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Case Reports

Near-Infrared Spectroscopy as a Hemodynamic Monitoring Tool during Neonatal Extracorporeal Life Support: A Case Series

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Abstract: Near-infrared spectroscopy (NIRS) is a non-invasive clinical tool allowing for real-time, continuous measurement of regional tissue oxygenation (rSO_2); though predominantly used for neuromonitoring, it also has the potential for early detection of hemodynamic compromise in the patients on extracorporeal life support (ECLS). The authors present two cases of neonates for whom continuous monitoring of multisite rSO_2 with NIRS provided the first indication of a significant compromise in hemodynamic status from catastrophic hemorrhagic complications while on ECLS ahead of conventional ECLS monitoring parameters. Routine NIRS monitoring of neonates on ECLS has utility for ongoing assessment of hemodynamic status and can be used for early detection of complications leading to impaired tissue perfusion. **Keywords**: neonatal extracorporeal life support (ECLS), near-infrared spectroscopy (NIRS), hemodynamic monitor, pericardial effusion, hemoperitoneum. *J Extra Corpor Technol. 2022;54:61–6*

Extracorporeal life support (ECLS) improves survival of neonates and adults with refractory respiratory and/or cardiac failure (1,2). Inherent in the use of ECLS are significant risks related to anticoagulation, thrombosis, and the mechanical complexity of the ECLS circuit. Although monitoring techniques used for patients on bypass may differ between centers, common parameters guiding ECLS management include pump flow and pressures; in-line blood gas monitoring; vital signs including heart rate, blood pressure, and SpO_2; laboratory values including hemoglobin and lactate; and invasive measures including central venous pressure and mixed venous saturation. However, all of these parameters ineffectively detect alterations in regional oxygen delivery and consumption and may only flag after significant hemodynamic changes have already occurred.

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Near-infrared spectroscopy (NIRS) is a non-invasive clinical tool allowing for real-time, continuous measurement of regional tissue oxygenation (rSO_2) of cerebral and somatic tissues including the kidney, splanchnic area, or muscle. Near-infrared light is emitted from a light source on the sensor, passes through the underlying skin and tissues, and is partially absorbed by oxygenated and deoxygenated hemoglobin before being reflected back to a detector. A tissue saturation is then calculated reflecting the balance between oxygen delivery and consumption in the underlying tissue. NIRS has been widely used in a variety of critical care settings including the operating room and intensive care, predominantly as a neuromonitoring tool. Limited investigations have occurred to determine the ability of NIRS to provide real-time detection of hemodynamic compromise in the patients on ECLS. We present two recent cases of neonates for whom continuous monitoring of multisite rSO_2 with NIRS provided the first indication of a significant deterioration in hemodynamic status from catastrophic hemorrhagic complications ahead of conventional ECLS monitoring parameters.

This study was approved by the Institutional Review Board at Stanford University (IRB-27032) with waiver of informed consent.

CASE 1

A female neonate was delivered vaginally with thick particulate meconium at 40 weeks and 6 days gestation with birthweight of 4,063 g. She presented with hypoxic respiratory failure due to meconium aspiration syndrome and persistent pulmonary hypertension. Initial echocardiogram demonstrated suprasystemic right ventricular pressure greater than 110 mmHg. She was placed on venoarterial (VA) ECLS on day of life 3 with a 14 Fr venous cannula in the right internal jugular vein (RIJV) and a 10 Fr arterial cannula in the right common carotid artery (RCCA). Chest radiograph demonstrated the arterial cannula at T3 and the venous cannula at T10. She was maintained on ECLS pump flow of 75 mL/kg/min and sweep .25–.80 L/min fraction of inspired oxygen (FiO_2) .3–.5 until ECLS day 7. ECLS was then gradually weaned to 20 mL/kg/min while systemic oxygenation as measured by pulse oximetry (SpO_2), arterial blood gases, blood pressures, urine output, and pump pressures remained stable. During this period, however, both cerebral and renal rSO_2 as measured by NIRS (INVOS 5100, Medtronic, Minneapolis, MN) steadily decreased over a 21-hour period (15:00–12:00) followed by an abrupt decrement from 56% to 42% and 57% to 29%, respectively, over a 2-hour period (12:00–14:00) (Figure 1). This change prompted a point-of-care ultrasound (Vivid-i, GE, Boston, MA) revealing a large

