Is ETCO2 a predictor of PaCO2 in ventilated neonates on the Neonatal Intensive Care Unit?

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Abstract

Background: A key focus to monitoring ventilator efficacy in critically ill neonates is to avoid the complications caused as a result of hypocarbia and hypercarbia. The current gold standard for monitoring ventilator efficacy is by measuring Arterial Blood Gases (ABGs). However more traditional methods of monitoring include Transcutaneous monitoring and Pulse oximetry (SpO2). Several reports outline the limitations associated with the accuracy and applicability of these methods.

Aim: To explore the use and contribution of end-tidal carbon dioxide (ETCO2) monitoring in ventilated neonates on the neonatal intensive care unit.

Search Methods: A comprehensive literature search was conducted by a selection of relevant search terms.

Selection criteria: The selection process was staged to ensure that credible robust evidence was selected against a set of predefined inclusion and exclusion criteria. Following this stringent process seven papers were selected.

Main results: Through analysis of the data presented in the seven studies it can be deduced that extension of this method of monitoring to the neonatal group is rendered more complicated by functional issues such as the relatively large dead space, rapid breathing rates with low tidal volumes and ventilation-perfusion mismatch as a result of underlying lung disease. However advances in capnometer technology have allowed for modifications to overcome such limitations. Rozycki et al (1998), Wu et al. (2003), Bhat and Abhishek (2008) and Nangia et al (1997) found a good correlation existed between ETCO2 and PaCO2 in patients without underlying lung disease.

Conclusions: Whilst all the studies in this review showed that a correlation exists between ETCO2 and PaCO2, this correlation was stronger in the groups with no underlying lung disease. In taking this forward it can be established that whilst ETCO2 cannot replace the gold standard, it can be used with caution as a valuable trending tool.

Key words: End-tidal carbon dioxide monitoring, capnography, ventilated neonate

Background

Neonates ventilated on the neonatal intensive care unit (NICU) are monitored closely for efficacy of ventilation in an attempt to reduce complications associated with hypoxia, hypocarbia and hypercarbia. This is achieved by a range of monitoring methods such as arterial blood gases (ABGs), pulse oximetry (SpO2) and transcutaneous (Tc) monitoring. Whilst an ABG remains the gold standard it only provides a snap shot view of ventilator efficacy, and sampling is associated with complications such as perfusion injuries, air emboli and infections.

Other modes of monitoring have evolved in an attempt to provide continuous non-invasive measurements. These include transcutaneous oxygen/carbon dioxide and SpO2 monitoring. Whilst these methods of monitoring have become standard practice in many neonatal units they themselves are associated with limitations such as those listed in the table below.

While the more traditional approaches to monitoring ventilation are well established, they have their limitations, and an awareness is required of the advancements in technology to enable one to improve the way in which neonatal ventilation is controlled. One such method is End-tidal carbon dioxide monitoring (ETCO2). This is a continuous non-invasive method of monitoring that is based on the principle that carbon dioxide (CO2) will be detected during expiration from a

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Table 1: Limitations of Transcutaneous and SpO2 Monitoring

Transcutaneous Monitoring	Pulse Oximetry
Thermal injury	Information on Oxygenation only
Long Stabilization time	Signal quality
Frequent calibrations required	Pressure sores from probe
Damage to skin with adhesive	Motion artifacts
Slow response time	Electromagnetic interferences

(Carter and Williams 2008)

correctly placed endotracheal tube (ETT). Initially adopted for anaesthetics, its use to confirm airway patency and lung ventilation has expanded over the last decade to include critical care, emergency medicine, field resuscitation and conscious sedation settings (ASA 2005).

End-tidal CO2 Monitoring

Capnometers are available as either a side-stream or mainstream sampling device. The use of capnography in neonatal practice is less well documented because of functional limitations including the additional dead space, failure to reach an expiratory plateau during rapid respiratory rates and the technical limitations of ETCO2 devices to interpret CO2 in small tidal volume states (Hammer 2006). Recent advances in technology have explored ways in which to overcome such limitations by modifying the capnometer to consider the dynamics of the neonatal lung model with resultant development of a micro-stream device (Colman and Krauss 1999). The clinical application of the device can be interpreted in the capnogram (Fig 1) which represents the concentration of CO2 in the airway through different phases of the respiratory cycle.

