Transcutaneous monitoring of pO_2 and pCO_2 in neonates - a blessing or a burden?

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Kaare E. Lundstrøm
Departments of Neonatology and Paediatric Intensive Care
National University Hospital Rigshospitalet
Blegdamsvej 9
2100 Copenhagen O
Denmark

Monitoring of blood gases is essential in neonatal intensive care. Traditionally arterial samples have been considered the gold standard, but in critically ill neonates physiological changes can happen within minutes to a degree endangering the newborn.

Clinicians can therefore not rely solely on intermittent monitoring.

In relation to blood gases, pulse oximetry has therefore become a new standard.

However, hypocapnia has in several publications been correlated to adverse cerebral outcome in sick neonates.

As hypocapnia compromising the cerebral circulation can develop within minutes, it seems that continuous monitoring of pCO_2(aB) is necessary, too.

Transcutaneous monitoring of pCO_2 and pO_2 provides information on both carbon dioxide status and oxygen delivery to the tissues. The continuous information thereby obtained seems indispensable.

In neonatology it is considered important to reduce the stress of the newborn, to minimize the number of blood samples and to avoid painful procedures if possible.

This concept of minimal handling is gaining worldwide acceptance.

It has been questioned whether transcutaneous monitoring can be considered part of a minimal handling strategy, or if it causes more stress to the newborn.

This article describes the need for monitoring pCO_2(aB) and advantages and disadvantages of transcutaneous monitoring of pCO_2 and pO_2.

Introduction

Monitoring of oxygen and carbon dioxide is still a cornerstone in the management of the sick child, and with many of the new, very effective treatment modalities perhaps even more so than before.

During recent years we have gained essential new knowledge of the influence of blood gases, especially carbon dioxide, on organ function and damage to the organs. It has also been demonstrated how appropriate monitoring can minimize the risk of adverse outcome.

Continuous monitoring of both oxygen and carbon dioxide is essential. Changes occur fast and may be left undetected for sufficient time for organ damage to develop if the clinician relies solely on intermittent monitoring like blood samples.

Several reports have shown improved outcome for preterm infants in units practicing the minimal handling strategy including acceptance of high levels of pCO_2(aB) (permissive hypercapnia) and minimal disturbance [1].

It seems that the less physiological impact of handling, the better the outcome. There is therefore a strong trend towards trying to avoid pain and reduce the number of procedures that the neonate is subjected to.

The question is whether the use of continuous monitoring devices like transcutaneous (tc) pO_2 and pCO_2 electrodes can reduce the stress of the newborn or if the number of procedures needed and the discomfort from the electrode itself actually worsen the situation for the newborn.

To discuss this it is necessary to understand the need for continuous monitoring of pCO_2 and the value of tcpO_2 monitoring.

The importance of monitoring of pCO_2

It is generally accepted that the arterial partial pressure of carbon dioxide (pCO_2(aB)) strongly influences the cerebral circulation with a response time of a few minutes. Decreasing pCO_2(aB) results in decreasing cerebral blood flow [2].

Several studies have demonstrated a strong correlation between low pCO_2(aB) and adverse cerebral outcome [3, 4]. It has not yet been established for how long time pCO_2(aB) must be below a certain value to cause brain damage, but there is reason to believe that the lower the value, the shorter the time needed to cause damage.

At values of 3.0 kPa (22.5 mmHg) or less, damage can occur in as little as a few minutes, but also exposure to slightly higher partial pressures for a longer period of time may be dangerous [5].

For this reason alone, continuous monitoring of pCO_2 in any acutely ill child requiring ventilatory support should be incorporated as a standard of practice to reduce the risk of brain damage.

High values of pCO_2 may not be dangerous for the cerebral circulation of the neonate as no correlation between high pCO_2 and adverse outcome has yet been demonstrated.

However, slight hypercapnia in animal studies has shown to have a protective effect on the brain suffering from ischemia [6]. Hypercapnia can result in acidosis, and in that case it may require treatment.

Sudden upward changes in pCO_2 indicate changes in the condition of the child or complications to the treatment and must therefore lead to a careful evaluation of the situation.

Pneumothorax in the newborn has a significant mortality and morbidity. Early diagnosis is likely to improve the outcome. It has recently been shown that the diagnosis of pneumothorax is often late; median time from onset to clinical diagnosis was 127 minutes [7].

Transcutaneous monitoring of pCO_2 was shown to allow the diagnosis to be made earlier and thereby possibly reduce the risk of adverse outcome.

Though still not proven beneficial in clinical, randomized studies of neonates permissive hypercapnia is a treatment strategy used in many centers [8, 9, 10]. The exact level of pCO_2 to aim for is not well defined and varies between centers.

When using permissive hypercapnia it is important to avoid too high levels of pCO_2 and acidosis. During the initiation of permissive hypercapnia, but also later in the course, it is a safe method to use transcutaneous monitoring of pCO_2 to avoid excessive hypercapnia and acidosis.

Monitoring oxygen status

Possibly the most important goal in the care of the sick neonate is to ensure an adequate oxygen supply to the tissues and organs. Hypoxia and ischemia are as dangerous in these patients as in any other patient, though the neonate is often more resistant to hypoxia than older patients.

Hyperoxia, however, seems to be particularly endangering for the preterm neonate, more so than for older patients [11]. This is presumably due to a lower antioxidant capacity.