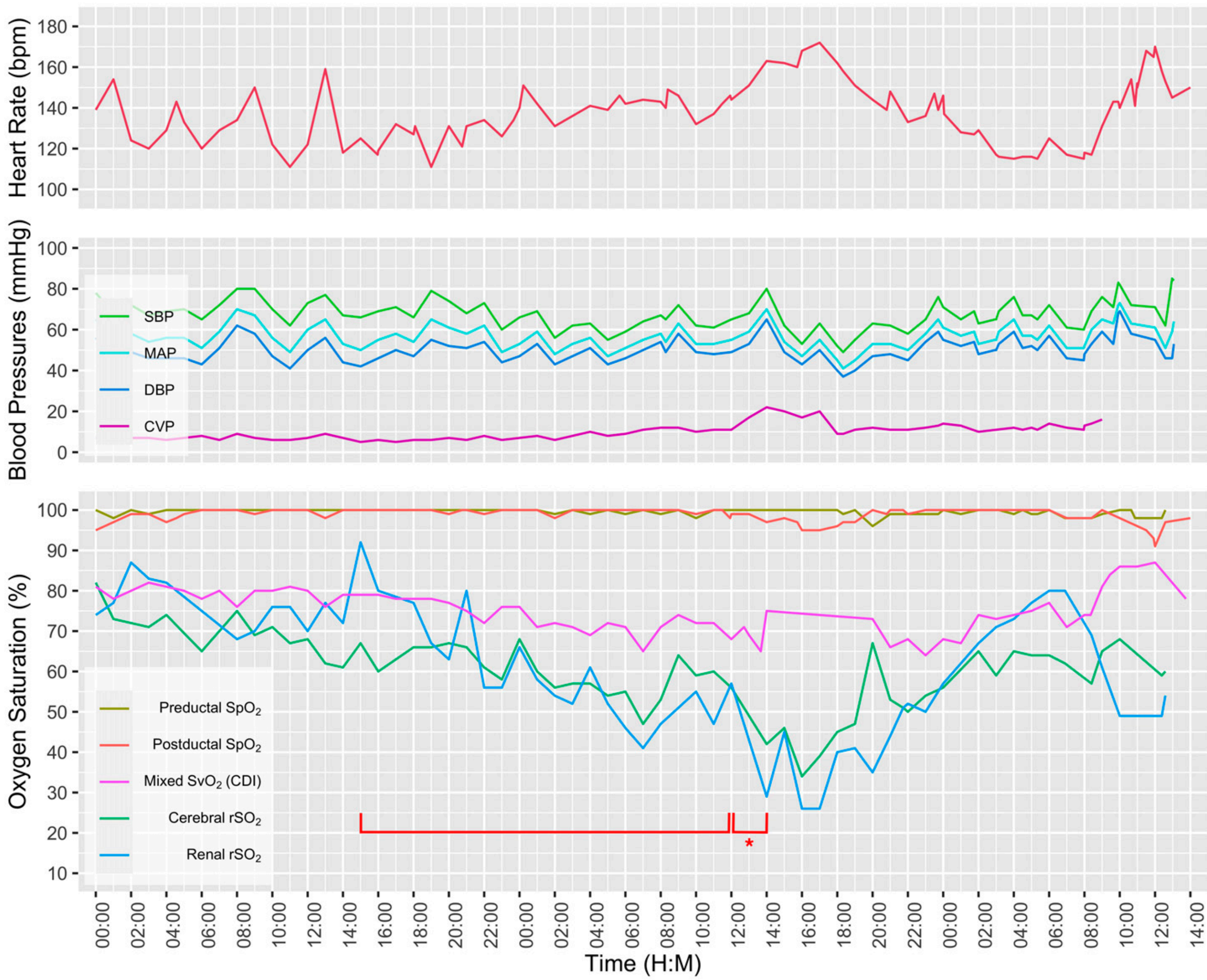

Figure 1. A multimodal graphic including vital signs and hemodynamic parameters. Note the gradual decline in renal and cerebral rSO_2 over a 21-hour period (bracket), followed by a 2-hour period with abrupt decrement (bracket with an asterisk).

pericardial effusion with the tip of the venous cannula at the inferior cavoatrial junction, which was confirmed by a formal echocardiography. A pericardial drain was placed with removal of 49 mL of bloody effusion while on full ECLS with subsequent improvement in both cerebral and renal rSO_2, and she was subsequently decannulated on ECLS day 8 without reaccumulation of hemopericardium or other hemorrhagic complications. The pericardial drain was removed 48 hours following decannulation. She was extubated on day 14 and discharged in stable condition with intact neurological exam at 17 days of age.

