Cardiology in the Young

cambridge.org/cty

Transthoracic intracardiac line use and complications in the paediatric single ventricle population

Nina Zook[1], Justin Kochanski[1], Shilpa Vellore Govardhan[2], John Nigro[3], Meredith Ray[4] and Pilar Anton-Martin[5]

[1]Department of Pediatric Cardiology, Stanford University, Palo Alto, CA, USA; [2]Department of Pediatric Cardiology, University of California San Diego School of Medicine, La Jolla, CA, USA; [3]Department of Surgery, University of California San Diego School of Medicine, La Jolla, CA, USA; [4]School of Public Health, The University of Memphis, Memphis, TN, USA and [5]Department of Anesthesiology and Critical Care, University of Pennsylvania Perelman School of Medicine, Philadelphia, PA, USA

Original Article

Cite this article: Zook N, Kochanski J, Vellore Govardhan S, Nigro J, Ray M, and Anton-Martin P (2025) Transthoracic intracardiac line use and complications in the paediatric single ventricle population. *Cardiology in the Young* **35**: 958–963. doi: 10.1017/S1047951125001623

Received: 20 December 2024
Revised: 3 March 2025
Accepted: 15 March 2025
First published online: 28 April 2025

Keywords:
Transthoracic intracardiac lines; single ventricle; paediatric cardiology

Corresponding author:
Nina Zook; Email: ninazook@stanford.edu

Abstract

Transthoracic intracardiac lines provide a unique access point for postoperative monitoring and management in paediatric cardiothoracic surgeries, particularly within the single ventricle population where preserving vasculature is crucial for future interventions. This retrospective review examined paediatric single ventricle patients undergoing cardiothoracic surgeries at a tertiary children's hospital between 2011 and 2018, focusing on the use of and factors associated with transthoracic line complications (infection, thrombosis, malfunction, and migration). A total of 338 lines were placed during the study period, with the majority occurring during palliative surgeries (86.5%). Lines remained in place for a median of 14 days postoperatively. Complications occurred in 21 lines (6.2%), comprising 8 migrations (2.4%), 7 thrombosis (2.1%), 4 malfunctions (1.2%), and 2 infections (0.6%). The presence of a surgical shunt was significantly associated with line complications (odds ratio 2.58, confidence interval 1.05 – 6.31; *P* 0.03). The use of transthoracic intracardiac lines seems to be safe and should be considered as a primary alternative to other central lines in the single ventricle population. A prospective assessment of transthoracic line complications, along with delineation of unit protocols, may further enhance outcomes in this complex population.

Introduction

Precise postoperative monitoring and management are essential in paediatric cardiothoracic surgery,[1] particularly for patients with single ventricle physiology, where postoperative morbidity and mortality rates remain elevated.[2] Transthoracic intracardiac lines have evolved to be common practice in postoperative care given their capacity to monitor intra-cardiac pressures, ventricular compliance, and for medication and nutrition administration.[3–6] These lines can also be advantageous for single ventricle patients, as they help preserve vascular access for future surgical palliations[7] and provide an alternative in patients for whom peripherally inserted central catheter access is not feasible.[6] Emerging literature suggests that the complication rates associated with transthoracic intracardiac lines are comparable to peripherally inserted central catheters[3,4,6,8,9]; however, the use and complications of transthoracic intracardiac lines in single ventricle patients remain understudied. This study aimed to more comprehensively characterise factors associated with transthoracic intracardiac line complications within the single ventricle population.

Materials and methods

Study cohort

We performed a retrospective cohort review of postoperative single ventricle patients undergoing cardiothoracic surgeries between January 1, 2011 and June 30, 2018 at a tertiary level paediatric cardiovascular ICU. Patients who had incomplete data were greater than 18 years of age or deemed to have biventricular physiology were excluded. Single ventricle physiology was determined by the specific anatomical lesion and/or by multidisciplinary discussion within the heart centre. This is a secondary analysis of the study by Anton-Martin et al[9] focusing exclusively on the single ventricle patient cohort and specifically refers to intra-atrial lines.

