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Abdominal near-infrared spectroscopy in preterm infants: A comparison of splanchnic oxygen saturation measurements at two abdominal locations

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ABSTRACT

Background: Splanchnic tissue oxygenation monitoring has been performed at both the liver and the infra-umbilical regions. It is unknown whether these measurements could be substituted one for the other when interpreting splanchnic oxygenation since they have not been measured simultaneously before.
Aims: To evaluate the feasibility and safety of liver and infra-umbilical near-infrared spectroscopy (NIRS) monitoring in preterm infants with suspected necrotizing enterocolitis (NEC) and to assess the correlation and agreement between NIRS measurements performed simultaneously at the two abdominal locations.
Study design and subjects: This study was part of a prospective observational cohort study. Preterm infants who were suspected of NEC or who had been diagnosed with NEC were included.
Outcome measures: Liver oxygen saturation and infra-umbilical oxygen saturation were monitored simultaneously and continuously for 48 h by NIRS.
Results: NIRS monitoring was performed in 20 out of 24 infants for the entire 48-hour study period. No adverse effects were observed. Values of liver and infra-umbilical oxygen saturation correlated weakly (Spearman's rho = 0.244, $P < .001$). On the Bland–Altman plot liver oxygen saturation was higher than infra-umbilical oxygen saturation (mean difference 6.6%, SD 22.5%).
Conclusions: Using NIRS as method for monitoring oxygen saturation simultaneously in both the liver and infra-umbilical regions is safe and feasible. Additionally, we demonstrated that values of liver and infra-umbilical oxygen saturation cannot be randomly substituted one for the other for the purpose of assessing splanchnic oxygenation.

1. Introduction

Near-infrared spectroscopy (NIRS) is a non-invasive tool that can be used to continuously measure the oxygen saturation of underlying tissue [1]. It is being used increasingly to investigate splanchnic oxygen saturation. Various locations, including the liver and infra-umbilical regions, have been selected for placing the NIRS sensors for this purpose [2–10]. Although this new technique seems promising for assessing splanchnic oxygen saturation, location-specific characteristics have been identified that may interfere with the reliability of the measurements. The infra-umbilical region covers non-solid and moving tissue. Movements of the intestines within the abdominal cavity as well as peristaltic movements may alter the reflected signal despite static sensor placement [11]. The liver, a solid and non-moving organ, relies on the portal vein for approximately 75% of its blood supply and on the hepatic artery for the remaining 25%. Due to the hepatic arterial buffer response, no direct linear relationship exists between the contributions of the two vessels to the hepatic blood supply, thus limiting the potential use of NIRS to monitor splanchnic oxygenation [12]. To date, it remains unclear whether liver and infra-umbilical oxygen saturation measurements obtained by NIRS can be substituted one for the other for interpreting splanchnic oxygenation, since splanchnic oxygen saturation in the liver and infra-umbilical regions have not been monitored simultaneously before. Additionally, it is difficult to compare the liver and infra-umbilical oxygen saturation values reported in the literature due to discrepancies between study groups and study methods.

The primary aim of this study was to evaluate the feasibility and safety of monitoring splanchnic oxygen saturation in the liver and

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infra-umbilical regions simultaneously by NIRS in preterm infants with suspected necrotizing enterocolitis (NEC). Our secondary aim was to compare the liver measurements with the infra-umbilical measurements and to assess the correlation and agreement between the oxygen saturation values obtained at the two abdominal locations.

2. Methods

2.1. Ethical statement

This study was part of a prospective observational cohort study registered with the Dutch Trial Registry under number NTR3239. The study was approved by the ethical review board of University Medical Center Groningen. Written informed parental consent was obtained in all cases.

2.2. Patients and procedures

We included preterm infants admitted to the neonatal intensive care unit of University Medical Center Groningen between October 2010 and March 2012, who were suspected of NEC or who had been diagnosed with NEC. Suspected NEC is defined as Bell stage I, in which case only non-specific symptoms of abdominal disease, such as gastric retention, abdominal distension, and mild ileus, are present [13,14]. Infants with abdominal wall defects were excluded. Monitoring splanchnic oxygen saturation by NIRS commenced as soon as possible after suspected or diagnosed NEC and was continued for 48 h.

2.3. Near-infrared spectroscopy

We used the INVOS 5100C near-infrared spectrometer (Somanetics Corporation, Troy, Michigan) in combination with the neonatal SomaSensors (Somanetics Corporation) to measure splanchnic oxygen saturation continuously and simultaneously in both the liver and infra-umbilical regions. Near-infrared light is emitted using two wavelengths (780 and 810 nm). By measuring the quantity of reflected light as a function of wavelength, the spectral absorption of the underlying tissue can be calculated. Since oxygenated and deoxygenated hemoglobin have different absorption spectra, NIRS can differentiate between the two. The ratio of oxygenated hemoglobin to total hemoglobin reflects the regional tissue oxygen saturation (rSO_2). The SomaSensor has a shallow and deep detector; on 3 and 4 cm distance from the near-infrared optode respectively. By subtracting the measurement of the shallow detector from the deep detector, oxygenation values of the deep detector, which reflect the tissue beneath the skin, are calculated. The depth of the signal is estimated to be around 15 to 20 mm [15].

