RADIOMETER

Oxygen monitoring in the NICU

Oxygen monitoring and treatment is a vital part of neonatal care and has been used for treatment of cyanosis in preterm infants for over 120 years [1].

From 1900 to 1950, preterm infants were treated with increased levels of inspired oxygen, as it was found to decrease cyanosis and episodes of apnea [1].

During the 1950s, it was found that increasing levels of oxygen led to an increased number of infants with retrolental fibroplasia, now called retinopathy of prematurity (ROP). This led to restrictions in how much oxygen preterm infants received, which again led to an increase in mortality and rates of cerebral palsy [1].

Since then, there has been debate on the optimal supplementation of oxygen and how to monitor oxygen levels in the preterm infant, and even though many studies have examined the relationship between oxygen levels and neonatal mortality and morbidity, it is still debated how to optimally monitor oxygenation and the optimal oxygen levels [2].

Oxygen monitoring in the preterm infant

Oxygen monitoring can be performed using either invasive or non-invasive methods. Invasive methods include blood gas analysis, while non-invasive methods include pulse oximetry, transcutaneous monitoring and near-infrared spectroscopy/NIRS among others.

For the last decades, blood gas analysis has been the gold standard for determining oxygenation levels in the NICU [3]. The arterial blood gas is precise and gives a direct measure of the oxygen levels in the blood but is invasive (either through an arterial puncture or most commonly from an indwelling catheter) and can lead to significant blood loss [3]. One study showed that neonatal blood sampling, with blood gases being the most common blood sample, led to a blood loss of nearly 60% of the endogenous blood volume in the first 2 weeks of life and that increasing rates of blood loss was associated with development of bronchopulmonary dysplasia (BPD) [4].

The capillary blood gas gives good approximations of the arterial blood gas but cannot be used to estimate the partial pressure of oxygen in the blood [5].

Research has shown that preterm infants can be subject to as many as 50 painful procedures over the first 4 weeks of life, with blood gas analyses being one of the most common [6]. As neonatal pain has been associated with adverse neurological outcome, painful procedures, such as capillary sampling, should be limited as much as possible [7].

Pulse oximetry first gained use in the NICU in the 1980s and is now considered standard-of-care in neonatal care to monitor oxygenation [2]. It is instantaneous and non-invasive, and the current generation of sensors have reduced motion errors significantly and increased the clinical reliability [8].

Due to the dissociation curve of hemoglobin, pulse oximeters are most precise in SpO_2 ranges of 70-95% [9]. This means that only relying on pulse oximetry for monitoring neonatal oxygenation carries a risk of overlooking hypoxia and/or hyperoxia, both of which are deleterious to the neonate.

A large study by Wackernagel and colleagues showed the discrepancy between SpO_2 readings and arterial oxygen saturation and oxygen tension in neonates [9]. Among over 27,000 SpO_2/SaO_2 pairs in 1908 patients, 57% of cases showed a PaO_2 < 6 kPa (hypoxia), while the SpO_2 reading was > 90%, and 19% of cases showed a PaO_2 > 11 kPa (hyperoxia) while SpO_2 was < 95%. This means that relying only on SpO_2 for monitoring neonatal oxygenation carries a non-negligible risk of overlooking both hyperoxia and hypoxia. This makes the authors conclude that “pulse oximetry readings did not fulfill the performance requirements for titrating oxygen supplementation in neonatal patients”. Furthermore, pulse oximetry results are dependent on the patient’s skin color, due to the skin’s absorption of near-infrared light. This has led to concerns about racial discrepancy in pulse oximeters [10]. Vesoulis and colleagues showed that there is a “modest but consistent difference in SpO_2 error between black and white infants, with increased incidence of occult hypoxemia in black infants” [11].

Transcutaneous monitoring is also non-invasive and can be used to estimate arterial oxygen and carbon dioxide levels. Transcutaneous monitoring has traditionally been done by placing a heated sensor on the skin that increases the capillary blood flow and amount of oxygen diffusing to the sensor.

Due to different diffusion rates, monitoring tcpCO_2 can typically be achieved using lower temperatures of 38-42°C, which is not feasible for tcpO_2, where temperature has to be kept at 43-44°C to achieve precise results [12]. This has fuelled fear about the risk of skin burns on the sensitive neonatal skin, though the reports of burns in recent decades are scarce.

Newer generation transcutaneous sensors using optical technology have been developed, though they still need to operate at 42-43°C [13].

Several studies have shown that high transcutaneous oxygen levels and oxygen variability is associated with a higher risk of ROP, and that transcutaneous monitoring of oxygen leads to less oxygen variability than SpO_2 monitoring [14, 15].

NIRS (near-infrared spectroscopy) is non-invasive and uses near-infrared light to estimate regional tissue saturation [16]. It has been used in neonatology primarily to monitor regional cerebral oxygenation, but also to assess splanchnic tissue perfusion and its correlation to the course of necrotizing enterocolitis [17].