Patient demographics, cardiac anatomy, surgical data, haematological profile, line characteristics, line duration, and complications were collected from the medical records. Patient demographics included age at surgery, prematurity (< 37 weeks gestation), weight,

gender, race, whether the patient's congenital heart disease was diagnosed prenatally, clinical syndrome/association, diagnosed genetic abnormality and presence of non-cardiac anomalies. Surgeries were classified as either staged palliation operations (Blalock-Taussig-Thomas shunt, central shunt, cavo-pulmonary connections, hybrid procedures or pulmonary artery banding) or non-palliation. Operational data included cardiopulmonary bypass time, cross clamp time, deep hypothermic circulatory arrest time, and preoperative or postoperative extracorporeal membrane oxygenation use.

Transthoracic intracardiac line details included number of lumens, duration of use, and time from line removal to discharge. Complications included line infection, malfunction, migration, and thrombosis, which were confirmed by chart review of medical documentation, echocardiograms, and blood cultures. Infection was defined as clinical signs of infection with positive blood culture obtained from the line. Malfunction was defined as catheter leakage or rupture, inability to infuse or aspirate from the line unrelated to a thrombus and/or no dampened or no waveform tracing. Migration was defined as accidental extrusion of the line outside of the atrium. Thrombosis was defined as inability to aspirate or infuse through the line requiring thrombolysis and/or a line-related thrombus in the atrium on echocardiogram. Intra-atrial pressure and a patient's haematological profile (haemoglobin, platelet count, prothrombin time, international normalised ratio, partial thromboplastin time, and fibrinogen) at time of line removal were also obtained. Outcomes were length of hospital stay, duration of mechanical ventilation, failed extubation, surgery to discharge time, and survival to hospital discharge.

Line placement, management, and removal

All lines were placed at the end of the operation by the cardiothoracic surgeon. Placement technique is patient specific. For specific surgical technique, refer to the main paper by Anton-Martin et al.[9] At this institution, typically all continuous medications were moved to the transthoracic intracardiac line within the first postoperative day if the patient was haemodynamically stable; the line was then used as the primary point of central access. Line position was confirmed by chest X-ray postoperatively and echocardiogram. Other central access lines were removed within 72 hours postoperatively unless additional access was needed.

Statistical analysis

Data were presented as medians and interquartile ranges (1^{st}, 3^{rd}) for continuous variables and as a count (percentage) for categorical variables. Bivariate analyses were conducted using Chi-squared tests and Wilcoxon–Mann–Whitney tests to ascertain the association between covariates and line complications. Backward selection was employed to identify potential predictors of complications. A priori, the variables considered included age, weight, prematurity, presence of a syndrome, chromosomal abnormalities, noncardiac anomalies, type of surgery (palliation vs. shunt), and line duration, based on their clinical relevance and the limited sample size (due to the small number of complications). Only pre-specified variables that demonstrated statistical significance in the bivariate analysis were incorporated into the model selection process. Odd ratios and 95% confidence intervals were provided for the final model. *P*-values were 2 sided and a *P*-value ≤ 0.05 was considered statistically significant. Analyses were performed using SAS (version 9.4, SAS Institute Inc., North Carolina, United States of America).

Results

Patient population

During the study period, 692 patients underwent cardiothoracic surgeries and 245 of them (35.4%) had single ventricle physiology. Of the single ventricle patients, there were a total of 338 transthoracic intracardiac lines placed through various admissions and surgeries. Median age and weight were 74.5 days (8, 207) and 3.6 kg (3.1, 6.2). Of those, 143 (58.4%) were neonates and 26 (10.6%) were premature. One hundred forty-seven (60%) patients were male and majority were Caucasian (52.7%). Roughly one-third of patients had concern for a genetic syndrome. Most surgeries were palliation (84%) and 35.5% of surgeries included a shunt of some type; 72% of surgeries were completed on bypass. Median time from surgery to discharge was 16 (11, 30) days. Overall mortality was 5.7% (Table 1).

