70 (14.5)
CoA	65 (13.5)
Dextrocardia	43 (8.9)
Heterotaxy	38 (7.9)
Dominant right ventricle	261 (54.0)
Pulmonary venous return anomaly	35 (7.2)
Anomalous systemic venous drainage	53 (11.0)
Bilateral SVC	48 (9.9)
Hepatic vein anomaly	7 (1.4)
Azygos continuation	16 (3.3)
Palliation and pre-Fontan condition	
Norwood/DKS procedure	199 (41.2)
PAB	78 (16.1)
Pulmonary artery reconstruction	148 (30.6)
AVV operation	50 (10.4)
APCs	126 (26.1)
Previous BCPS	434 (89.9)
Age at BCPS	0.5 (0.3-1.0)
Interval BCPS and TCPC	1.6 (1.2-2.2)

IQR, Interquartile ranges; TCPC, total cavopulmonary connection; HLHS, hypoplastic left heart syndrome; DILV, double inlet left ventricle; TA, tricuspid atresia; PAIVS, pulmonary atresia and intact ventricular septum; ccTGA, congenitally corrected transposition of the great arteries; AVSD, atrioventricular septal defect; AVV, atrioventricular valve; TV, tricuspid valve; MV, mitral valve; TGA, transposition of the great arteries; DORV, double outlet right ventricle; CoA, coarctation of the aorta; SVC, superior vena cava; DKS, Damus-Kaye-Stansel; PAB, pulmonary artery banding; APCs, aortopulmonary collaterals; BCPS, bidirectional cavopulmonary shunt.

Operative and Perioperative Data

The operative data are shown in Table 2. Lateral tunnel-TCPC was performed in 50 (10.4%) patients and extracardiac conduit-TCPC was performed in 433 (89.6%) patients. The median cardiopulmonary bypass (CPB) time was 64 minutes, and 139 (28.8%) patients needed aortic crossclamp.

Concomitant AVV procedure was performed in 69 (14.3%) patients. The median ICU LOS was 7 (interquartile range 5-9) days. Pleural effusion needing drainage more than >7 days and/or needing redrainage during the ICU stay was observed in 236 (49%) patients, chylothorax in 92 (19%), ascites requiring drainage in 94 (20%), tachyarrhythmia in 24 (5%), infection in 10 (2%), hepatic insufficiency in 8 (2%), thromboembolic complication in 6 (1%), and renal insufficiency in 5 (1%). There were 20 patients, who demonstrated respiratory insufficiency and/or low arterial saturation postoperatively, and needed catheter intervention during the ICU stay. Catheter interventions included 9 stent implantations in the pulmonary artery (PA), 7 coil occlusions of APCs, 3 occlusions of venovenous collaterals, 3 balloon angioplasties of PA, and 1 stent implantation for re-coarctation of the aorta. A secondary fenestration was necessary in 7 (1.4%) patients.

Eight patients died in ICU within 30 days, postoperatively. The causes of death are shown in Table E3. These patients were excluded from the risk analysis; because they discharged ICU without recovery and their ICU LOS were inappropriate for analysis of probability of ICU discharge.

Factors Associated With Length of ICU Stay

The preoperative factors influencing ICU stay were analyzed with Cox regression model. The results are shown in Table E1. The following potentially important factors had no significant *P* values: age at TCPC (*P* = .202), weight at TCPC (*P* = .159), nonstaged Fontan completion (*P* = .457), and age at BCPS (*P* = .174), and impaired ventricular function (*P* = .647).

Figure 1 demonstrates the *P* value, hazard ratio (HR), and 95% confidence interval (CI) of significant preoperative variables with univariate Cox regression analysis. Among morphologic variables, HLHS (*P* = .039), single tricuspid valve (*P* = .010), dextrocardia (*P* = .062), anomalous SVD (*P* = .003), and dominant RV (*P* = .001) were identified as risk factors for the longer ICU LOS with univariate analysis (Figure 1). Among hemodynamic variables, preoperative high hemoglobin levels (*P* = .058), high mean PAP (*P* = .054), high TPG (*P* = .040), low SO₂ (*P* = .039), and presence of APCs (*P* = .081) were identified as risk in the univariate model. As for preoperative ventricular and AVV function, preoperative impaired ventricular function did not influence the ICU LOS (*P* = .708). However, presence of significant AVV regurgitation (*P* = .064) was a risk for the ICU LOS with univariate analysis. In the multivariate model, anomalous SVD (*P* < .01), HLHS (*P* = .001), high TPG (*P* = .037), and low SO₂ (*P* = .031) were identified as independent risks for the longer ICU LOS. Kaplan-Meier curves comparing the time to ICU discharge after a TCPC procedure for the patients with and without anomalous SVD was shown in Figure 2.

