Evolution of the Norwood operation outcomes in patients with late presentation

Mohamed F. Ismail, MD,^{a,b} Ahmed F. Elmahrouk, MD,^a Amr A. Arafat, MD,^c Tamer E. Hamouda, MD,^{a,d} Bayan A. Alshaikh, MBChB,^e Mohammad S. Shihata, MD,^a Ahmed A. Jamjoom, MD,^a and Osman O. Al-Radi, MBBS, MSc, FRCSC^{a,f}

ABSTRACT

Objectives: We present the evolution of Norwood operation outcomes and practice pattern changes over 15 years from a single institution in Saudi Arabia. We intended to identify time trends in patient selection, procedural details, and outcome predictors over time.

Methods: Patients who underwent a Norwood operation ($n = 145$) between 2003 and 2018 with the use of a Blalock–Taussig shunt (BT group; $n = 72$), right ventricle to pulmonary artery shunt (Sano group; $n = 66$), or a primary cavopulmonary shunt (CPS group; $n = 7$) were included. The study outcomes were operative mortality, long-term survival, and multistate transition to CPS, Fontan, and death.

Results: Median age was 29 days. Predictors of operative mortality were lower weight ($P = .026$), and longer bypass time ($P = .014$), whereas age, and type of shunt were not. Predictors of improved long-term survival were greater weight at operation ($P = .0016$), later era ($P = .006$), and shorter bypass time ($P = .001$). The multistate model revealed that patients with lower weight were more likely to undergo Sano versus BT ($P < .001$), and if BT was chosen in such patients, they were more likely to die ($P = .027$). The likelihood of receiving Sano shunt was 3-fold greater in the recent era ($P = .003$).

Conclusions: Improved outcomes of the Norwood operation are evident in the recent era and with Sano shunt, especially in patients of smaller weight. Late presentation or older age is not a contraindication to Norwood operation. The incorporation of a primary CPS at stage one operation is feasible in selected patients. (J Thorac Cardiovasc Surg 2020;159:1040-8)

The effect of era and type of shunt on long-term survival after the Norwood operation.

CENTRAL MESSAGE

Sano shunt is associated with improved outcomes, especially in smaller patients. CPS, as a component of the initial Norwood operation, is feasible in patients with low pulmonary vascular resistance.

PERSPECTIVE

The current outcomes of the Norwood operation warrant offering the treatment to most patients with hypoplastic left heart syndrome and similar lesions even with delayed presentation. The use of Sano shunt was associated with improved outcomes. Use of the CPS as a component of the initial Norwood operation is feasible and safe in carefully selected patients with low pulmonary vascular resistance.

See Commentary on page 1049.

The Norwood operation is the mainstay of initial palliation for hypoplastic left heart syndrome (HLHS) and other single-ventricle lesions with inadequate left-side cardiac

structures. Since the introduction of the Norwood procedure, several shunt types have been described with variable outcomes.¹⁻³ Early in the development of Norwood

From the ^aDivision of Cardiac Surgery, Cardiovascular Department, King Faisal Specialist Hospital and Research Center, Jeddah, Saudi Arabia; ^bCardio-thoracic Surgery Department, Mansoura University, Mansoura, Egypt; ^cCardiothoracic Surgery Department, Tanta University, Tanta, Egypt; ^dCardio-thoracic Surgery Department, Benha University, Benha, Egypt; ^eCardiac Surgery, King Fahad Armed Forces Hospital, Jeddah, Saudi Arabia; and ^fCardiac Surgery Section, Department of Surgery, King Abdulaziz University, Jeddah, Saudi Arabia.

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Address for reprints: Osman O. Al-Radi, MBBS, MSc, FRCSC, MBC J-16, P. O. Box 40047, Jeddah 21499, Saudi Arabia (E-mail: oradi@kau.edu.sa).