The majority of transthoracic intracardiac lines were double lumen (88.9%). Lines remained in place a median of 14 (8, 23) days and generally were removed the day of discharge. There was no significant coagulopathy or thrombocytopenia at the time of removal and intra-atrial pressures averaged at 7 mmHg (4, 10). A total of 21 (6.2%) line complications occurred. The most frequent complication was migration ($n = 8$, 2.4%) followed by thrombosis ($n = 7$, 2.1%). Four (1.2%) lines malfunctioned, and 2 (0.6%) lines became infected. There was no mortality associated with transthoracic intracardiac line complications. However, line migration necessitated emergent interventions, including pericardial drainage ($n = 1$), chest tube placement (n = 1), and blood transfusion ($n = 1$). Characteristics are summarised in Table 1.

Table 2 summarises patient and surgical characteristics, outcomes, and management of transthoracic intracardiac lines on their associations with line complications. Complications occurred more frequently in patients with shunts (57.1% vs 34.1%; *P* 0.03) and in those who needed postoperative extracorporeal membrane oxygenation (14.3% vs 3.5%; *P* 0.03). Line duration was longer in patients with complications compared to those without [20 (7, 44) vs 13 (7, 21) days; $P < 0.001$]. In patients without complications, line removal was performed closer to the time of hospital discharge [0 (0, 3) vs 8 (0, 34) days; $P < 0.0001$]. Patients who had complications generally had a longer length of stay [52 (23, 71) vs 22 (12, 40) days; $P < 0.0001$] and longer mechanical ventilation time [8 (3, 28) vs 3 (1, 12); $P < 0.01$]. Among the variables evaluated for inclusion in model development, shunt placement and line duration met criteria for further consideration. Following model selection, only shunt placement was found to be a significant predictor of line complications (odds ratio 2.58, confidence interval 1.05 – 6.31; *P* 0.03).

Discussion

This is the first study to characterise the use of transthoracic intracardiac lines and to evaluate factors associated with complications specifically in patients with single ventricle physiology; a population that necessitates meticulous lifelong care. The cohort's overall complication rate was 6.2% which is similar when compared to other transthoracic intracardiac line studies (0.6–19%)[3,4,6,8–13] and other central venous access (2.2 −31.3%).[14–18] The most common complication was migration of

https://doi.org/10.1017/S1047951125001623 Published online by Cambridge University Press

Table 1. Characteristics of single ventricle patients, transthoracic intracardiac lines, complications, and outcomes

Patient Characteristics	
Demographics	Total patients (n = 245)
Age (days)[a]	17 (7, 144)
Premature (<37 weeks)[b]	26 (10.6)
Age Group [b]	
• Neonate (<30 days)	143 (58.4)
• Infant (30 days – 1year)	59 (24.1)
• Child (>1 year)	43 (17.5)
Weight (kg)[a]	3.6 (3.1, 6.2)
Male[b]	147 (60)
Race[b]	
• Caucasian	129 (52.7)
• Hispanic	72 (29.4)
• African American	19 (7.7)
• Indigenous Peoples	15 (6.1)
• Asian	8 (3.3)
• Other	2 (0.8)
Clinical Data	Total patients (n = 245)
Prenatal cardiac diagnosis[b]	175 (71.4)
Non-cardiac anomalies[b]	66 (26.9)
Clinical syndrome/association[b]	81 (33.1)
Chromosomal abnormality[b]	18 (7.3)
Surgical Characteristics	Total Surgeries (n = 338)
Palliation surgery[b]	212 (86.5)
Shunt placement[b]	118 (48.2)
Preoperative ECMO[b]	6 (2.4)
Utilisation of CBP[b]	171 (69.8)
CBP time (minutes)[a]	139.5 (101, 192.5)
Cross clamp time (minutes)[a]	48.5 (36, 62.5)
DHCA time (minutes)[a]	7 (4, 24.5)
Postoperative ECMO[b]	14 (5.7)
Outcomes	Total Surgical Admissions (*n* = 338)
Length of hospital stay (days)[a]	25 (16, 43)
MV duration (days)[a]	4 (1, 13)
Failed extubation[b]	71 (29)
Surgery to discharge time (days)[a]	16 (11, 30)
Survival to discharge[b]	231 (94.3)
Transthoracic Intracardiac Line Characteristics	
Line Characteristics[b]	Total lines (n = 338)
Single	8 (2.4)
Double	233 (68.9)
Triple	21 (6.2)
Unknown	76 (22.5)
Management, Removal and Laboratory Data[a]	Total lines (n = 338)
Line duration (days)	14 (8, 23)
Line removal to hospital discharge time (days)	0 (0, 5)
PT at time of removal (seconds)	15.3 (13.7, 16.7)
INR at time of removal	1.3 (1.2, 1.4)
PTT at time of removal (seconds)	36.1 (29.7, 41.2)
Fibrinogen at time of removal (mg/dL)	209 (188, 305)
Platelet count at time of removal (per microL)	293 (210, 396)
Haemoglobin before removal (g/dL)	14.6 (13.5, 15.6)
Haemoglobin after removal (g/dL)	14.8 (13.5, 15.9)
Intra-atrial pressure at time of removal (mmHg)	7 (4, 10)
Line Complications[b]	Total lines (n = 338)
Infection	2 (0.6)
Malfunction	4 (1.2)
Migration	8 (2.4)
Thrombosis	7 (2.1)