CASE 2

A female neonate was delivered by Cesarean section for preterm labor and placenta previa at 36 weeks and 5 days gestation with birthweight of 2,450 g. She had a prenatally diagnosed large right congenital diaphragmatic hernia with heterotaxy. She was placed on VA ECLS shortly after birth due to hypoxic respiratory failure secondary to severe pulmonary hypoplasia and pulmonary hypertension. The infant was cannulated with an 8 Fr arterial cannula in the RCCA and a 10 Fr venous cannula in the RIJV. Given inability to significantly wean ECLS and failure to achieve improvement in lung aeration, she underwent diaphragmatic hernia repair with Gore-Tex patch and excision of two accessory spleens on ECLS day 13. She remained on full ECLS with pump flow 120 mL/kg/min, sweep 1.3–1.5 L/min, and FiO_2 .55–.60 with stable cerebral rSO_2 greater than 65% and renal rSO_2 greater than 50%. On postoperative day 3, the renal rSO_2 gradually decreased to 30–40% over a 9.5-hour period (21:00–06:30) (Figure 2). She then developed oliguria, abdominal distension, and a significant decline in hemoglobin, while maintaining stable SpO_2, blood pressures, heart rate, and cerebral rSO_2. A 15-mL/kg red blood cell transfusion transiently improved renal rSO_2; however, it subsequently declined to 21%. Her abdomen became discolored, rigidly distended, and peritonitic on exam. An urgent abdominal ultrasound identified a large hemoperitoneum with marked compression of both kidneys as well as loss of flow in the aorta and inferior vena cava. Her abdomen was emergently explored, and 400 mL of hematoma was evacuated. No obvious bleeding source was identified. A Jackson-Pratt drain was placed at the end of the surgery for continuous monitoring and drainage of the abdomen. To accommodate the intra-abdominal organs and to facilitate a second-look operation, a Gore-Tex mesh was sutured to the fascia, which then was covered by Ioban™ (St. Paul, MN) dressing. She was decannulated from ECLS on the following day (DOL 18). During a second-look abdominal exploration, a subcapsular liver bleeding under the Gore-Tex patch was identified and managed with a combination of electrocautery and topical hemostatic agents. Her post-ECLS course was complicated by persistent pulmonary hypertension and resultant heart failure despite maximal medical management. She was transitioned to comfort care and died at 22 days of age.

DISCUSSION

We described two clinical examples where multisite NIRS monitoring during ECLS led to an early identification of dramatic changes in cerebral and somatic perfusion from catastrophic hemorrhagic complications when other conventional parameters failed to detect any change in the hemodynamic status.

In case 1, a consistent downward trend occurred in both cerebral and renal rSO_2 over a 21-hour period before the diagnosis of a large hemopericardium in an infant who otherwise appeared to be stable clinically without changes in other hemodynamic parameters. Renal rSO_2 rapidly declined to a critical value of 29% along with cerebral rSO_2 of 42% at the end of a 2-hour period. There was a slight increase in heart rate, but not significantly out of range for the patient's intrinsic heart rate variability. In retrospect, the diagnosis of a potentially life-threatening large pericardial effusion would have been significantly delayed without attention to the notable decline in rSO_2 provided by NIRS monitoring.

In case 2, an isolated decline in renal rSO_2 occurred secondary to an abdominal compartment syndrome from a rapidly expanding hemoperitoneum in the absence of changes in other hemodynamic parameters. Moreover, this change in NIRS was noted hours before clinical signs of abdominal distension and discoloration, decreased urine output, and acute anemia became evident. As demonstrated by this case, systemic arterial pressures and systemic oxygenation may be maintained even in cases of massive intra-abdominal bleeding on full ECLS. In contrast, regional perfusion was severely compromised due to increased intra-abdominal pressure and resultant decreased renal and splanchnic perfusion pressures, which can be best detected by NIRS monitoring.