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Abbreviations and Acronyms

BT	= Blalock–Taussig
CoA	= coarctation of the aorta
CI	= confidence interval
CPB	= cardiopulmonary bypass
CPS	= cavopulmonary shunt
ECMO	= extracorporeal membrane oxygenation
HLHS	= hypoplastic left heart syndrome
HR	= hazard ratio
PA	= pulmonary artery
PTFE	= polytetrafluoroethylene
Qp	= pulmonary blood flow
Qs	= systemic blood flow
RV	= right ventricle

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procedure, large right ventricle (RV) to pulmonary artery (PA) conduit/shunt was attempted as a source of pulmonary blood flow after the Norwood procedure.⁴ This technique was abandoned in favor of a modified Blalock–Taussig (BT) shunt, with a polytetrafluoroethylene (PTFE) tube connecting the subclavian artery and the PA.⁵ Decades later, in 2003 Sano and colleagues⁶ reported a modification of the Norwood procedure by placing a larger PTFE graft between the RV and the PAs but not as large as the original Norwood RV-PA conduits.

RV-PA conduit (Sano) may be associated with improved operative outcomes, but the long-term survival and ventricular function could be affected because of the ventriculotomy. In a propensity score-matched study,⁷ patients with a Sano shunt had better survival compared with a BT shunt, and RV function was not different. In another series, RV function was lower after the first stage with a BT shunt compared with Sano shunt; however, RV function improved after the second and third stages of palliation.⁸ Ventricular arrhythmia occurred more frequently after Sano shunt, which correlated with late mortality in those patients.⁹ Despite the improved results of the Norwood procedure recently, heart failure and listing for transplant are common after the procedure.¹⁰

The consistent performance and acceptable outcomes of the Norwood operation have not been reported outside the developed countries.¹¹ Unique challenges exist in this setting, mainly delayed diagnosis and presentation, and physiologic consequences of unprotected pulmonary blood

flow. We sought to present the evolution of the Norwood operation, practice changes, and outcomes over 15 years from a single institution in Saudi Arabia. Moreover, we intended to identify time trends in patient selection, procedural details, and outcomes as well as predictors of success or failure over follow-up time.

PATIENTS AND METHODS

Study Population

The study included all patients who underwent Norwood procedure (n = 145) at King Faisal Specialist Hospital and Research Center, Jeddah, Saudi Arabia, between March 2003 and March 2018. Indications for the Norwood operation were HLHS, HLHS variants, other univentricular anomalies with coarctation, and/or arch hypoplasia, and severe forms of the Shone's complex. Data are part of the Congenital Cardiac Surgery Database, available at www.ccsdb.org, and were populated prospectively.

Study Design

This is a retrospective cohort study in which the prospectively collected data in the computerized surgical database were augmented with retrospective chart review and direct or phone interview to assure currency of follow-up, which was completed in 98% of patients within 6 months of the study date. The patients were grouped based on the type of shunt used to provide pulmonary blood flow into 3 groups. The “BT” group received a modified BT shunt using a synthetic tube graft made of PTFE, the “Sano” group received a RV to PA shunt also made of PTFE but a larger size, and the “CPS” group received a superior cavopulmonary shunt (CPS) during the Norwood operation as the sole source of pulmonary blood flow. A CPS was only used if there was objective evidence of very low pulmonary vascular resistance and high pulmonary blood flow (Qp) to systemic blood flow (Qs) ratio despite unrestricted pulmonary blood flow. This was confirmed both clinically and by invasive catheterization. Patients were offered a primary CPS if they had low weight for age, arterial oxygen saturation by noninvasive oximetry >95% on room air, and Qp/Qs ≥ 2.3:1 or greater by invasive cardiac catheterization.

The Institutional Research Ethics Committee of King Faisal Specialist Hospital and Research Center Jeddah approved the study protocol (reference number IRB 2016-61, CVD-J/237/38).

