



The Use of Near-Infrared Spectroscopy During an Extubation Readiness Trial as a Predictor of Extubation Outcome

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Objectives: To determine whether the measurement of cerebral and somatic regional oxygen saturation during an extubation readiness trial predicts extubation failure in postoperative cardiac patients.

Design: Prospective observational study.

Setting: Tertiary care center cardiac ICU.

Patients: Pediatric patients 1 day to 21 years old following cardiac surgery for congenital heart disease. Patients were included if they were intubated for greater than 12 hours and were undergoing an extubation readiness trial.

Interventions: None.

Measurements and Main Results: Data collection included patient demographic, procedural, laboratory, and physiologic variables. Regional oxygen saturation values were recorded using near-infrared spectroscopy at baseline, during a 2-hour extubation readiness trial, and in the first 2 hours postextubation. Ninety-nine extubation readiness trials were conducted in 79 patients. Adjusting for baseline somatic regional oxygen saturation, logistic regression analysis demonstrated that patients with a decline in their minimum somatic regional oxygen saturation of at least 10% during an extubation readiness trial had a 6-time increased odds of extubation failure ($p = 0.02$; 95% CI, 1.26–29.8). Receiver-operating characteristic curve analysis demonstrated that a 12% decline in the minimum regional oxy-

gen saturation best predicted extubation failure with 54% sensitivity and 82% specificity.

Conclusions: A 12% decline in somatic regional oxygen saturation during an extubation readiness trial is associated with an increased risk of extubation failure following a successful extubation readiness trial. The addition of somatic regional oxygen saturation measurements to an extubation readiness trial may improve our ability to predict extubation outcome. (*Pediatr Crit Care Med* 2013; 14:587–592)

Key Words: airway extubation; cardiac surgical procedures; congenital cardiac defects; near-infrared spectroscopy; pediatric intensive care unit; ventilator weaning

Failed extubation occurs in 10% to 19% of pediatric patients following cardiac surgery (1). The most common etiologies of extubation failure are cardiac dysfunction, airway edema, unresolved lung disease, and decreased respiratory drive (1). Adverse consequences associated with extubation failure include the need for emergent reintubation, prolongation of mechanical ventilation, increased ICU and hospital lengths of stay, and a five-fold increased risk of death (2, 3). A reliable tool to predict extubation success in children is necessary to avoid the adverse consequences of extubation failure.

Indices such as the Rapid Shallow Breathing Index and Compliance, Resistance, Oxygenation, Pressure Index have been used successfully in adult patients to predict extubation readiness but have not performed as reliably in pediatric populations (3–5). Extubation readiness trials (ERTs) are formal trials of spontaneous breathing with predefined criteria for success or failure. In the mechanically ventilated patient, an ERT may be performed using continuous positive airway pressure, pressure support with positive end-expiratory pressure, or by T-piece. Although ERTs are commonly used, evidence that they improve the prediction of extubation outcome is lacking and 8–14% of pediatric patients who have passed an ERT require reintubation (3). The limitations of an ERT may relate to an emphasis on respiratory parameters and only an indirect assessment of cardiac output.

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In children with cardiac disease, the increased afterload and increased metabolic demand of extubation and the transition to negative pressure breathing frequently result in extubation failure. Cardiac dysfunction has been found to be the etiology of extubation failure in 27–65% of children with congenital heart disease (1, 6). In addition, vasoactive medication dependence is associated with extubation failure (7) and children who fail extubation frequently require increased vasoactive support and develop metabolic acidosis (6). Accurate prediction of extubation success requires assessment of not only respiratory function but also cardiac performance.

Near-infrared spectroscopy (NIRS) is a noninvasive technique used to continuously measure regional oxygen saturation ($r\text{SO}_2$). NIRS monitoring was initially used in the operating room to assess decline in cerebral blood flow during cardiopulmonary bypass (8). Its use has since been extended to the critical care unit in patients at risk for multiple organ dysfunction or death. $r\text{SO}_2$ as assessed by NIRS has been shown to correlate with other measures of oxygen balance including central venous saturation (9–11) and serum lactate level (12, 13). A recent review of literature suggests that NIRS is effective as a monitor of cardiac output in critically ill children (14). We hypothesize that a decline in either somatic or cerebral $r\text{SO}_2$ during a preextubation pressure support breathing trial will be predictive of extubation failure.