NIRS is being used with increasing frequency in the neonatal intensive care unit (NICU) primarily as a neuromonitoring device. Cerebral NIRS measures have been validated with venous blood drawn from a cephalad catheter in neonates on venovenous ECLS. Excellent agreement between measured cerebral venous saturation by co-oximetry and cerebral NIRS values were found demonstrating the potential to trend

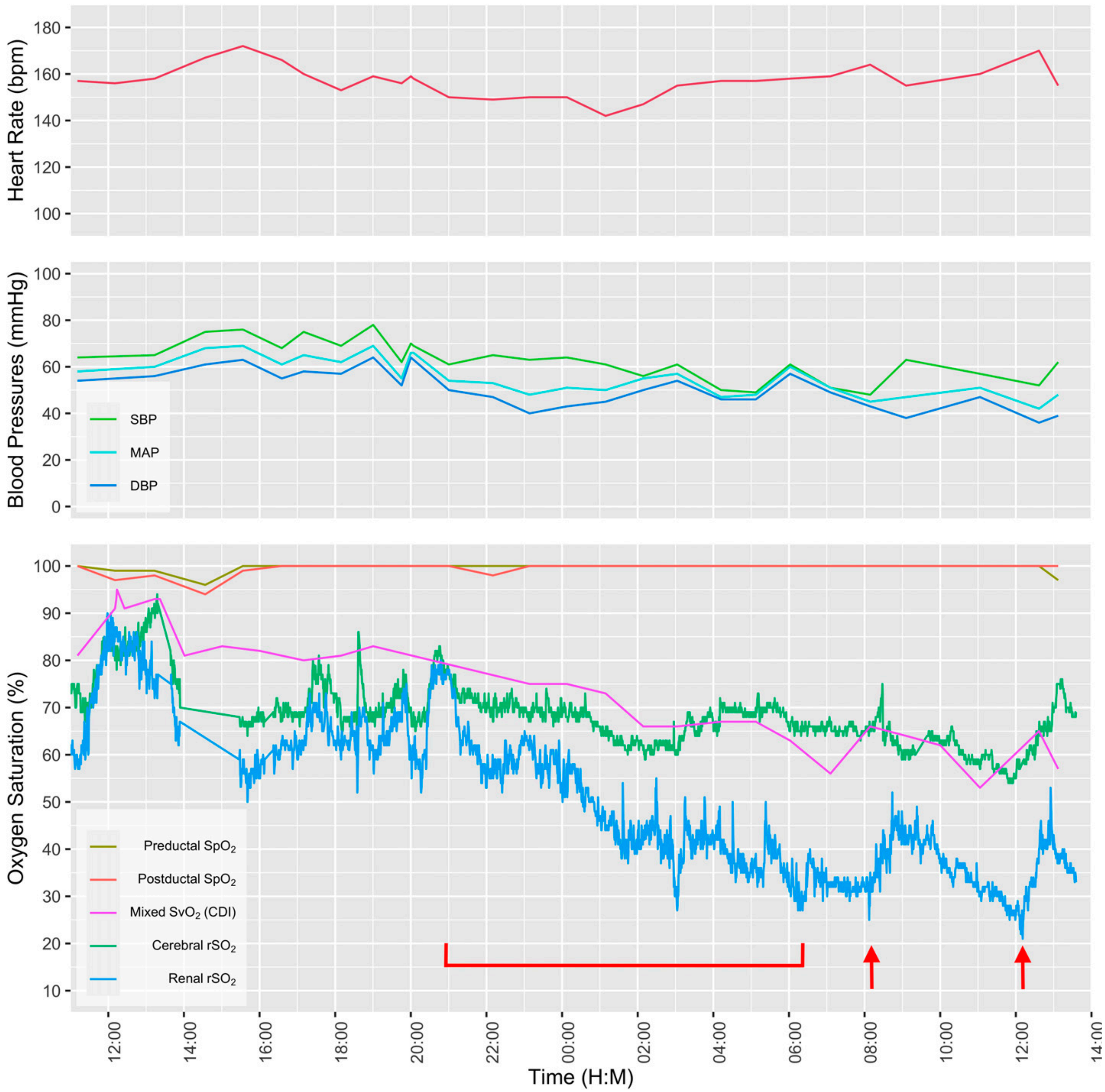

Figure 2. A multimodal graphic including vital signs and hemodynamic parameters. Note the downward trend of renal rSO_2 over a 9.5-hour period (bracket). Red arrows indicate timing of red blood cell transfusions with transient increase in rSO_2.