TABLE 2. Perioperative variables and their association with ICU LOS

Variables	N (%) or median (IQR)	P value
Number of patients	483	
Operative data		
Type of TCPC		.869
Intracardiac	50 (10.4)	
Extracardiac	433 (89.6)	
Early era (before 2009)	251 (52.0)	.002
CPB time, min	64 (45-103)	.003
AXC	139 (28.8)	.089
AXC time, min	46 (26-73)	.400
Concomitant procedure	153 (31.7)	.100
DKS	12 (2.5)	.177
AVV procedure	69 (14.3)	.030
PA reconstruction	54 (11.2)	.992
Atrioseptectomy	23 (4.8)	.292
SAS/VSD enlargement	8 (1.7)	.569
Pacemaker implantation	9 (1.9)	.117
Fenestration at TCPC	35 (7.2)	.317
Postoperative data		
Ventilation time, h	9 (4-20)	
Chest tube drainage, d	4 (2-6)	
Reintubation	30 (6.2)	
ICU stay, d	7 (5-9)	
Hospital stay, d	20 (14-28)	
Complications		
Pleural effusion	198 (41.0)	
Chylothorax	91 (18.8)	
Ascites	95 (19.7)	
Arrhythmia	21 (4.3)	
Infection	9 (1.9)	
Hepatic insufficiency	8 (1.7)	
Thromboembolism	5 (1.0)	
Renal insufficiency	5 (1.0)	
Secondary fenestration	7 (1.4)	

Bold indicates $P < .05$. IQR, Interquartile ranges; ICU, intensive care unit; LOS, length of stay; TCPC, total cavopulmonary connection; CPB, cardiopulmonary bypass; AXC, aortic crossclamp; DKS, Damus-Kaye-Stansel anastomosis; AVV, atrioventricular valve; PA, pulmonary artery; SAS, subaortic stenosis; VSD, ventricular septal defect.

Among 128 patients presented with significant APCs, 60 (46.9%) patients underwent intervention preoperatively and/or intraoperatively (36 coil embolization, 25 intraoperative closures at the TCPC, and 3 intraoperative closures at the BCPS). There was no significant difference in the ICU LOS between the patients with and without APCs closure pre/at TCPC ($P = .503$). Postoperatively, 22 patients (17.2%) needed coil embolization of APCs. When these 22 patients were compared with the remaining 108 patients, postoperative ICU LOS was significantly longer in these patients ($P = .011$).

Era analysis was performed. Early era was a significant risk for longer ICU LOS ($P = .002$; HR, 1.027; 95% CI, 1.010-1.044). When era was included in multivariable models, era ($P < .001$; HR, 1.045; 95% CI, 1.024-1.067),

HLHS ($P < .001$; HR, 1.610; 95% CI, 1.262-2.053), anomalous SVD ($P = .001$; HR, 1.748, 95% CI, 1.267-2.409), low SO_2 ($P = .010$; HR, 1.025, 95% CI, 1.006-1.044), and APCs ($P = .008$; HR, 1.367, 95% CI, 1.083-1.724) were identified as independent risk factors.

Among operative variables, type of TCPC ($P = .869$) and fenestration at TCPC ($P = .317$) had no significant P values (Table 2). CPB time ($P = .003$; HR, 1.003; 95% CI, 1.001-1.005) and concomitant AVV procedure ($P = .030$; HR, 1.342, 95% CI, 1.029-1.751) were the variables, which had significant P value $< .05$.

Postoperative variables associated with the ICU LOS were analyzed using Cox model with time varying covariates. As results, pleural effusion ($P < .001$), chylothorax ($P = .001$), ascites ($P < .001$), and infection ($P = .029$) were significantly associated with the ICU LOS (Table 3).