Although NIRS has been shown to be able to reduce the burden of hypoxia and hyperoxia in preterm infants, it has not yet been proved to reduce neonatal morbidity, though a large multi-center study is undergoing to help answer this [18, 19].

Conclusions:

Titrating the correct amount of oxygen to a neonate is a difficult balance, where many questions about levels of oxygenation and methods to monitor oxygenation are still unanswered.

The different monitoring methods contain advantages and disadvantages, which make some authors argue that oxygen monitoring in neonates should ideally consist of a combination of the different methods [20].

References

1. Robertson AF. Reflections on errors in neonatology: I. The "Hands-Off" years, 1920 to 1950. Journal of perinatology: official journal of the California Perinatal Association 2003; 23, 1: 48–55.
2. Saugstad OD. Oxygenation of the Immature Infant: A Commentary and Recommendations for Oxygen Saturation Targets and Alarm Limits. Neonatology 2018; 114, 1: 69–75.
3. Tan RNGB, Mulder EEM, Lopriore E, Te Pas AB. Monitoring Oxygenation and Gas Exchange in Neonatal Intensive Care Units: Current Practice in the Netherlands. Frontiers in pediatrics 2015; 3: 94.
4. Hellström W, Forssell L, Morsing E, Sävman K, Ley D. Neonatal clinical blood sampling led to major blood loss and was associated with bronchopulmonary dysplasia. Acta paediatrica (Oslo, Norway: 1992) 2020; 109, 4: 679–87.
5. Goenka A, Bhoola R, McKerrow N. Neonatal blood gas sampling methods. South African Journal of Child Health 2012; 6, 1: 3–9.
6. Counsilman CE, Heeger LE, Tan R *et al*. Iatrogenic blood loss in extreme preterm infants due to frequent laboratory tests and procedures. J Matern Fetal Neonatal Med 2021; 34, 16: 2660–65.
7. Walker SM. Long-term effects of neonatal pain. Seminars in fetal & neonatal medicine 2019; 24, 4: 101005.
8. Hay WW, Rodden DJ, Collins SM, Melara DL, Hale KA, Fashaw LM. Reliability of conventional and new pulse oximetry in neonatal patients. Journal of perinatology: official journal of the California Perinatal Association 2002; 22, 5: 360–66.
9. Wackernagel D, Blennow M, Hellström A. Accuracy of pulse oximetry in preterm and term infants is insufficient to determine arterial oxygen saturation and tension. Acta paediatrica (Oslo, Norway: 1992) 2020; 109, 11: 2251–57.
10. Sjoding MW, Dickson RP, Iwashyna TJ, Gay SE, Valley TS. Racial Bias in Pulse Oximetry Measurement. The New England journal of medicine 2020; 383, 25: 2477–78.
11. Vesoulis Z, Tims A, Lodhi H, Lalos N, Whitehead H. Racial discrepancy in pulse oximeter accuracy in preterm infants. Journal of perinatology: official journal of the California Perinatal Association 2021.
12. Jakubowicz JF, Bai S, Matlock DN *et al*. Effect of Transcutaneous Electrode Temperature on Accuracy and Precision of Carbon Dioxide and Oxygen Measurements in the Preterm Infants. Respir Care 2018; 63, 7: 900–06.
13. van Weteringen W, Goos TG, van Essen T *et al*. Novel transcutaneous sensor combining optical tcPO_2 and electrochemical tcPCO_2 monitoring with reflectance pulse oximetry. Medical & biological engineering & computing 2020; 58, 2: 239–47.
14. Flynn JT, Bancalari E, Snyder ES *et al*. A cohort study of transcutaneous oxygen tension and the incidence and severity of retinopathy of prematurity. N Engl J Med 1992; 326, 16: 1050–54.
15. Quine D, Stenson BJ. Does the monitoring method influence stability of oxygenation in preterm infants? A randomised crossover study of saturation versus transcutaneous monitoring. Arch Dis Child Fetal Neonatal Ed 2008; 93, 5: F347-50.
16. Dix LML, van Bel F, Lemmers PMA. Monitoring Cerebral Oxygenation in Neonates: An Update. Front Pediatr 2017; 5, 46.
17. van der Heide M, Hulscher JBF, Bos AF, Kooi EMW. Near-infrared spectroscopy as a diagnostic tool for necrotizing enterocolitis in preterm infants. Pediatric research 2021; 90, 1: 148–55.
18. Hyttel-Sorensen S, Pellicer A, Alderliesten T *et al*. Cerebral near infrared spectroscopy oximetry in extremely preterm infants: Phase II randomised clinical trial. BMJ (Clinical research ed.) 2015; 350: g7635.
19. Gorm Greisen. ClinicalTrials.gov: Safeguarding the Brain of Our Smallest Infants Phase III (SafeBoosC). Available from: URL:https://clinicaltrials.gov/ct2/show/NCT03770741.
20. Poets CF. Noninvasive Monitoring and Assessment of Oxygenation in Infants. Clin Perinatol 2019; 46, 3: 417–33.