MATERIALS AND METHODS

Patients

We performed a prospective observational study identifying all postoperative cardiac surgery patients younger than or equal to 21 years admitted to the Children's National Medical Center Cardiac Intensive Care Unit between September 29, 2010, and April 24, 2011. Patients were included if they were postoperative cardiac surgical patients, were intubated for greater than 12 hours, and were undergoing an ERT. Patients were studied with a waiver of documentation of informed consent, as no intervention was performed and all data were stripped of identifiers that might compromise patient confidentiality. The Institutional Review Board of Children's National Medical Center approved this study.

Regional Oxygen Saturation Monitoring

An INVOS 5100c cerebral/somatic oximeter (Somanetics, Troy, MI) was used to assess $r\text{SO}_2$. Cerebral and somatic sites were monitored with a sensor placed on the forehead and flank at the level of the T12 to L2 vertebrae, respectively. $r\text{SO}_2$ values were continuously collected and stored in the monitors every 30 seconds. $r\text{SO}_2$ data were obtained 2 hours before an ERT, during an ERT, and 2 hours after extubation. The mean and minimum saturations were determined from each time period and used for analysis.

Data Collection

Review of the electronic health record was conducted to collect demographic and clinical data. Baseline data collection

included age, gender, diagnoses, surgical procedure(s), days of mechanical ventilation, vasoactive medications, arterial blood gas values, and vital signs. During the ERT, heart rate and respiratory rate were recorded 1 hour in the ERT and an arterial blood gas was collected at the completion of the 2-hour breathing trial. A postextubation arterial blood gas was obtained on each patient per routine practice. Patients were monitored for 48 hours postextubation for extubation failure, defined as a need for reintubation or initiation of noninvasive respiratory support including bilevel positive airway pressure or high-flow nasal cannula with a flow rate of greater than 10 L/min.

Extubation Readiness Trial

Our institution used a standard ERT during the study period. A 2-hour spontaneous breathing trial was conducted on all intubated patients prior to extubation. During the trial, the mechanical ventilator settings were reduced to positive end-expiratory pressure with pressure support for spontaneous respirations. The pressure support provided was dependent on the size of the endotracheal tube of the patient. Current practice includes a pressure support of 10 cm H_2O for 3.0–3.5 mm tubes, a pressure support of 8 cm H_2O for 4.0–4.5 mm tubes and a pressure support of 6 cm H_2O for 5.0 mm or larger tubes. The ERT was initiated when the inspired oxygen content was less than or equal to 50% and the positive end-expiratory pressure was less than or equal to 5 cm H_2O . The trial was considered successful when patients maintained their baseline oxygen saturation, had inspired tidal volumes of 5 mL/kg or greater, and maintained a respiratory rate within 20 breaths/min of their baseline respiratory rate for the 2-hour duration of the trial. In addition, patients were required to maintain their baseline arterial oxygenation and ventilation as measured by arterial blood gas post-ERT. An ERT was considered a failure for clinical signs of respiratory distress (retractions, nasal flaring), increased respiratory rate of greater than 20 breaths/min above baseline, inadequate inspired tidal volumes, inability to maintain oxygen saturation or arterial oxygen tension on less than 50% inspired oxygen, or hypercarbia (> 65 mm Hg) on arterial blood gas monitoring.

Endpoints

Patients were extubated after having successfully completed an ERT. However, clinicians had the option of overriding the decision to extubate after successful ERTs. Successful ERTs that did not result in extubation were excluded from this analysis ($n = 2$). Postextubation, patients were monitored for 48 hours for a need for reintubation or initiation of noninvasive respiratory support. For all extubation failures, clinicians were required to complete a questionnaire detailing their assessment of the etiology of the failure.

Data Analysis

Contingency table analyses were used to describe participants overall and to compare those who were and were not successfully extubated. Multiple logistic regression analysis was used

