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Case Report

Near-infrared Spectroscopy in Transport With a Patient in Multi-factorial Shock

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A B S T R A C T

A 14-year-old male with a history of repaired truncus arteriosus presented to an outside hospital emergency room in respiratory distress. The triage report to the transport referral center included the following vital signs: temperature of 36.6°C, respiratory rate (RR) of 26 breaths/min, heart rate (HR) of 144 beats/min, and blood pressure (BP) of 113/52 mm Hg with peripheral capillary oxygen saturation (SpO_2) of 95% on 4 L via an OxyMask (SouthMedic, Barrie, Ontario, Canada). Additional information indicated severe right ventricle to pulmonary artery conduit stenosis; anuria for 2 days; and cool, mottled extremities. The transport team was dispatched via helicopter. The vital signs upon arrival were as follows: temperature of 36.5°C, HR of 153 beats/min, RR of 48 breaths/min, BP of 81/52, mean arterial pressure of 62, and SpO_2 of 96% on 8 L via an OxyMask. Physical assessment revealed the patient was alert and oriented, tachypneic, tachycardic, and displaying poor perfusion. An epinephrine drip was initiated while the patient was being prepared for transport. Near-infrared spectroscopy (NIRS) was initiated with cerebral NIRS of 71% and renal NIRS of 39%. The epinephrine drip was escalated, and norepinephrine was initiated and titrated up for continued poor perfusion and low renal NIRS. Vitals at the transfer of care at the receiving facility were HR of 142 beats/min, BP of 91/51 mm Hg, RR of 56 breaths/min, SpO_2 of 99%, and cerebral NIRS of 75% and renal NIRS of 53%. The patient required mechanical circulatory support shortly after admission. NIRS monitoring was used to help measure perfusion and reassess interventions made during transport.

Near-infrared spectroscopy (NIRS) is a technology that estimates regional oxyhemoglobin saturation (rSO_2) by measuring the differential absorption of light between oxygenated and deoxygenated hemoglobin.[1] NIRS measurements are nonpulsatile readings, unlike pulse oximetry, and show real-time changes in rSO_2. NIRS is non–waveform based and uses near-infrared light to capture regional tissue oxygenation saturation.[2] The sensors are 3 cm in length, resulting in a penetration depth of 1.5 cm beneath the surface. The application sites are typically the cerebral and renal areas for multisite monitoring. The emitted light is partially scattered, reflected, and absorbed as it passes through the skin, bone, and tissue, and the measured difference in absorption of deoxygenated and oxygenated hemoglobin represents the oxygen saturation of the tissue.[2] The trends in rSO_2 can depict changes in metabolic demand or oxygen supply.[3] Trends in rSO_2 help detect changes in circulation that occur before shock. In patients with shock, elevated sympathetic tone allows for blood pressure (BP) maintenance at the expense of splanchnic and mesenteric regions. Regional ischemia may be present but silent throughout transport. NIRS allows for continuous noninvasive organ-specific perfusion monitoring during patient transport.[4] This additional monitoring provides an opportunity for earlier interventions and reassessment of interventions both at bedside and during interfacility transport.

NIRS monitoring can be used in interfacility transport with transport teams that carry NIRS monitoring equipment. The pediatric/neonatal critical care transport team that was used in this scenario was dispatched from a level 1 pediatric trauma hospital. This transport team routinely uses NIRS monitoring when the transported patient's disposition is expected to be in intensive care. The use of NIRS on transport allows for nurse clinicians and respiratory therapists to detect and treat changes in regional and global circulation while the patient is en route.

Case Presentation

The pediatric/neonatal transport referral center fielded a call from an outside hospital emergency room requesting the transport of a 14-year-old, 98-kg male patient. The clinical information relayed