Follow-up and Study Outcomes

The operative outcomes, including the use of extracorporeal membrane oxygenation (ECMO) and death during hospitalization of any cause, were studied. Surviving patients were followed in an outpatient setting every 2 to 6 weeks until the second stage palliation and less frequently thereafter. Families of patients lost to follow-up were contacted to ascertain their vital status and wellbeing. All interventions and subsequent operations were recorded and included in the analysis. Cardiac catheterization performed before second- and third-stage operations were examined.

Operative Technique

A median sternotomy was done in all patients, full exposure of the aorta including the arch, and proximal part of the descending aorta was achieved. Cannulation of the main PA, aorta, innominate artery either directly or through a PTFE graft was used for arterial perfusion. Cannulation of the right atrium was used for venous drainage. Cardiopulmonary bypass (CPB) was established with systemic hypothermia from 18°C to 20°C. Antegrade cerebral perfusion was used in 111 patients (76.6%), and no retrograde cerebral or distal aortic perfusion methods were used. Antegrade cardioplegia was given through an aortic cannula or retrogradely into the aortic arch. The PAs were occluded to optimize systemic cooling and avoid pulmonary edema. After cooling, the ductus arteriosus was divided. The

coarctation was excised if a significant posterior shelf was present. Aortic continuity was re-established by direct aorta to aorta anastomosis postero-lateral. The arch and descending aorta were augmented with homograft tissue; bovine or equine pericardium. The main PA was divided and incorporated into the arch repair forming a Damus–Kay–Stansel connection. After arch reconstruction, the arch was perfused, and the patient rewarmed. Atrial septectomy was done via a small right atrial incision. The construction of a BT, Sano, or CPS shunt concluded the operation.

At the beginning of our experience, we tended to use BT shunt for all Norwood procedures; this practice was gradually changed, and Sano shunt gained more popularity among the team. However, some surgeons are still using BT shunt if the aortic valve is not atretic and the ascending aorta and the origin of the brachiocephalic artery are of good size.

In our current practice, Sano is preferred in patients of lower weight; however, we do not have a specific cut-off weight. Five surgeons contributed to the data set. Shunt type and size were determined by the surgeon's preference and experience. In the BT group, a 3.5- or 4-mm PTFE graft was anastomosed to the innominate artery and the PA confluence. In the Sano group, a size 5 or 6 PTFE graft was sutured to an anterior ventriculotomy and the PA confluence. The proximal anastomosis was done with several different techniques, including direct beveled anastomosis, direct anastomosis with a pericardial hood, and with a ring reinforced conduit inserted into the wall of the RV (ProPaten; Gore-Tex; W. L. Gore & Associates, Inc, Flagstaff, Ariz). The graft was placed on the left of the reconstructed arch in most patients. In the CPS group, the superior vena cava was divided and anastomosed to the right PA as a bidirectional CPS. At the end of surgery, the chest was left open if deemed necessary by the surgeon. No patients were extubated in the operating room.

All patients were under continuous monitoring in the intensive care unit, by direct arterial pressure, end-tidal CO₂, and pulse oximetry. Arterial and venous blood gas analyses were drawn in 2- to 3-hour intervals, and urine output was collected hourly. Afterload reduction was achieved with milrinone infusion and occasional Nipride infusion. When clinical stability was achieved, and laboratory findings were normalized, delayed sternal closure was performed in the intensive care unit. Repeated echocardiogram studies were performed before discharge to assess anatomic and hemodynamic parameters. Patients were discharged when clinically stable.

All patients were followed up by pediatric cardiologists. Cardiac catheterization was performed for all patients before second-stage palliation to assess pulmonary vascular resistance, PA pressure, and Qp/Qs ratio. Anatomical problems were carefully studied, and residual problems treated interventionally if possible. Second-stage palliation with a bidirectional CPS was undertaken within 3 to 9 months after stage I palliation using a direct anastomosis between the superior vena cava and the right PA. The previous shunt was divided, and Fontan completion (extracardiac; fenestrated or not) was done between 2 and 5 years of age.