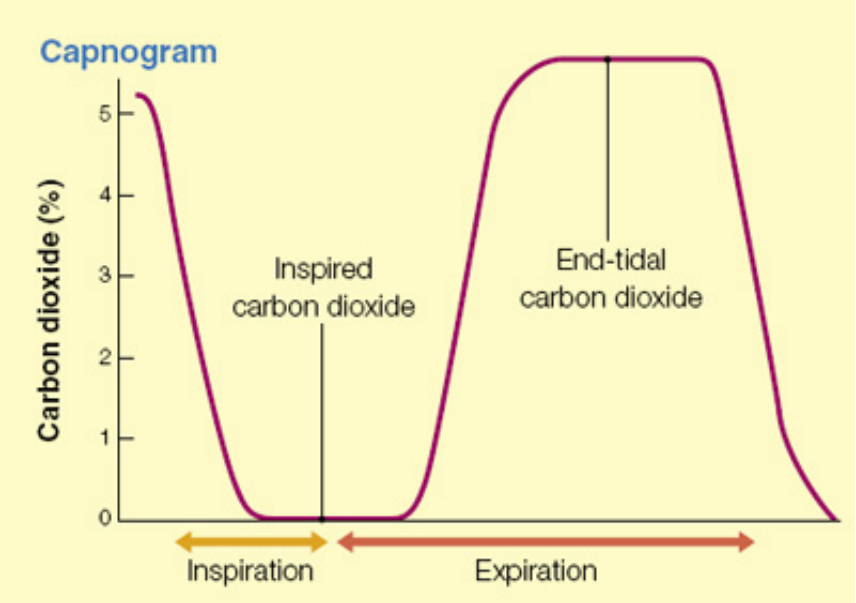

Figure 1: The Time Capnogram – Represents the plot of the concentration of carbon dioxide as measured in the airway sample against the time axis of the phases of respiration

A typical time capnogram can be considered in two parts, i.e. an inspiratory and an expiratory phase. The normal airway CO2 values are 6-7%, which equates to 45-55mmHg. The CO2 concentration reflects cardiac output and pulmonary blood flow as the gas is transported by the venous system to the right side of the heart and then pumped to the lungs by the right ventricle (West 2008). When CO2 diffuses out of the lungs into the exhaled air, a device called the capnometer measures the partial pressure or maximal concentration of CO2 at the end of exhalation. This represents the ETCO2 (Fig 1).

Review Process

In undertaking a literature search potential confounding factors were considered.

Aim

Several key drivers have led to the development of an evidence based healthcare, requiring one to make use of best evidence to inform practice (Thomson and Dowding 2002).

This review examines the applicability and use of ETCO2 in ventilated newborn infants on the NICU.

Search Strategy

A search strategy was undertaken covering the period May 2009 to February 2010. The initial stages of this literature search involved identifying primary sources, grey literature and expert opinions relating to the use of ETCO2. The second stage of this search process was formalised by entering search terms namely: "Capnography or End-tidal CO2 AND ventilated neonates". The databases accessed included Medline, British Nursing Index, Cumulative Index of Nursing (CINAHL), Pubmed, Cochrane, Journals and Books at Ovid, Health Management Information Consortium (HMIC), The Excerpta Medical Database (EMBASE), Biomed Central, Web of Knowledge, Turning Resource into Knowledge (TRIP), Register for Clinical Trials, Health Information Resources and the Electronic Table of Contents (ZETOC).

Selection Criteria

Studies were included in this review if they were primary research articles published after 1990 studying ventilated neonates on a NICU and focused on the comparison of ETCO2 measurement with PaCO2 values.

Studies were excluded if they included older infants, adults or animal studies. To ensure that the search strategy incorporated recent advances in technology, studies prior to 1990 were excluded.