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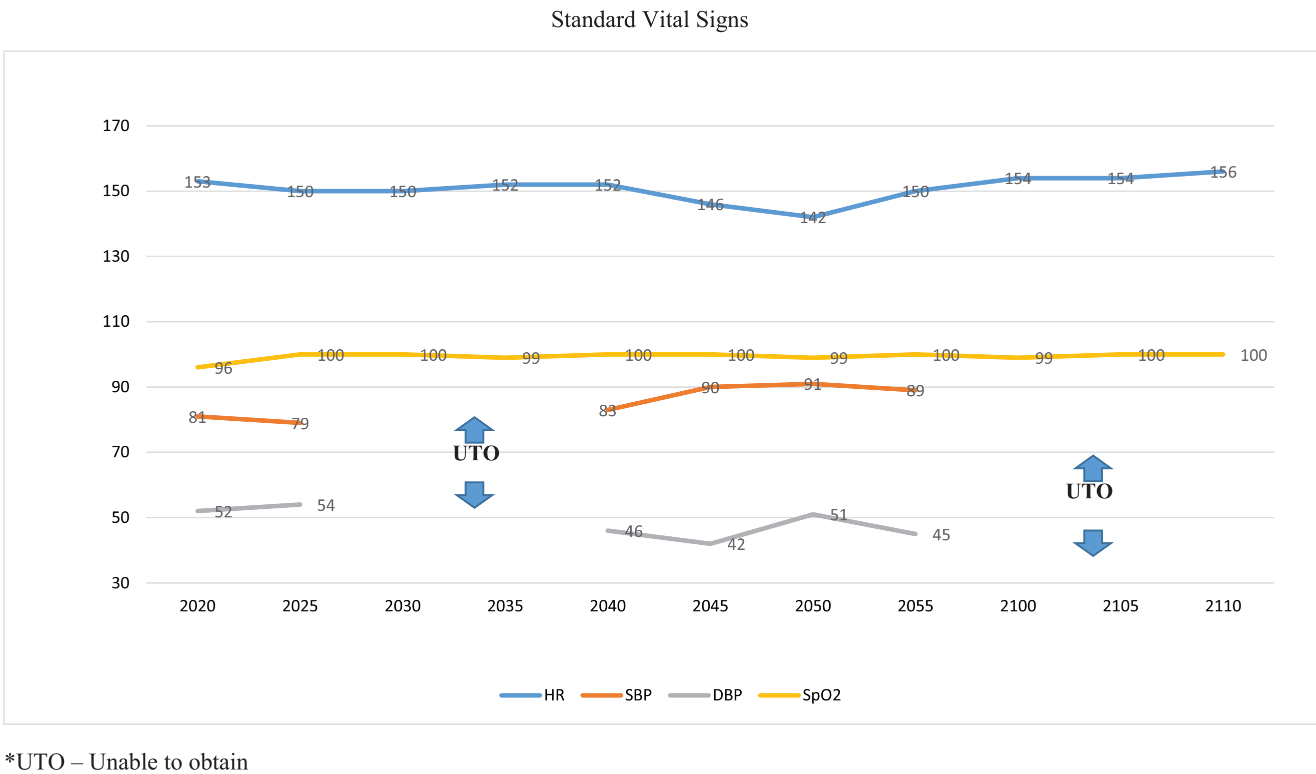

Figure 1. Standard vital signs recorded over the course of the transport.

to the referral center indicated that the patient was known to have a history of repaired truncus arteriosus now presenting to an outside hospital emergency room with respiratory distress. The patient's vital signs were as follows: temperature of 36.6°C, heart rate (HR) of 144 beats/min, respiratory rate of 26 breaths/min, and BP of 113/52 mm Hg with a peripheral capillary oxygen saturation of 95% on 4 L via an OxyMask. A bedside echocardiogram revealed severe right ventricle to pulmonary artery conduit stenosis with poor visualization of function. The concerning assessment findings included anuria of 2 days and cool, mottled extremities. The outside facility infused a 500-mL normal saline bolus, drew blood cultures, and administered Zosyn (Pfizer, New York, New York).

The decision was made to fly via a rotor wing to transport this patient. The transport team, comprised of a transport nurse clinician and a transport respiratory care practitioner, was dispatched to the outside facility. The initial vital signs upon transport team arrival indicated a temperature of 36.5°C, HR of 153 beats/min, respiratory rate of 48 breaths/min, BP of 81/52 mm Hg with a mean arterial pressure of 62, and a peripheral capillary oxygen saturation of 100% on 8 L via an OxyMask. The physical assessment findings reported to medical control included level of consciousness as alert and oriented × 3. The patient was in respiratory distress with bilateral wheezes and mild retractions. A previously known right bundle branch block was observed. The patient was cyanotic, mottled, and had a capillary refill time of greater than 7 seconds, with peripheral pulses only detectable by sound Doppler. The initial cerebral NIRS (cNIRS) was 71%, and renal NIRS (rNIRS) was 39%. Figure 1 shows standard vital sign trends over the course of the transport; of note, blood pressures were unable to be obtained for almost half of the transport. Figure 2 displays cNIRS and rNIRS trends over the course of the transport along with escalation of vasopressor support in relation to vital signs and NIRS readings. Please note that the brief gap in rNIRS data was because of the NIRS patch becoming disconnected during patient transfer in the helicopter. An epinephrine drip was initiated during the transport because of inadequate perfusion and hypotension. The transport monitoring equipment was only able to measure intermittent BPs. Therefore, rNIRS, in conjunction with physical examination findings and recorded vitals, helped in assessing the patient's perfusion status.

