ORIGINAL RESEARCH

Resource Utilization for Prenatally Diagnosed Single-Ventricle Cardiac Defects: A Philadelphia Fetus-to-Fontan Cohort Study

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***Background*—**Healthcare resource utilization is substantial for single-ventricle cardiac defects (SVCD), with effort commencing at time of fetal diagnosis through staged surgical palliation. We sought to characterize and identify variables that influence resource utilization for SVCD from fetal diagnosis through death, completed staged palliation, or cardiac transplant.

***Methods and Results*—**Patients with a prenatal diagnosis of SVCD at our institution from 2004 to 2011 were screened. Patients delivered with intent to treat who received cardiac care exclusively at our institution were included. Primary end points included the total days hospitalized and the numbers of echocardiograms and cardiac catheterizations. Subanalysis was performed on survivors of completed staged palliation on the basis of Norwood operation, dominant ventricular morphology, and additional risk factors. Of 202 patients born with intent to treat, 136 patients survived to 6 months after completed staged palliation. The median number of days hospitalized per patient-year was 25.1 days, and the median numbers of echocardiograms and catheterizations per patient-year were 7.2 and 0.7, respectively. Mortality is associated with increased resource utilization. Survivors had a cumulative length of stay of 57 days and underwent a median of 21 echocardiograms and 2 catheterizations through staged palliation. Right-ventricle–dominant lesions requiring Norwood operation are associated with increased resource utilization among survivors of staged palliation.

***Conclusions*—**For fetuses with SVCD, those with dominant right-ventricular morphology requiring Norwood operation demand increased resource utilization regardless of mortality. Our findings provide insight into care for SVCD, facilitate precise prenatal counseling, and provide information about the resources utilized to successfully manage SVCD. **(*J Am Heart Assoc*. 2019;8: e011284. DOI: 10.1161/JAHA.118.011284.)**

Key Words: congenital heart disease • fetal echocardiography • hypoplastic left heart syndrome • resource utilization • single ventricle

The development of staged surgical palliation culminating in a total cavopulmonary connection has enabled survival for patients with single-ventricle cardiac defects (SVCD). Advances in surgical technique and postoperative management for SVCD have led to 5-year survival rates approaching 70%.[1–3] As more patients with SVCD survive beyond the neonatal period, SVCD remains among the most healthcare-resource–intense birth defects.[4–6] The inpatient costs of SVCD during staged surgical palliation admissions now show evidence of stabilization after decades of increases due to improved outcomes and longer hospital lengths of stay (LOS).[7,8]

Resource utilization in SVCD, particularly outside of surgical admissions, has not been well characterized in a composite manner from the point of earliest diagnosis. The widespread adoption of fetal echocardiography as a surveillance and diagnostic tool initiates healthcare expenditures before birth. During higher risk postnatal periods, such as the interstage palliation period, vigilant monitoring programs involve increased outpatient imaging surveillance and likely have resulted in increased provider encounters and hospitalizations.[9] No studies to date have assessed the longitudinal resource utilization of comprehensive care from the time of fetal diagnosis through Fontan palliation for SVCD. This knowledge gap significantly limits our ability to understand the resources required for optimal SVCD care and the extent

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Clinical Perspective

What Is New?

- This study outlines the magnitude of specific resources utilized in a large single-center cohort to manage prenatally diagnosed single-ventricle cardiac defects from the time of prenatal diagnosis through death, transplant, or completed staged palliation.
- Independent risk factors for increased resource utilization were death before completed staged palliation, low birth weight, and right-ventricular–dominant lesions with Norwood operation.

What Are the Clinical Implications?

- This study provides practical information for congenital heart specialists to use in counseling expectant parents on the anticipated spectrum of healthcare resources utilized during staged palliation for single-ventricle cardiac defects.
- Even among patients who survive to completed staged palliation, those with right-ventricular–dominant lesions requiring Norwood operation encounter higher morbidity and greater resource utilization compared with other morphologic subgroups.

to which the fetal cardiologist is able to counsel the family about postnatal expectations in relation to the burden of health care necessary to achieve success.

We report on a unique cohort of patients with a prenatal diagnosis of SVCD who received longitudinal comprehensive fetal, postnatal inpatient, and outpatient cardiac care at a single large academic center. The purpose of our study is to characterize the resource utilization of patients with SVCD from the time of prenatal diagnosis through the anticipated time course for completion of staged palliation, with successful achievement of Fontan completion, death, or cardiac transplantation.