For this study, we placed the neonatal SomaSensors just below the right costal arch to measure liver oxygen saturation ($r_{liv}SO_2$) and just below the umbilicus on the central abdomen to measure the intestinal oxygen saturation ($r_{int}SO_2$). The SomaSensors were held in place by elastic bandaging and were removed only during moments of routine nursing care, clinical assessment, and radiographic examination; afterwards they were replaced onto the same location. There was no overlap between the sensors at any time. $R_{liv}SO_2$ and $r_{int}SO_2$ were measured every 6 s for 48 h. The measurements were saved on the INVOS 5100C near-infrared spectrometer and were downloaded at the end of the study and stored off-line for future analysis. Afterward we only removed data obtained during documented incorrect sensor placement.

2.4. Clinical variables

We prospectively collected neonatal characteristics including gestational age, postnatal age at first NIRS measurement, birth weight, and gender. We documented the following characteristics as well: respiratory support at the time of NEC suspicion/diagnosis, mean systemic blood pressure in the first hour after start of NIRS monitoring, patency of the ductus arteriosus (PDA) from 48 h before NEC suspicion/diagnosis until the first 48 h after NEC suspicion/diagnosis or until surgery took place, whichever came first, whether or not the PDA was hemodynamically significant, the first lactate value, and need for fluid resuscitation and inotropes for circulatory support from 1 h before NEC suspicion/diagnosis until 48 h after NEC suspicion/diagnosis, or until surgery took place, whichever came first.

Hemodynamically significant PDA was defined as a diastolic forward flow in the branches of the pulmonary artery, a diastolic backflow in the descending aorta, and a left ventricular end diastolic diameter >p 95.

2.5. Statistical analysis

We used medians (range) to describe sample characteristics. To determine and compare the courses of $r_{liv}SO_2$ and $r_{int}SO_2$, we calculated mean 1-hour and mean 12-hour values of 5-minute measurements of $r_{liv}SO_2$ and $r_{int}SO_2$ during the 48-hour study period. The 5-minute measurement is based on one oxygen saturation value obtained during these 5 min. The differences between the simultaneously obtained 12-hour mean values of $r_{liv}SO_2$ and $r_{int}SO_2$ were analyzed using the Wilcoxon signed rank test.

To determine the variability of the measurements, we calculated each infant's daily intraindividual variability, defined as the daily percentage of time that 1-hour mean $r_{liv}SO_2$ or $r_{int}SO_2$ values were 15% or more below or above the infant's daily mean [16].

To compare the two abdominal locations at which we monitored splanchnic oxygen saturation, we determined the correlation coefficient of the mean 1-hour period values of $r_{liv}SO_2$ and $r_{int}SO_2$, using the Spearman rank test. Furthermore, to determine if the direction of change in oxygen saturation was comparable between $r_{liv}SO_2$ and $r_{int}SO_2$ values, we calculated the differences between consecutive 1-hour measurements for $r_{liv}SO_2$ and $r_{int}SO_2$ values independently, leading to 47 delta values per child. We analyzed the correlation between these delta $r_{liv}SO_2$ and $r_{int}SO_2$ values using the Spearman rank test. Finally, we constructed a Bland–Altman plot to assess the agreement between the measurements of the two locations.

Since our primary aim was to assess the feasibility and safety of monitoring in both the liver and infra-umbilical regions and to assess the correlation and agreement between oxygen saturation values measured at the two abdominal locations, we did not analyze the correlation between NIRS measurements and type of treatment and/or patient outcome.

We used the Statistical Package for the Social Sciences (SPSS 20.0, SPSS Inc., Chicago, IL, USA) for all statistical analyses. Statistical significance was defined as $P < .05$.

3. Results

3.1. Patient characteristics

We included 24 infants with a median gestational age of 28.4 weeks (range, 25.0–35.9), a median birth weight of 1279 g (range, 570–2400), and a median postnatal age at the first measurement of 9 days (range, 3–41). The patient characteristics are presented in Table 1.

3.2. NIRS monitoring

NIRS monitoring was started within 48 h after suspected or diagnosed NEC and was continued for 48 h in twenty infants. In one infant, data were partially lost due to technical problems. In three other infants, NIRS monitoring was stopped after a median of 4 h (range, 3–11) due to progressive circulatory failure leading to the death of one infant an hour later and due to abdominal surgery for NEC in the other two infants. Three infants were not monitored in the liver region due to shortage of equipment. Two infants were not monitored in the infra-umbilical