Statistical Methods

Categorical variables were presented as frequency and percentage. Continuous variables are presented as 25th, 50th (median), and 75th quartiles, and the range was used when appropriate. Operative outcomes, including in-hospital mortality of any cause and ECMO use, were analyzed with Pearson test for categorical variables and Kruskal–Wallis test for continuous variables. Multivariable logistic regression was used to identify independent predictors of in-hospital mortality. Time-related survival was studied using a multivariable Cox proportional hazard model. Survival plots were generated using Kaplan–Meier methods, and 0.67% (1 standard deviation) error bands were used to generate the shaded area with the log-log method.¹²

A multistate stage semi-Markov model was also used to examine the frequency of transition of patients between 6 distinct states, namely unoperated, BT, Sano, CPS, Fontan, and dead. Group differences and predictors of each transition were studied. There were 11 possible transitions namely from birth to BT, Sano, CPS, or death; from BT to CPS or death; from Sano

to CPS or death; from CPS to Fontan or death, and from Fontan to death. Patients who died without surgery were not included in the study. Therefore, the transition from birth to death was not applicable. The mstate package^{13,14} of the R-project software was used.

A *P* value of less than .05 was considered significant. All analyses were done using the R-project statistical program (version 3.3.2, R Development Core Team, R Foundation for Statistical Computing, Vienna, Austria; www.R-project.org).

RESULTS

Preoperative and Operative Data

One hundred forty-five patients were included in the analysis (Figure 1). The median age at the Norwood operation was 29 days (range, 2–344). The type of shunt in the initial Norwood operation was BT in 72, Sano in 66, and CPS in 7 patients. Five surgeons performed the operations with varied practice lengths. Patients with CPS had significantly greater weight (median: 3.6 kg; *P* = .004). The Sano group had more patients with aortic atresia and mitral atresia (*P* = .001) and longer deep hypothermic circulatory arrest time (*P* < .001), Table 1. The number of Norwood operations performed annually, and the corresponding operative mortality changed over time from 4 cases in 2004 with 50% mortality to 15 cases in 2017 with 7% mortality, Figure 2.

Seven patients were candidates for a primary CPS after diagnostic cardiac catheterization. Two patients had HLHS, and the third patient had HLHS and right atrial isomerism. The fourth patient had mitral atresia, coarctation of the aorta (CoA), and double-outlet right ventricle; the fifth baby had mitral atresia, CoA, and d-transposition of great arteries. Patient number 6 was diagnosed with double-inlet left ventricle, CoA, and aortic arch hypoplasia, and the last patient had tricuspid atresia, d-transposition of great arteries, and interrupted aortic arch.

Patients thought to be potential candidates for a primary CPS underwent cardiac catheterization. The median pulmonary vascular resistance for those patients on room air was 2.1 woods unit (25th–75th percentiles: 1–3.6), and median Qp/Qs was 5.3 (25th–75th percentiles: 2.5–7.6).

Postoperative Outcomes

There was no difference in hospital stay (*P* = .548) and ECMO use (*P* = .324) among the groups, Table 2. All-cause mortality in patients who required ECMO was 71.4% (*n* = 10; 9 of them were hospital mortality) in the BT group, and 88.9% in the Sano group (*n* = 8, 6 of them were hospital mortality).

Over the study period, operative mortality was 32% (23/72) in the BT group, 27% (15/66) in the Sano group, and 0% (0/7) in the CPS group. Independent predictors of operative mortality were lower weight (*P* = .026) and longer bypass time (*P* = .014). Age and type of shunt were not significant predictors of operative mortality. Long-term survival stratified by the shunt type and operation era is shown in Figure 3. Independent predictors of improved

Norwood	Norwood-CPS	Sano	Stage II	Fontan	Deaths
72	7	66	75	31	74

■ Operational Deaths
■ Eventual Deaths

FIGURE 1. The flowchart of patients included in the study. BT, Blalock–Taussig shunt; CPS, cavopulmonary shunt.

long-term survival were greater weight at operation ($P = .0016$), later time era (2011-2018 vs 2004-2012) ($P = .006$), and shorter bypass time ($P = .001$). There was no difference in the freedom from an arch or PA/shunt interventions among the groups ($P = .931$ and $.358$; respectively).

