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Development of a Cardiac Anesthesia Tool (CAT) to Predict Intensive Care Unit (ICU) Admission for Pediatric Cardiac Patients Undergoing Non-cardiac Surgery: A Retrospective Cohort Study

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Abstract

Background and aim: **of the work: Pediatric cardiac patients often undergo non-cardiac surgical procedures and many of these patients would require intensive care unit admission, but can we predict the need for ICU admission in pediatric cardiac patients undergoing non-cardiac procedures. Numerous preoperative and intraoperative variables were strongly associated with ICU admission. Given the variations in the underlying cardiac physiology and the diversity of non-cardiac surgical procedures along with the scarce predictive clinical tools, we aimed to develop a simple and practical tool to predict the need for ICU admission in pediatric cardiac patients undergoing non-cardiac procedures.**

Material and methods: **This is a retrospective study, where all files of pediatric cardiac patients who underwent non-cardiac surgical procedures from January 1, 2015, to December 31, 2019, were reviewed. We retrieved details of the preoperative and intraoperative variables including age, weight, comorbid conditions, and underlying cardiac physiology. The primary outcome was the need for ICU admission. We performed multiple logistic regression analyses and analyses of the area under receiver operating characteristics (ROC) curves to develop a predictive tool.**

Results: **In total, 519 patients were included. The mean age and weight were 4.6 ± 3.4 year and 16 ± 13 Kg respectively. A small proportion (n = 90, 17%) required ICU admission. Statistically, there was strong association between each of American society of anesthesiologist's physical status (ASA-PS) class III and IV, difficult intubation, operative time more than 2 hours, requirement of transfusion and the failure of a deliberately planned extubation and ICU admission. Additional analysis was done to develop a Cardiac Anesthesia Tool (CAT) based on the weight of each variable derived from the regression coefficient. The CAT list is composed of the ASA-PS, operative time, and requirement of transfusion, difficult intubation and the failure of deliberately planned extubation. The minimum score is zero and the maximum is eight. The probability of ICU admission is proportional to the score.**

Conclusion: **CAT is a practical and simple clinical tool to predict the need for ICU admission based on simple additive score. We propose using this tool for pediatric cardiac patients undergoing non-cardiac procedure.**

Keywords: ICU admission Predictors, Non-cardiac procedures, Pediatric anesthesia, Pediatric cardiac patients, Predictive clinical tools

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Key points

Question: Can we predict the need for ICU admission in pediatric cardiac patients undergoing non-cardiac procedures?
Findings: Numerous preoperative and intra-operative variables were strongly associated with ICU admission.
Meaning: The development of a Cardiac Anesthesia Tool (CAT), a practical, valuable, and sensitive clinical tool that inform clinical decision-making.

Glossary

ASA-PS	American Society of anesthesiologists' physical status
CAT	Cardiac Anesthesia Tool
COMPL	complications
CHD	congenital heart disease
ICU	Intensive Care Unit
INO	Inotrope
LVOTO	Left Ventricular Outflow Tract Obstruction
M&M	Morbidity and Mortality
NMD	neuromuscular disease
OSA	Obstructive Sleep Apnea
PHT	Pulmonary Hypertension
RVOTO	Right Ventricular Outflow Tract Obstruction
RBC	Packed Red Blood Cells
SVP	Single Ventricle Physiology
VFUNC	Ventricular Function

1. Introduction

The presence of congenital heart disease increases morbidity and mortality (M&M)of children undergoing non cardiac surgery. Consequently, anesthesiologists are inquiring and focusing on the perioperative care of children with CHD who will have an anesthetic for non-cardiac surgical and diagnostic procedures. Predicting the risk associated with a non-cardiac intervention under anesthesia is an area of debate and conflict among the care providers [1]. Despite the increased risk for children with CHD undergoing non-cardiac surgery, there is no clear method to identify that risk in the preoperative period. A system that integrates these risks can produce a severity scoring system that identifies patients with higher risk, and allow for better preparation and improved outcome for these patients [2]. The methods available for predicting risks in children with CHD, such as the Risk Adjustment for Congenital Heart Surgery Score (RACHS-1), the Aristotle Basic Complexity score (ABC score), and the Society of Thoracic Surgeons and the European Association for Cardiothoracic Surgery Mortality score (STS-EACTS score) are limited to children undergoing only cardiac surgery [3].

Developing such a score can help the anesthesiologist to predict the need for post-operative ICU admission which will help in decision making and assures safe performance of the procedure whether in tertiary care center or as an outpatient in a day surgery center.