Methods

Patient Selection

The data, analytical methods, and research materials used in this study will not be made available for the purpose of reproducing results or replicating the procedure. We performed a retrospective chart review and identified all patients evaluated in the fetal heart program at the Children's Hospital of Philadelphia between July 1, 2004, and December 31, 2011, and diagnosed with SVCD. This time period was selected to allow for adequate longitudinal postnatal follow-up through all stages of surgical palliation: neonatal care with no immediate intervention, stage 1 with Norwood operation, or shunt placement without a Norwood operation; stage 2 or superior cavopulmonary anastomosis; and stage 3 or total cavopulmonary anastomosis (Fontan operation). Overall survival outcomes for the Philadelphia "fetus-to-Fontan" cohort have been described previously.[10] SVCD is defined as any cardiac anatomical arrangement that resulted in prenatal counseling for staged surgical palliation with the anticipated goal of a total cavopulmonary anastomosis. This determination was made by an experienced fetal cardiologist at the final prenatal visit before delivery. We then included only patients who survived to birth with intent to treat and were followed exclusively at our institution. *Intent to treat* is defined as a decision on the part of the family and the healthcare provider to pursue staged surgical palliation. Participants who chose termination of pregnancy, who opted prenatally for nonintervention palliative care at birth, or who experienced fetal demise were excluded. Patients were followed until death, orthotopic heart transplant, or 6 months after completed staged palliation. Patients who did not complete staged palliation at the time of data collection were censored at 4 years of age. The study was approved by the institutional review board at the Children's Hospital of Philadelphia (no. 15-012216CR1). The requirement of informed consent by participants in the study was waived.

Clinical End Points

Because specific monetary charges associated with cardiac care vary widely between regions and institutions,[6] we sought to describe resource utilization through hospital LOS, echocardiograms, and cardiac catheterization procedures. Consequently, the primary end points for the study include total number of days hospitalized, number of echocardiograms, and number of catheterization procedures. Primary end points were indexed in patient-years to allow for comparison between survivors and nonsurvivors. The following potential risk factors for increased resource utilization were analyzed: (1) prematurity <37 weeks gestation, (2) birth weight <2500 g, (3) presence of heterotaxy syndrome, (4) chromosomal abnormality, (5) extracardiac anomaly, or (6) need for extracorporeal membrane oxygenation support at any point of care. Subset analysis was performed on all patients who had transplant-free survival to 6 months after completed staged palliation for comparison based on (1) initial palliation with Norwood operation and (2) dominant ventricular morphology.

Statistical Analysis

Descriptive statistics of the demographic information and clinical end points are reported. Continuous data are presented as median (range) or mean±SD, as appropriate

based on normalcy of distribution. Categorical data are presented as frequencies with percentages. Differences in resource utilization and relative predictive power among potential risk factors were compared using multivariate negative binomial regression. Two-tailed $P<0.05$ was considered statistically significant for comparison between nonsurvivor and survivor groups. For statistical rigor, 2-tailed $P<0.0083$ following Bonferroni correction was considered statistically significant for pairwise comparison in subset analysis. Analyses were performed using SAS software (v9.3; SAS Institute).

Results

We identified 501 patients prenatally diagnosed with SVCD at the fetal heart program between July 1, 2004, and December 31, 2011 (Figure). In total, 347 patients survived to birth with intent to treat. Among these, 202 patients were followed exclusively at our institution, with 136 (68%) reaching transplant-free survival at 6 months after completed staged palliation. An additional 10 patients (5%) either underwent postnatal conversion to biventricular repair or did not complete staged palliation.

The distribution of anatomic subtypes of SVCD heavily favored dominant right-ventricle (RV) lesions (73%, n=148). These lesions were broadly defined as cardiac anatomy in which the right ventricle was designated as the systemic ventricle. Hypoplastic left heart syndrome was the most common right-dominant lesion, accounting for 42% of all patients (Table 1). Of the 54 dominant left-ventricle (LV) lesions, tricuspid atresia was the most common, totaling 37% of left-dominant conditions.

Resource utilization of the entire cohort indexed to patient-years is listed in Table 2. Patients had a median LOS of