Impact of the ICU LOS on Late Outcomes

Of the 475 early survivors, 10 patients (2.1%) were lost to follow-up after hospital discharge. The median length of follow-up was 6 (1.5-11.6) years for the remaining 465 patients. Fifteen patients experienced a late death. The causes of death are shown in Table E3. One patient required heart transplantation 5 months after TCPC. The estimated overall survival is demonstrated in Figure E1. A cardiac reoperation was necessary for 40 patients (27.3%) in group A (13 AVV procedures, 4 aortic valve procedures, 5 ascending aorta/aortic arch procedures, 7 revision of the TCPC tunnel, and 1 resection of a subaortic stenosis, 1 PA procedure, and 10 secondary fenestration procedures; 1 patient had 2 procedures concomitantly). The estimated freedom from cardiac reoperation is demonstrated in Figure E2. A catheter intervention was required for 88 patients: freedom from a catheter intervention is demonstrated in Figure E3. According to the Cox regression model, risk factor analysis for late mortality, late cardiac reoperation, and late catheter intervention was performed (Table 4). As a result, the ICU LOS was a significant risk factor for late mortality ($P < .001$), late cardiac reoperation ($P < .001$), and late catheter intervention ($P = .014$) in the univariate model. Furthermore, the ICU LOS was found to be significantly associated with mortality and late reoperation in the multivariate model.

DISCUSSION

In this study, HLHS, anomalous SVD, preoperative high TPG, and preoperative low SO_2 were independent risk factors for the ICU LOS. The main causes of the longer ICU LOS were pleural effusion, chylothorax, and ascites. The ICU LOS was found to be significantly associated with late mortality and late reoperation (Video 1).

Risk Factors for Prolonged ICU Stay

Our results demonstrated that dominant RV, single TV, and HLHS were the risk factors for the longer ICU LOS.

FIGURE 1. Preoperative risk factors that influenced ICU LOS after total cavopulmonary connection analyzed with a Cox regression model. Graphic demonstrates the HR (blue square) and 95% CI (black linear). Among morphologic variables, HLHS, single TV, dextrocardia, anomalous SVD, and dominant RV were significant risk factors with univariate analysis. Among cardiac catheter findings, greater hemoglobin level, greater mean PAP, greater TPG, lower SO₂, presence of APCs, and AVV regurgitation were significant risk factors with univariate analysis. With multivariate analysis, HLHS, anomalous SVD, greater TPG, and lower SO₂ were identified as independent risk factors for longer ICU LOS. *ICU*, Intensive care unit; *HR*, hazard ratio; *HLHS*, hypoplastic left heart syndrome; *TV*, tricuspid valve; *SVD*, systemic venous drainage; *RV*, right ventricle; *PAP*, pulmonary artery pressure; *TPG*, transpulmonary gradient; *SO₂*, arterial oxygen saturation; *APCs*, aortopulmonary collaterals; *AVV*, atrioventricular valve; *CI*, confidence interval.

Although a recent study¹⁵ and our previous study² demonstrated that dominant RV is not a risk for mortality after Fontan procedure, dominant RV has been reported as a risk for staged reconstruction of single ventricle. Nordmeyer and colleagues³ demonstrated that patients with systemic RV needed a longer ICU LOS compared with those with a systemic left ventricle in their 173 consecutive patients who underwent TCPC. d’Udekem and colleagues¹⁶ demonstrated RV dominance was a risk for mortality before BCPS. Alsoufi and colleagues¹⁷ suggested dominant RV and associated tricuspid valve failure might influence the late outcomes. Furthermore, Iyengar and colleagues⁴ reported that dominant RV and HLHS were associated with prolonged effusions, and HLHS was the strongest risk factor with multivariate model. These results were quite consistent with our results.

In this study, anomalous SVD also was identified as an independent risk for longer ICU LOS. Anomalous SVD

included bilateral superior vena cava, azygos continuation, and anomalous hepatic venous drainage. Bilateral superior vena cava was the most common form of this anomaly and needed bilateral BCPS. It produces flow stagnation at the level of the PA confluence leading to unfavorable growth of the central PAs. The special flow dynamics after bilateral BCPS might influence the longer ICU LOS after Fontan completion. Another explanation might be that anomalous SVD surrogates for the complex type of single ventricle other than HLHS. Typical configuration is RV-type single ventricle, transposition of the great arteries or double outlet right ventricle, common AVV or single tricuspid valve, frequently associated with anomalous pulmonary venous drainage, dextrocardia, and/or heterotaxy. Our results demonstrated frequent association with anomalous SVD and these morphologic features. The complexity of the anatomy might require additional surgical procedures and present with worse pre-Fontan

FIGURE 2. Kaplan–Meier curves comparing the time to ICU discharge after a TCPC procedure for the patients with and without anomalous SVD. The patients associated with anomalous SVD needed significantly longer time to ICU discharge ($P < .001$ by log-rank test). ICU, Intensive care unit; TCPC, total cavopulmonary connection; SVD, systemic venous drainage.

conditions. These associated conditions might result in longer ICU LOS.