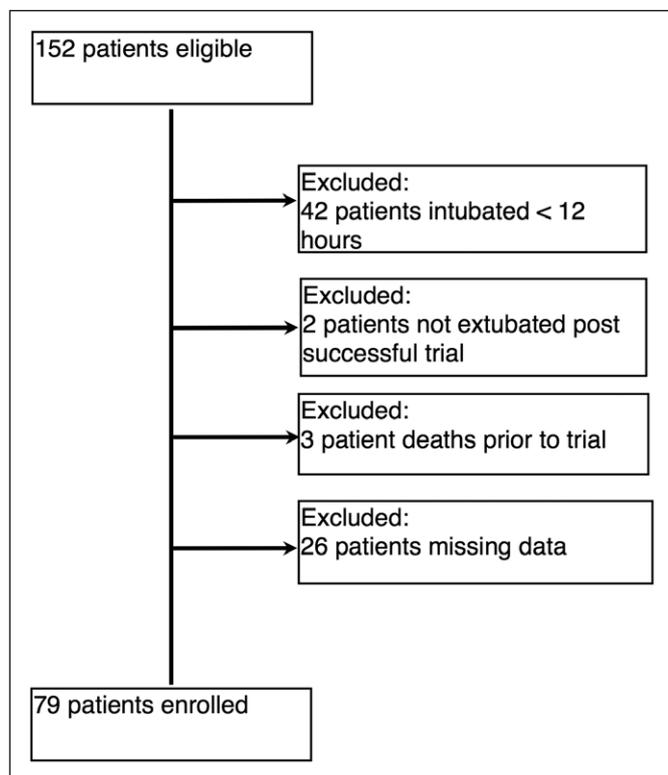


Figure 1. Study participants and reasons for exclusion.

to relate NIRS monitoring results to the odds of extubation failure while controlling for pretrial (baseline) $r\text{SO}_2$. Receiver-operating characteristic analyses were used to evaluate NIRS performance overall and in terms of sensitivity and specificity for predicting extubation failure across a range of cut-points.

RESULTS

One hundred fifty-two patients were admitted to the cardiac ICU after cardiac surgery. Seventy-three patients were excluded because of extubation within 12 hours of admission ($n = 42$), missing NIRS data ($n = 26$), death before ERT ($n = 3$), and no extubation after successful ERT ($n = 2$; **Fig. 1**). Seventy-nine patients were included in the study. Patient characteristics are listed in **Table 1**. The median age of patients

was 3.5 months (interquartile range 1–10 mo). There were 38 women and 44 men (46 and 53%, respectively). Trisomy 21 was present in 10 patients (12%). Thirty-four patients (43%) were intubated for greater than 48 hours. Twenty patients (25%) had univentricular congenital heart disease. There were no demographic differences among those who were successfully extubated and those who were not successfully extubated (**Table 1**). Performed cardiac procedures are listed in **Table 2**. Cardiopulmonary bypass was used in 66 patients (83%). There were no differences in cardiac diagnoses or surgical procedures between the two groups ($p = 0.93$).

Ninety-nine ERTs were conducted in 79 patients, of which 11 were failures. The etiologies of the ERT failures are shown in **Table 3**. Of the 11 ERT failures, two failures were attributed to respiratory acidosis, with carbon dioxide levels of greater than 65 mmHg. Two patients were not extubated after a successful ERT, and neither had a significant drop from baseline in somatic or cerebral NIRS. Eighty-six extubations occurred following successful ERTs. Failed extubation occurred in 13 patients (15%) who passed an ERT. Eleven of 13 failures occurred less than 12 hours after extubation. One failure occurred 12–24 hours following extubation and one failure occurred 24–48 hours following extubation. Etiologies of extubation failure are displayed in **Table 4**. Arterial carbon dioxide levels rose less than 10 mmHg during the 2-hour ERT in 11 of 13 patients and remained less than or equal to 60 mmHg in 12 of 13 patients.

Adjusting for baseline somatic $r\text{SO}_2$, logistic regression analysis demonstrated that in patients who passed an ERT, a decline in their minimum somatic $r\text{SO}_2$ of at least 10% during the ERT was associated with a six-fold increased odds of extubation failure ($p = 0.02$; 95% CI, 1.26–29.8). **Table 5** details the results of logistic regression analysis. **Figure 2** displays the probability of extubation failure stratified by decline in minimum somatic $r\text{SO}_2$. Receiver-operating characteristic curve analysis (**Fig. 3**) demonstrated that a 12% decline in the minimum $r\text{SO}_2$ best predicted extubation failure. A 12% decline in minimum somatic $r\text{SO}_2$ was associated with 54% sensitivity and 82% specificity for extubation failure (area under the curve, 66%; 95% CI, 50.0–82.0%). No significant associations were found between decline in cerebral $r\text{SO}_2$ and extubation outcome ($p = 0.3$).

TABLE 1. Characteristics of Patients Undergoing Extubation Readiness Trials Following Cardiac Surgery

Characteristic	Extubation Success No. (%) ($n = 68$)	Extubation Failure No. (%) ($n = 11$)	p
Age (mo)	3.5 (IQR 1–9)	2.5 (IQR 0.5–22)	0.82
Male sex	36 (53)	7 (64)	0.75
Prematurity (< 36 gestational age)	1 (1)	1 (9)	0.26
Intubated > 48 hr	28 (41)	6 (55)	0.41
Trisomy 21	9 (13)	1 (9)	1.00
Vasoactive use	42 (62)	6 (55)	0.65

IQR = interquartile range.