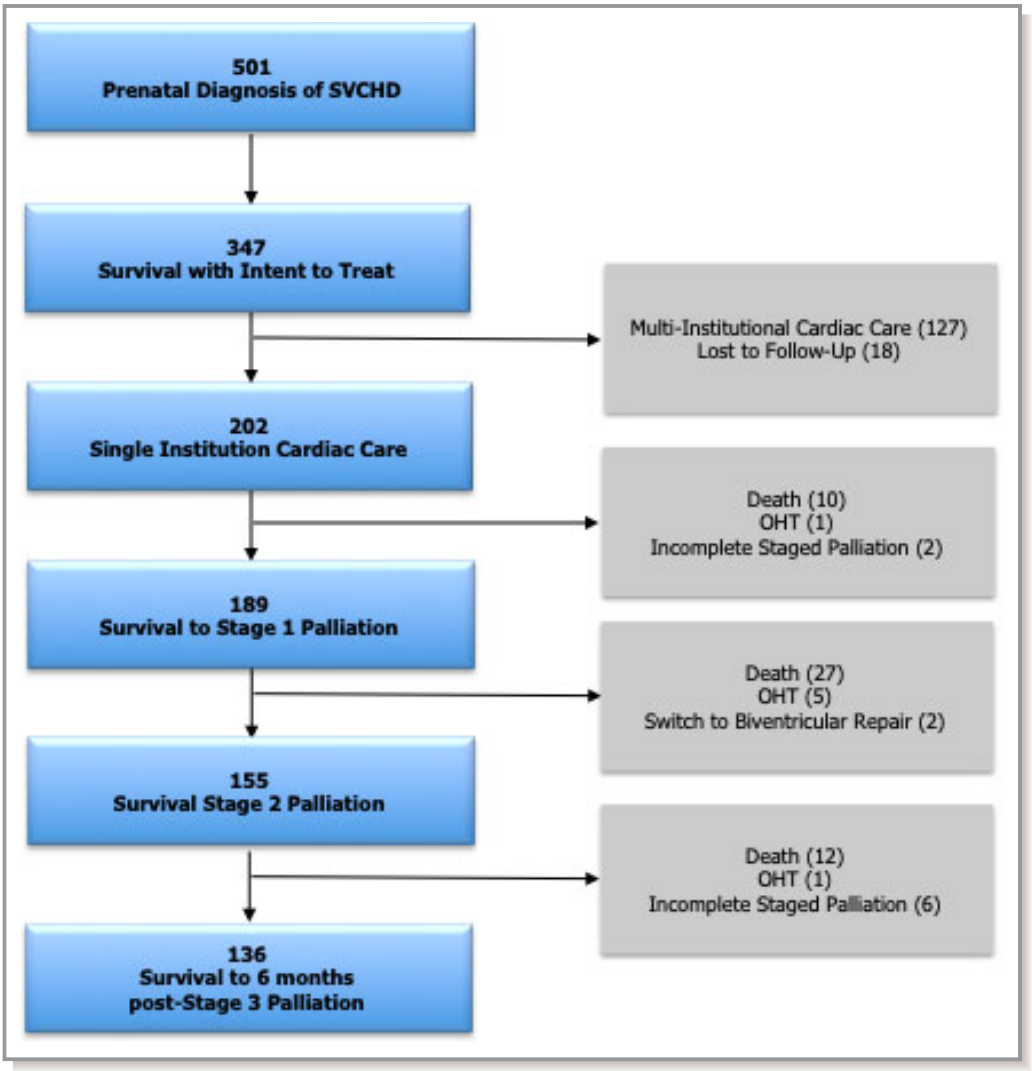

Figure. Outcomes of 501 patients with prenatally diagnosed SVCD. OHT indicates orthotopic heart transplant; SVCD, single-ventricle cardiac defects.

Table 1. Anatomic Distribution of SVCD Type

Diagnosis	n	%
Right dominant	148	
HLHS	84	41.6
Unbalanced CAVC to right	19	9.4
DORV with mitral atresia or stenosis	12	5.9
Other right-dominant single ventricle	33	16.3
Left dominant	54	
Tricuspid atresia	20	9.9
Double-inlet left ventricle	6	3.0
Ebstein anomaly	3	1.5
Pulmonary atresia with intact ventricular septum	2	1.0
Unbalanced CAVC to left	2	1.0
Other left-dominant single ventricle	21	10.4

CAVC indicates complete atrioventricular canal defect; DORV, double-outlet right ventricle; HLHS, hypoplastic left heart syndrome; SVCD, single-ventricle cardiac defects.

25.1 days per patient-year and underwent a median of 7.2 echocardiograms and 0.7 cardiac catheterization per year of life. Participants had a median of 4 fetal echocardiograms.

Patients who died before completed staged palliation (n=49) demonstrated increased resource utilization compared with all survivors (n=153; Table 3). The indexed LOS was higher among patients who died compared with those who survived (365.3 versus 18.2 days per patient-year, $P<0.0001$). There were also higher rates of echocardiogram studies (62.0 versus 5.8 per patient-year, $P<0.0001$) and catheterizations (3.9 versus 0.6 per patient-year, $P<0.0001$).