Having an ICU predictor score may limit unnecessary preoperative cardiology consultation prior to elective procedures and will save the resources by limiting unjustified postoperative ICU admission [4].

Risk stratification is crucial for daily clinical decision-making. Numerous preoperative and intra-operative variables were strongly associated with ICU admission. Given the variations in the underlying cardiac physiology and the diversity of non-cardiac surgical procedures along with the scarce predictive clinical tools, and due to the lack of an evidence-based clinical tool to support the decision, we aimed to develop a practical tool to predict the need for ICU admission in cardiac patients undergoing non-cardiac procedures.

2. Material and methods

2.1. Study population

After approval from the Institutional Research Board, we reviewed all files of pediatric cardiac patients who underwent non-cardiac surgical procedures in King Abdulaziz Medical City in Riyadh, Saudi Arabia from January 1, 2015 to December 31, 2019.

Patients undergoing cardiac catheterization procedure or patients who were intubated and were admitted to ICU preoperatively were excluded. The primary outcome was the need for ICU admission following the non-cardiac procedure. As the aim of this study was to develop a simple and easy to use clinical tool, the operative time was dichotomized based on the best cutoff value for maximum sensitivity and specificity in predicting ICU admission.

2.2. Sample size

519 patients.

2.3. Statistical analysis

Continuous data are presented as mean and standard deviation and the categorical data as proportions. Univariable analysis was performed for individual variables using t-test for continous variables and chi square test for categorial variables.P-value of less than 0.05 was used as a significant value. Statistically significant variables ($p < 0.05$) were entered in a multivariable logistic regression model. Additional variable selection was based on the statistical significance using various selection techniques, including stepwise, forward and backward methods. The final model was tested for fit using Hosmer–Lemeshow (H-L) goodness of fit statistics and the predictive ability of the model was assessed using c-statistics. Analysis was performed with the area under ROC curve to optimize the predictive tool. The statistical software system SAS, version 9.4, Cary, USA was used for all statistical analysis.

3. Results

The study cohort consisted of 519 patients who underwent non-cardiac procedures. In total, 90 patients (17%) required ICU admission. The mean age and weight were 4.6 ± 3.4 years, 16 ± 13 kg respectively. The general characteristics of these patients are summarized in (Table 1).

Table 1. The general characteristics of the study cohort.

Variable	Number (Proportion)
The Whole number of the study cohort	519
Demographic data	
Age (year)	4.6 ± 3.4
Weight (kg)	16 ± 13
Sex	
Male	255 (49%)
Female	264 (51%)
ASA-PS	
I and II	203 (39%)
III and IV	316 (61%)
Anesthesia provider	
Specialist in cardiac anesthesia	101 (19%)
Specialist in pediatric anesthesia	418 (81%)
Anesthesia type	
General	486 (94%)
General + Caudal	33 (6%)
Operative time more than 2 hours	183 (35%)
Comorbidities	
Single ventricle physiology	42 (8%)
Pulmonary hypertension	24 (5%)
Left ventricular outflow tract obstruction	17 (3%)
Right ventricular outflow tract obstruction	17 (3%)
Presence of preoperative tracheostomy	10 (2%)
Presence of preoperative history of seizures	25 (5%)
Presence of preoperative history of stroke	8 (2%)
Presence of preoperative history of neuromuscular disease	40 (8%)
Presence of preoperative renal disease	50 (10%)
Intraoperative complications	7 (1%)
ECHO	
Normal Ventricular function	469 (90%)
Abnormal Ventricular function	50 (10%)
Complications	
Need for intraoperative blood transfusion	25 (5%)
Difficult intubation	50 (10%)
Failure of deliberately planned OR extubation	59 (11%)
Need for intraoperative inotropic support or vasopressor	2 (0.4%)
Need for ICU admission	90 (17%)

3.1. Comparison based on admission to ICU

The Univariable comparison between the group who required ICU admission and the non-ICU admission group indicated statistical significance for the following variables age, weight, sex, ASA-PS, difficult intubation, need for intraoperative blood transfusion, need for intraoperative inotropic support or vasopressor, Extubation failure which is defined as failure of deliberately planned extubation inside OR, tracheostomy, renal disease, single ventricle physiology, anesthesia subspecialty and operative time more than 2 hours (Table 2).

3.2. Multivariable analysis

The significant variables were entered into a multiple logistic regression model (all variable analysis) and the resultant significant variables were confirmed by selection techniques, including forward, backward and stepwise. The final model included five variables and had excellent predictive statistics ($c = 0.92$) and Hosmer–Lemeshow goodness of fit of 0.7 (Table 3).