The epinephrine drip was escalated, and a norepinephrine drip was initiated when BP, rNIRS, and clinical perfusion examination failed to improve. Norepinephrine was escalated before arrival at the accepting facility again because of a lack of improvement in vital signs and perfusion status. Upon arrival at the accepting facility, he was intubated and placed on venoarterial extracorporeal membrane oxygenation and underwent emergent open heart surgery to correct right ventricle to pulmonary conduit stenosis. The patient's right ventricular function was found to be severely diminished. The patient was also found to have methicillin-sensitive *Staphylococcus aureus* sepsis.

Discussion

Based on the report received from the referring hospital, the patient appeared to have some degree of end organ damage as evidenced by physical examination and anuria. The patient's vital signs over the duration of the transport did not change drastically despite interventions; however, it is notable that BP was unable to be measured for over half of the transport. NIRS technology provides rSO_2 readings. rSO_2 measured by cNIRS has been shown to correlate with jugular venous bulb saturation, which is the standard for assessing global cerebral saturation. The range of cerebral rSO_2 is 55% to 80% with less than 50% as an indicator for intervention.[5] In animal studies, cerebral $rSO_2 < 45\%$ was associated with cerebral anaerobic metabolism.[1,4] For this patient, a cNIRS reading of 71% indicates that the patient was still receiving cerebral perfusion within acceptable limits in an ordinarily acyanotic patient.

When discussing rNIRS, readings in a patient group of 30 neonates with a normal oxygen saturation had an average somatic rSO_2 of 88%.[3] Renal oxygen extraction is low under resting circumstances

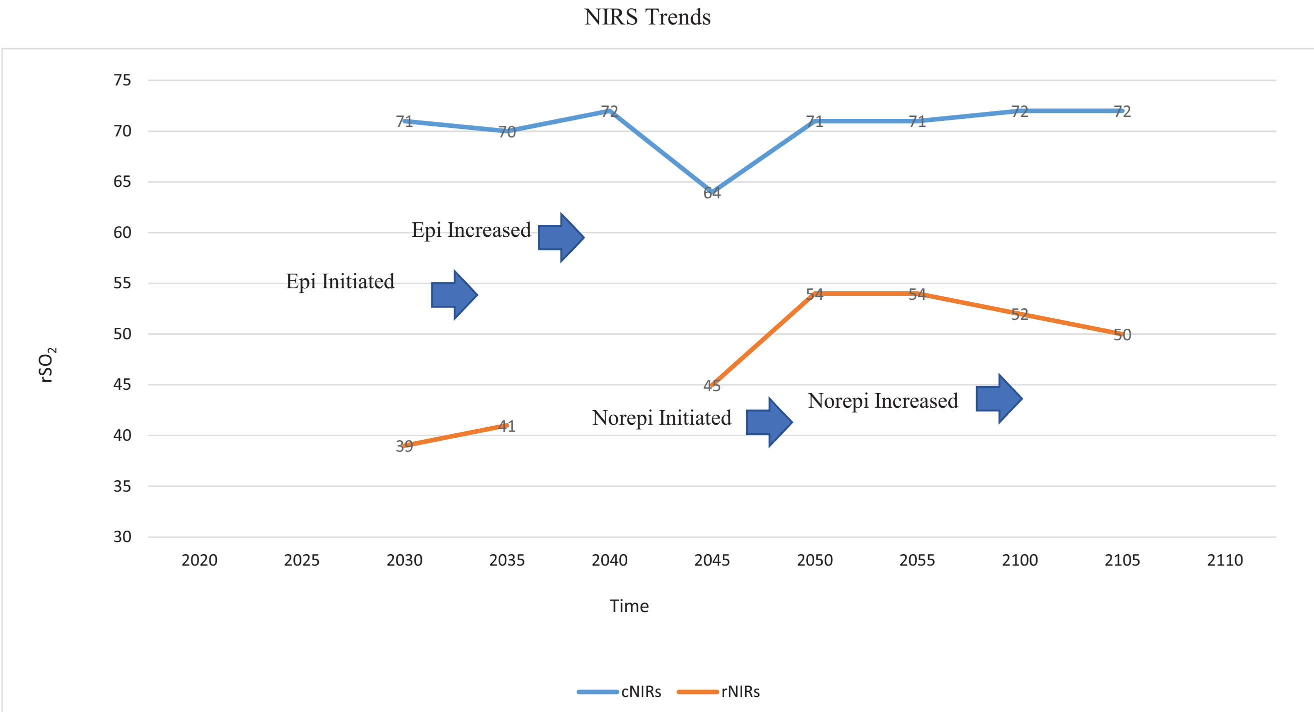

Figure 2. rSO^2 readings from NIRS recorded over the duration of the transport. Real time vasopressor changes noted.

