Clinical parameters to predict adverse outcomes in patients with shunt-dependent physiology with a Blalock–Taussig–Thomas shunt

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ABSTRACT

In patients with shunt-dependent physiology, early risk factor identification can facilitate the prevention of adverse outcomes. This study aims to determine a scoring system to estimate the risk for adverse outcomes after Blalock–Taussig–Thomas shunt placement. Of the 39 neonates with Blalock–Taussig–Thomas shunt placement, 10 experienced the composite outcome. The resulting risk score from clinical and hemodynamic variables attributed 1 point for each of the following: central venous pressure >7.8, serum lactate >1.8 mmol/L, renal oxygen extraction ratio >32, and vasoactive-inotrope score >8.7. A score of 0 was associated with a 0% risk of the composite outcome, a score of 1 or 2 with a 15% risk, and a score of 3 or 4 with a 60% risk. A combination of increased central venous pressure, increased serum lactate, increased renal oxygen extraction ratio, and increased vasoactive-inotrope score are highly accurately associated with the risk of cardiopulmonary arrest, need for extracorporeal membrane oxygenation, or inpatient mortality after a Blalock–Taussig–Thomas shunt in patients with shunt-dependent physiology.

Keywords: Blalock–Taussig–Thomas, hemodynamics, shunt

INTRODUCTION

Shunt-dependent physiology, wherein the arterial saturation of blood in the pulmonary and systemic circulations is equal, is associated with a high risk for morbidity and mortality due to the dependence of the arterial saturation on the systemic venous saturation as well as the interdependence of flow in the pulmonary and systemic circulations.[1] Identification of risk factors associated with cardiopulmonary arrest and subsequent monitoring of these identified risk factors promotes prevention of adverse outcomes.[2-4] This study aims to determine a scoring system to estimate the risk for adverse outcomes after Blalock–Taussig–Thomas shunt placement.

Access this article online	
Quick Response Code:	**Website:** https://journals.lww.com/aopc
	DOI: 10.4103/apc.apc_135_23

MATERIALS AND METHODS

Study design

This was a single-center retrospective study including neonates (<30 days old) with shunt-dependent physiology who underwent a Blalock–Taussig–Thomas shunt placement between January 2013 and January 2022. Patients were excluded if they had alternate sources of pulmonary blood flow, as having alternate sources may confound hemodynamics.

How to cite this article: Shah SP, Loomba RS. Clinical parameters to predict adverse outcomes in patients with shunt-dependent physiology with a Blalock–Taussig–Thomas shunt. Ann Pediatr Card 2023;16:345-8.

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Submitted: 08-Sep-2023 **Revised:** 17-Nov-2023 **Accepted:** 23-Jan-2024 **Published:** 01-Apr-2024

Variables and time points of interest

The following hemodynamic variables were collected at intensive care unit admission, and 6, 12, 24, and 48 h after admission: heart rate (beats per minute), systolic and diastolic blood pressure (mmHg), central venous pressure (mmHg), respiratory rate per minute, pulse oximetry (%), and cerebral and renal near-infrared spectroscopy (%). Hemoglobin and serum lactate were collected from arterial blood gases. Vasoactive-inotrope score, a validated predictor of morbidity and mortality after cardiopulmonary bypass in infants, was also collected. The cerebral oxygen extraction ratio and renal oxygen extraction ratio were calculated from near-infrared spectroscopy and pulse oximetry data.

A composite outcome included cardiopulmonary arrest, need for extracorporeal membrane oxygen, and inpatient mortality. A smoothened average of hemodynamic and clinical variables for the first 48 h postoperatively was used to model outcomes for the entirety of the admission. This was done purposely as the first 48 h is the period, in which there is generally most hemodynamic instability.

Statistical analyses

Variables of interest were compared between the two groups using a Fisher exact text for descriptive variables and a Mann–Whitney *U*-test for continuous variables. Receiver operator curve analyses were conducted for all continuous variables. For those with an area under the curve of >0.60, an optimal cutoff point was identified using the area from the diagonal line. Based on the cutoff value, the variables were converted into a binary variable, and a score was assigned. A separate receiver operator curve analysis was conducted to determine the utility of this risk assessment tool in identifying those with the composite outcome.