Our results demonstrated that certain hemodynamic and laboratory factors, such as preoperative greater PAP, greater TPG, greater hemoglobin levels, and lower SO_2 , were also associated with longer ICU LOS. These factors might be representative of patients' condition with extended cyanosis, underdevelopment/hypoplasia of PAs, and high pulmonary vascular resistance. These clinical findings were quite similar to the reports from Gupta and colleagues⁶ and Sasaki and colleagues.¹⁸ The presence of APCs was also identified as a risk for longer ICU LOS. In a study using cardiac magnetic resonance, Grosse-Wortmann and colleagues¹⁹ assessed APC blood flow quantitatively and demonstrated that patients with a BCPS routinely acquire a large amount of APC flow and that the hemodynamic

consequences of APC flow translate into adverse outcomes early after TCPC. Odenwald and colleagues²⁰ also demonstrated patients with greater APC flow had increased postoperative chest drain volume, chest drain duration, and ICU stay after TCPC. In our study, APCs were observed approximately one third of patients, and the presence of APCs influenced the ICU LOS. The precise mechanism through which APCs adversely affect the early postoperative outcomes in these patients is still incompletely understood. Maybe there is a confounding variable such as elevated pulmonary vascular resistance and extended cyanosis that independently causes the APC development and an adverse postoperative outcome. This is an area that warrants further study.

Generally, the Fontan circuit relies on systemic venous pressure to propel blood through the lungs; it therefore depends on low pulmonary vascular resistance, which in turn is affected by such factors as PA distortion or increased time intervals in infancy with high pressure or volume load of the pulmonary circulation. Longer ICU LOS, an indication of postoperative morbidities, appears a potential consequent of underlying complexity and sub-optimal conditions for Fontan completion. ICU LOS may be a surrogate for other patient or operation related risk factors.

Causes of Longer ICU LOS and Therapeutic Options

Although it is not possible to identify the exact reasons why individual patients remained in the ICU, pleural effusion, chylothorax, and ascites were the main complications most strongly associated with long ICU LOS. The factor

TABLE 3. Postoperative variables influencing ICU stay using Cox model with time varying covariates

Variables	P value	HR (95% CI)
Pleural effusion	<.001	2.467 (1.66-4.781)
Chylothorax	.001	1.463 (1.10-2.20)
Ascites	<.001	2.333 (1.51-5.15)
Arrhythmia	.779	1.061 (0.74-1.85)
Infection	.029	2.039 (0.90-7.38)
Hepatic insufficiency	.218	1.515 (0.76-85.64)
Thromboembolism	.280	0.614 (0.40-1.31)
Renal insufficiency	.223	1.662 (0.71-4.99)

HR, Hazard ratio; CI, confidence interval.

TABLE 4. Risk factor analysis for late outcomes based on the Cox regression model