For the 136 patients who survived all stages of surgical palliation, the median cumulative LOS through 6 months after completed staged palliation was 57 days (Table 4). The median LOS for anticipated surgical procedures was 21.5 days for birth through the first stage, 8 days for stage 2, and 10 days for stage 3. Patients completing staged palliation had a median LOS of 2 days during the interstage period. Survivors of completed staged palliation underwent a median of 4 fetal echocardiograms and 21 total postnatal studies. The median number of catheterization procedures per patient was 2. These procedures occurred more frequently within the group during the interstage period and the interval between stages 2 and 3.

Table 2. Resource Utilization of 202 Patients With Prenatally Diagnosed SVCD

	Median (IQR)
LOS, days per patient-year	25.1 (13.1–85.4)
Echocardiograms	
Fetal, total	4 (3–4)
Postnatal, per patient-year	7.2 (5.1–15.4)
Cardiac catheterizations, per patient-year	0.7 (0.3–1.4)

IQR indicates interquartile range; LOS, length of stay; SVCD, single-ventricle cardiac defects.

Impact of Risk Factors and Cardiac Morphology on Resource Utilization

The prevalence of potential risk factors for increased resource utilization among survivors and nonsurvivors are displayed in Table 5. Nonsurvivors were more likely to be premature, to have low birth weight, and to require extracorporeal membrane oxygenation but had no significant difference in the frequency of other potential risk factors.

Subanalysis of survivors of completed staged palliation was performed to assess patterns of resource utilization among 4 subgroups based on dominant ventricular morphology (right or left) and Norwood operation. The distribution of potential risk factors for increased resource utilization by cardiac morphology is listed in Table 6. Prematurity, low birth weight, and heterotaxy syndrome were more common in patients with RV-dominant lesions not requiring Norwood palliation.

Multivariate analysis with previously identified risk factors as covariates was performed to compare resource utilization among the 4 subgroups. Patients with RV-dominant lesions requiring Norwood operation had the longest total LOS and the highest number of postnatal echocardiograms (Table 7).

Among 90 patients with right-dominant lesions, prior Norwood operation was associated with longer total LOS (70 versus 60 days, $P=0.001$), with longer LOS during admissions for stage 3 palliation, and a trend toward longer LOS during admission for stage 2 palliation. Of 46 patients with LV-dominant lesions, no difference in total LOS was observed between patients with and without a prior Norwood operation (52 versus 39 days, $P=0.31$) or during stage 2 or 3 palliation admissions (Table 7).

Of 77 patients who underwent a Norwood operation, right-dominant lesions were associated with increased total LOS (70 versus 52 days, $P=0.002$) and longer LOS for admissions at stage 2 palliation (8.5 versus 6 days, $P=0.0009$) and stage 3 palliation (10 versus 9 days, $P=0.007$) compared with left-dominant lesions. In the 59 patients without Norwood operation, no statistical difference in total LOS (60 versus 39 days, $P=0.26$) was noted, and LOS was similar for admissions for stage 2 and 3 palliation. Patients with right-dominant lesions without Norwood operation and patients with left-dominant lesions with Norwood operation had no difference in total LOS (60 versus 52 days, $P=0.94$).

Table 3. Indexed Resource Utilization Among Survivors and Nonsurvivors

	Survival (n=153)	Death (n=49)	*P* Value
LOS, days per patient-year	18.2 (11.0–30.1)	365.3 (247.1–365.3)	<0.0001
Echocardiograms			
Fetal, total	4 (3–4)	3 (3–4)	0.49
Postnatal, per patient-year	5.8 (4.7–8.2)	62.0 (34.1–121.8)	<0.0001
Catheterizations, per patient-year	0.6 (0.3–1.0)	3.9 (0–10.7)	<0.0001

Values expressed as median (IQR). Survival group includes patients who underwent cardiac transplant and did not complete staged palliation at 4 years of age. IQR indicates interquartile range; LOS, length of stay.

RV-dominant patients who underwent the Norwood operation received more echocardiograms than those without a Norwood operation, although this difference did not meet statistical significance (22 versus 19, P=0.06; Table 7). In contrast, RV-dominant patients with a Norwood operation received more echocardiograms than patients with LV-dominant lesions with a Norwood operation (22 versus 20, P=0.008) and without a Norwood operation (22 versus 18, P=0.005). There was no significant difference in the number of postnatal echocardiograms between RV-dominant patients without a Norwood operation compared with LV-dominant patients with or without a Norwood operation.