Multistate Transition Model

The frequency and predictors of the transition of patients between 6 distinct states, namely unoperated, BT, Sano, CPS, Fontan, and dead, were evaluated. The proportion of patients in each state at follow-up times is shown in Figure 4. The multistate model revealed that patients of lower weight were more likely to undergo Sano versus BT or CPS (hazard ratio [HR], 2.4; 95% confidence interval [CI], 1.6- 3.7; $P < .001$), and if BT was chosen for patients with lower weight, they were more likely to die (HR, 1.7; 95% CI, 1.1- 2.7; $P = .027$). Lower weight may also be associated with a greater risk of death in the Sano group; however, this association did not reach statistical significance, $P = .07$. Moreover, the likelihood of receiving a Sano shunt was 3-fold greater in the recent time era versus the older time era ($P = .003$), and the hazard of death after a

Norwood with Sano shunt improved in the recent time era (HR, 0.29; 95% CI, 0.11-0.77; $P = .01$). The risk of death from a Norwood BT was also lower in the recent time era; (HR, 0.5; 95% CI, 0.2- 1.2); however, this did not reach the statistical significance level ($P = .13$) (Table 3, Figure 1).

DISCUSSION

The management of HLHS and similar lesions still presents a challenge, especially with delayed presentation, and the optimal shunt for the first stage Norwood palliation is a topic of ongoing research. BT Norwood had the drawback of diastolic runoff and increased pulmonary blood flow, which was found to be associated with poor outcomes.¹⁵ Sano conduits were associated with good operative outcomes; however, the right ventriculotomy may affect the long-term outcomes.¹⁶ Therefore, the long-term survival benefit of Sano versus BT shunt is still debatable. In addition, the optimal shunt type for delayed presentation patients has not been studied in the literature.

In this series, we compared 3 shunt types used for first-stage Norwood palliation, namely, BT, Sano, and CPS. The latter was used as a primary shunt type in patients

TABLE 1. Descriptive statistics of preoperative and operative variables by type of shunt (N = 145)

	N	BT, N = 72	CPS, N = 7	Sano, N = 66	P value
Sex: male	145	0.57 (41)	0.57 (4)	0.64 (42)	.716*
Age, days	145	18.00 29.50 51.00	66.00 112.00 149.00	16.00 26.00 46.75	.002†
Weight, kg	143	2.8 3.2 3.6	3.3 3.6 4.8	2.7 3.0 3.3	.004†
Type of HLHS anatomy	121				.001*
AAMA		0.17 (9)	0.14 (1)	0.45 (28)	
AAMS		0.02 (1)	0.14 (1)	0.10 (6)	
ASMA		0.15 (8)	0.00 (0)	0.13 (8)	
ASMS		0.37 (19)	0.29 (2)	0.06 (4)	
Other		0.29 (15)	0.43 (3)	0.26 (16)	
Time era: [2011, 2018]	145	0.29 (21)	1.00 (7)	0.86 (57)	<.001*
Surgeon	145				
A		0.67 (48)	0.29 (2)	0.33 (22)	<.001*
B		0.25 (18)	0.00 (0)	0.11 (7)	
C		0.00 (0)	0.00 (0)	0.09 (6)	
D		0.01 (1)	0.00 (0)	0.17 (11)	
E		0.07 (5)	0.71 (5)	0.30 (20)	
CPB time, min	142	128.00 162.00 185.00	68.50 73.00 79.00	84.50 127.50 165.75	<.001†
Aortic clamp time, min	137	63.25 81.50 100.00	32.00 35.00 70.50	49.75 66.00 92.25	.012†
DHCA time, min	143	0.0 0.0 7.5	19.0 24.0 34.5	2.0 36.0 65.0	<.001†
Total circulatory arrest	145	0.028 (2)	0.85 (6)	0.39 (26)	<.001*
Antegrade cerebral perfusion	145	0.95 (69)	0.28 (2)	0.60 (40)	<.001*

