End-tidal carbon dioxide monitoring in neonates

Carbon dioxide monitoring is vital in the management of ventilated newborn babies. This is usually done by arterial or capillary blood gas analysis. In this article an alternate non-invasive method of carbon dioxide monitoring – end-tidal carbon dioxide monitoring – is reviewed.

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Key points

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1. End-tidal carbon dioxide monitoring is not as reliable as arterial blood gas analysis for monitoring $PaCO_2$, however it may have a role in monitoring the trend of $PaCO_2$.
2. $EtCO_2$ monitoring is not a reliable indirect measure of $PaCO_2$ in ventilated infants undergoing transfer.
3. A calorimetric $EtCO_2$ detector can be used for rapid assessment of endotracheal tube placement.

The gold standard for monitoring the adequacy of ventilation and oxygenation of ventilated babies is arterial blood gas analysis. However, over the years there has been a gradual decline in the reliance on arterial blood samples due to several factors. Arterial blood gas sampling leads to blood loss which may increase the need for blood transfusions. Also monitoring by arterial blood gas requires central or peripheral arterial catheters, which are not without risks – there have been incidences of digital ischaemia and arterial spasm[1]. Continuous pulse oximetry provides a non-invasive method of monitoring oxygenation in neonatal intensive care unit (NICU)[2]. Hence, there is a need for alternate modes of monitoring carbon dioxide.

It is essential to maintain optimal carbon dioxide levels as this may help to prevent chronic lung disease and periventricular leukomalacia[3,4]. Alternative methods of carbon dioxide monitoring include measurement of capillary blood gases, partial pressure of end-tidal carbon dioxide ($PetCO_2$) and transcutaneous partial pressure of carbon dioxide ($TcPaCO_2$). Carbon dioxide monitors have been proved to be effective and rapid indicators of endotracheal intubation[5]. They may also be used to monitor trends of carbon dioxide during neonatal transfers. In this review the efficacy of end-tidal carbon dioxide monitoring is examined. An in-depth review of $TcPaCO_2$ is outside the scope of this review.

End-tidal carbon dioxide monitoring or capnography

End-tidal carbon dioxide ($EtCO_2$) monitoring is an attractive method as it is non-invasive, portable and relatively inexpensive. The technique has been widely used in the adult and paediatric intensive care setting, and has been found to be an accurate method of estimating $PaCO_2$ in term infants, however, it has not been widely accepted in NICU as it provides only a rough estimation of $PaCO_2$ in infants with significant lung disease[6,7].

$EtCO_2$ detectors measure the levels of carbon dioxide in exhaled breath. $EtCO_2$ is the carbon dioxide at its maximum level at the end of expiration. A good end-tidal plateau in exhaled $PaCO_2$ usually represents alveolar $PaCO_2$ which is readily measurable in adults and older children with large tidal volumes. However, this can be difficult in sick neonates who often have a rapid respiratory rate. The carbon dioxide can be measured by chemical reaction, referred to as calorimetry or actual measurement of carbon dioxide molecules. The latter method is a better measure in the intensive care setting as it provides a numerical value.

The two basic types of carbon dioxide monitors are the capnometer and the capnograph, which use infrared absorption or mass spectrometry to measure the carbon dioxide and display the carbon dioxide tension in mmHg or percentage of carbon dioxide[8]. The capnometer displays $EtCO_2$ values while the capnograph, which measures carbon dioxide during each inspiratory/expiratory cycle, displays both a carbon dioxide waveform and numerical value (**FIGURE 1**).

Two types of sampling techniques are available for capnometry – mainstream and sidestream sampling.