[a]Median, interquartile range (1st IQR, 3rd IQR).
[b]Frequency (%).
CPB = cardiopulmonary bypass, DHCA = deep hypothermic circulatory arrest; g/dL = grams per decilitre; INR = international normalised ratio; IQR = interquartile ranges; ECMO = extracorporeal membrane oxygenation; mg/dL = milligrams per decilitre; mmHg = millimetres of mercury; MV = mechanical ventilation; PT = prothrombin time; PTT = partial thromboplastin time.

the line which was 2.4% and similar to other transthoracic line studies (1.2-5.3%).[4,8,10,11]

Surgery involving a shunt placement was associated with higher rates of line complications. Single ventricle patients with shunts typically have tenuous cardiopulmonary haemodynamics resulting in elevated rates of morbidity and mortality.[2,19–23] This may have influenced the observed findings. Furthermore, their severity of illness and associated high incidence of complications, such as necrotising enterocolitis,[24,25] often necessitate long-term vascular access, which may further influence the overall complication rates.

Sustaining peripheral access in any cardiac patient can be challenging, and certain protocols have been formed to help preserve vascular sites.[26] The single ventricle population in particular is medically fragile, often necessitating frequent admissions with the need for long-term vascular access.[27] Additionally, any procedure involving peripheral access or administration of anaesthetics poses a risk of cardiopulmonary collapse in this population.[20,28–30] Thoughtful evaluation of placement and maintenance of vascular access is thus essential to help preserve these sites for future use.[26] Utilising transthoracic lines as the primary access point following cardiac surgery in these patients may contribute significantly to achieving this endeavour.

Generally, there is a preference for patients with single ventricle physiology to sustain lower extremity peripherally inserted central catheters to preserve the upper chest vasculature from thrombosis.[7] This preservation is imperative and life sustaining for future interventions, including superior cavo-pulmonary connections, cardiac catheterizations, and the potential need for heart transplantation.[7] Furthermore, single ventricle patients are at increased risk of lymphatic complications due to factors such as inadvertent thoracic duct injury or obstruction, change in venous flow from palliative surgeries, and increased lymphatic production from elevated venous pressures.[31–33] While recent literature suggests that

https://doi.org/10.1017/S1047951125001623 Published online by Cambridge University Press

Table 2. Demographic and clinical characteristics of all transthoracic intracardiac lines with and without complications