3.3. Scoring system development and validation

The scoring system was developed based on the regression coefficients. It was simplified by rounding to the next integer. The relative weight of each variable was assigned as follows: ASA-PS = 1, Operative time more than 2 hours = 1, Need for intraoperative blood transfusion = 1, difficult intubation = 2 and failure of deliberately planned OR extubation = 3. The minimum score is zero and the maximum eight. The logistic model with the

Table 2. Univariable comparison based on reintervention.

Variable	No ICU (N = 429)	ICU (N = 90)	p-Value
Age (year)	4.9 ± 3.2	2.8 ± 3.6	<0.001
Weight (kg)	17.2 ± 12.3	12.6 ± 16.7	<0.001
Male	220 (51%)	35 (39%)	0.03
ASA-PS	233 (54%)	83 (92%)	<0.001
Pediatric Anesthetist	369 (86%)	49 (54%)	<0.001
Anesthesia Type	31 (7%)	2 (2%)	0.08
Operative time more than 2 hours	120 (28%)	63 (70%)	<0.001
Comorbidities			
Single ventricle physiology	26 (6%)	16 (18%)	<0.001
Pulmonary hypertension	18 (4%)	6 (7%)	0.3
Left ventricular outflow tract obstruction	26 (6%)	3 (3%)	0.3
Right ventricular outflow tract obstruction	13 (3%)	4 (4%)	0.5
Presence of preoperative tracheostomy	4 (1%)	6 (7%)	<0.001
Presence of preoperative history of seizures	22 (5%)	3 (3%)	0.5
Presence of preoperative history of stroke	5 (1%)	3 (3%)	0.1
Presence of preoperative history of neuromuscular disease	31 (7%)	9 (10%)	0.4
Presence of preoperative renal disease	34 (8%)	16 (18%)	0.004
Intraoperative complications	6 (1.4%)	1 (1%)	0.8
ECHO			
Ventricular function	38 (9%)	12 (13%)	0.2
Complications			
Need for intraoperative blood transfusion	11 (3%)	14 (16%)	<0.001
Difficult intubation	4 (1%)	12 (13%)	<0.001
Failure of deliberately planned OR extubation	5 (1%)	54 (60%)	<0.001
Need for intraoperative inotropic support or vasopressor	0 (0%)	2 (2%)	0.002

ASA-PS American Society of Anesthesiologists physical status.
The data are expressed as Mean ± Standard Deviation (SD) and as numbers (%). $P < 0.05$ = non-significant difference. $P > 0.001$ = significant difference.

total score as the predictor of ICU admission performed excellent with c = 0.921 and HL goodness of fit = 0.51. The scoring system performance was tested graphically against the observed probability. The observed and expected probabilities were matching, Fig. 1.

3.4. Final scoring system and interpretation

The Cardiac Anesthesia Tool (CAT) is displayed in (Table 4).

4. Discussion

In our study, we were able to identify five variables that had excellent predictive statistics for ICU admission in children with CHD undergoing noncardiac surgery: ASA-PS, Operative time more than 2 hours, intraoperative blood transfusion, difficult intubation and failure of deliberately planned OR extubation. Based on these 5 variables scoring system was developed The relative weight of each variable was assigned as follows: ASA-PS = 1, Operative time more than 2 hours = 1, Need for intraoperative blood transfusion = 1, difficult intubation = 2 and failure of deliberately planned OR extubation = 3. The minimum score is zero and the maximum eight. In addition, other variables had statistical significance included age, weight, ASA-PS, need for intraoperative inotropic support or vasopressor, tracheostomy, renal disease, and single ventricle physiology were excellent predictors of ICU admission. SVP children appear to be at increased risk of ICU admission while children with other CHD disease classified as severe were not correlated with the incidence of ICU admission.

The presence of CHD is associated with an increased risk of anesthesia and surgery in children.

Table 3. Details of the final statistical model.

Variable	Odds Ratio	Lower 95% confidence limit	Upper 95% confidence limit	p-value
ASA-PS	4.700	1.812	12.191	<0.0001
Operative time more than 2 hours	4.837	2.292	10.207	0.0015
Difficult intubation	19.152	3.582	102.407	<0.0001
Need for intraoperative blood transfusion	3.560	1.102	11.500	0.0006
Failure of deliberately planned OR extubation	91.682	31.321	268.364	0.0338

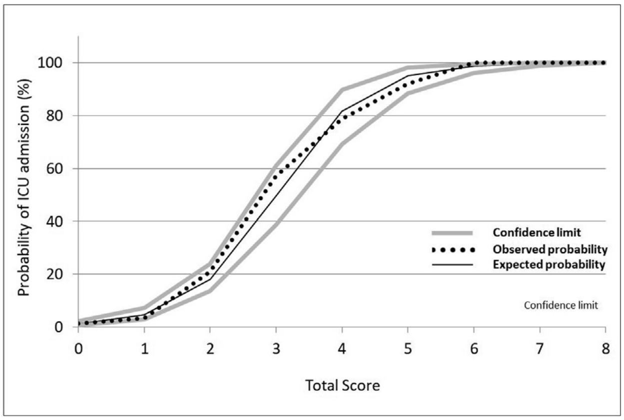

Fig. 1. Observed and predicted probabilities.