Variables	Univariable model		Multivariable model	
	P value	HR (95% CI)	P value	HR (95% CI)
Late mortality (>30 d)				
Length of ICU stay	<.001	1.045 (1.030-1.061)	<.001	1.041 (1.024-1.058)
HLHS	.188			
Single TV	.594			
Dextrocardia	.016			
Anomalous SVD	.015	3.692 (1.283-10.630)		
Dominant RV	.967			
Hemoglobin levels	.051			
Mean PAP	.009	1.172 (1.041-1.319)	.044	1.130 (1.004-1.272)
TPG	.009	1.256 (1.057-1.493)		
SO ₂	.385			
APCs	.796			
Heterotaxy	.019	3.885 (1.252-12.055)		
Late cardiac reoperation				
Length of ICU stay	<.001	1.029 (1.013-1.046)	.007	1.024 (1.006-1.042)
HLHS	.057	1.971 (0.979-3.967)		
Single TV	.021	2.129 (1.121-4.045)		
Dextrocardia	.257			
Anomalous SVD	.271			
Dominant RV	.012	2.424 (1.216-4.829)	.011	2.532 (1.232-5.025)
Hemoglobin levels	.668			
Mean PAP	.258			
TPG	.023	1.160 (1.021-1.319)	.049	1.135 (1.001-1.286)
SO ₂	.137			
APCs	.845			
Anomalous PVD	.032	2.815 (1.091-7.261)		
AVV operation	.005	2.538 (1.324-4.867)		
Late intervention				
Length of ICU stay	.014	1.018 (1.004-1.033)		
HLHS	.001	2.070 (1.324-3.238)		
Single TV	.002	1.932 (1.264-2.951)		
Dextrocardia	.588			
Anomalous SVD	.915			
Dominant RV	<.001	2.430 (1.538-3.837)	.001	2.388 (1.436-3.971)
Hemoglobin levels	.249			
Mean PAP	.018	1.073 (1.012-1.137)	.008	1.094 (1.023-1.169)
TPG	.216			
SO ₂	.039	0.958 (0.919-0.998)	.029	0.958 (0.922-0.996)
APCs	<.001	2.488 (1.619-3.823)	<.001	2.393 (1.476-3.880)
CoA	.026	1.783 (1.073-2.963)	.010	2.672 (1.189-3.612)

HR, Hazard ratio; CI, confidence interval; ICU, intensive care unit; HLHS, hypoplastic left heart syndrome; TV, tricuspid valve; SVD, systemic venous drainage; RV, right ventricle; PAP, pulmonary artery pressure; TPG, transpulmonary gradient; SO₂, aortic oxygen saturation; APCs, aortopulmonary collaterals; PVD, pulmonary venous drainage; AVV, atrioventricular valve; CoA, coarctation of the aorta.

most strongly associated with long ICU LOS was prolonged postoperative pleural effusion. This traditionally reported morbidity has been considered a marker of suboptimal hemodynamics, although the underlying mechanism is poorly understood. This may relate at least in part to noncardiac comorbidities, not explicitly captured as covariates in the study. Pleural effusions after the Fontan procedure are unpredictable. Development of pulmonary vasculature, pulmonary vascular resistance, and obstruction of PAs might

influence the postoperative effusions. Our results of hemodynamic and laboratory data suggest this hypothesis. The influence of APCs is also thought to be one of the possible mechanisms. In our study, APCs were frequently observed in approximately one third of patients, and the presence of APCs had influence on the ICU LOS.

Although our results demonstrated that preoperative ventricular dysfunction did not affect the ICU LOS, postoperative ventricular dysfunction might cause the pleural

VIDEO 1. Video of the author explaining the importance and relevance of this study. Video available at: [https://www.jtcvs.org/article/S0022-5223\(18\)32964-7/fulltext](https://www.jtcvs.org/article/S0022-5223(18)32964-7/fulltext).

effusion. Garofalo and colleagues²¹ demonstrated that ventricular diastolic stiffness predicts perioperative morbidity and duration of pleural effusions after the Fontan operation. It was typically observed in nonstaged older patients or in patients with significant AVV regurgitation requiring concomitant AVV repair at TCPC.

Therapy includes diuretics and surgical drainage of effusions, surgical, and catheter intervention for pathway obstruction, and secondary fenestration for early Fontan failure. A defined management strategy might reduce the amount of effusion and shorten the ICU LOS.^{22,23} Since 2009, our institution adopted an early extubation strategy,¹⁴ and impact of this strategy on late outcomes should be analyzed in the future study.

Surgical approaches to shortening ICU LOS include optimal development of PAs and assessment of APCs before Fontan completion. Preoperative PA condition is thought to be the variable that has the biggest impact on the ICU LOS. Our results demonstrated that greater PAP and greater TPG were predictors of longer ICU LOS. As for the assessment of APCs, routine cardiac magnetic resonance to measure the volume of APC blood flow might further our understanding of pulmonary vascular condition and lead to management strategies to prevent persistent effusion after Fontan procedure.