	With Compilations (n = 21)	Without Complications (n = 317)	*P*--Value
Patient Characteristics			
Demographics			
Age (days)[a]	12 (7, 108)	80 (9, 229)	0.97
Prematurity (<37 weeks)[b]	3 (14.3)	33 (10.4)	0.30
Age Group[b]			0.28
• Neonate (<30 days)	12 (57.1)	131 (41.3)	
• Infant (30 days – 1year)	7 (33.3)	120 (37.9)	
• Child (>1 year)	2 (9.5)	66 (20.8)	
Weight (kg)[a]	3.7 (3.1, 5.6)	4.7 (3.3, 7.4)	0.84
Male[b]	11 (52.4)	189 (59.6)	0.51
Race[b]			0.55
• Caucasian	15 (71.4)	167 (52.7)	
• Hispanic	3 (14.3)	93 (29.3)	
• African American	2 (9.5)	26 (8.2)	
• Indigenous Peoples	1 (4.8)	17 (5.4)	
• Asian	0 (0)	12 (3.8)	
• Other	0 (0)	2 (0.6)	
Clinical Data[b]			
Prenatal cardiac diagnosis	4 (19)	85 (26.8)	0.58
Non-cardiac anomalies	4 (19)	91 (28.7)	0.34
Clinical syndrome/association	7 (33.3)	100 (31.5)	0.86
Chromosomal abnormality	1 (4.8)	25 (7.9)	0.55
Surgical Characteristics			
Palliation surgery [b]	20 (95.2)	264 (83.3)	0.22
Shunt placement [b]	12 (57.1)	108 (34.1)	**0.03**
Preoperative ECMO [b]	1 (4.8)	8 (2.5)	0.44
Utilisation of CBP [b]	14 (66.7)	233 (73.5)	0.68
CBP time (minutes)[a]	145 (116, 196)	131.5 (83, 188)	0.11
Cross clamp time (minutes)[a]	52 (43, 72)	48 (32, 73)	0.32
DHCA time (minutes)[a]	4 (3, 10)	9 (4, 25)	0.07
Postoperative ECMO [b]	3 (14.3)	11 (3.5)	<**0.05**
Outcomes			
Length of stay (days)[a]	52 (23, 71)	22 (12, 40)	<**0.0001**
MV duration (days)[a]	8 (3, 28)	3 (1, 12)	<**0.01**
Failed extubation [b]	9 (42.9)	94 (29.7)	0.20
Surgery to discharge (days)[a]	47 (20, 66)	14 (9, 24)	<**0.0001**
Survival to discharge [b]	19 (90.5)	303 (95.6)	0.26
Transthoracic Intracardiac Line Characteristics			
Line Characteristics [b]			
• Single lumen	1 (4.8)	7 (2.9)	0.31
• Double lumen	20 (95.2)	213 (88.4)	
• Triple lumen	0 (0)	21 (8.7)	

(*Continued*)

https://doi.org/10.1017/S1047951125001623 Published online by Cambridge University Press

Table 2. (*Continued*)

	With Compilations (n = 21)	Without Complications (n = 317)	*P*--Value
Management, Removal and Laboratory Data[a]			
Line duration (days)	20 (7, 44)	13 (7, 21)	<**0.001**
Line removal to hospital discharge (days)	8 (0, 34)	0 (0, 3)	<**0.0001**
PT at time of removal	15.8 (15.5, 16.3)	14.9 (13.7, 16.5)	0.18
INR at time of removal	1.4 (1.3, 1.4)	1.3 (1.2, 1.4)	0.44
PTT at time of removal	30.9 (26.8, 56.7)	35.8 (29.7, 40.6)	0.28
Fibrinogen at time of removal (mg/dL)	290 (219, 338)	211 (190, 305)	0.49
Platelet count at time of removal (per microL)	348 (221, 442)	308 (219, 397)	0.41
Haemoglobin before removal (g/dL)	14.2 (12.8, 16)	14.7 (13.5, 15.6)	0.68
Haemoglobin after removal (g/dL)	14.8 (14.1, 15.3)	14.7 (13.2, 15.8)	0.34
Intra-atrial pressure at time of removal (mmHg)	6 (4,10)	7 (4, 10)	0.37