Table 4. Resource Utilization Among 136 Survivors Completing Staged Palliation

	Median (IQR)
LOS, d	
Birth to S1P	21.5 (14.8–34.3)
Interstage	2 (0–9)
S2P	8 (6–11)
S2P to S3P	3 (0–12.3)
S3P	10 (8–14)
LOS nonsurgical admissions	12 (3.8–29)
Total LOS	57 (38–106)
Echocardiograms	
Fetal	4 (3–5)
Birth to S1P	4 (3–7)
S1P to 6 mo after S3P	16.5 (12–21)
Total echocardiograms	21 (16–28)
Cardiac catheterizations	
Birth to S1P	0 (0–2)
Interstage	1 (1–1)
S2P	0 (0–0)
S2P to S3P	1 (0–1.3)
S3P and S3P to 6 mo after S3P	0 (0–0)
Total catheterizations	2 (1–3)

IQR indicates interquartile range; LOS, length of stay; S1P, stage 1 palliation; S2P, stage 2 palliation; S3P, stage 3 palliation.

Repeated analysis of total LOS excluding the duration of hospitalization for the initial palliative procedure was performed to control for anticipated differences in LOS related to morbidity of the Norwood operation (Table 8). Patients with RV-dominant lesions requiring a Norwood operation demonstrated longer LOS compared with patients with LV-dominant lesions with a Norwood operation (43 versus 21 days, P<0.0001) and without a Norwood operation (43 versus 23.5 days, P=0.001), as well as those with right-dominant lesions without prior Norwood (43 versus 28 days, P=0.003).

The relative predictive impact of risk factors on resource utilization among survivors of staged palliation is displayed in Table 9. Low birth weight was associated with an 81% increase in total LOS (exponent of coefficient 1.81, P=0.005) and a 27% increase in postnatal echocardiogram utilization (exponent of coefficient 1.27, P=0.02). RV-dominant lesions with the Norwood operation were associated with a 56% increase in total LOS (exponent of coefficient 1.56, P<0.0001) and a 24% increase in the number of echocardiograms (exponent of coefficient 1.24, P=0.0003) compared with all other morphologic subtypes. No other potential risk factor was associated with significantly increased resource utilization.

Discussion

Staged palliation for SVCD, whether single LV or RV, is consistently demonstrated as the most resource-intensive intervention in congenital heart disease and ranks among the most burdensome pediatric conditions in terms of health care in the United States.[6,11] In this study, we characterized resource utilization in a cohort of patients from a single center who were managed in a consistent manner and who had a broad variety of SVCD, from fetal diagnosis through completed staged palliation.

The majority of patients with SVCD today are diagnosed before birth.[12,13] This diagnosis presents an opportunity for

Table 5. Prevalence of Potential Risk Factors Contributing to Resource Utilization

	Total (n=202)	Survival (n=153)	Death (n=49)	*P* Value
Prematurity	30 (14.8)	18 (11.8)	12 (24.4)	0.03
Heterotaxy	26 (12.9)	20 (13.1)	6 (12.2)	0.88
Chromosomal anomaly	14 (6.9)	9 (5.9)	5 (10.2)	0.30
Extracardiac anomaly	27 (17.6)	18 (11.8)	9 (18.3)	0.24
Birth weight <2500 g	29 (14.4)	17 (11.1)	12 (24.5)	0.02
Need for ECMO	22 (10.8)	4 (2.6)	18 (36.7)	<0.0001

Values expressed as n (%). Prematurity defined as birth at <37 weeks of gestational age. Extracardiac anomaly excludes patients with heterotaxy syndrome. ECMO indicates extracorporeal membrane oxygenation.

extensive counseling as expectant parents approach decisions surrounding their pregnancy, including possible termination. Prenatal counseling improves parental understanding of congenital heart disease and may reduce parental distress in the neonatal period.[14,15] Nevertheless, parents often desire more information regarding the anticipated quality of life of children with congenital heart disease than cardiologists are currently able to provide.[16] Our study examined longitudinal resource utilization in the SVCD population with a prenatal diagnosis. Specifically, we quantified the total LOS, echocardiograms, and catheterizations typical for those who survive all stages of surgical palliation. This approach provided practical information for the fetal cardiologist to use when informing expectant parents about what to anticipate in the best-case scenario for those choosing surgical palliation.

Previous analyses have reported a cumulative LOS for surgical admissions for staged palliation of 44 to 66 days in hypoplastic left heart syndrome.[7,8] We found a median cumulative LOS of 57 days from birth through 6 months after completed staged palliation, with >20% of the LOS occurring outside of scheduled surgical admissions. Our findings expand previous efforts to characterize resource utilization by quantifying the use of echocardiography and catheterization during staged palliation. The need for diagnostic and surveillance cardiac assessment results in a median of 4 fetal echocardiograms, 21 postnatal echocardiograms, and 2 cardiac catheterizations per patient with SVCD.

