RADIOMETER

Importance of invasive & non-invasive CO_2 monitoring in the NICU

Preterm birth is a leading cause of mortality & morbidity for newborns in most parts of the world [1]. As treatment for extreme premature infants has matured, neonatologists are now routinely treating infants born in gestational week 22 and 23, which was earlier thought to be on the limit of viability [2].

As survival for the smallest infants have increased, there has been an increased focus on long-term consequences of being born premature [2]. For a long time, it has been known that it is important to tightly monitor the CO_2 levels of premature infants to increase the chance of a good outcome [3]. Both hypocapnia and hypercapnia has been associated with adverse long-term outcomes for the neonate, including increased risk of bronchopulmonal dysplasia (BPD), intraventricular hemorrhage (IVH), and cerebral injury [4].

Due to the importance of CO_2 monitoring, the current guidelines from the UK National Institute for Health and Care Excellence (NICE) advise for CO_2 monitoring of neonates right after initial stabilization until discharge [5].

CO_2 monitoring can be done invasively (through a heel stick, vein/arterial puncture or blood obtained through an indwelling catheter) or non-invasively (for example through end-tidal or transcutaneous monitoring). The current consensus is that non-invasive monitoring cannot replace invasive monitoring but can supplement the invasive monitoring [6].

CO_2 and cerebral autoregulation

Cerebral autoregulation is the phenomenon where cerebral blood flow is kept constant throughout a wide range of cerebral perfusion pressures [7]. This means that fluctuations in blood pressure, which are common in premature infants, do not lead to a change in cerebral blood flow and oxygen delivery (Figure 1).

Cerebral autoregulation has 3 main purposes: to deliver a constant amount of O_2 to the brain, to eliminate CO_2 and other metabolites and to keep cerebral blood flow constant [7]. Though cerebral autoregulation has been studied since the 1970s the underlying mechanism are not completely understood.

Cerebral autoregulation can be altered by many conditions in premature infants, including prematurity, hypoxia, respiratory diseases, congenital heart disease and necrotizing enterocolitis. These conditions can affect the cerebral blood vessels reactivity to CO_2 and O_2 [7].

The altered reactivity can lead to changes in cerebral blood flow with fluctuations in CO_2 and O_2, increasing the risk of intraventricular hemorrhage (IVH) and thus poor neonatal outcome [8]. Therefore, tight CO_2 monitoring is especially important for neonates affected by the conditions mentioned above.

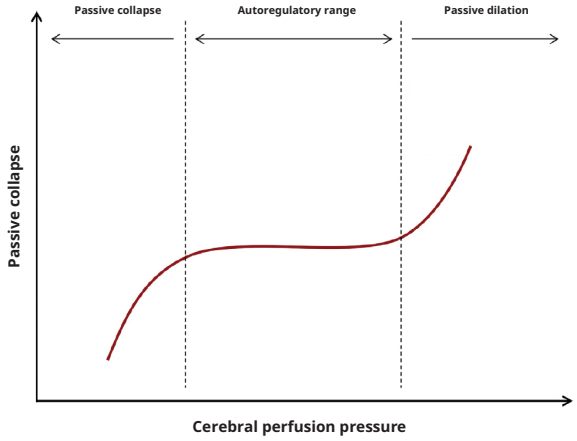

Figure 1. Correlation between cerebral perfusion pressure and cerebral blood flow. In the autoregulatory range, cerebral blood flow is kept constant even when cerebral perfusion pressure changes. Adapted from [7].

Non-invasive CO_2 monitoring in neonatal non-invasive ventilation

While mechanical ventilation & surfactant administration has been key in improving neonatal outcomes, it has also become increasingly clear that mechanical ventilation, especially for a prolonged period of time, can also be damaging to the developing lung, increasing the risk for BPD [9]. This has led to increased interest in non-invasive ventilation methods and less-invasive administration of surfactant (LISA) [9].

Non-invasive methods of ventilation of neonates includes ventilation with nasal continuous positive airway pressure (NCPAP), nasal intermittent positive pressure ventilation (NIPPV), high-frequency oscillatory ventilation (HFOV) & high-flow nasal canula (HFNC) [10].

For most of these ventilation modes, end-tidal capnography is not feasible due to the characteristics of the neonatal lung & ventilation, with small tidal volumes, large ventilatory dead space, high respiratory rates & short expiration time [11].

In these situations, transcutaneous monitoring of CO_2 is a feasible non-invasive method of providing continuous values of CO_2. This is reflected in the American Association For

Respiratory Care (AARC) guidelines, where transcutaneous monitoring is recommended for "Mechanical ventilation, including conventional modes of ventilation, high-frequency ventilation, steady state high frequency jet ventilation and noninvasive ventilation" [12].
Scrivens and colleagues conclude that compared to end-tidal monitoring "$TCCO_2$ provides a safe and meaningful way of monitoring PCO_2 while reducing blood sampling and parents can be reassured that adequate monitoring is taking place" [13].

Quality improvements & safety using transcutaneous monitoring of CO_2

Using transcutaneous monitoring of CO_2 has been shown to be able to reduce the number of blood draws preterm infants by up to 25% [14].
This is both important to reduce the number of painful procedures a neonate is subject to, as well as the associated blood loss which can be up to 1/3 of the total blood volume over the first couple of weeks of life for an extreme preterm infant [15].

Transcutaneous monitoring uses a heated sensor, typically heated between 38-44 ◦C in infants, which has led to considerations about the safety especially for extreme premature infants with very sensitive skin [16].

This understanding was fueled by early case reports of skin lesions which were thought to be due to the temperature of the transcutaneous sensor [17].
Prizant and colleagues reported on neonatal skin lesions (neonatal anetoderma) that were thought to be complications due to other sensors used in neonatal care (ECG, temperature probe & adhesive), and the risk of persistent skin damage might be due to lack of rotation of sensor placement, rather than only due to exposure to high temperatures [18].
Newer transcutaneous devices typically use a lower temperature for monitoring CO_2 in neonates and in recent literature there has not been reports of long-term skin damage. One study reported transient erythema at the site of application in 2% of infants monitored and no permanent skin burns [19].

Summary

Continuous monitoring of CO_2 is an important part of neonatal care, especially for the smallest & sickest infants who are at risk of cerebral perfusion changes due to CO_2 fluctuations. Optimally CO_2 monitoring will be done with a combination of invasive and non-invasive methods. Transcutaneous monitoring of CO_2 can be used regardless of the method of respiratory support and provides safe & non-invasive monitoring that may reduce the number of blood samples needed to properly monitor the neonate.

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