[a]Median, interquartile range (1st IQR, 3rd IQR).
[b]Frequency (%).
CPB = cardiopulmonary bypass, DHCA: deep hypothermic circulatory arrest; ECMO = extracorporeal membrane oxygenation, g/dL = grams per decilitre; INR = international normalised ratio; mg/dL = milligrams per decilitre; mmHg = millimetres of mercury; MV = mechanical ventilation; PTT = partial thromboplastin time.

upper extremity peripherally inserted central catheters in patients with single ventricle physiology are associated with low rates of catheter-associated thrombosis and venous stenosis,[7] they may exacerbate the potential risk of increased lymphatic pressure and chylothorax.[34–36] The utilisation of transthoracic intracardiac lines can mitigate these risks while preserving vascular access in both the upper and lower extremities.

Our study is subject to several limitations. This cohort was derived from a single-centre and employed a retrospective design. Additionally, we were unable to adjust for severity of illness, which is likely an important confounder in our findings. Institutional practices and experience must also be considered when interpreting the applicability of these results. The specific surgical techniques for transthoracic intracardiac line placement may vary, with certain methods potentially increasing the risk of line complications such as migration and malfunction.[10] In our cohort, the technique employed a securing cuff positioned beneath the skin, which may have helped mitigate these complications.[9] Additionally, it is essential to recognise the learning curve associated with these procedures; therefore, establishment of protocols and techniques for placement, maintenance, and removal of these lines, as well as ongoing education for nursing staff, advanced practice providers, physical and occupational therapists, and physicians is crucial to ensure safe management of these lines and to minimise risk to patients.

Transthoracic intracardiac lines, particularly intra-atrial lines, represent safe alternatives to other central catheters and should be strongly considered as a primary option for long-term access in patients with single ventricle physiology in the postoperative period. Implementing multidisciplinary heart centre protocols for surgical techniques, management, and removal of these lines can contribute to reduced complication rates and, consequently, improved outcomes in this high-risk population.

Acknowledgements. None.

Financial support. The statistical work was supported by the St Jude Pediatric Research Recruitment Support Fund hosted by P.A.M. (R079700556).

Competing interests. The authors declare no conflicts of interest with respect to the authorship and/or publication of this manuscript.

Ethical standards. The authors assert that all procedures contributing to this work comply with the ethical standards of the Helsinki Declaration of 1975, as revised in 2008, and has been approved by The Institutional Review Board of Phoenix Children's Hospital.

References

1. Spenceley N, MacLaren G, Kissoon N, Macrae DJ. Monitoring in pediatric cardiac critical care: a worldwide perspective. Pediatr Crit Care Med 2011; 12 (4 Suppl): S76–S80. doi: 10.1097/PCC.0b013e3182211d66.
2. Oster ME, Knight JH, Suthar D, Amin O, Kochilas LK. Long-term outcomes in single-ventricle congenital heart disease. Circulation 2018; 138 (23): 2718–2720. doi: 10.1161/CIRCULATIONAHA.118.036821.
3. Krishnamoorthy V, Gadhinglajkar SV, Palanisamy N, Sreedhar R, Babu S, Dharan BS. Transthoracic intracardiac catheters in perioperative management of pediatric cardiac surgery patients: a single-center experience. Asian Cardiovasc Thorac Ann 2021; 29 (8): 735–742. doi: 10.1177/0218492320983492.
4. Flori HR, Johnson LD, Hanley FL, Fineman JR. Transthoracic intracardiac catheters in pediatric patients recovering from congenital heart defect surgery: associated complications and outcomes. Crit Care Med 2000; 28 (8): 2997–3001.
5. Abdullah I. Into the depths of the heart: the case for transthoracic intracardiac lines placed during cardiac surgery. J Thorac Cardiovasc Surg 2015; 149 (4): 1214. doi: 10.1016/j.jtcvs.2014.12.052.
6. Beham K, Dave H, Kelly J, Frey B, Hug MI, Brotschi B. Transthoracic intracardiac catheters in pediatric cardiac patients: a single-center experience. Pediatr Anesth 2017; 27 (9): 918–926. doi: 10.1111/pan.13204.
7. Kaipa S, Mastropietro CW, Bhai H, Lutfi R, Friedman ML, Yabrodi M. Upper body peripherally inserted central catheter in pediatric single ventricle patients. World J Cardiol 2020; 12 (10): 484–491. doi: 10.4330/wjc.v12.i10.484.
8. Gold JP, Jonas RA, Lang P, Elixson EM, Mayer JE, Castaneda AR. Transthoracic intracardiac monitoring lines in pediatric surgical patients: a ten-year experience. Ann Thorac Surg 1986; 42 (2): 185–191. doi: 10.1016/S0003-4975(10)60515-2.