10 studies were identified. To provide a robust review of evidence, studies that mapped well on the hierarchy of evidence were included in this review. Following further evaluation, 3 papers were excluded as they focused around the clinical applications of capnography to the neonatal speciality.

7 studies were identified as eligible for inclusion as they examined the correlation existing between ETCO2 and PaCO2. A key strength of these seven studies where that they took place in tertiary centres.

Author / Year / Country	Hierarchy of Evidence	Aim(s) of study	Sample	Methodology	Results
Kugelman, A.	Level 2b	To evaluate a novel method of distal end-tidal CO_2 ($DETCO_2$) by comparison with $PaCO_2$ and with a more standard method that measures mainstream end-tidal CO_2 in intubated infants.	27 infants with median birth weight : 1835 grams	Prospective quantitative study	$DETCO_2$ had a good correlation with $PaCO_2$ (where n=222, r= 0.72, p<0.001).
Geiger-Aginsky, D., Bader, D., Shoris, I., Riskin, A.			(490g-4790g)	Al infants intubated with a double lumen ETT. Neonates had indwelling arterial lines.	The study further highlighted that $DETCO_2$ was a better predictor of $PaCO_2$ in neonates with underlying lung pathology.
2008				Infants were connected simultaneously to proximal $ETCO_2$ and $DETCO_2$ monitors and measurements were compared to $PaCO_2$.	
Israel			Mean gestational age :		
			32 weeks (24.8-40.8)		
			222 $DETCO_2$- $PaCO_2$ pairs		
			212 $ETCO_2$-$PaCO_2$ pairs		
Singh, A. S.	Level 2b	To study the correlation and agreement between $ETCO_2$ and $PaCO_2$ in ventilated extremely low birth weight (ELBW) infants in the first week of life.		Retrospective chart review	Good overall correlation and agreement between $ETCO_2$ and $PaCO_2$ in surfactant treated, ventilated ELBW babies during the first week of life.
Signal, N.			31 ELBW infants: < 1000g		The Pearsons Correlation Co-efficient was 0.71 with a 95% Confidence Interval.
2005			21 male and 10 female	All admissions to the NICU	The Bland Altman plot demonstrated a good correlation and the study further demonstrated an intraclass correlation co-efficient of 0.81 (p<0.0001).
Canada			All ventilated	Infants were mechanically ventilated and had indwelling arterial catheters insitu.	
				All infants were connected to a mainstream capnometer. 754 simultaneous $ETCO_2$ and $PaCO_2$ pairs collected and analysed.	

Wu, Ch., Chou, H.C., Hseih, W.S., Chen, W.K., Huang, P.Y. and Tsao, P.N.	Level 2b	To estimate $PaCO_2$ by $ETCO_2$ monitoring in the NICU	61 Patients recruited. 20 term and 41 preterm infants.	Prospective non randomised single arm study.	This study did not show a difference in measurements between preterm or term neonates with underlying lung disease.
2003			All patients were ventilated and had indwelling arterial catheters.	130 $ETCO_2$/$PaCO_2$ pairs were analysed from 61 patients.	The researchers showed a positive correlation between $ETCO_2$ and $PaCO_2$.
Taiwan			Main reasons for intubation were either Respiratory Distress Syndrome (RDS) or cardiac disease.		An overall correlation showed 'r'=0.83 where p<0.001.
					In the term group 'r' = 0.779, p< 0.001 and in the preterm group 'r'= 0.849, p< 0.001.
					The overall $ETCO_2$ bias (mean +/- SD) was 3.5 +/- 7.1mmHg and a 95% Confidence Interval for the mean of 2.2-4.7.
Rozycki,H.J.,	Level 2b	To determine the accuracy and precision of $ETCO_2$ monitoring in NICU patients	45 Newborn infants.	Prospective non randomised single arm quantitative study.	Patients were stratified into two groups.
Sysyn,G.D.,			All mechanically ventilated and had indwelling arterial access.	411 $ETCO_2$/$PaCO_2$ pairs were analysed from 45 patients.	
Marshall,M.K., Malloy, R. and Wiswell, T.E.			A predefined subsample of infants with birthweight < 1000g, < 8 days old and who received surfactant therapy.	The correlation co-efficient was 0.83, with a 95% Confidence Interval and a 63% accuracy in predicting hypocarbia and hypercarbia.	However patients in the SUB groups and ALL groups regardless of gestational age or underlying lung disease demonstrated similiar correlation between $ETCO_2$ and $PaCO_2$ ('r' = 0.833 and 0.821 respectively with p<0.001).
1998			Patients categorised into SUB group and an ALL group based on the abovementioned criteria.	The SUB group was incorporated into the ALL group.	
United States					