Mainstream capnometer

The carbon dioxide analyser is built into an adaptor, inline and close to the endotracheal tube. The main advantage of the mainstream analyser is its fast response as the

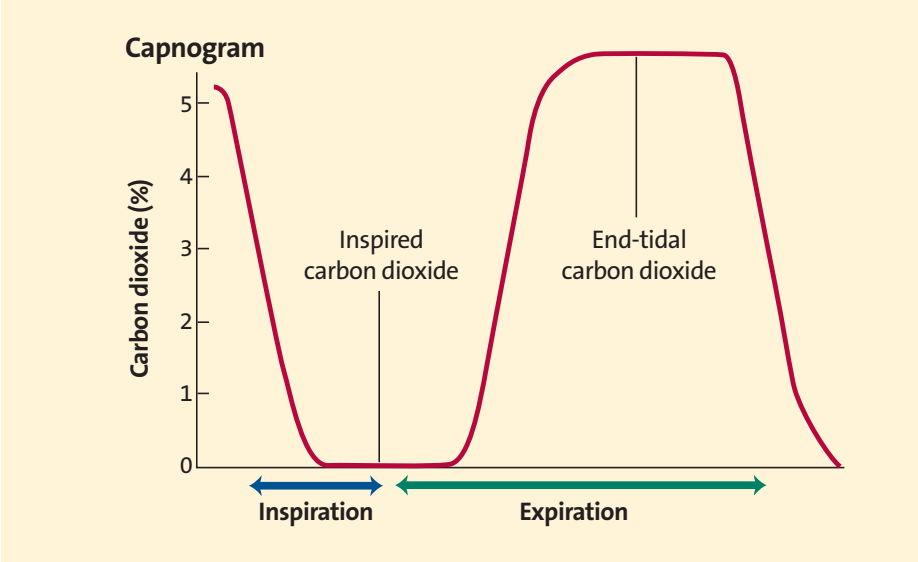

FIGURE 1 A capnograph illustrating the expiratory CO_2 waveform.

measurement chamber is part of the breathing circuit[9]. However the major disadvantage of the mainstream analyser is that it is bulkier and results in extra dead space. However, smaller ones are now available for neonates, which reduce the problem with dead space.

Sidestream capnometer

A sampling tube is attached to a T-piece adapter at the airway opening through which airway gases are aspirated for analysis of carbon dioxide[9].

The main advantage of the sidestream analyser is there is no extra dead space and it is light. Disadvantages include longer response time, risk of dilution of expired gas and potential to block with secretions.

Validity of $EtCO_2$

Clinical studies have shown a relationship between $EtCO_2$ and $PaCO_2$ with some proving a much stronger correlation than others. Watkins and Weindling in a study of 19 infants (69 samples) observed a poor overall correlation (r=0.39)[10]. On the other hand, Wu et al described a good correlation between $PetCO_2$ and $PaCO_2$ in both term (44 samples) and preterm infants (86 samples), r=0.78 and 0.85 respectively, and concluded that $PetCO_2$ was a valid non-invasive monitoring technique in both these groups. They even went as far as to recommend that it replaces blood gas sampling on the NICU[11]. However, this study only looked at the correlation between the two methods and not the level of agreement. Nangia et al studied 152 samples in preterms <32 weeks and observed significant correlation ($p<0.001$)[12]. Aliwalas et al studied 27 infants preterm ≤28 completed weeks' gestation and concluded that there was a moderate agreement between the non-invasive methods and $PaCO_2$ in the first 24 hours (r=0.61,0.56 and 0.57 at 4, 12 and 24 hours) but this method could not be used to substitute $PaCO_2$ analysis in preterm infants during this critical period[13]. Singh et al conducted a retrospective chart review of extremely low birthweight infants (ELBW) with 754 paired samples and showed good correlation (r=0.81) and agreement between $EtCO_2$ and $PaCO_2$ in the $EtCO_2$ range between 30-50mmHg in the first week of life. They concluded that $EtCO_2$ monitoring could be helpful in trending of carbon dioxide levels and for screening abnormal $PaCO_2$ in ELBW infants in the first week of life[14].

Hegerty et al found that low-flow capnography with Microstream technology accurately measured alveolar PCO_2 in neonates without pulmonary disease as demonstrated by normal $PetCO_2$-$PaCO_2$ gradient. However, in neonates with pulmonary disease the measured $PetCO_2$-$PaCO_2$ gradient was higher[6].

End-tidal CO_2 monitors have been tried during inter-hospital transfers. Tingay et al studied infants undergoing inter-hospital transfer and found there was a linear relation between $PetCO_2$ and $PaCO_2$, but $PetCO_2$ underestimated $PaCO_2$ by 1.04kPa ± 0.98SD in 21 infants. This degree of bias was considered clinically unacceptable and $PetCO_2$ was found to be neither a precise nor reliable method during the transfer of neonates[15]. On the contrary, Rozyscki et al described a mean degree of bias of 0.92kPa in 45 infants and the authors concluded that despite this difference $PetCO_2$ provided a reliable estimate of $PaCO_2$ trends[7].