a, *b*, and *c* represent the 25th quartile *a*, the median *b*, and the 75th quartile *c* for continuous variables. *N* is the number of nonmissing values. Numbers after proportions are frequencies. DHCA was included in the aortic clamp time but not part of the total bypass time. Tests used: *Pearson test; †Kruskal–Wallis test. *BT*, Blalock–Taussig shunt; *CPS*, cavopulmonary shunt; *Sano*, right ventricle to pulmonary artery shunt, *HLHS*, hypoplastic left heart syndrome; *AAMA*, aortic atresia with mitral atresia; *AAMS*, aortic atresia with mitral stenosis; *ASMA*, aortic stenosis with mitral atresia; *ASMS*, aortic stenosis with mitral stenosis; *CPB*, cardiopulmonary bypass; *DHCA*, deep hypothermic circulatory arrest.

who presented late and had objective evidence of low pulmonary vascular resistance despite the unrestricted pulmonary blood flow. During the study period, Sano conduits were more commonly used in the recent era (2011–2018) compared with BT shunts. The mortality improved markedly with the use of Sano shunts, but this also coincided with the overall improved mortality in the recent era. Preoperatively, patients with CPS were older and had greater body weight compared with other groups, albeit still, they were small for age as they presented later. The delayed presentation was due to deficiencies in antenatal diagnosis and timely access to tertiary care facilities mainly because of shortages of neonatal intensive care beds. Norwood centers are limited in our country and children diagnosed with HLHS are started on prostaglandin then the referral system is activated. The transfer may take several weeks.

Similar to what was reported by Mair and colleagues,¹⁷ there was no difference in total CPB and aortic clamp time between BT and Sano groups; however, CPS group had significantly lower CPB and clamp times in our series. The lower CPB and clamp time in CPS group could be attributed to the smaller numbers of anastomoses in this group; in addition, there may be a surgeon effect, as the

surgeon who performed this approach has lower times in other groups, too. The hospital stay was not different among the groups, similar to what was reported in the literature.^{3,7,18} ECMO support for patients with HLHS after stage I palliation was increasingly used; however, mortality remained high.¹⁹ Early deployment of ECMO and careful management to avoid complications might help improve survival.^{20,21} In a study of 149 infants who underwent a stage I reconstruction, Tabbutt and colleagues²² did not record any difference in ECMO support between the 2 shunt types (14% for BT group and 13% in Sano group). In our cohort, 14 patients (19%) in the BT group were subjected to ECMO due to hemodynamic instability compared with 9 patients in the Sano group (15.3%); one-third of them survived to hospital discharge. In contrast, none of the CPS group required ECMO support post-Norwood. This difference was found statistically nonsignificant because of the small sample.

Shunt type did not predict operative mortality in our series, and lower birth weight and longer bypass time were independent predictors of operative mortality. In addition, long-term survival was not affected by the shunt type and greater weight at operation, later era (2011–2018 vs

FIGURE 2. Operative mortality per year shown by shunt type; shunt. *BT*, Blalock–Taussig shunt; *Sano*, right ventricle to pulmonary artery shunt; *CPS*, cavopulmonary shunt.

2004–2012), and shorter bypass time predicted better long-term survival. The Single Ventricle Reconstruction (SVR) trial randomized 555 patients undergoing the Norwood procedure to receive either BT or Sano shunt, and their primary endpoint was the incidence of mortality or cardiac transplantation. After 6 years, patients receiving a Sano had

better transplant-free survival but did not reach a significant level, and no difference was found in hazard of death and catheter-based reintervention between groups.^{2,3}

The interstage period is recognized as a period of fragility, with a high incidence of sudden and unexpected death.³ The multistate analysis showed that Sano was

TABLE 2. Descriptive statistics of postoperative events by type of shunt (N = 145)