Table 4. CAT scoring system.

Variable	Weight
ASA-PS > 2	1
Operative time more than 2 hours	1
Need for intraoperative blood transfusion	1
Difficult intubation	2
Failure of deliberately planned OR extubation	3
Clinical Interpretation:	**Exact Predicted probabilities**
0–1: Low Risk	0–>1%
2: Moderate Risk	1–>5%
3–4: High Risk	2–>18%
4–8: Certain	3–>50%
	4–>82%
	5–>95%
	6–>99%
	7–>100%
	8–>100%
	$P = \frac{e^{-4.5082+(1.5007x\ Total\ Score)}}{1+e^{-4.5082+(1.5007x\ Total\ Score)}}$

Although there are guidelines for the perioperative management in these children, they are based on expert opinion without strong evidence [5,6]. The diversity of malformations, each with specific physiological, hemodynamic consequences, and severity, makes perioperative management challenging [7].

Children with significant CHD undergoing non-cardiac surgery have an increased risk of mortality and morbidity [8]. Carmosino and his colleagues reviewed the perioperative complications in children with pulmonary hypertension undergoing non-cardiac surgery and reported significant complications, including cardiac arrest in 4.5% [9]. Patients with a residual lesion require an individualized approach to anesthesia and surgical care [10]. Pediatric patients with severe CHD have a higher mortality rate, with a significantly higher rate of ICU admission postoperatively. Developing a tool to predict postoperative ICU admission will support the clinician to define the at-risk population, improve the use of resources, reduce unnecessary ICU admission, and decrease the length of hospital stay (LOS) [8]. Faraoni and his group identified eight predictors of mortality in children with CHD, including emergency procedures, severe CHD, single ventricle physiology, previous surgery within 30 days, inotropic support, preoperative CPR, acute or chronic kidney injury and mechanical ventilation [11]. In 2019, Nasr and her colleagues categorized surgical procedures in four groups of surgical risk, based on the 30-day mortality of 659 procedures. They developed a risk stratification model that included five variables, body weight, ASA-PS classification, preoperative sepsis, inotropic support, and preoperative ventilator dependence, all within 24 hours before surgery [12].

The ASA-PS classification is one of our variables with excellent predictivity. The ASA-PS score was a statistically independent predictor of postoperative outcome. Physiologically well-compensated patients, referred from the outpatient setting, would be expected to have a lower risk for elective general surgery procedures [13]. The study by Nasr and her colleagues demonstrated that there is wide variability in the objectively obtained PRAm score (Pediatric risk assessment) [12]. A difficult intubation is another important predictor for ICU admission after non-cardiac procedures for CHD patients. Patients known to be difficult to intubate or suspected to be difficult to intubate or accidently have been difficult to intubate may require postoperative ICU admission. A multicenter study with 1018 children with difficult airways in 13 pediatric centers, demonstrated that more than two direct laryngoscopy attempts with a difficult tracheal intubation, are associated with a high failure rate of extubation and an increased incidence of severe complications [14]. Intraoperative blood loss and the need for blood transfusion is another predictor of ICU admission identified in the current study. Preoperative transfusion was one of the predictors of mortality after non-cardiac surgery in children with congenital heart disease [11]. RBC transfusion can be lifesaving, however emerging safety concerns suggests that morbidity and mortality may be increased in patients who receive blood transfusions [15]. Redlin and his colleagues analyzed the effect of transfusion on the length of mechanical ventilation and ICU stay in pediatric cardiac surgery, and the duration was significantly lower in the group with no transfusion [16]. Redlin Analyzed the effects of blood transfusion on the postoperative morbidity in a large group of infants treated with a comprehensive blood-sparing approach intraoperatively. The results appear to support our results that transfusion is associated with complications, an increased duration of ventilation and ICU stay and is a predictor of ICU admission [17].