Thus, past research has found conflicting results as to the validity of $PetCO_2$.

Calorimetric $EtCO_2$ detectors

A calorimetric $EtCO_2$ detector can be used for rapid assessment of endotracheal tube (ETT) placement in the trachea and has been found to be useful in adults, children and neonates[16-20]. It is a portable and disposable device that connects in series between the ventilator and ETT. The device contains a pH sensitive reversible chemical indicator which changes from purple to yellow with expired carbon dioxide. Six complete breaths need to be delivered before the colour change can be relied upon[21]. The minimum carbon dioxide needed for colour change has been shown to be 0.5kPa and maximum colour change occurs above 2-5 kPa. The dead space in Pedi-Cap, a paediatric calorimeter, is 3mL and it can be used briefly in infants up to one kilogram[22] (**FIGURE 2**).

FIGURE 2 Pedi-Cap® CO_2 courtesy of Covidien (UK) Commercial Ltd.

Intubation can be difficult with a success rate of less than 40% in infants less than 28 weeks' gestation[23]. Clinical signs may not always help in ascertaining the correct positioning of an ETT. A secondary measure to aid in the correct positioning of the ETT would be welcome. Aziz et al studied 49 newborns requiring intubation using calorimetric capnography (Pedi-Cap). Thirty of the 33 newborns who were successfully intubated on the first attempt showed colour change with a 91% true positive and 9% false positive. The three newborns with false positives had severe cardiopulmonary disease. There were no false positives in the twelve babies who had oesophageal intubation[19].

Calometeric $ETCO_2$ detectors in neonates are not without limitations. They cannot detect hypocarbia or hypercarbia[22]. They cannot be relied upon in neonates during severe cardiopulmonary arrest[19]. Poorly compliant lungs and poor or absent pulmonary blood flow can give rise to false negative results[24]. False positives may occur in situations when the calorimetric detector is contaminated with gastric fluids or drugs. False negatives may occur in neonates requiring venoarterial extracorporeal membrane oxygenation, extremely low birthweight infants, hypocarbia and cardiopulmonary arrest[21].

Hence, the calorimetric $ETCO_2$ detector is a valuable tool providing the user is aware of its limitations.

Transcutaneous carbon dioxide monitoring

Transcutaneous carbon dioxide ($TcPCO_2$) monitoring is the more commonly used non-invasive carbon dioxide monitor in neonates and has been shown to accurately predict $PaCO_2$ and monitor carbon dioxide trends[25,26].

$TcPCO_2$ measurement is based on the principle that carbon dioxide diffuses through the body tissues and can be detected by a sensor with a gas-permeable membrane at the skin surface. Though the thin epidermal layer of the skin of preterm infants is advantageous in $TcPCO_2$ measurement, it has some disadvantages. It can be difficult to use due to sensor preparation and positioning and it requires repeated change of the sensor location and is bulky. It can cause skin damage and burns from electrodes[27,28]. Poor tissue perfusion and acidosis can alter $TcPCO_2$ values. $TcPCO_2$ is more reliable than $EtCO_2$ monitors during transport as the latter has a significant under-recording bias, by about 1kPa[15,25].

Several studies have been done comparing $TcPCO_2$ and $PetCO_2$ with $PaCO_2$ and found $TcPCO_2$ to be a better indicator of $PaCO_2$. An in-depth review of $TcPCO_2$ is outside the scope of this article.

Summary

Measurement of $EtCO_2$ does not reflect the exact arterial $PaCO_2$ value and hence cannot replace arterial blood gas monitoring, which is still the gold standard in monitoring carbon dioxide. The small tidal volumes and rapid respiratory rate in neonates may result in a wide variation in $EtCO_2$ values. However, studies have shown that there is a reasonable correlation between the $EtCO_2$ and $PaCO_2$, and hence $EtCO_2$ monitors may have a role for monitoring the trend in $PaCO_2$. They can also be used for rapid assessment of endotracheal tube placement.

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