Nangia, S. Saili, A. and Dutta, A.K. 1997 New Dehli, India	Level 2b	To determine the correlation between $ETCO_2$ and $PaCO_2$ in various clinical situations.	A total of 152 samples from arterial catheters were analysed from babies with birth weights from 900g to 3400g, with gestational ages from 28 weeks to 42, ventilated for various indications such as Severe Birth Asphyxia (SBA), Meconium Aspiration Syndrome (MAS), and Hyaline Membrane Disease (HMD).	Prospective non randomised quantitative study. A total of 152 $ETCO_2$/$PaCO_2$ pairs analysed.	This study showed that $ETCO_2$ correlates closely with $PaCO_2$ in most clinical situations in neonates. Patients with underlying lung disease had the lowest correlation coefficient ('r' =0.55), whilst patients who were ventilated for non pulmonary reasons demonstrated a higher correlation coefficient ('r'=0.96).
Bhat, Y.R. and	Level 2b	To determine the correlation and agreement between $ETCO_2$ and $PaCO_2$ in newborns ventilated for various clinical conditions.	A total of 133 $ETCO_2$/$PaCO_2$ pairs were analysed from 32 ventilated newborns.	Prospective nonrandomised quantitative study.	The overall correlation coefficient was 0.73, with a $p < 0.001$. The $ETCO_2$ value was lower than the corresponding $PaCO_2$ value in 86.5% pairs.
Abhishek, N.			Mean gestational age was 34.6 +/- 3.8 weeks.	Total of 133 $ETCO_2$/$PaCO_2$ pairs from 32 patients.	'r' more than or equal to 0.92 in neonates ventilated for sepsis, asphyxia and apnoea of prematurity. 'r' =0.67 in the HMD group and 'r' = 0.69 in MAS group.
2008			Birthweight was 2200 grams +/- 780 grams.		Neonates who received surfactant had a better 'r' value than those than did not (0.76 vs 0.60).
India				The researchers stratified the patients according to reasons for ventilation. Patients in the pulmonary group were further stratified into those who received surfactant and those who did not.	

Haggerty, J.J.,	Level 2b	To evaluate the accuracy of a new low flow side stream capnography and analyse the components of the capnogram in ventilated newborns with and without pulmonary disease.	20 patients (13 in the pulmonary group and 7 in the non pulmonary group).	Prospective nonrandomised pilot study.	Low flow capnography accurately measured alveolar CO_2 in newborns without pulmonary disease.
Kleinman, M.E.,			Eligible infants were mechanically ventilated and had indwelling arterial catheters insitu.	Capnography was performed through a side port in the proximal ETT.	
Zurakowski, D.,				$PeTCO_2$ was measured for one minute pre and post ABG sampling.	The measured $PeTCO_2$ -$PaCO_2$ gradients were much higher in newborns with underlying pulmonary disease.
Lyons,A.C. and			2 groups were identified: newborns who were receiving ventilation for underlying pulmonary disease and newborns receiving post operative mechanical ventilation with no underlying pulmonary disease.		
Krauss, B				Newborns in the pulmonary group (n=13) and newborns in the control group (n=7)were matched for birthweight, gestational age and postnatal age.	4 Waveforms were quantified which may be useful differentiating patients with pulmonary disease from those without.
2002					
United States				Mean $PeTCO_2$ - $PaCO_2$ gradients were different between the two groups.	