	N	BT, N = 72	CPS, N = 7	Sano, N = 66	P value
Postoperative length of stay, d	140	10.75 25.00 39.25	26.00 31.00 34.50	11.00 22.00 38.00	.548*
ECMO	145	0.19 (14)	0.00 (0)	0.14 (9)	.324†
Arch intervention: None	145	0.83 (60)	0.86 (6)	0.82 (54)	.002†
Post-Glenn balloon		0.00 (0)	0.14 (1)	0.00 (0)	
Pre-Glenn-balloon		0.11 (8)	0.00 (0)	0.12 (8)	
Pre-Glenn-CoA stent		0.06 (4)	0.00 (0)	0.06 (4)	
PA or shunt intervention: none	144	0.93 (67)	1.00 (7)	0.88 (57)	.635†
Pre-Glenn-PA stent		0.03 (2)	0.00 (0)	0.08 (5)	
Pre-Glenn-shunt stent		0.04 (3)	0.00 (0)	0.05 (3)	
Operative outcome: alive	145	0.68 (49)	1.00 (7)	0.77 (51)	.127†

a, *b*, and *c* represent the 25th quartile *a*, the median *b*, and the 75th quartile *c* for continuous variables. *N* is the number of non-missing values. Numbers after proportions are frequencies. Tests used: *Pearson test; †Kruskal–Wallis test. *BT*, Blalock–Taussig shunt; *CPS*, cavopulmonary shunt; *Sano*, right ventricle to pulmonary artery shunt; *ECMO*, extracorporeal membrane oxygenation; *CoA*, coarctation of the aorta; *PA*, pulmonary artery.

FIGURE 3. Kaplan–Meier survival curve for the 3 shunt groups stratified by the time era (2004–2010 and 2011–2018). Patients at risk are shown *underneath* the figure. 0.67% (1 standard deviation) error bands were used to generate the *shaded area* with the log-log method. *BT*, Blalock–Taussig shunt; *Sano*, right ventricle to pulmonary artery shunt; *CPS*, cavopulmonary shunt.

more likely to be performed in patients with lower birth weight, and when BT shunt was performed in this subset of patients, the transition to death was significantly greater.

Our current practice does not recommend a BT shunt in low-weight babies (<2.7 kg), atretic aortic valve, small ascending aorta (<2.5 mm), or small origin of the

FIGURE 4. The proportion of patients and the transition between 6 distinct states namely; unoperated, BT, Sano, CPS, Fontan, and dead are shown in the y-axis versus follow-up time in the x-axis. *BT*, Blalock–Taussig shunt; *Sano*, right ventricle to pulmonary artery shunt; *CPS*, cavopulmonary shunt.

TABLE 3. Multistate model, predictors of transitions between states

From \ to	BT			Sano			CPS			Fontan			Death		
Hazard ratio for lower weight (by 1 kg)															
Birth	0.846	1.170	1.617 (.3)	1.573	2.398	3.654 (<.001)	0.587	1.091	2.031 (.8)	-	-	-	-	-	NE
BT	-	-	-	-	-	-	0.799	1.034	1.339 (.8)	-	-	-	1.061	1.691	2.694 (.027)
Sano	-	-	-	-	-	-	0.875	1.861	3.959 (.107)	-	-	-	0.942	2.137	4.852 (.069)
CPS	-	-	-	-	-	-	-	-	-	0.602	0.840	1.173 (.3)	0.551	1.223	2.715 (.6)
Fontan	-	-	-	-	-	-	-	-	-	-	-	-	0.152	0.455	1.357 (.16)
Hazard ratio for time era [2013-2018] vs [2003-2013]															
Birth	0.133	0.222	0.372 (<.001)	1.454	2.954	5.999 (.003)	-	-	*	-	-	-	-	-	NE
BT	-	-	-	-	-	-	0.706	1.437	2.924 (.3)	-	-	-	0.204	0.501	1.234 (.13)
Sano	-	-	-	-	-	-	0.221	0.801	2.897 (.7)	-	-	-	0.108	0.288	0.766 (.013)
CPS	-	-	-	-	-	-	-	-	-	0.554	1.909	6.581 (.3)	0.055	0.238	1.039 (.056)
Fontan	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*