with normal oxygen supply. Therefore, NIRS readings from somatic fields are usually higher than from cerebral fields where oxygen extraction is higher.[1] The somatic-cerebral saturation gradient is typically about 10% to 15% in well-supported patients. In patients with shock, increased systemic vascular resistance maintains perfusion of the heart and brain at the expense of perfusion to kidneys and mesenteric organs.[4] When this occurs, there is a narrowing in the somatic-cerebral gradient, and patients may even exhibit a negative gradient. In the patient in the case study, the initial rNIRS reading was 39%, indicating that this patient had somatic hypoperfusion. rNIRS $<$ 70% is associated with necessitating lifesaving interventions such as fluid resuscitation, vasopressors, and blood products.[6] In this case, the transport team was aware of his 2-day history of anuria, and the rNIRS reading was incorporated to confirm end organ dysfunction was most likely the result of hypoperfusion.

Multisite NIRS is a strategy commonly used in critical care units and the perioperative setting and includes targeting 2 separate organ beds for monitoring. Cerebral circulation and a somatic bed, which can include the renal and mesenteric circulation, are the typical regionally monitored beds. Multisite NIRS monitoring can aid in the tracking of the distribution of cardiac output. A reduction in rNIRS compared with cNIRS can be indicative of regional ischemia and global shock.[1]

Multisite NIRS monitoring is used along with traditional vital signs and physical examination to assess a patient's state of perfusion. What makes NIRS a valuable tool in transport is its reliability. NIRS readings are unaffected by motion artifact, a common concern with other vital signs. When in the confines of a helicopter, physical assessment capabilities are diminished because of noise, space, and lighting. When physical assessment techniques and standard vital signs are limited because of environmental factors, NIRS is a valuable tool to aid in the assessment of perfusion.

Beyond the inability to perform an effective physical assessment within the confines of a helicopter, vital signs within the aircraft are often unreliable. Pulse oximetry is a commonly used vital sign in many settings. However, it is a measurement that needs pulsatile blood flow for measurement. Although pulse oximetry is a standard of care for pediatric critical care monitoring, there are circumstances for error. Movement artifact, interfering light sources, dyshemoglobinemia, cardiac output, tissue pigment, temperature, and dyes can all impact pulse oximetry readings. Additionally, there is a slower response time to change in saturation on the monitor.[2,7]

BP readings can be affected by vibrational artifact within the helicopter and in any mode of transport that elicits vibration. Sudden transient movements can result in significant signal changes. The challenging issue is that artifact signals can degrade the accuracy of BP measurement or produce erroneous readings altogether.[8] It is interesting to note that according to Abderahman et al,[8] there is no standard for validating BP devices under operating conditions that elicit vibration.

NIRS can allow for the assessment of regional perfusion even if other vital sign readings are affected by motion artifact. Weatherall et al[9] performed a study on 33 patients in road ambulances and rotor wing aircraft that showed that there were no instances in their trial of a signal loss in the NIRS module as a result of patient movement or vehicle/aircraft vibrations. An additional study of NIRS by Hamrin et al[10] looked at the reliability of NIRS readings during ground and air transport as opposed to readings from when the patients were on nursing units. The median values for reliable measurements during air and ground transport for both cNIRS and rNIRS were greater than 95%. It was noted that although NIRS measurements are feasible during transport that reliable numbers were lower compared with numbers collected during patients' stay on a nursing floor.[10] The possible reasons for lower reliability could be bright ambient light and poor patch adhesion to skin.

In this case study, NIRS monitoring in conjunction with traditional vital signs and physical assessment techniques assisted the transport team in escalating inotropic and vasopressor support rapidly in a precardiac arrest state in a patient who was found to be in cardiogenic and septic shock. The patient's physical assessment and vital signs, independent of NIRS values, would indicate that this patient was in shock, although NIRS did provide a real-time value that the transport team was able to use to evaluate interventions despite the patient's continued poor perfusion. NIRS assisted clinician decision making and guided reassessment of interventions when the transport team was unable to rely on standard vital signs or physical examination findings. NIRS can be considered as an additional tool for use during interfacility transfer of critically ill pediatric patients.

Supplementary materials

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.amj.2019.03.005.

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