Table 2: Detail of selected studies

Methodology

Study Design

This review focuses on analysing the relationship between ETCO2 and PaCO2 which requires potential confounding factors to be tightly controlled. All studies in this review were therefore correlational and non randomised.
To ensure the validity of results and minimise subjective bias, all patients were evaluated using both the reference standard (ABG) and the test of interest (ETCO2). Although this method of allocation can potentially lead to systematic bias, the researchers stratified patients into cohorts based on patient characteristics.

Data Collection

The manner in which data is obtained can be susceptible to influences that can alter the results (Polit and Beck 2010). In addition, clearly defined standard protocols for data collection are important in avoiding verification and workup bias (Dawes et al 2005). In all the studies, patients received both ABG and ETCO2 monitoring, thereby ensuring workup bias was avoided. However, none of the studies discussed a standard protocol of data gathering or analysis. For interventional trials, the accepted analysis is by intention to treat. The equivalent in this study would equate to ensuring that all recorded samples were assessed and that each paired ETCO2 and PaCO2 was assessed. Wu et al (2003) refers to measurements being scattered throughout the course of the disease but no further information is provided to allow for reproducibility outside this study. Bhat and Abhishek (2008) and Rozycki et al (1998) stated that ABGs were performed at the discretion of the clinician, whilst Singh and Singhal (2005) have not provided any information on how data was collected. This limitation lends itself to various degrees of errors in measurement and biases. Failure to establish uniformity in data gathering influences the reliability of results. In the study performed by Nangia et al (1997), it is unclear whether the tests were performed independently of each other thereby possibly lending to reviewer bias. However Haggerty et al (2002) provided a basic guide for data collection which correlated with waveform analysis. Wu et al (2002), attempted to minimise inter-observer bias through use of the same respiratory therapist to collect all data.

Data Analysis

Ethics

Rozycki et al (1998), Wu et al (2003) and Haggerty et al (2002) explicitly demonstrated in their studies the application of the ethical principles of research (ICN 2003).

Type of capnometer used

The capnometers used in the clinical setting utilise either side-stream or mainstream sampling. Kirpalani et al (1991) showed that side-stream sampling underestimates PaCO2 due to the relatively low tidal volumes and rapid breathing rates in neonates resulting in falsely low ETCO2 readings. Another disadvantage is the delay between sampling and measurement of ETCO2 (Pascucci et al 1989). However McEvedy et al (1990) showed that both mainstream and sidestream technology produced similiar results.
For the studies in this review, Rozycki et al (1998), Wu et al (2003), Bhat and Abhishek (2008) and Singh and Singhal (2005) used mainstream sampling, whilst Nangia et al (1997) used side-stream sampling and Haggerty et al (2002) used micro-stream sampling. However Kugelman et al (2008) aimed to demonstrate that distal ETCO2 (DETCO2) was a better predictor of PaCO2 than mainstream ETCO2. The use of different methods of ETCO2 monitoring used across the various studies allowed for a comparison to be made between the different types of capnography .

Reliability and accuracy of the capnometer

Reliabiity refers to the accuracy and consistency of the information obtained (Polit and Beck 2010). One method of quantifying this would be through proper calibration and application of the capnometer to the breathing circuit. In addition, assessment of sensitivity and specificity will strengthen the reliability of the capnometer allowing the end user to interpret these findings with a degree of confidence.
Rozycki et al (1998), Wu et al (2003), Bhat and Abhishek (2008), Nangia et al (1997) and Singh and Singhal (2005) reported that capnometers were calibrated as per manufacturer's recommendations. Kugelman et al (2008) and Haggerty et al (2002) did not report any control for calibration of these monitors. All studies in this review used the 'gold standard' (ABG) as a reference interval. The researchers further validated the studies by allowing for upper and lower thresholds for CO2 concentrations to be determined, providing reference ranges for hypocarbia and hypercarbia.

Patient population characteristics

Singh and Singhal (2005), Kugelman et al (2008), Bhat and Abhishek (2008), Haggerty et al (2002) and Rozycki et al (1998) demonstrated a good degree of homogeneity about gestational age, postconceptual age, birth weight, gender, diagnosis and management strategies. In the study conducted by Wu et al (2003), it is established that the researchers did not provide information about baseline characteristics of the patients recruited into the study. Nangia et al (1997) demonstrated a good degree of generalisability by dividing the group into 3 cohorts.