Mortality is associated with higher rates of resource utilization. Although this finding is expected, the disparity observed in our cohort between survivors and nonsurvivors was dramatic and serves as a stark reminder of the magnitude of mortality-related expenditures. It also highlights the current practice model of dedicating more resources toward a critically ill population that requires frequent assessment and intervention. Our findings support prior reports of increased LOS and hospital charges during admissions that result in mortality for patients with hypoplastic left heart syndrome.[17] Mortality most often occurred early in life, during the stage 1 admission or interstage period, and reflects a larger proportion of time spent in the resource-intense early postnatal period.

Survivors with RV-dominant lesions requiring a Norwood operation consumed more resources than the other 3 subgroups, even after controlling for a number of potential risk factors and anticipated differences in LOS during the stage 1 admission. Multiple possible explanations exist. The

Table 6. Prevalence of Potential Risk Factors Contributing to Resource Utilization Among Cardiac Morphological Subsets of Survivors Who Completed Staged Palliation

	RV Norwood (n=66)	RV (n=24)	LV Norwood (n=11)	LV (n=35)	*P* Value
Prematurity	5 (7.8)	6 (25.0)	1 (9.1)	2 (5.7)	0.009
Heterotaxy	1 (1.5)	13 (54.2)	0	1 (2.9)	<0.0001
Chromosomal anomaly	3 (4.5)	0	0	2 (5.7)	0.69
Extracardiac anomaly	4 (6.1)	1 (4.2)	1 (9.1)	7 (20.0)	0.10
Birth weight <2500 g	5 (7.8)	7 (29.2)	1 (9.1)	0	0.004
Need for ECMO	1 (1.5)	0	1 (9.1)	1 (2.9)	0.46

Values expressed as n (%). Prematurity defined as birth at <37 weeks of gestational age. Extracardiac anomaly excludes patients with heterotaxy syndrome. RV or LV describes dominant ventricular morphology. Norwood denotes aortic arch reconstruction with either Blalock–Taussig shunt or RV-to-pulmonary-artery shunt. ECMO indicates extracorporeal membrane oxygenation; LV, left ventricle; RV, right ventricle.

Table 7. Multivariate Subset Analysis of Resource Utilization Among Survivors of Completed Staged Palliation

	Value	RV Norwood (n=66)	RV (n=24)	LV Norwood (n=11)	LV (n=35)
Total LOS, d					
RV Norwood	70 (46–117)	···	0.001	0.002	0.002
RV	60 (39–86)	0.001	···	0.94	0.26
LV Norwood	52 (37–63)	0.002	0.94	···	0.31
LV	39 (34–75)	0.002	0.26	0.31	···
S2P LOS, d					
RV Norwood	8.5 (6–17)	···	0.015	0.0009	0.029
RV	7 (6–8)	0.015	···	0.57	0.29
LV Norwood	6 (5–7)	0.0009	0.57	···	0.06
LV	8 (6–11)	0.029	0.29	0.06	···
S3P LOS, d					
RV Norwood	10 (8–19)	···	0.0003	0.007	0.003
RV	10 (9–11)	0.0003	···	0.53	0.14
LV Norwood	9 (8–13)	0.007	0.53	···	0.48
LV	9.5 (8–13)	0.003	0.14	0.48	···
Echocardiograms					
RV Norwood	22 (19–30)	···	0.060	0.008	0.005
RV	19 (15–23)	0.060	···	0.51	0.98
LV Norwood	20 (12–23)	0.008	0.51	···	0.45
LV	18 (15–24)	0.005	0.98	0.45	···

Values expressed as median (IQR). *P* values listed for pairwise comparisons (statistical significance determined by $P<0.0083$). RV or LV describes dominant ventricular morphology. Norwood denotes aortic arch reconstruction with either Blalock–Taussig shunt or RV-to-pulmonary-artery shunt. Covariates included genetic or extracardiac abnormality, prematurity, heterotaxy syndrome, and birth weight <2500 g. IQR indicates interquartile range; LOS, length of stay; LV, left ventricle; RV, right ventricle.