9. Anton-Martin P, Zook N, Kochanski J, Ray M, Nigro JJ, Vellore S. Right atrial lines as primary access for postoperative pediatric cardiac patients. Pediatr Cardiol 2023; 44 (3): 702–713. doi: 10.1007/s00246-022-03000-0.
10. Kumar TKS, Subramanian S, Tansey JB, et al. Optimum position of transthoracic intracardiac line following cardiac surgery†. Interact CardioVasc Thorac Surg 2017; 25 (6): 883–886. doi: 10.1093/icvts/ivx204.
11. Pratap H, Millar J, Butt W, d'Udekem Y. Complications of intrathoracic lines placed during cardiac surgery. J Thorac Cardiovasc Surg 2015; 149 (4): 1212–1213. doi: 10.1016/j.jtcvs.2014.11.082.
12. Stein ML, Quinonez LG, DiNardo JA, Brown ML. Complications of transthoracic intracardiac and central venous lines in neonates undergoing cardiac surgery. Pediatr Cardiol 2019; 40 (4): 733–737. doi: 10.1007/s00246-019-02057-8.
13. Garcia X, Pye S, Tang X, Gossett J, Prodhan P, Bhutta A. Catheter-associated blood stream infections in intracardiac lines. J Pediatr Intensive Care 2017; 6 (3): 159–164. doi: 10.1055/s-0036-1596064.
14. Gonzalez R, Cassaro S. Percutaneous Central Catheter. In: StatPearls. StatPearls Publishing; 2024. Accessed September 4, 2024. http://www.ncbi.nlm.nih.gov/books/NBK459338/.
15. Patel JR, Govardhan SV, Anton-Martin P. Complications associated with peripherally inserted central catheters in paediatric cardiac patients. Cardiol Young 2023; 33 (1): 79–85. doi: 10.1017/S1047951122000300.
16. Jain A, Deshpande P, Shah P. Peripherally inserted central catheter tip position and risk of associated complications in neonates. J Perinatol 2013; 33 (4): 307–312. doi: 10.1038/jp.2012.112.
17. Tan LH, Hess B, Diaz LK, et al. Survey of the use of peripherally inserted central venous catheters in neonates with critical congenital cardiac disease. Cardiol Young 2007; 17 (2): 196–201. doi: 10.1017/S1047951107000261.
18. de Jonge RCJ, Polderman KH, Gemke RJBJ. Central venous catheter use in the pediatric patient: mechanical and infectious complications. Pediatr Crit Care Med 2005; 6 (3): 329–339. doi: 10.1097/01.PCC.0000161074.94315.0A.
19. Alsoufi B, McCracken C, Oster M, Shashidharan S, Kanter K. Genetic and extracardiac Anomalies are associated with inferior single ventricle palliation outcomes. Ann Thorac Surg 2018; 106 (4): 1204–1212. doi: 10.1016/j.athoracsur.2018.04.043.
20. Brown ML, DiNardo JA, Odegard KC. Patients with single ventricle physiology undergoing noncardiac surgery are at high risk for adverse events. Paediatr Anaesth 2015; 25 (8): 846–851. doi: 10.1111/pan.12685.
21. Oster ME, Lee KA, Honein MA, Riehle-Colarusso T, Shin M, Correa A. Temporal trends in survival among infants with critical congenital heart defects. Pediatrics 2013; 131 (5): e1502–e1508. doi: 10.1542/peds.2012-3435.
22. Spector LG, Menk JS, Knight JH, et al. Trends in long-term mortality after congenital heart surgery. J Am Coll Cardiol 2018; 71 (21): 2434–2446. doi: 10.1016/j.jacc.2018.03.491.