TABLE 2. Surgical Procedures of Patients Undergoing Extubation Readiness Trials

Surgical Procedure	Extubation Success No. (%) (n = 68)	Extubation Failure No. (%) (n = 11)
Atrial septal defect repair	4 (6)	1 (9)
Ventricular septal defect repair	7 (10)	1 (9)
Complete atrioventricular canal repair	5 (7)	2 (18)
Coarctation of aorta repair	5 (7)	1 (9)
Norwood operation	6 (9)	1 (9)
Tetralogy of Fallot repair	13 (19)	1 (9)
Fontan operation	7 (10)	1 (9)
Other repair	21 (31)	3 (27)

TABLE 3. Clinician's Perception of Extubation Readiness Trial Failure Etiology

Etiology of Extubation Readiness Trial Failure	No. Patients
Tachypnea	4
Desaturation	3
Respiratory acidosis	2
Sedation	2

TABLE 4. Clinician's Perception of Extubation Failure Etiology

Etiology of Extubation Failure	No. Patients
Increased work of breathing	7
Decreased respiratory effort	3
Upper airway obstruction	2
Decreased cardiac output	1

DISCUSSION

We found that a decline in the minimum somatic rSO_2 during an ERT was associated with a six-fold increase in the odds of extubation failure following a successful ERT. A 12% decline in minimum somatic rSO_2 during an ERT best predicted extubation outcome and was associated with 54% sensitivity and 82% specificity for extubation failure. Fifteen percent of patients in this study failed extubation after successfully completing an ERT. This rate is similar to the 8–14% failure rate reported in other PICUs (3). These findings suggest that the addition of somatic NIRS measurements to ERTs can improve our ability to predict extubation outcomes by enhancing the specificity of the breathing trial. The sensitivity of NIRS as a sole predictor of extubation failure may be low because those patients who failed an ERT and were thus likely to fail extubation were not included in the analysis. NIRS monitoring has an important role in preventing adverse consequences and physiologic stress in a high-risk cardiac population. It is also useful as a tool to assess extubation readiness by focusing on the detection of etiologies of extubation failure not assessed by the ERT alone. Further research will need to be conducted to determine the utility of NIRS monitoring as a sole predictor of extubation outcome in the absence of an ERT, and thus evaluate the true sensitivity of NIRS monitoring in predicting extubation failure.

In our study, only one extubation failure was attributed to an overt decrease in cardiac output, while seven extubation failures were ascribed to increased work of breathing, a

nonspecific sign that may have either cardiac or respiratory origins. This highlights the challenges of detecting inadequate cardiac output and abnormal oxygen transport balance. Critical care physicians' predictions of cardiac output using vital signs, physical examination findings, and laboratory data are often discordant from measured values (15). In addition, detection of changes in cardiac output is especially difficult in children with hypoplastic left heart syndrome, where vital signs and arterial blood gas values are not different between postoperative survivors and nonsurvivors (16).

Our results parallel other studies assessing cardiac function during ERTs. Central venous and mixed venous oxygen saturations, while not different at baseline, progressively fell during spontaneous breathing trials in adults who failed extubation compared to no change in those successfully extubated (17, 18). The need for central venous sampling and associated risks limits the application of this technique in children. B-type natriuretic peptide levels, a sensitive biomarker of cardiac function, rise during ERTs in adults without clinical signs of congestive heart failure who fail extubation (19). While this test had high sensitivity and specificity, intermittent measurement may miss or delay recognition of acute deterioration. NIRS, as a noninvasive and continuous monitor, may overcome these limitations and improve our detection of cardiac dysfunction during an ERT.

No significant association was found between changes in cerebral rSO_2 values and extubation failures. This lack of association can be explained by cerebral autoregulation, where cerebral blood flow is maintained in the face of decreases in cardiac