Indication for Fenestration

It is still controversial whether fenestration should be created at the time of Fontan completion. In their prospective, randomized study, Lemler and colleagues⁹ demonstrated that fenestration at time of Fontan surgery improved short-term outcome by decreasing pleural drainage, hospital LOS, and need for additional postoperative procedures. In our study, fenestration was created in a small number of patients. Therefore, it is impossible to evaluate the effect of fenestration on postoperative outcomes. Our results demonstrated that most of the patients could accomplish Fontan completion without fenestration. Presently, we can manage post-Fontan patients well without

fenestration, using short CPB time, modified ultrafiltration, early extubation, and physiotherapy. However, the relative long ICU LOS in our study might be partially due to our nonfenestration policy. We believe that fenestration is not necessary for optimal Fontan candidates. However, we cannot always obtain optimal condition for all Fontan candidates. In this context, fenestration should be reconsidered for patients with risks identified in this study.

Study Limitations

This study was limited by its retrospective and single-center design. Data were not available at consistent follow-up periods for every patient. Changes over time in surgical and medical management might have affected the outcomes. Reasons for longer ICU LOS might vary between hospitals. In our center, patients requiring drains for pleural effusion are generally treated on the ICU until drains are removed. This can make results not comparable with other reports.

CONCLUSIONS

In conclusion, certain morphologic and hemodynamic features were associated with patients who had longer ICU LOS after TCPC. Similar to previous report, longer ICU LOS is a significant risk factor for late outcomes. ICU LOS may be a surrogate for other patient or operation-related risk factors. Special attention is needed for postoperative care in patients with HLHS and anomalous SVD. Presence of untreated APCs might cause the postoperative complications.

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

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Key Words: intensive care unit, total cavopulmonary connection, pleural effusion, hypoplastic left heart syndrome, anomalous systemic venous drainage

FIGURE E1. Estimated survival after TCPC. *TCPC*, Total cavopulmonary connection.

FIGURE E3. Freedom from intervention after TCPC. *TCPC*, Total cavopulmonary connection.

FIGURE E2. Freedom from reoperation after TCPC. *TCPC*, Total cavopulmonary connection.

TABLE E1. Risk analysis for potentially preoperative variables influencing ICU stay

Variables	P value	HR	95% CI
Baseline characteristics			
Age at TCPC	.202		
Weight at TCPC	.159		
Associated genetic disorder	.107		
Extracardiac anomaly	.187		
Anatomic diagnosis			
HLHS	.039	1.247	1.011-1.536
DILV	.424		
TA	.051	0.779	
AVV morphology and function			
Single TV	.010	1.283	1.060-1.553
CAVV	.140		
Associated anomaly			
TGA	.033	0.817	
DORV	.938		
CoA	.385		
Dextrocardia	.062	1.364	0.985-1.890
Heterotaxy syndrome	.152		
Dominant RV	.001	1.352	1.127-1.623
Anomalous PVD	.105		
Anomalous SVD	.003	1.570	1.170-2.110
Palliative and pre-TCPC procedures			
Norwood/DKS procedure	.398		
APS	.836		
PAB	.195		
Pacemaker implantation	.558		
PA reconstruction	.979		
AVV operation	.722		
BCPS	.457		
Age at BCPS	.174		
Catheterization data at TCPC			
Hemoglobin level, g/dL	.058	1.044	0.999-1.092
Mean pulmonary artery pressure, mm Hg	.054	1.030	1.000-1.062
Mean left atrium pressure, mm Hg	.619		
Transpulmonary gradient, mm Hg	.040	1.048	1.002-1.096
Single-ventricle systolic pressure, mm Hg	.165		
Single-ventricle end-diastolic pressure, mm Hg	.916		
Aortic oxygen saturation (%; per 1% decrease)	.039	1.019	1.001-1.037
Presence of APCs	.081	1.200	0.978-1.473
Ventricular and AVV function at TCPC			
Impaired ventricular function (EF <50%)	.647		
AVV regurgitation	.064	1.086	0.995-1.179

Bold indicates $P < .10$. HR, Hazard ratio; CI, confidence interval; TCPC, total cavopulmonary connection; HLHS, hypoplastic left heart syndrome; DILV, double inlet left ventricle; TA, tricuspid atresia; AVV, atrioventricular valve; TV, tricuspid valve; CAVV, common atrioventricular valve; TGA, transposition of the great arteries; DORV, double outlet right ventricle; CoA, coarctation of the aorta; RV, right ventricle; PVD, pulmonary venous drainage; SVD, systemic venous drainage; DKS, Damus–Kaye–Stansel; APS, aortopulmonary shunt; PAB, pulmonary artery banding; PA, pulmonary artery; AVV, atrioventricular valve; BCPS, bidirectional cavopulmonary shunt; APCs, aortopulmonary collaterals; EF, ejection fraction.