States in left column indicate the “from” states and those in top row indicate the “to” state for each transition. Hyphen indicate invalid transitions. Each cell shows the effect of the predictor as a hazard ratio (HR) with 95% confidence intervals (CI) in subscripts, lower 95%CI HR higher 95%CI. Numbers between brackets represent P values; significant P values are shown in bold. BT, Blalock–Taussig shunt; Sano, right ventricle to pulmonary artery shunt; CPS, cavopulmonary shunt; NE, no events. *Indicates that the number of cases and events are too small for reliable statistics.

brachiocephalic artery. Further analysis of our data revealed that the hazard of death had significantly decreased in the recent era, especially with Sano and CPS patients. This could be attributed to the building experience, the more liberal use of ECMO support, and improvement of our referral system. In a study by Tabbutt and associates,²² patients with Sano returned earlier for their stage II palliation, which could be explained by the earlier development of PAs following RV-PA conduit, which was demonstrated in earlier studies.^{2,24,25} In contrast, Fiore and colleagues²⁶ found that the timing of the second-stage palliation was similar with both shunts. Patients with Sano shunts could come earlier to the second stage due to increasing cyanosis secondary to narrowing at the proximal or distal conduit anastomosis, and the technique of retaining the PTFE ring

as a stent for the outflow anastomosis had prevented early conduit failure.^{27,28}

The SVR trial reported an increased incidence for balloon dilation or stent placement in the shunt or branch PAs in Sano group.² A study by Gist and colleagues²⁹ reported no shunt or PA intervention for the BT group and 15% for the Sano group, and they attributed this to the difficult access to the PA for intervention in this group. Mery and colleagues³⁰ explained the greater incidence of central PA stenosis in Sano patients by the anterior pull on the PA confluence by the conduit as the child grows. In our series, we found no difference in the incidence of the PA or shunt intervention between the BT and Sano groups. None of the CPS patients required intervention. These results indicate the feasibility and safety to perform CPS with first-stage palliation in selected patients presenting late and demonstrating low pulmonary vascular resistance.

Study Limitations and Strengths

The major limitation of the study is the retrospective nature of the study, with the selection and referral bias inherited to this study design. Different measured and unmeasured patient characteristics could have affected the outcomes, and patient and procedure risks were not equally distributed between the groups. However, we used multivariable logistic and Cox regression analysis to adjust for the measured variables and identify the predictors of mortality and long-term survival. Another limitation of the study is the single-center experience, and generalization of the results may be problematic. However, the study presents a large experience in the management of HLHS and variants over 15 years with complete follow-up in 98% of the

VIDEO 1. Video presentation summarizing the study and explaining the indications of Cavo-pulmonary shunt as first stage Norwood operation. Video available at: [https://www.jtcvs.org/article/S0022-5223\(19\)33096-X/fulltext](https://www.jtcvs.org/article/S0022-5223(19)33096-X/fulltext).

patients. In addition, the study presents CPS shunt as a primary shunt for the first stage Norwood palliation in selected patients and shows its safety and feasibility in those patients.

CONCLUSIONS

Improved outcomes of the Norwood operation are evident in the more recent time era and with more frequent use of the Sano shunt, especially in patients with smaller weight. Late diagnosis or older age should not be considered a contraindication to the Norwood operation. Use of the CPS as a component of the initial Norwood operation is feasible and may be safe in carefully selected patients with low pulmonary vascular resistance. The current outcomes of the Norwood operation warrant offering the treatment to most patients with HLHS and similar lesions even with delayed presentation (Video 1).

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

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Key Words: Norwood operation, Sano shunt, BT shunt, cavopulmonary connection, HLHS