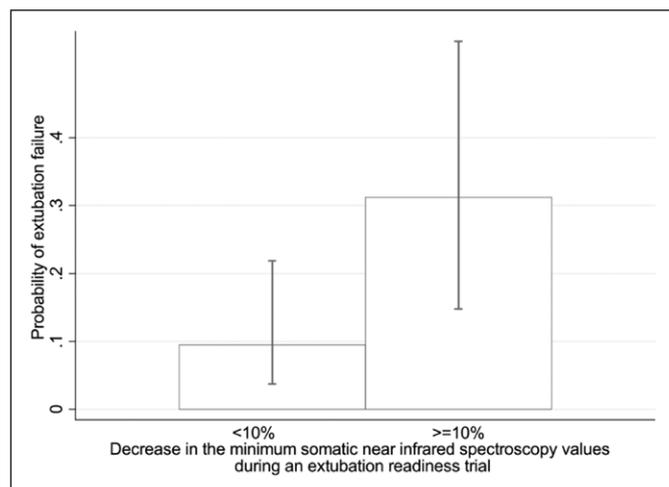
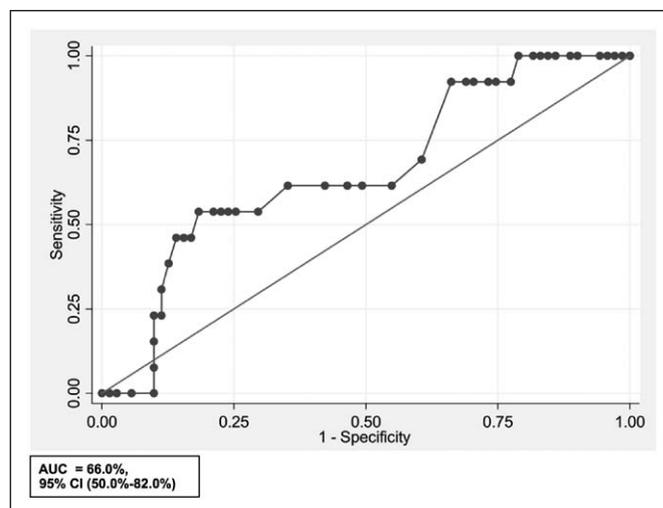
TABLE 5. Logistic Regression of Extubation Failure

Variable	Odds Ratio	95% CI	p
Somatic NIRS minimum at baseline	0.97	0.93–1	0.12
Somatic NIRS minimum during ERT	6.14	1.26–29.8	0.02
Cerebral NIRS minimum at baseline	0.98	0.94–1	0.48
Cerebral NIRS minimum during ERT	2.45	0.4–14.8	0.32

NIRS = near-infrared spectroscopy; ERT = extubation readiness trial.

output. As such, somatic NIRS is likely a more sensitive indicator of early declines in cardiac output than cerebral NIRS. In addition, hypoventilation and rising carbon dioxide levels lead to increased cerebral blood flow. Cerebral rSO₂ in cardiac surgery patients has been shown to correlate with changes in carbon dioxide values (11). Cerebral blood flow and cerebral NIRS values may increase as carbon dioxide values increase during failed ERTs and extubations because of poor respiratory effort and hypoventilation.

This study was conducted in postoperative cardiac patients who have a higher prevalence of cardiac dysfunction than general pediatric patients. Consequently, the utility of NIRS in a general PICU population remains to be determined. This study was limited to a single center and conducted in postoperative cardiac patients who have a higher prevalence of cardiac dysfunction than general pediatric patients. Consequently, a larger prospective trial of the utility of NIRS in a broader population of critically ill children is warranted. Although it is our institutional practice to supply pressure support based on the size of the endotracheal tube of the patient during an ERT, there is wide variability in levels of respiratory support and the

**Figure 2.** Probability of extubation failure.**Figure 3.** Receiver-operating characteristic curve for extubation failure. AUC = area under curve.

duration of an ERT across different institutions which may or may not affect the utility of NIRS. An additional limitation of this study is the lack of blinding of the clinical team to rSO₂ values. Although the team members were not blinded to the NIRS values, the impact of this awareness is likely negligible. An ERT without NIRS monitoring has been used in our institution since 2006 as a standard practice. Subjectivity exists in the decision regarding when to perform an ERT. There is potential variability among different providers on when to initiate an ERT and whether pre-ERT NIRS values influenced providers to initiate an ERT cannot be ascertained. However, once a patient has passed an ERT, it is rare that a provider will not proceed with an extubation attempt as evident in this study where only two patients were not extubated after a successful ERT.

CONCLUSIONS

In conclusion, a decline in somatic rSO₂ during an ERT is associated with an increased risk of extubation failure following a successful ERT. The addition of somatic rSO₂ measurements to an ERT is an important adjunct to detect inadequate cardiac response and may enhance our ability to predict extubation outcome. Further research is necessary to confirm these findings in larger sample and to determine the applicability of these results to critically ill pediatric patients without congenital cardiac disease.

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