morphological RV is thought to be at a mechanical disadvantage when placed in systemic circulation because of inherent differences in myocardial contractility and diastolic function that render the ventricle poorly suited for systemic pressure work. Recent analyses have demonstrated worse systolic function in patients with right-dominant SVCD during staged palliation.[18,19] The tricuspid valve is also thought to be more susceptible to insufficiency as a result of ventricular dilatation.[20] The role of dominant ventricular morphology in long-term survival in SVCD is a subject of ongoing debate and is beyond the scope of this study.[21–23] However, our findings are consistent with a growing body of evidence showing that dominant RV morphology may provide a less favorable substrate within the spectrum of SVCD, and they suggest that additional morbidity is conferred even among survivors of staged palliation. Future efforts directed toward describing

Table 8. Multivariate Subset Analysis of Total LOS After Admission for Initial Palliation Among Survivors of Completed Staged Palliation

	LOS (d)	RV Norwood (n=66)	RV (n=24)	LV Norwood (n=11)	LV (n=35)
RV Norwood	43 (23–83)	···	0.003	<0.0001	0.001
RV	28 (25–46)	0.003	···	0.41	0.43
LV Norwood	21 (15–34)	<0.0001	0.41	···	0.07
LV	23.5 (19–34)	0.001	0.43	0.07	···

Values expressed as median (IQR). *P* values listed for pairwise comparisons (statistical significance determined by $P<0.0083$). RV or LV describes dominant ventricular morphology. Norwood denotes aortic arch reconstruction with either Blalock–Taussig shunt or RV-to-pulmonary-artery shunt. Covariates included genetic or extracardiac anomaly, prematurity, heterotaxy, and birth weight <2500 g. IQR indicates interquartile range; LOS, length of stay; LV, left ventricle; RV, right ventricle.

Table 9. Multivariate Regression Model Showing Relative Predictive Power of Potential Risk Factors of Resource Utilization Among Survivors of Completed Staged Palliation

	Exponent of Coefficient	95% CI	*P* Value
Total LOS, d			
Genetic/extracardiac anomalies	1.13	0.82–1.54	0.46
Heterotaxy	1.16	0.84–1.60	0.37
Prematurity	0.99	0.71–1.37	0.94
Birth weight <2500 g	1.81	1.30–2.52	0.005
RV Norwood	1.56	1.28–1.90	<0.0001
S2P LOS, d			
Genetic/extracardiac anomalies	0.77	0.49–1.19	0.24
Heterotaxy	0.78	0.50–1.24	0.30
Prematurity	0.93	0.58–1.50	0.78
Birth weight <2500 g	1.16	0.72–1.86	0.54
RV Norwood	1.64	1.24–2.16	0.0004
S3P LOS, d			
Genetic/extracardiac anomalies	1.00	0.67–1.49	0.99
Heterotaxy	0.99	0.65–1.50	0.95
Prematurity	0.74	0.48–1.13	0.16
Birth weight <2500 g	2.14	1.43–3.21	0.0002
RV Norwood	1.76	1.37–2.27	<0.0001
Echocardiograms			
Genetic/extracardiac anomalies	1.20	1.00–1.44	0.05
Heterotaxy	0.90	0.74–1.09	0.28
Prematurity	0.98	0.80–1.20	0.85
Birth weight <2500 g	1.27	1.04–1.54	0.02
RV Norwood	1.24	1.11–1.40	0.0003

Prematurity defined as birth at <37 weeks gestational age. RV or LV describes dominant ventricular morphology. Norwood denotes aortic arch reconstruction with either Blalock–Taussig shunt or RV-to-pulmonary-artery shunt. LOS indicates length of stay; RV, right ventricle; S2P, stage 2 palliation.

the hospital course of these patients may help to further characterize this disparity and identify potential targets for intervention.

We identified 4 subgroups of survivors who completed staged palliation; subgroups were based on dominant ventricular morphology and Norwood operation, with differential LOS and echocardiogram utilization between groups. In some instances, these differences were profound; for example, over the total course of staged palliation, patients with both dominant RV morphology and a Norwood operation spent 1 month longer in the hospital than patients with a left-dominant lesion who similarly underwent a Norwood operation (P=0.002). Interestingly, in all comparisons, we did not find any significant difference in resource utilization between those patients with a dominant RV who did not have a Norwood operation compared with those with a dominant LV either with or without a Norwood operation. This finding suggests not only that the combination of a dominant RV and a Norwood operation are associated with higher resource utilization but also that this particular anatomic subtype, even among survivors of staged palliation, carries an overall higher morbidity risk than the other anatomic subtypes. This was underscored in our analysis of LOS during stage 2 and 3 operations. During hospital admission for stage 3, patients with RV-dominant lesions requiring a Norwood operation spent significantly more time in the hospital than their counterparts. This outcome was also seen during stage 2, although only comparison to the group with right-dominant lesions without a Norwood operation met statistical significance (P=0.0009). An unexpected finding was that there was no significant difference in resource utilization between LV-dominant patients regardless of having undergone a Norwood procedure. The cohort with LV-dominant lesions and Norwood (n=11) was small and may have resulted in an analysis that was underpowered to detect significant differences. Nevertheless, our findings of a substantial burden of resource utilization in those with a morphological RV and a need for a Norwood operation distinguishes this subgroup within SVCD as perhaps biologically different than other forms of SVCD, with a clinical profile that prompts further analysis as to the pathophysiology of this condition (dominant RV morphology in combination with critical anatomical impediment to systemic perfusion).