23. Sower CT, Romano JC, Yu S, Lowery R, Pasquali SK, Zampi JD. Early and midterm outcomes in high-risk single-ventricle patients: hybrid vs norwood palliation. Ann Thorac Surg 2019; 108 (6): 1849–1855. doi: 10.1016/j.athoracsur.2019.06.061.
24. Giannone PJ, Luce WA, Nankervis CA, Hoffman TM, Wold LE. Necrotizing enterocolitis in neonates with congenital heart disease. Life Sci 2008; 82 (7): 341–347. doi: 10.1016/j.lfs.2007.09.036.
25. Kelleher ST, McMahon CJ, James A. Necrotizing enterocolitis in children with congenital heart disease: a literature review. Pediatr Cardiol 2021; 42 (8): 1688–1699. doi: 10.1007/s00246-021-02691-1.
26. Aiyagari R, Cooper DS, Jacobs JP. Vascular access in children with congenital heart defects. Pediatrics 2020; 145 (Supplement_3): S294–S295. doi: 10.1542/peds.2019-3474N.
27. Tabtabai S, DeFaria Yeh D, Stefanescu A, Kennedy K, Yeh RW, Bhatt AB. National trends in hospitalizations for patients with single-ventricle anatomy. Am J Cardiol 2015; 116 (5): 773–778. doi: 10.1016/j.amjcard.2015.05.053.
28. Christensen RE, Gholami AS, Reynolds PI, Malviya S. Anaesthetic management and outcomes after noncardiac surgery in patients with hypoplastic left heart syndrome: a retrospective review. Eur J Anaesthesiol 2012; 29 (9): 425–430. doi: 10.1097/EJA.0b013e328355345a.
29. Gottlieb EA, Andropoulos DB. Anesthesia for the patient with congenital heart disease presenting for noncardiac surgery. Curr Opin Anaesthesiol 2013; 26 (3): 318–326. doi: 10.1097/ACO.0b013e328360c50b.
30. Leyvi G, Wasnick JD. Single-ventricle patient: pathophysiology and anesthetic management. J Cardiothor Vasc An 2010; 24 (1): 121–130. doi: 10.1053/j.jvca.2009.07.018.
31. Dori Y, Smith CL. Lymphatic disorders in patients with single ventricle heart disease. Front Pediatr 2022; 10: 828107. doi: 10.3389/fped.2022.828107.
32. Kristensen R, Kelly B, Kim E, Dori Y, Hjortdal VE. Lymphatic Abnormalities on magnetic resonance imaging in single-ventricle congenital heart defects before glenn operation. J Am Heart Assoc 2023; 12 (12): e029376. doi: 10.1161/JAHA.123.029376.
33. Chang YM, Huang SC, Chen SJ, et al. An unusual cause of chylothorax after norwood stage one reconstruction. Thorac Cardiovasc Surg 2009; 57 (2): 120–122. doi: 10.1055/s-2008-1038668.
34. Hsu HF, Chou YH, Wang CR, Wu SC. Catheter-related superior vena cava syndrome complicated by chylothorax in a premature infant. Chang Gung Med J 2003; 26 (10): 782–786.
35. Tawhai P, van den Boom J, Cama J. Chylothorax associated with a PICC line in a very low birth weight infant. J Pediatr Surg Case Rep 2022; 76: 102120. doi: 10.1016/j.epsc.2021.102120.
36. Dhande V, Kattwinkel J, Alford B. Recurrent bilateral pleural effusions secondary to superior vena cava obstruction as a complication of central venous catheterization. Pediatrics 1983; 72 (1): 109–113. doi: 10.1542/peds.72.1.109.

https://doi.org/10.1017/S1047951125001623 Published online by Cambridge University Press