TABLE E2. Pre-TCPC catheterization and echocardiographic data

Variables	n (%) or mean $\pm$ SD
Catheterization data	n = 472
Hemoglobin, g/dL	16.3 $\pm$ 1.9
Mean pulmonary artery pressure, mm Hg	9.6 $\pm$ 3.1
Mean left atrial pressure, mm Hg	5.5 $\pm$ 2.4
Transpulmonary gradient, mm Hg	3.9 $\pm$ 2.0
Systolic ventricular pressure, mm Hg	82.9 $\pm$ 13.5
Ventricular endo-diastolic pressure, mm Hg	7.5 $\pm$ 2.9
Aortic systolic pressure, mm Hg	80.2 $\pm$ 13.7
Aortic mean pressure, mm Hg	57.2 $\pm$ 10.8
Aortic oxygen saturation, %	82.6 $\pm$ 5.4
APCs	126 (26.7)
Echocardiographic data	n = 483
Ventricular dysfunction	
Normal	439 (90.9)
Impaired	44 (9.1)
Atrioventricular valve regurgitation	
None	173 (35.8)
Trivial	160 (33.1)
Mild	87 (18.0)
Moderate	56 (11.6)
Severe	7 (1.4)

SD, Standard deviation; APCs, aortopulmonary collaterals.

TABLE E3. Characteristics of patients who died within 30 days or after 30 days after TCPC

Case	Diagnosis	Age at TCPC, y	Concomitant procedure	Cause of death	Period
30-d mortality					
1	DILV	2	Dams–Kaye–Stansel	Cerebral infarction	5 d
2	imbalanced AVSD	1	AVV plasty	Cardiac failure	2 d
3	imbalanced AVSD	4	PLSVC closure	Cardiac failure	9 d
4	SV, CoA	12		Hepatic vein thrombosis	17 d
5	SV, TAPVC	16		Cardiac failure	8 d
6	ccTGA, hypo TV	1	MV plasty, TV closure	Cardiac failure	1 d
7	DILV, TV straddling	3	TV plasty, atrioseptostomy	Cerebral infarction	7 d
8	IAA, small LV	2		Cardiac failure	5 d
Late mortality					
1	DILV, TGA	5	PA reconstruction	PLE	10 y
2	SV, TGA	2		Cardiac failure	10 y
3	DIRV, DORV	2		PLE	4 y
4	SV, TAPVC, heterotaxy	5	Dams–Kaye–Stansel	Cardiac failure, PLE	1 y
5	SV, heterotaxy	5		Sepsis	2 mo
6	PAIVS	11	PA reconstruction, TV closure	Sudden death by delivery	8 y
7	SV, CAVV, heterotaxy	18	AVV replacement	Cardiac failure	4 mo
8	DILV	3		Cardiac failure	7 y
9	SV, CAVV, heterotaxy	10		hypoxia	6 y
10	HLHS	1	TV replacement	Cardiac failure	1 y
11	DORV, hypo LV	4	MV closure	Cardiac failure	3 mo
12	TA Ic	3	PV enlargement	Plastic bronchitis, MOF	2 y
13	TA Ic, CoA	1		Encephalopathy	6 y
14	TA Ib	1		Virus infection	2 mo
15	SV, MA	1		MOF	1 mo

TCPC, Total cavopulmonary connection; DILV, double inlet left ventricle; AVSD, atrioventricular septal defect; AVV, atrioventricular valve; PLSVC, persistent left superior vena cava; SV, single ventricle; CoA, coarctation of the aorta; TAPVC, total anomalous pulmonary venous connection; ccTGA, congenitally corrected transposition of the great arteries; hypo, hypoplastic; TV, tricuspid valve; MV, mitral valve; IAA, interruption of the aorta; LV, left ventricle; PA, pulmonary artery; PLE, protein losing enteropathy; TGA, transposition of the great arteries; DIRV, double-inlet right ventricle; DORV, double-outlet right ventricle; PAIVS, pulmonary atresia intact ventricular septum; CAVV, common atrioventricular valve; HLHS, hypoplastic left heart syndrome; TA, tricuspid atresia; MOF, multiple organ failure; MA, mitral atresia.