Confounding Factors

The researchers had to demonstrate tight control of confounding factors for both ETCO2 and PaCO2 measurements so that the relationship between these could be understood, thereby eliminating any factors that may obscure the relationship and contribute to type 1 and type 2 errors (Polit and Beck 2010). In order to assess for confounding factors, Rozycki et al (1998) established 2 groups based on the difference between PaCO2 and ETCO2 where the difference of </- 5mmHg was defined as a low bias group and a difference of >/- 5mmHg was defined as a high bias group. Similiarly Singh and Singhal (2005), Kugelman et al (2008), Wu et al (2003) and Bhat and Abhishek (2008) demonstrated an assessment of confounding factors by assessing for high and low bias groups.

Results

An important feature of clinical trials is that they should be comparative. All studies in this review used a control group of patients without co-existing lung disease, i.e. non pulmonary group. The aim of this review was to determine whether ETCO2

is a good predictor of PaCO2. One such method of quantifying this relationship would be to examine the relationship between these two variables. All the researchers, with the exception of Haggerty et al (2002) demonstrated this relationship using correlation coefficients. Haggerty et al used the Pearson's Correlation. In a study conducted by Wu et al (2003) of 60 neonates, the researchers observed a correlation in both term infants (44 samples, r = 0.78, p<0.001) and preterm infants (86 samples, r = 0.85, p<0.001). Similarly, Rozycki et al (1998) in a study of 45 newborns demonstrated a good correlation between ETCO2 and PaCO2 in ventilated neonates including preterm infants, showing correlation coefficients of 'r' = 0.833 and 0.821 respectively with a 95% CI for the biases and p< 0.001. In the study conducted by Bhat and Abhishek (2008), the researchers were able to show a correlation and agreement between ETCO2 and PaCO2 by demonstrating a correlation coefficient of 'r' = 0.73, with a CI of 95%, where p< 0.001. Although a good correlation was demonstrated, the correlation between ETCO2 and PaCO2 was greater in the group who were ventilated for sepsis, asphyxia, and apnoea versus those ventilated for Hyaline Membrane Disease or Meconium Aspiration Syndrome. A similiar finding was demonstrated in all studies. This leads to the conclusion that conditions with parenchymal lung pathology produce a lower correlation.

Singh and Singhal (2005) conducted a retrospective chart review of extremely low birth weight infants (ELBW) of 754 paired samples using simple linear regression. The researchers reported an intraclass correlation of 0.81.

Bhat and Abhishek (2008) and Haggerty et al (2002), demonstrated a higher gradient between ETCO2 and PaCO2 when comparing infants ventilated for pulmonary disease to those ventilated for non pulmonary conditions. Similarly Nangia et al (1997) studied 152 samples in preterm infants <32 weeks gestational age and reported a correlation of 0.55 in the HMD group. This finding conforms to the theory that ETCO2 poorly predicts PaCO2 in ventilated neonates with lung disease (Watkins and Weindling 1987) and would be consistent with the disease pattern of these babies i.e. atelectasis with consequent ventilation-perfusion mismatch.

Kugelman et al (2008) found that DETCO2 was a reliable predictor of PaCO2 where 'r' = 0.72 with a p value <0.001, and mainstream ETCO2 was a poor predictor of PaCO2 with 'r'= 0.21 and a p value of <0.005.

All the reviewed studies strengthened the outputs of their studies by using a control non pulmonary group. In all these studies, patients in the non pulmonary group showed a better correlation between ETCO2 and PaCO2.

Discussion

From conducting this review it can be deduced that limitations exist when applying ETCO2 monitoring to ventilated neonates. Advances in technology have allowed modification of capnometers to address the challenges posed by the neonatal physiology. This is supported by a study done by Hopper et al in a rabbit model. Here researchers were able to show that inducing lung injury with meconium instillation reduced the correlation between ETCO2 and PaCO2 from 0.94 to 0.80 and raised the bias.