Too much oxygen has been shown to reduce the cerebral blood flow for hours after normalization of oxygen status in newborn preterm infants [12]. Toxicity to the lungs has also been demonstrated [13]. Hyperoxia must therefore be avoided, especially in preterm infants [14].

Little is known about optimal target levels for pO_2(aB) and sO_2(aB) in newborns with a high total concentration of hemoglobin and high amounts of fetal hemoglobin. It is important to keep in mind that fetuses develop and grow with pO_2 of 2.5-3 kPa (19-23 mmHg) and sO_2 of 65-70 %.

The oxygen status of the neonate changes rapidly, and adequate monitoring therefore includes continuous monitoring.

Possibly, the best monitoring is a combination of tcpO_2 and pulse oximetry with intermittent arterial blood samples including lactate measurements.

Pulse oximetry provides a fast response to changes in oxygen uptake and transport. The tcpO_2 offers trend information on the oxygen delivery to the tissues [15, 16]. Blood samples are necessary to correlate the non-invasively measured values to the arterial values and to get an in-depth overview of the oxygen status.

Measurement of lactate is important to evaluate the adequacy of the oxygen supply to the tissues as the lactate production increases when oxygen supply is compromised, and anaerobic metabolism takes place.

Blood samples, a necessary dilemma in neonatology
Arterial blood samples remain the standard of blood gas evaluation. However, the quality of blood sampling is essential for the results, and blood samples are always just momentary pictures of the status.

The interpretation of blood samples is significantly improved when combined with continuous monitoring. The sampling itself can disturb the newborn and changes in blood gas values in relation to sampling often happen.

This invalidates the interpretation of blood gas results, unless the difference between the stable condition and the condition during sampling has been recorded by continuous monitoring.

Blood samples can have undesired side effects. Repeated samples may not only disturb and stress the patient, they may also cause the need for blood transfusion. The number of blood samples should therefore be reduced to a necessary minimum.

A recent study showed significant changes in cerebral circulation with impaired oxygenation in relation to sampling from umbilical artery catheters [17]. Care has to be taken to minimize this impairment.

Capillary samples can, if collected correctly, to some extent substitute arterial samples. Capillary samples

are, however, even more susceptible to preanalytical errors, and this must be kept in mind when results are interpreted [18].

Oxygen status and lactate in capillary samples may not correlate well with arterial values, especially in the child with compromised peripheral circulation.

Transcutaneous monitoring of pCO_2 - non-invasive minimal handling?

Continuous monitoring of pCO_2 is necessary to avoid especially too low values in the neonate receiving ventilatory support.

Invasive procedures like cannulation of a vessel and blood sampling, where there is penetration of the skin, not only cause pain, they also increase the risk of infections.

End-tidal pCO_2 monitoring has proven to be unreliable in neonates with cardio-pulmonary disease. Transcutaneous monitoring of pCO_2 is therefore the only non-invasive option for continuous monitoring of pCO_2, and is therefore recommended.

However, like other techniques transcutaneous monitoring of pCO_2 has to be learned.

There is a risk of an increase in the number of blood samples taken, if the clinician does not rely on the continuous monitoring and wants a blood sample for control every time the values change. Physiological fluctuations are normal in the sick neonate, and there is a learning curve for acceptance of these.

The clinician has also to believe in the results of the continuous monitoring and react on them directly. In clinics used to transcutaneous monitoring it is normal to adjust ventilator settings as well as to wean from ventilators without blood samples [19].

Traditionally, there are concerns regarding transcutaneous electrodes: The heating of the skin and potential risk of burn wounds and pressure-induced necrosis. These risks can be eliminated or minimized by following some advice.

- The thinner the skin (i.e. the more premature the baby is), the lower the temperature that can be used. In adults and children a temperature of 44 °C is recommended, and this temperature can be used for neonates and even preterm neonates. A temperature of 43.5 °C, however, is sufficient in term neonates, and temperatures as low as 42 °C can be used, especially in very preterm infants. The lower the temperature, the less the risk of heat-induced skin changes. It is important to remember that when monitoring at the lower temperature, there will be a longer response time and greater difference between arterial and transcutaneous oxygen tensions.
- It is important to change electrode site every three to four hours. On patients with thin, gracile skin, every two hours, possibly every hour. This can be done by attaching two or three fixation rings and change position of the electrode between these. By not removing the fixation rings every time the electrode position is changed, the influence on the skin is minimized. The fixation ring should, however, be removed from the skin every 12 to 24 hours, depending on the condition of the skin.
- Direct pressure should never be placed on a transcutaneous electrode while on the patient. Additionally, the electrode should be placed so that the patient cannot lie directly on top of it. Both the above-mentioned incidences may invalidate the measurements and/or cause skin necrosis.

Conclusion

Transcutaneous monitoring of pO_2 and pCO_2 is a non-invasive method of monitoring the patient's oxygen and carbon dioxide status. The technique provides unique information that, in combination with other monitoring modalities, reduces the stress of the newborn and safeguards against inadvertently high or low blood gas values.

It is therefore likely that the use of transcutaneous

monitoring of pO_2 and pCO_2 can improve the outcome for the sick neonate.

It is, however, more complicated to use transcutaneous monitoring of pO_2 and pCO_2 than to use a pulse oximeter. It is therefore important to follow the recommendations given as well as the guidelines and instructions from the user's manual, provided with the instrument.

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