RESULTS

A total of 39 patients were included in the analyses. Of these, 10 (26%) experienced the composite outcome. One patient required reintervention, had cardiac arrest, and died. Two patients required reintervention and suffered cardiac arrest. Two patients only had cardiac arrest. Five patients required reintervention only. The median shunt size was 4.0 mm. All patients included in the study had underlying pulmonary atresia as the indication for Blalock–Taussig–Thomas shunt. Additional cardiac malformations included a ventricular septal defect, heterotaxy, common atrioventricular valve, and/or total anomalous pulmonary venous return [Table 1]. Most importantly, the underlying physiology of all patients was shunt-dependent physiology, allowing for comparison of hemodynamic and clinical variables despite coexisting cardiac malformations. There was no significant difference in gender or age at surgery between patients who did or did not experience the composite outcome.

Table 1: Primary and associated cardiac lesions in the study cohort

Lesion	*n*
Pulmonary atresia/ventricular septal defect (*n*=16)	
DORV	2
DORV with L-TGA	1
DORV with DILV	1
Tricuspid atresia and LV noncompaction	1
Tricuspid atresia and L-SVC to the coronary sinus	1
Heterotaxy with right atrial isomerism and TAPVR	2
Dextrocardia, crisscross ventricles with straddling mitral valve, dysplastic tricuspid valve with L-TGA, discontinuous LPA	1
No associated lesions	7
Pulmonary atresia/intact ventricular septum (*n*=17)	
RV-dependent coronary circulation	5
Non-RV-dependent coronary circulation	8
Dysplastic tricuspid valve or tricuspid atresia without RV-dependent coronary circulation	4
Pulmonary atresia/common AV valve (*n*=5)	
L-SVC	1
Heterotaxy with left atrial isomerism and unbalanced AV canal defect	1
Heterotaxy with right atrial isomerism and TAPVR	2
DORV	1
DORV with coarctation (*n*=1)	

DORV: Double outlet right ventricle, AV: Atrioventricular, L-TGA: L-transposition of the great arteries, L-SVC: Left superior vena cava, TAPVR: Total anomalous pulmonary venous return, RV: Right ventricle, LPA: Left pulmonary artery, LV: Left ventricle

Significant differences were noted in four variables: central venous pressure, serum lactate, renal oxygen extraction ratio, and vasoactive-inotrope score [Table 2]. Receiver operator curve analyses demonstrated that central venous pressure (0.71), serum lactate (0.81), renal oxygen extraction ratio (0.69), and vasoactive-inotrope score (0.76) had the highest areas under the curve [Table 3]. Thus, the resulting risk score was as follows with 1 point being assigned for a central venous pressure >7.8, 1 point for serum lactate >1.8 mmol/L, a renal oxygen extraction ratio of >32, and a vasoactive-inotrope score of >8.7. The resulting score had an area under the curve of 0.84 with an optimal cutoff of 2.5. A score of 0 was associated with a 0% risk of the composite outcome, a score of 1 or 2 a 15% risk, and a score of 3 or 4 a 60% risk.

DISCUSSION

This study demonstrates that smoothened averages for hemodynamic and clinical values in the first 48 h after a Blalock–Taussig shunt in children with shunt-dependent physiology are associated with risk of cardiopulmonary arrest, need for extracorporeal membrane oxygenation or inpatient mortality. A combination of a central venous pressure >7.8 mmHg, serum lactate >1.8 mmol/L, a renal oxygen extraction ratio of >32, and a vasoactive-inotrope score >8.7 were associated with the increased risk.