A common finding in the studies in this review was that in neonates with underlying lung disease ETCO2 poorly correlated with PaCO2. In looking at this group further it was concluded that the patients were predominantly preterm with surfactant deficient lung disease. Surfactant is necessary for lung alveoli to overcome surface tension and remain open. Without adequate surfactant, the shearing forces exerted trying to open alveoli by either the infant's own inspiratory effort or by a mechanical ventilator can induce lung damage. The deficiency in surfactant decreases lung compliance and functional residual capacity resulting in an increased physiological dead space leading to ventilation/perfusion mismatch and poor tidal volumes. This pathological picture may explain why ETCO2 poorly correlates with PaCO2 in neonates with underlying lung disease. The studies under review showed that preterm infants who received surfactant therapy showed an improved correlation between ETCO2 and PaCO2.

This fits with the theory that following surfactant administration, surface tension is reduced, more alveoli are recruited,and tidal volumes improve thereby reducing ventilation-perfusion mismatch.

In analysing the data presented, it has become clear that whilst ETCO2 monitoring cannot replace the gold standard of measuring PaCO2 it can provide useful information if used as a trending tool. This is further supported by Rozycki et al (1998), Wu et al (2003), Bhat and Abhishek (2008)and Nangia et al (1997) who found a good correlation exists between ETCO2 and PaCO2 in patients without underlying lung disease. Whilst the researchers were able to demonstrate a good degree of transferability and generalisability through appropriate methods of sampling and methodology, the data was further validated by statistical analysis relevant to this type of study.

In the research presented by Haggerty et al (2002), Singh and Singhal (2005) and Kugelman et al (2008), although the researchers were able to demonstrate a good correlation between ETCO2 and PaCO2, inconsistencies lie in the way in which data was collected and communicated. Singh and Singhal (2005) limited the study to extremely low birth weight infants making the findings less transferable, thus making it difficult to extend comparison to infants outside this cohort. Whilst Haggerty et al (2002) demonstrated a good degree of agreement by evaluating the use of the capnometer across two groups, the researchers did not provide any confidence limits or intervals and a correlational relationship between ETCO2 and PaCO2 was not established.

Summary

Pulse oximetry and transcutaneous monitoring have been accepted methods of monitoring in the NICU for decades. Interpretation of SpO2 is a representation of oxygenation only and can be flawed by limitations such as signal to noise ratio induced as a result of poor perfusion and motion artefact. Whilst technologic and engineering advances have addressed these known shortcomings, no definitive solution has been derived to date to ensure an accurate SpO2 reading for any patient under any circumstances. Whilst SpO2 monitoring provides valuable data regarding oxygenation its contribution to monitoring ventilation efficacy is limited as it provides no data about CO2 or metabolic balance that is otherwise obtained from arterial blood gas measurement.

Transcutaneous monitoring represents a simple non invasive technique for contin-

uous monitoring of O2 and CO2. Accuracy of this method of monitoring is limited by factors such as thermal injury, skin maturity, long stabilisation times and the need for frequent calibrations and site rotation.

Whilst it can be appreciated that advances in technology have allowed the capnometer to be more applicable to the neonatal population, it cannot replace the gold standard of ABG monitoring. ABGs not only provide valuable data measuring efficacy of ventilation but can also provide a range of valuable data such as electrolytes, blood glucose, lactate etc.

All the studies in this review have explored the correlational relationship between ETCO2 and PaCO2. It has become clear that the accuracy of ETCO2 in predicting PaCO2 in ventilated newborn infants is limited by various components specific to neonatal pulmonary physiology and the presence or absence of co-existing parenchymal lung disease. However, by accepting and understanding its limitations, capnometry is easily applied and does provide continuous trending data that can rapidly alert clinicians to significant changes in PaCO2 that may require prompt respiratory assessment. Further advances in capnometer design e.g. micro-stream sampling, will necessitate further evaluation of this modality in clinical practice anticipating that the current performance will be improved upon. The ability to continuously display ETCO2 can therefore potentially provide a valuable adjunct to our monitoring and assist in optimising the management of the ventilated newborn infant on the neonatal unit.

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