There is no uniform definition of the severity of surgery in current studies. Considering the impact of surgery (type and complexity) on outcomes, some clinicians graded surgical severity according to their own criteria [18]. In this study, we classified the intrinsic severity of surgeries in low and high risk. We considered a procedure exceeding 2 hours at a higher level of risk and we determined that, in this population, patients with CHD undergoing a non-cardiac procedure exceeding 2 hours are at higher risk for ICU admission postoperatively.

Extubation failure is associated with a prolonged length of stay of pediatric ICU patients with CHD [19,20]. Failure of a deliberately planned extubation at the end of the procedure was a significant predictor of ICU admission. The etiology was multi-factorial, including all causes of airway obstruction, such as laryngospasm, upper airway edema, bleeding causing a hematoma compressing the airway externally or clots internally obstructing the airway, accumulation of respiratory secretions, tracheal collapse due to tracheomalacia, or upper airway soft tissue collapse secondary to the effects of anesthetics, opioids, and muscle relaxants. These mechanisms resulting in extubation failure are frequently described as extubation-related airway complications or airway-related adverse events at extubation [21−23].

At-risk extubation is a situation where the ability of a patient to maintain airway patency or oxygenation after tracheal extubation is uncertain. This definition was recently proposed. It follows a risk stratification process, based on airway-related factors and general clinical conditions. A potentially difficult reintubation or general risk factors such as “full stomach, unstable cardiovascular physiology, acid-base derangement, or temperature control” characterize this condition [23]. Conditions such as obesity, OSA [21,24−26], major head or neck and upper airway surgery [21,27,28], and cervical spine procedures [29−33] significantly increase the risk of extubation failure and are frequently associated with difficult airway management [21,24−29]. Populations at a particularly high risk of respiratory depression and upper airway collapse after anesthesia and the administration of opioids, are obese/OSA patients and patients who had oral and maxillofacial surgery. Although no comparable guidelines are available for children with CHD, undergoing non-cardiac surgery, our results and literature support the creation of such networks [30−36].

5. The limitations of the study

Although this study included large sample size over a long period, there are inherent biases in the retrospective design: our analysis is based on only a small proportion (n = 90, 17%) which required ICU admission, the wide spectrum of the patient population and the numerous clinical factors that interact, which includes the discretion of healthcare professional and personal biases. However, we postulate that the CAT scoring system is a practical, valuable, and sensitive clinical tool to inform clinical decision-making.

6. Conclusion

Children with major CHD who undergo non-cardiac surgery have an increased need of post-operative ICU admission, with a higher incidence of life-threatening post-operative outcomes, compared to children without CHD. The CAT is an easy and practical tool to support the clinician to identify patients with a high probability for ICU admission after non-cardiac surgery. Such an evidence-based decision will decrease unnecessary admissions, ensuring the best use of resources, improving the outcome, and decreasing the LOS. We propose to use the CAT to guide clinical decision-making.

Author contribution

Conception and design of Study; A.M.A. Metwally, A.H.M. Mahmoud, A.A. Alghamdi. Literature review; A.M.A. Metwally, A.H.M. Mahmoud, A.A. Alghamdi. Acquisition of data; A.M.A. Metwally, A.H.M. Mahmoud, A.A. Alwakeel, A.M. Aljamous, R.S. Aldusari, F. Hijji, F.A. Al Tuwaijri, S.E.M. Hassan, M. Ebid, A.A. Alghamdi. Analysis and interpretation of data; A.A. Alghamdi. Research investigation and analysis; A.M.A. Metwally, A.H.M. Mahmoud, A.A. Alwakeel, A.M. Aljamous, R.S. Aldusari, F. Hijji, F.A. Al Tuwaijri, S.E.M. Hassan, M. Ebid, A.A. Alghamdi. Data collection; A.M.A. Metwally, A.H.M. Mahmoud, A.A. Alwakeel, A.M. Aljamous, R.S. Aldusari, F. Hijji, F.A. Al Tuwaijri, S.E.M. Hassan, M. Ebid. Drafting of manuscript; A.M.A. Metwally, A.H.M. Mahmoud, A.A. Alwakeel, A.M. Aljamous, R.S. Aldusari, F. Hijji, F.A. Al Tuwaijri, S.E.M. Hassan, M. Ebid, A.A. Alghamdi. Revising and editing the manuscript critically for important intellectual contents; A.M.A. Metwally, A.H.M. Mahmoud, A.A. Alghamdi. Data preparation and presentation; A.M.A. Metwally, A.H.M. Mahmoud, A.A. Alghamdi. Research coordination and management; A.M.A. Metwally, A.H.M. Mahmoud.

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None.

Conflict of interest

None to declare.

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