Table 2: Comparison of average values over the course of the admission between those who did and did not experience the composite endpoint

	No composite endpoint	Composite endpoint	*P*
Age at surgery (days)	6.0 (2.0–11.0)	5.5 (1.0–14.0)	0.33
Heart rate (bpm)	159 (142–178)	164 (137–173)	0.94
Systolic blood pressure (mmHg)	81 (60–94)	67 (56–90)	0.08
Diastolic blood pressure (mmHg)	36 (26–45)	39 (31–46)	0.17
Central venous pressure (mmHg)	7 (4–11)	8 (6–13)	0.02
Hemoglobin (mg/dL)	14.0 (11.6–18.3)	13.7 (11.6–18.2)	0.82
Lactate (mmol/L)	1.5 (0.9–6.3)	2.2 (1.5–8.9)	<0.01
Pulse oximetry (%)	85 (76–95)	85 (78–95)	0.53
Cerebral oxygen extraction ratio (%)	37 (19–56)	36 (20–52)	0.71
Renal oxygen extraction ratio (%)	21 (5–46)	33 (10–62)	0.04
Vasoactive-inotrope score	5 (0–15)	10 (4–17)	<0.01

Table 3: Results of receiver operator curve analyses

	The area under the curve	Cutoff value
Serum lactate (mmol/L)	0.81	1.8
Central venous pressure (mmHg)	0.71	7.8
Renal oxygen extraction ratio (%)	0.69	32
Vasoactive-inotrope score	0.76	8.7

Only variables with an area under the curve of >0.60 are included

Previous studies have identified factors associated with cardiopulmonary arrest in critically ill children. Previous studies have demonstrated ST-segment variability, vasoactive-inotrope score, higher inadequate oxygen delivery index, venous saturation, serum lactate, cerebral dysfunction by electroencephalography, a history of a previous cardiac arrest, specific cardiac lesions, and specific cardiac surgeries among others[3-16] as risk factors for adverse outcomes. Risk factors for mortality have often mirrored the risk factors for cardiac arrest. Compared to previous studies, the current study aimed to identify postoperative hemodynamics and routine clinical variables in a more static, binary approach so that the findings can be more easily applied at the bedside.

The cardiovascular system's sole purpose is to ensure that adequate oxygen is delivered to other organs. Systemic oxygen delivery is proportional to the arteriovenous oxygen saturation difference.[17] From this, it is not surprising that renal oxygen extraction ratio and serum lactate were found to be significantly associated with adverse outcomes in the current study, as both are markers of the adequacy of systemic oxygen delivery. Vasoactive-inotrope score likely represents human action in response to the perceived inadequacy in systemic oxygen delivery. As for central venous pressure, there is systemic vasoconstriction in response to lower cardiac output, which explains how increased central venous pressure preceding cardiorespiratory arrest may be an indicator of lower cardiac output and subsequently lower systemic oxygen delivery.[18]

Furthermore, of note is that blood pressure was not found to be a predictor of adverse events. Blood pressure is the product of flow and systemic vascular resistance and thus increases in systemic vascular resistance alone can lead to increased blood pressure but not necessarily an increase in flow. This makes blood pressure a poor surrogate for cardiac output and systemic oxygen delivery.[19,20]

This study has a few limitations. The exact cutoffs for variables defined here may be variable at different institutions due to institution-specific nuances in management. However, the overall physiologic states that are more favorable should not change and it is unlikely that the absolute cutoffs are greatly different. In addition, a few patients had complex and multiple cardiac lesions, which may contribute to outcomes. However, none of the patients with heterotaxy had a composite outcome due to infection. There was one patient who underwent concomitant total anomalous pulmonary venous repair with shunt placement, however, that patient's reintervention was related to the shunt, and cardiac arrest was related to extracorporeal membrane oxygenation thrombus. The absolute frequency of the composite outcome was also relatively low which does limit the effect size that could be detected. Nonetheless, statistically significant differences were identified.

CONCLUSIONS

A combination of increased central venous pressure, increased serum lactate, increased renal oxygen extraction ratio, and increased vasoactive-inotrope score are highly accurately associated with the risk of cardiopulmonary arrest, need for extracorporeal membrane oxygenation, or inpatient mortality after a Blalock–Taussig–Thomas shunt in patients with shunt-dependent physiology.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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