In addition to ventricular morphology, aortic arch reconstruction carries the additional potential complication of recoarctation, which affects up to 10% of patients after Norwood.[24,25] This complication may serve as one of the potential sources of hospitalizations for percutaneous or surgery-based intervention in this patient group, although this possibility was not quantified in the current study. This concern may have contributed to the increased number of echocardiograms performed in patients with right-dominant lesions with a Norwood operation, as a method of surveillance; interestingly, though, we did not observe a significant difference in LOS or number of echocardiograms in LV-dominant patients on the basis of prior a Norwood operation.

Our analysis confirms previous reports of increased morbidity among patients who are born with a low birth weight.[26–29] Meanwhile, heterotaxy syndrome and prematurity were not found to be associated with significantly increased resource utilization, and this finding is consistent with prior studies.[28,30] Chromosomal or extracardiac abnormalities were not associated with increased resource

utilization among survivors of staged palliation and were not found to be more prevalent among patients who died before completed staged palliation. This finding runs counter to previous analyses[31,32] and to reported findings from our larger cohort.[10] It suggests the present study was likely underpowered to characterize the impact of this risk factor. Given our previously published data on the association between extracardiac and chromosomal anomalies and mortality, a multi-institutional study may be needed to confidently define the influence of extracardiac anomalies on resource utilization.

Fetal echocardiography has rapidly progressed to the extent that fetal cardiologists can now reliably assess various cardiovascular features such as anatomical variability, ventricular function, and atrioventricular valvular competence during fetal life. The prognostic utility of this information remains uncertain. To date, no studies have examined whether resource utilization in SVCD can be predicted before birth. Our series suggests that dominant RV morphology with a Norwood operation is associated with increased resource utilization during staged palliation. In many cases, these characteristics are known at the time of diagnosis. This information should facilitate precise counseling because the focus of conversations between practitioners and expectant families shifts from probabilities of survival to anticipated quality of life. The prognostic capacity of fetal assessment presents an area for future research efforts.

Our study has several limitations. SVCD encompasses a wide variety of anatomical configurations, some of which may be "borderline" for 2-ventricle repair. Consequently, we used the clinical impression of fetal cardiologists at our institution at the time of prenatal counseling to predict the presence of SVCD. Ten patients with a prenatal diagnosis of SVCD were ultimately able to undergo biventricular repair or to live with a single ventricle without a Fontan procedure. Furthermore, additional patients with borderline ventricular hypoplasia in the fetal period who were deemed at fetal counseling as likely to undergo 2-ventricle repair were excluded, even if they ultimately underwent SVCD staged palliation. Our population may reflect selection bias because the fetal heart program at our institution is a large referral center through which many families seek care at our institution, specifically for aggressive care of complex anatomic lesions. Although all patients in the study received surgical care and outpatient cardiac care at our institution, it is possible that some patients may have presented to outside hospitals for short periods of urgent care between admissions for surgical palliation, and we may not have captured that. Additional studies employing multicenter databases may facilitate our ability to further elaborate on the differences among SVCD subgroups, with the possibility of identifying variations in practice that may influence resource utilization. Outcomes specific to the critical care setting, such as cumulative LOS within an intensive care unit, were not examined in this report but represent an important next step to further enrich counseling at the time of prenatal diagnosis.

Conclusion

In this large single-center retrospective study of patients with prenatally diagnosed SVCD, we provide a benchmark for resource utilization from fetal diagnosis through completed staged palliation. Dominant RV morphology with need for a Norwood operation is associated with substantially increased resource utilization. These findings provide important insight to the morbidity of SVCD and will greatly enhance the ability of the fetal cardiologist to provide informed and complete prenatal counseling. In addition they identify patients with right-dominant lesions and a Norwood operation as those at risk of higher morbidity, even among survivors, through all stages of surgical palliation. Future studies will explore identifying fetal predictors of resource utilization that may improve the prognostic ability of prenatal diagnosis in single-ventricle congenital heart disease.

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Disclosures

None.

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