cerebral saturation as a continuous, non-invasive measure in neonates (3). NIRS has been used in a variety of clinical scenarios. Chock et al. described its use in neonates with hypoxic ischemic encephalopathy (HIE), patent ductus arteriosus, cerebral hypoperfusion due to hypocarbia while on mechanical ventilation, hypoplastic left heart syndrome (HLHS), severe anemia, and intraventricular hemorrhage (4). Other reports presented neonatal and adult cases where reduction in NIRS predicted clinical deterioration from duct-dependent congenital heart diseases and cardiac arrest (5,6). In these clinical scenarios, the value of monitoring both cerebral and somatic rSO_2 is highlighted. Monitoring of cerebral rSO_2 can identify neonates at risk for brain injury due to cerebral hypoxia and alert the clinician to these changes. Several clinical studies have suggested that maintaining cerebral $rSO_2 > 55\%$ in extremely low-birth weight infants decreases the burden of cerebral hypoxia and is associated with lower rates of severe intracranial hemorrhage and abnormal electroencephalography (EEG) patterns (7,8). Although cerebral perfusion is better autoregulated, renal saturation is an excellent indicator of decreased somatic perfusion and hemodynamic compromise. In several studies detailing the use of NIRS in newborns with HLHS, Hoffman et al. have demonstrated that cerebral and renal NIRS when used in combination allow identification of pulmonary overcirculation and circulatory shock in the preoperative period, while predicting early mortality and ECLS use in the post-operative period (9,10).

Several authors have published their experiences with cerebral and somatic rSO_2 monitoring in ECLS patients. Clair et al. reported that lower cerebral rSO_2 values were seen in ECLS patients <3 months of age who died or had brain injury, suggesting a potential role for NIRS in prediction of outcome (11). A study of cerebral rSO_2 monitoring during ECLS found that low cerebral saturation was common ($rSO_2 < 40\%$ in 24% of patients and $rSO_2 < 60\%$ in 70% of patients), whereas simultaneous pulse oximetry was unreliable in some cases due to low cardiac output or cardiac arrest (12). As cerebral oximetry relies on direct measurement of tissue saturation and pulsatile flow is not necessary, the effectiveness of chest compressions can also be assessed. In newborns with congenital diaphragmatic hernia on ECLS, renal rSO_2 was found to decrease with anuria and oliguria and preceded a drop in mean arterial pressure (13). The authors concluded that NIRS has promise as a non-invasive tool to monitor renal perfusion and urine output.

Several publications have also reported on the use of NIRS in adult ECLS. NIRS has been used for assessment of distal-limb perfusion primarily in VA-ECMO with femoral cannulation. It was shown to be useful for early detection of limb ischemia and compartment syndrome, preventing the need for fasciotomy compared to a control group of adult ECLS patients without NIRS monitoring (14). In a small case series of two adult and one newborn ECLS patients, NIRS was used to detect pericardial hematoma, lung overinflation, and tension pneumothorax that compromised cardiac output during VA-ECLS (15). Similar to our findings, the authors concluded that monitoring of tissue saturation with NIRS allowed for early detection of ECLS complications.

The use of NIRS during ECLS is variable across centers. A survey performed in 2009 reported that only 70% of centers used cerebral oximetry (16). One of the explanations might be a perceived limitation from intra- and inter-subject variability. rSO_2 values are age and condition-dependent and preclude application of uniform guidelines across all individuals. For example, rSO_2 values in premature infants or those with congenital heart disease are typically lower than in term infants (7,9). Instead, use of NIRS must be tailored to specific neonatal populations. At our institution, use of multisite (cerebral and somatic) NIRS monitoring is standard protocol in infants with respiratory and/or circulatory failure including those on ECLS or for infants at risk for needing ECLS. Infants have NIRS and amplitude-integrated EEG in place for the duration of ECLS, given risks of hemodynamic instability affecting end organ perfusion and function. In addition, all preterm infants less than 29 weeks gestation, infants with congenital heart disease, and those with HIE undergoing therapeutic hypothermia receive routine multisite NIRS monitoring. We emphasize that routine NIRS monitoring and close attention to rSO_2 trends over time in patients at risk for hemodynamic instability provide significant benefits. A decrease in rSO_2 values beyond physiologic intra-individual variability warrants close attention and further investigation.

CONCLUSION

As a continuous, non-invasive clinical monitor of end organ perfusion, NIRS provides critical information for neonates on ECLS. Changes in rSO_2 were the earliest signs of hemodynamic compromise before changes in other hemodynamic parameters occurred in the two cases described. Routine NIRS monitoring and close attention to rSO_2 trends over time in neonates on ECLS have utility for ongoing assessment of hemodynamic status and early identification of complications leading to impaired tissue perfusion.

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